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NOAA's Tides & Currents Program

NOAA Center for Operational Oceanographic Products and Services

Tidal current predictions: Helping ships navigate safely in U.S. coastal waters

—by Laura Rear and Christopher Paternostro
NOAA Center for Operational Oceanographic Products and Services

Knowledge of the speed and direction of the tidal current is important for maneuvering ships through tight channels, or coming into port at the correct stage of tide to dock without damaging the ship and/or pier. Search and rescue operations use tidal current predictions and real-time current information to determine where a missing target may travel. In addition, HAZMAT personnel use currents information to track and predict oil spill hazards. Fishermen use tidal current information to determine optimal fishing conditions.

The NOAA Center for Operational Oceanographic Products and Services (CO-OPS) is responsible for updating and maintaining the U.S. Tide and Tidal Current Tables. Its National Current Observation Program (NCOP) is responsible for determining locations and priorities for updating and adding or deleting tidal current entries into the tables and the Coastal and Estuarine Circulation Analysis Team (CECAT) works with NCOP to process and analyze the data. The final predictions are calculated and published by the User Services Team within CO-OPS.

Since the mid-1840s NOAA and its predecessors have been collecting and analyzing tidal current data to provide the maritime community with predictions on current speed and direction to enhance safer and more efficient maritime transportation. Over the last 150 years, the technology has changed significantly, but the concepts remain the same.

Early surface current measurements in the U.S Coast and Geodetic Survey (USC&GS), NOAA's predecessor, were made using a current-pole-and-log line. The pole was 15 feet long and weighted at one end so it floated with about one foot out of the water. The log line was attached to the current pole. The line was marked by pieces of cotton string with knots tied in it. The amount of knots payed out during a 60 second time frame corresponded to the speed of the current in that location. The spacing of the knots was 101.33 feet, equivalent to the distance a current with velocity of one knot can carry the line in 60 seconds. The angle of the pole was an indication of the direction of the current and was normally determined by compass or sextant. (USC&GS 1950). The accuracy of this mea-

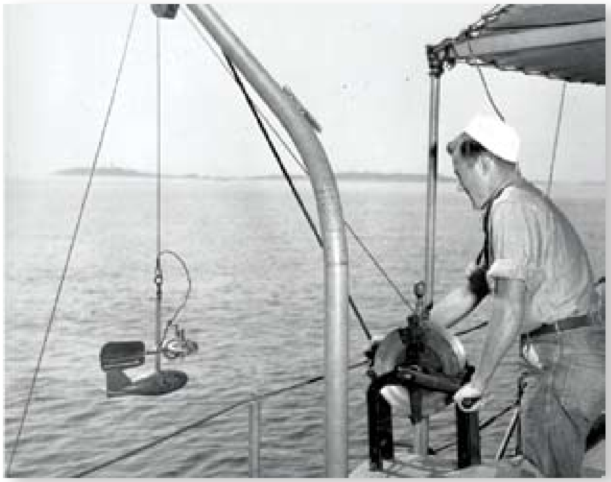

Figure 1. Historic deployments of a Price current meter (above) and Roberts Radio current meter (below).

Figure 2. Examples of acoustic Doppler current profilers.

surement was low because the pole moved with the current and, as a result, was measuring multiple locations at once; the speed of a current can vary significantly over a few hundred feet.

The U.S. Army Corps of Engineers later designed the Price Current Meter which consisted of a wheel with conical cups that would spin depending on the current speed. The speed was determined by an observer listening electronically on the surface to the number of rotations during a specific time interval. The meter could be lowered to different depths in the water column to obtain measurements over depth. The USC&GS usually took measurements at 2-tenths, 5-tenths, and 8-tenths of the water depth at a particular station. Eventually, the human listener was replaced by an automated recorder device. Direction was not measured and was normally determined by an observer.

In the 1930s the Ekman current meter was developed by a Swedish scientist named Dr. V. Walfrid. Unfortunately, the maximum current that could be measured to avoid instrument damage was 1.8 knots. The USC&GS recommended this meter not be used in speeds over 1.5 knots, thus significantly limiting areas where currents could be measured. It was also necessary to raise the instrument out of the water to read the speed on the dials after each reading. An internal compass determined the currents' direction.

The Coast and Geodetic Survey developed the Roberts Radio Current meter that measured both speed and direction. The advantage of this meter was that it could be deployed from an anchored buoy. The meter was normally deployed 15 ft below the surface. The buoy was cabled with a radio transmitter that would transmit the data to a shore or ship station via a radio signal. A receiving antenna would have a corresponding chronometer for determining the time of data transmission. A chronograph would record the time data, in seconds, as well as the radio signals. The meter had a rotating impeller that was triggered by the current. The impeller was connected to a device that made an electric circuit with two contacting devices. The number of seconds between contacts was determined, and the corresponding velocity was given by a rating table. Direction was recorded with a magnetic compass. The Roberts Radio Current Meter was used for several decades until more automated meters were developed.

The developments of the CPU, electronic storage media, and long-life batteries have made it possible to achieve greater instrument precision, longer duration of measurements with higher frequency, and less personnel to conduct the measurements. As a result, studies can now be conducted with greater area coverage. Presently, the two major technologies employed by CO-OPS in field observations of currents are the acoustic Doppler current meter and the high-frequency surface current mapper.

The acoustic Doppler current meter is the principal technology CO-OPS uses to collect current data. There are various types and manufacturers of this instrument but the basic technology is the same. A series of acoustic heads on the instrument send out an acoustic pulse through the water. The sound travels through the water, bouncing off suspended material such as sediment, plankton, algae, even air bubbles, along the way. The assumption is this suspended material is traveling at the same speed as the water that carries it. The returning echoes from the reflections off this material are recorded by the heads of the instrument.

In a moving body of water, the frequency of the pulse experiences a Doppler shift which is calculated by the instrument to determine the speed of the water moving directly toward or away from an acoustic head. The Doppler meter can determine both the speed and direction (velocity) of the water flow from a combination of two or more acoustic heads offsets at a known angle.

Water velocity can be calculated for multiple slices of the water column being measured. Using the speed of sound in water, i.e., the time between transmitting the signal and the multiple returns of the echoes, one can calculate the distance the signal has travelled from the current meter; the more time taken by the sound to bounce back, the greater the distance to the slice of water measured.

The Doppler current meter represents a significant improvement over older technology because it can provide information at many depth bins throughout the measurement column, not just at a discrete point at the depth where a meter is deployed. Thanks to this technology, CO-OPS has been adding increasingly more surface, mid-depth, and deep tidal current predictions to the Tidal Current Tables.

Placing current meters in a heavily transited basin so that they cannot be damaged or stolen can present challenges. The meters can be deployed in an upward-looking, downward-looking, or side-looking orientation. But, since they only record distant points through the column of water directly in line with their sensors' heads, the flow of the body of water to be measured is paramount importance.

CO-OPS deploys current meters on the bottom of basins in various retrievable mounts which are safely deeper than the hull of ships. Increasingly, the meters are being deployed mounted alongside the red and green Aids-to-Navigation buoys marking the primary shipping lanes. When docking large vessels is hazardous due to unknown currents, CO-OPS deploys meters on a pier sideways, looking out.

Any of these mounts can be deployed with the capabilities to have the data cabled or transmitted to a shore station then sent to Silver Spring where the data are reviewed for quality and displayed real-time on the Internet. The CO-OPS Physical Oceanographic Real-Time System (PORTS) uses long-term deployments of current meter systems to provide real-time current data for port operations on a 24/7 basis.

Current measurements can also be collected using high-frequency surface current mappers (HF-SCM). This new technology utilizes the unique physical properties of radio signals to provide a synoptic map of the water flow in the top one meter of the ocean's surface.

To acquire the data, a series of antennas are deployed on the shoreline around the basin to be observed. The antennas transmit and receive high-frequency band radio waves at a specific frequency. The radio waves have a length equal to the ocean waves which absorb the energy and return a Doppler-shifted signal which is detected using the principle known as "Bragg scattering." CO-OPS and a larger mapping community are working on developing products that will map the water flow to just below or in the top one meter of the ocean's surface at a high spatial resolution in half hour or full hour increments.

Modern instruments for current measurement yield time series of digital data on the speed and direction of water flow at regular intervals over a period of time. The data are analyzed using techniques of harmonic analysis—the least squares harmonic method and the Fourier harmonic method— developed by the classical mathematicians Gauss and Fourier.

Harmonic processes were observed centuries ago but it was not until 1867 that Sir William Thomson (Lord Kelvin) developed a harmonic method for predicting the tides, based on work done almost 100 years earlier by Pierre Simon Marquis de Laplace suggesting that tides be represented by a series of harmonic oscillations (Parker 2007). In areas dominated by tidal currents, normally about 85-95% of the current is tidal and can be defined as a series of sines and cosines.

Harmonics are any number of sinusoidal waves found in nature. The most obvious form of sinusoidal motion in oceanography is the up-and-down oscillation of water known as the tide. This vertical motion has an analogous horizontal component which is necessary to move the water toward the tidal bulges. Measurements of the advection of water reveal similar sinusoidal patterns in the two horizontal directions of water flow.

The forces causing harmonic tidal motions are due to the interplay of the gravitational forces and the counter forces from the Sun and Moon. The known and predictable motions of the Earth, Moon, and Sun system allows the time series data to be mathematically decomposed into individual harmonics with known astronomical frequencies. Harmonic analysis techniques help determine an amplitude (the amount of movement) and phase (the timing) for each harmonic frequency. These empirically derived values are known as harmonic constants.

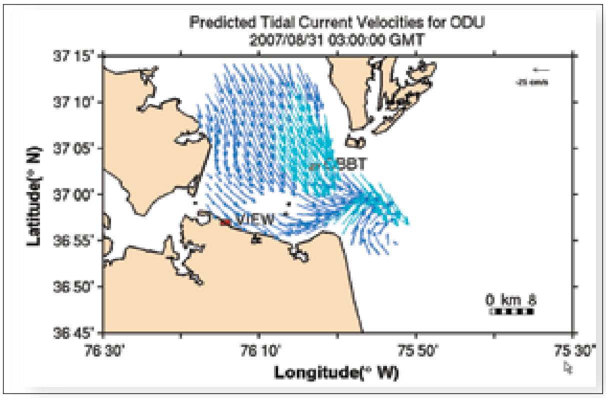

Figure 3. CO-OPS prototype display of tidal current predictions made from HF-SCM data in lower Chesapeake Bay.

The accurate prediction of the three-body astronomical system allows the re-composition of the many sinusoidal harmonics, each with a unique amplitude and phase, into a prediction for any time in the past, present, or future. (For more information on tide and tidal current predictions, please see article entitled "Using the past to predict the future." *ASCM Bulletin*, June 2008, No. 233, p. 46-).

CO-OPS and its predecessors in the USC&GS have been collecting current measurements and other information to enhance safe navigation and engineering along the U.S. coast and its in navigable rivers. Currently, NCOP is challenged with keeping an inventory of over 2500 station locations up to date. High-priority areas are determined for update each year, with up to 70 being updated per year, which is significantly more than the 10 sites that were updated annually just a decade ago.

Navigation channels with only a few days of data collected originally are prime candidates for updates. Sites that are more than 30 years old are also strong candidates for updating. In 2008 for example, CO-OPS collected data at the North Inian Pass in South East Alaska, which previously was collected in 1901. One hundred plus years later we are anxiously awaiting the data retrieval to help determine the changes of the tidal current in that location over time.

Changes to tidal currents can occur for several reasons. One that CO-OPS encounters often is that not enough data were collected the first time around to resolve the tidal constituents. In addition, if there is more freshwater input occurring, the tidal current may be modified. Also, changes to the bathymetry may cause tidal characteristics to change.

Often, such changes are detected by users who then request updates of the area they are concerned about. For example, the

Hudson River, NY, pilots were concerned with an area in Haverstraw Bay. In 2004, CO-OPS updated the information collected at that location, and after analyzing a month of data we determined a small timing and velocity difference existed when compared to the historic data. Using input from the pilots and other river users, in 2005 and 2006, CO-OPS completed a full survey of the entire river from Manhattan to Troy, NY. The updated tidal current predictions were included in the 2008 Tidal Current Tables.

Another example is from Panama City, Florida. NCOP was contacted by the President of the pilots association because there was no historic currents information in that area, due to past lack of technology to resolve diurnal tide. In 2008, CO-OPS completed a survey of the port of Panama City and the area surrounding St. Andrew Bay using updated software and algorithms developed for analyzing such tides. Those predictions will appear in the 2010 Tidal Current Tables.

In the coming years, as ships are built with deeper draft and made to carry more cargo while ports increase their capabilities, it will become ever more necessary for accurate tidal current predictions to be made available to help guide these ships through the U.S. coastal waters.

The speeds and directions of tidal currents can be highly variable over a given geographic area and can vary with depth, and so it is always a challenge to install instrumentation at the number of locations required to completely understand the tidal current regime. In the future, the current meter and HF-SCM data sets are also envisioned to be integrated with nowcast/forecast model outputs to give the user a three-dimensional view of current speeds and directions that can be applied to decision-making support tools.

References

- Parker, B. 2007. Tidal analysis and prediction. NOAA Special Publication NOS CO-OPS 3. U.S. Department of Commerce. pp. 180-193.
- U.S. Coast and Geodetic Survey. 1950. *Manual of current observations*. Special Publication 215. Washington, DC. 87 p.

Figure 4. Deploying a current meter in Penobscot Bay, ME, from the US Coast Guard Cutter Abbie Burgess (above); and in the Hudson River, NY, from the *Rosemary Miller*, a contracted vessel (below).

ACSM LOBBY DAY 2008

Expected to drive fast-paced and productive sessions, lobby teams were identified during a planning meeting preceding the ACSM Lobby Day and briefed on key surveying and mapping issues to be brought up in discussions with representatives and their staffers. Each attendee of this year's Lobby Day also had an opportunity to meet with their respective U. S. Representative in one-on-one meetings, through appointments set up by members themselves. The full report on Lobby Day 2008 will be published in the October issue of the *ACSM Bulletin*.