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# AN OVERVIEW OF SAN FRANCISCO BAY PORTS

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## ABSTRACT

The Physical Oceanographic Real-Time System (PORTS) provides observations of tides, tidal currents, and meteorological conditions in real-time. The San Francisco Bay PORTS (SFPORTS) is a decision support system to facilitate safe and efficient maritime commerce. In addition to real-time observations, SFPORTS includes a nowcast numerical model forming a San Francisco Bay marine nowcast system. SFPORTS data and nowcast numerical model results are made available to users through the World Wide Web (WWW). A brief overview of SFPORTS is presented, from the data flow originated at instrument sensors to final results delivered to end users on the WWW. A user-friendly interface for SFPORTS has been designed and implemented. Appropriate field data analysis, nowcast procedures, design and generation of graphics for WWW display of field data and nowcast results are presented and discussed. Furthermore, SFPORTS is designed to support hazardous materials spill prevention and response, and to serve as resources to scientists studying the health of San Francisco Bay ecosystem. The success (or failure) of the SFPORTS to serve the intended user community is determined by the effectiveness of the user interface.

## I. Introduction

Located near the middle of California coast, San Francisco Bay estuarine ecosystem is one of the most complex coastal plain estuaries on the west coast of the United States. The waterways in San Francisco Bay are traveled heavily by tankers and cargo ships serving the population centers surrounding the bay. The San Francisco Bay region is also a center of commerce, industry, and recreation. Consequently, the Bay system also is subject to the disposal of industrial and municipal wastes. Despite all preventive measures, vessel traffic accidents will be difficult to avoid completely. To protect this already fragile estuarine ecosystem, authorities are considering preventive measures, and implementing a strategic plan for a rapid and effective response to minimize any damages in case of an accident.

National Oceanic and Atmospheric Administration (NOAA) initiated installations of Physical Oceanographic Real-Time System (PORTS) in Tampa Bay, Florida, Houston-Galveston Harbor, Texas, and New York Harbor starting from 1985. Between 1995-1998, NOAA completed the installation of PORTS in San Francisco Bay, California (SFPORTS). In addition to real-time observations, SFPORTS includes a nowcast numerical model forming a San Francisco Bay marine nowcast system (Cheng and Smith, 1998). SFPORTS data and nowcast numerical model results are delivered to users through a user-friendly web-based interface on the WWW. In the following sections, the data flow from PORTS instrument sensors in the field to a web server; the appropriate field data processing; the data analysis and archives; the nowcast procedures; the characteristics of the user interface; and the graphics for WWW display are presented and discussed.

## II. SFPORTS Data

### II.1 Data Flow

San Francisco Bay estuary is a geographically and bathymetrically complex tidal system that is characterized by broad shoals (less than 2 m deep at MLLW) and narrow channels (typically 10-20 m deep). SFPORTS consists of five shore stations where water level (tides), wind speed and direction, wind gust, air temperature, and barometric pressure are measured and reported every six minutes. Five Acoustic Doppler Current Profilers (ADCPs) have been installed to measure water velocity profiles every six minutes. The instrument sensor locations are shown in Figure 1. Salient characteristics of sensors, and precise sensor locations can be found on the WWW at URL-sfports (1998) by pointing-and-clicking on the sensor box in the sensor location map.

The original sensor data are first sent to a NOAA data acquisition system. These data are reformatted to a PORTS Uniform Flat File Format (PUFFF). There are four basic PUFFF data types designed for reporting observations of water level, conductivity and temperature, current (ADCP), and meteorological data. Each file contains a single data type representing the latest observation. The details of PUFFF are documented by Evans et al. (1997). Since PUFFF files are in ASCII, they can be sent conveniently to a server by e-mail whenever a new observation becomes available (once every six-minute). E-mail is chosen as the messenger for transmitting field data (PUFFF) to server; it is designed to minimize data loss due to communication problems between computers. The mail server spool at each site is used as a buffer to temporarily hold undelivered data when the communication between systems has a glitch. Back-logged data will be delivered to the web-server when communication between systems is restored.

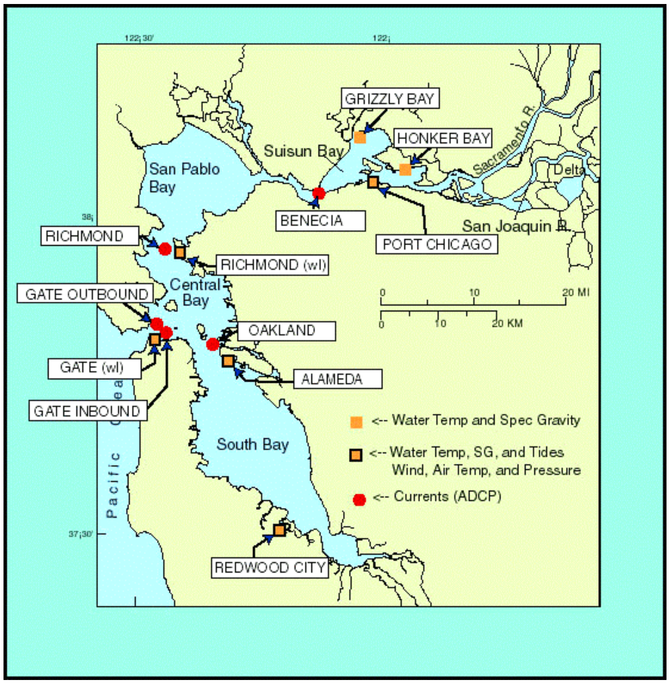


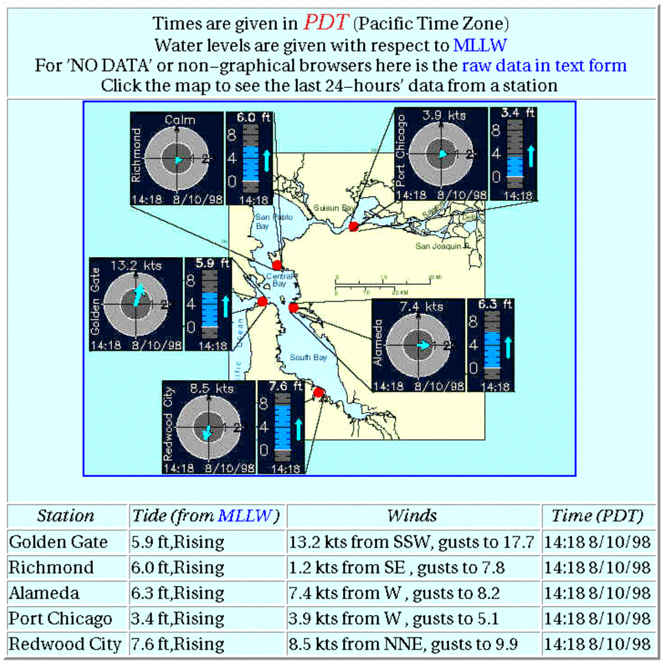
Figure 1. The San Francisco Bay estuary and SFPORTS instrument sensor location index map.

On the server, the incoming field data from each sensor are sorted and archived as time-series files by sensor stations. A computer program has been written to sort the incoming data (e-mails) and archive them in a time-series format common to all hydrodynamic studies of the U. S. Geological Survey. The two basic time-series data types are: 1) Observations of tides, winds, and climate at shore stations; and 2) In-situ ADCP velocity measurements. In addition to archived time-series data, a copy of 'now time-series' data for each station and for each ADCP is maintained on the server. The 'now time-series', which contain the observations for the immediate previous 24-hour, are updated every six-minute on a sliding time-scale. These files are ready for further scrutiny, analysis, and processing.

## III. User Interface

The marine nowcast system for San Francisco Bay is expected to provide observed tides (sea level) and currents, weather conditions, and nowcast model results to users at near to real-time. Recent advances in internet technologies and the explosion in web usage have demonstrated that the internet is the appropriate conduit for data transmission in this application. This approach was successfully tested by making the real-time regional diagnostic wind distribution over the San Francisco Bay region available on WWW for public use since February 1996 (Ludwig et al., 1997; URL-wind, 1996). User feedback provides further reassurance that the San Francisco Bay marine nowcast system should be a WWW-based system due to its effectiveness of delivery information. By combining the nowcast numerical model results, the real-time field observations, and internet technologies, the San Francisco Bay marine nowcast system is a unique and potentially very powerful system.

The vast amount of field data and nowcast results must be delivered to users in a user-friendly, comprehensive and attractive format, and in a timely manner. A user interface should be computationally efficient, simple and elegant in graphical presentation of results, and efficient in data transmission through the WWW. The menu should be flexible to achieve easy access to the desired field data or nowcast numerical model results. The design of the SFPORTS user interface has considered the balance of computational efficiency, limitations in the rate of data transmission, and effective graphics presentation. A research site and a production site for the San Francisco Bay marine nowcast system have been established. At the research site (URL-sfports, 1998), new features for user interface are being explored and tested. When new components are proven to be useful and robust, they are then transferred to the production site maintained by Marine Exchange of the San Francisco Bay region (URL-sfmx, 1998). Thus, the principal components and results at these two sites are virtually identical; also, each serves as a backup for the other system.



Times are given in *PDT* (Pacific Time Zone)
Water levels are given with respect to MLLW
For 'NO DATA' or non–graphical browsers here is the raw data in text form
Click the map to see the last 24–hours' data from a station

| *Station* | *Tide (from MLLW)* | *Winds* | *Time (PDT)* |
|---|---|---|---|
| Golden Gate | 5.9 ft,Rising | 13.2 kts from SSW, gusts to 17.7 | 14:18 8/10/98 |
| Richmond | 6.0 ft,Rising | 1.2 kts from SE , gusts to 7.8 | 14:18 8/10/98 |
| Alameda | 6.3 ft,Rising | 7.4 kts from W , gusts to 8.2 | 14:18 8/10/98 |
| Port Chicago | 3.4 ft,Rising | 3.9 kts from W , gusts to 5.1 | 14:18 8/10/98 |
| Redwood City | 7.6 ft,Rising | 8.5 kts from NNE, gusts to 9.9 | 14:18 8/10/98 |

Figure 2. Wind and Tides map showing the latest observations at five shore stations.

The home-site of San Francisco Bay marine nowcast system (URL-sfports, 1998; URL-sfmx, 1998) has a main panel in which results are displayed. A menu panel is shown on the left. The menu panel lists the possible options including the background information about the San Francisco Bay PORTS project, its objectives and its partnership. The remaining menu includes choices such as 1) Sensor location map, Figure 1, 2) Sensor data status, 3) Products, 4) Other resources, and 5) Feedback. The core of the technical results is contained in 'Products' which is further divided into a) Most recent data and b) Model results. For example, 'Winds and Tides' distribution map shows the latest observations of tides and wind vectors, Figure 2, along with the tabulated values of tides, wind speed, wind-gust at all five shore stations. A similar display for the latest ADCP observations can be found under 'Current Profiles'.

## IV. Results

In order to extract more useful and physically significant information from the SFPORTS data, most field data require further processing. In the following sections, data analysis and a procedure to nowcast tides for the next 24 hours are presented. A user-friendly interface has been built to show the three-dimensional ADCP data from a perspective view. Other tools and interfaces for displaying numerical nowcast model results are presented and discussed below.

### IV.1 Data Analysis and Nowcast of Tides

The time-series of tides and weather data are processed for display on the WWW. Tides (sea level) are one of the basic and most useful information to mariners. The observed tides can be harmonically decomposed as

$$\varsigma(t-t_o)=\varsigma_o+\sum_{i=1}^{N}\varsigma_i\cos[\omega_i(t-t_o)-\phi_i] \qquad (1)$$

where

$\zeta$ = Water level measured from mean-lower low-water (MLLW);

$\zeta_o$ = A reference water level;

$\zeta_i$ = Amplitude of the i-th tidal constituent;

$t$ - $t_o$ = Time measured from a referenced time $t_o$;

$\omega_i$ = Frequency (speed) of the i-th tidal constituent;

$\phi_i$ = Phase of the i-th tidal constituent.

The amplitudes and phases, ($\zeta_i$, $\phi_i$), are referred to as harmonic constants. If the harmonic constants were deduced from sufficiently long and reliable time-series, then (1) can be used to predict the astronomical tides at that location for any given time. The tide table published by NOAA is produced using the astronomic tides described in (1). If non-astronomical forcing, such as river inflows, winds and variations of barometric pressure becomes important, it could cause large variations in the reference sea level, $\zeta_o$. Every hour, the mean difference squared, $\Delta^2$, between the observed and predicted tides, for the past 24-hours, is computed for each station by

$$\Delta^2=\frac{1}{240}\sum_{i=1}^{240}[\varsigma^o(t_i)-\varsigma^p(t_i)]^2 \qquad (2)$$

where $\varsigma^o(t_i),\varsigma^p(t_i)$ are the observed and predicted tides at time $t_i$ in six-minute intervals. A nowcast algorithm is proposed to correct astronomical tidal prediction by

$$\varsigma^n(t_i)=\varsigma^p(t_i)+\Delta \qquad (3)$$

where $\varsigma^n(t_i)$ is the nowcast adjusted prediction of tides for the 48 hours centered at the present time. The observed tides, nowcast predicted tides, and tide table values (astronomical tides) for each SFPORTS shore station are computed and ready for display on WWW. For example, during a major storm on February 6-7, 1998, the nowcast prediction of tides matched very well with the observations. The sea level estimated by the nowcast prediction was more than two feet higher than the tide table predictions published by NOAA causing flooding in some lowland areas around the bay (San Francisco Chronicle, February 7, 1998), Figure 3. Similar time-series of nowcast tides, at each shore station, can be selected to display the comparison of the real-time observations, nowcast (predicted) tides, and tide table values. On the bottom of the time-series plot, there are three

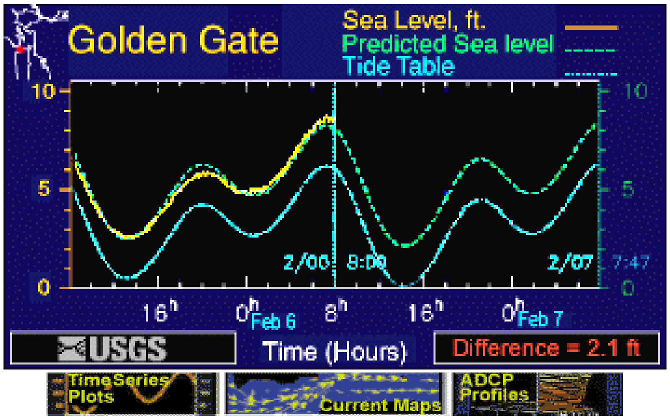


Figure 3. The observed (yellow), nowcast (green), and tide table (blue) predicted tides during a storm in February 6-7, 1998.

additional options for 1) refreshing the time-series plot, 2) showing the nowcast model results near this station, and 3) displaying an ADCP velocity profile from the nearest ADCP deployment. These options are designed to allow users to cross-reference different hydrodynamic properties at (or) near the selected station.

### IV.2 ADCP observations

The invention of Acoustic Doppler Current Profiler (ADCP) for flow measurements in rivers, streams, and estuaries is one of the major technology breakthroughs for water sciences in recent years. The ADCP can be deployed in the middle of a waterway with the acoustic transceivers pointing vertically up to measure a 3-D velocity profile time-series. Because the instrument is non-intrusive (it occupies a small height at the bottom), nearly the entire water column is left for vessel traffic at the ADCP deployment site. This instrument configuration permits deployment of ADCP at locations where data are most needed, such as in the middle of shipping channels without the instrument being a hazard to vessel traffic (Figure 1).

The ADCP in SFPORTS sends a velocity profile to the server in PUFFF once every 6-minute. Similar to other data types, the ADCP data are archived in a time-series file and a 'now time-series' file for each station. The ADCP time-series uses a format that is compatible with analysis tools developed at the USGS. Each ADCP record represents a 3-D velocity profile. To visualize the three-dimensional nature of the tidal current, a 3-D perspective view of the velocity profile can be displayed for any ADCP velocity measurement in the bay, Figure 4. The velocity profile shows the directions of velocity vectors, color-coded for different depth-levels and their projections on the bottom where each ring is scaled to 1 nautical mile per hour. Similarly, on the bottom of the ADCP plot, there are three additional options for 1) showing a time-series plot of the ADCP data for the past 24-hours, 2) displaying nowcast model results near this ADCP site, and 3) refreshing the ADCP profiling plot. Again, these options allow users to cross reference different hydrodynamic properties at or near the selected site.

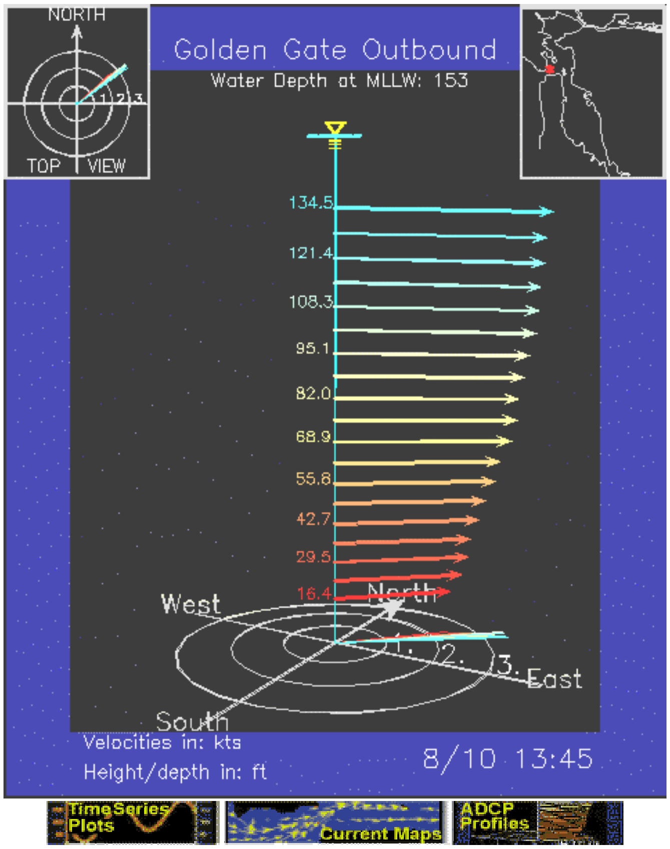


Figure 4. 3-D perspective view of the velocity profile observed by an ADCP deployed in the middle of the outbound lane near Golden Gate showing near surface velocity exceeding 3 knots flowing to approximately 60° north.

### IV.3 Nowcast Numerical Model Results

A nowcast numerical model is an integral part of the San Francisco Bay marine nowcast system. The nowcast numerical model is designed to reproduce tides and tidal current distributions in San Francisco Bay for the past 24-hours. Based on the results of model simulations and by an assimilation algorithm, the field observations in the past 24-hours are used to guide an optimal numerical simulation of the tides and tidal currents in the bay for the next 24 hours. The nowcast model results are updated once an hour. The assimilation algorithm and the over-all nowcast numerical modeling procedures are presented by Cheng and Smith (1998) and will not be repeated here.

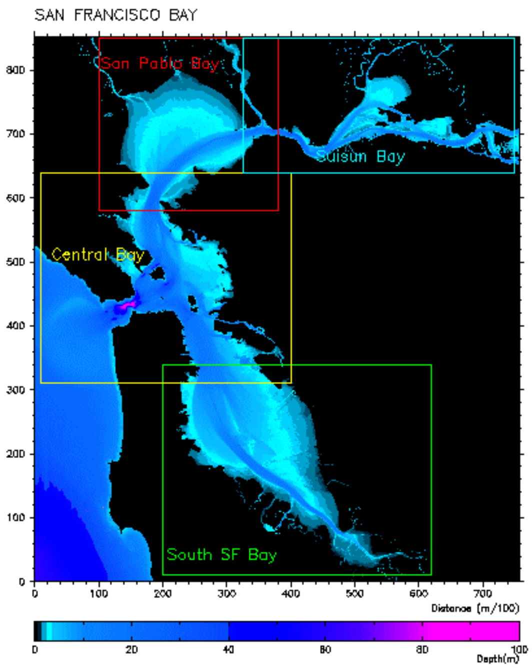


Figure 5. Index map of the San Francisco Bay nowcast numerical model. The color background is an index of the water depth.

Starting from the main menu panel of the San Francisco Bay marine nowcast system (URL-sfports, 1998), an index "current map" for tidal current distribution can be selected under the category of 'model outputs', Figure 5. The index map shows water depth distribution within the model domain in a color-coded background. By pointing-and-clicking the mouse, the index map can be zoomed into Suisun Bay, San Pablo Bay, Central Bay, or South Bay. At this level, an areal velocity distribution is also shown. Technically, it might be possible to allow users to zoom in continuously into the region of interest for greater details of the velocity distribution. This flexibility would require enormous amount of computing power of the server, and often the response time would be too long to maintain interest of a potential user. As a compromised solution, the modeled region is divided up into tiles. The tidal velocity distribution, in each tile, at the nearest hour to the present time is pre-processed. A detailed and quantitative velocity distribution within one tile can be obtained by pointing-and-clicking the cursor at the location of interest. The nowcast model velocity vectors are mapped on a navigation chart published by NOAA, Figure 6. The velocity distribution in the eight neighboring maps can be visualized by pointing-and-clicking at NORTH, NE, E, SE, SOUTH, SW, W, AND NW on the edge of the tile. The nowcast model results are superimposed on a navigation chart because it is the most familiar format to the maritime community. These real-time data and nowcast results of tides and tidal currents are extremely useful in all maritime activities.

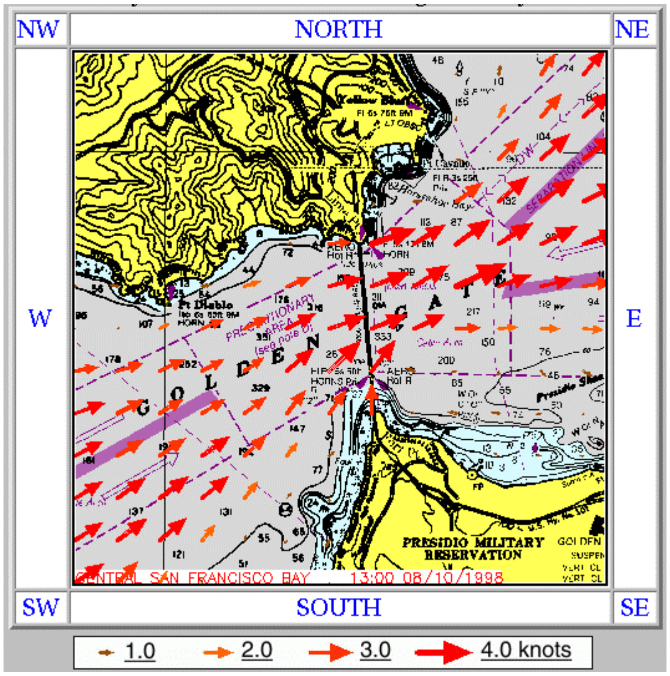


Figure 6. An example of tidal current distribution near Golden Gate Bridge, entrance to San Francisco Bay from the Pacific Ocean.

## V. Summary and Conclusion

NOAA installed Physical Oceanography Real-Time System in San Francisco Bay (SFPORTS), California to provide real-time observations of tides, tidal currents, and meteorological conditions. The decision of installing PORTS in San Francisco Bay presents an opportunity for the development of a comprehensive marine nowcast system for optimizing vessel operations and for improving marine navigation safety. A nowcast numerical model has been successfully installed and tested. It has become an integral part of the San Francisco Bay marine nowcast system. If a wireless modem is available, then the real-time tide, tidal currents and nowcast results are available to ship operators when the vessel is under way. The development of user interface is an ongoing endeavor. The present version of the SFPORTS user interface is an early release of efforts by the authors. The user interface will no doubt be further modified after an evaluation of user feedback. Appropriate enhancements will be introduced as new technologies for addressing web-related issues emerge.

**Acknowledgement**

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