Ocean Observations and Its Applications

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Abstract

Ocean observation serves many useful purposes. A well designed environmental monitoring network can provide valuable information for ocean users such as coastal zone managers, ship pilots, and marine traffic controllers. Long term observations can also enable researchers to gain insight into natural phenomena. Understanding of ocean processes and data obtained from observations not only help scientists in developing better numerical models, but also in evaluating and verifying models. In addition, quality data sets can be used to improve the accuracy of model forecast through data assimilation technique.

This paper describes a national water level observation network, a real-time harbor/bay monitoring network, and a coastal ocean forecast system at the U.S. National Ocean Service. Aspects of the observation network, including user services, measurement technology, data quality assurance, and its applications to coastal ocean forecast are discussed.

I. Introduction

In scientific studies, observations are instrumental in improving the understanding of ocean's physical processes and thus lead to the development of more accurate numerical forecast models. In practical applications, observation networks are being used for marine environmental monitoring and management, ship navigation, marine pollution response, ocean resource exploration and exploitation, and national defense.

Observation data are usually more accurate, but sparse in both space and time. Model data, on the other hand, are complete in space and time but may have large uncertainties. Observation and numerical model, therefore, can complement each other in several ways:

1. Observations improve model formulation through better understanding of physical processes,
2. Model needs observations to verify its performance,
3. Observations improve model performance through data assimilation,
4. Model provides complete coverage of fields within its domain,
5. Model provides guidance in observation network design.

The role of observations in an ocean forecast system was illustrated in Fig. 1 by Robinson [12]. The usefulness of data assimilation in model forecast will increase the need of observation data in quantity and quality. It has been shown [11,13] in both oceanic and atmospheric forecast models that better initial conditions using data assimilation significantly improves the forecasts over that achieved by upgrading the model formulation.

This paper discusses two coastal ocean observation networks and a coastal ocean forecast system at the National Ocean Service (NOS) of the U.S. National Oceanic and Atmospheric Administration (NOAA). The observation networks are the infrastructures for the development of forecast system. Various aspects of the coastal observation networks including measurement technologies, data quality assurance, products and users, and applications to the coastal forecast system development are presented.

II. NOS Observation Networks

Two ocean observation networks, the National Water Level Observation Network (NWLON) and the Physical Oceanography Real-Time System (PORTS), are maintained by the NOS. Fig. 2 shows the locations of these network stations. The measurement technology and data quality aspects of these two networks are described below.

1. NWLON - There are 189 permanent water level measurement stations in the network along the U.S. coasts, offshore islands, and the Great Lakes. These long-term stations provide data of water levels and other meteorological, oceanographic, and hydrological parameters. Water level data are collected at 6-minute intervals and are transmitted through GOES satellite every 3 hours to a central office for processing, analysis, and

archiving. The data can also be acquired through telephone or radio links in real-time mode [10]. Satellite transmission can be made at a faster rate when triggered by storm surge and tsunami events.

A. Measurement Technology. Each NWLON station is equipped with a primary (air acoustic) and a backup (pressure) water level sensors. The primary measurement system is accurate within 1 cm. Up to one week's digital data can be stored in the main data collection/ transmission platform. The automatic system reduces human interferences to a minimum.

B. Data Quality Assurance. To maintain high data quality, the following procedures have been implemented:

a. measurement system error analysis and design engineering to mitigate total measurement errors,
b. sensor self-calibration capability,
c. acceptance test prior to system installation,
d. yearly laboratory sensor calibration,
e. annual station datum stability check and field inspection,
f. automated check for outlier during data acquisition,
g. daily data quality reports,
h. software data quality checks in database,
i. backup measurements to fill up data gaps.

In addition, a thorough test and evaluation phase is required prior to adaption of a new measurement system. Long-term comparisons (10 years) are maintained when upgrading measurement systems.

2. PORTS - Since 1991, NOS has installed four PORTS in the nation's major harbors/bays. These sites are Tampa Bay, Houston/Galveston Harbor, San Francisco Bay, and New York/New Jersey Harbor. Each site uses existing NWLON water level stations as the backbone and with additional water level, current, salinity, temperature, wind, visibility, and other sensors to provide real-time environmental information to facilitate marine commerce and safe navigation.

A. Measurement Technology. Water levels, currents, winds visibility, air and water temperature, barometric pressure, salinity, and waves are some of the typical measurements in PORTS. The technology for water level measurement is the same as that used by the NWLON. Currents are measured by bottom mounted Acoustic Doppler Current profiling instruments. Current data are transmitted to shore base station via underwater cable. These sensors are installed at strategic locations critical to navigation safety. Data from all sensors are pooled to a base station via line-of-sight radio links and are updated every 6 minutes. These information are broadcasted over NOAA weather radio and users can also acquire information from a voice system via telephone or radio, and hard copy of summary data sheet via Internet. The data are also sent to local U.S. Coast Guard marine traffic control center for display and to a central office for archiving in an open GIS database. Fig. 3 shows the observation system at Tampa Bay, Florida [2].

B. Data Quality Assurance. In addition to regular maintenance and calibration of the measurement systems, a Continuous Operational Real-Time Monitoring System is being developed to provide automated monitoring of real-time systems. It will determine data quality in real-time and calls for quick response to system performance issues.

III. Applications to NOS Programs

1. Products and Users of NWLON - The products of NWLON include water levels in real-time or near real-time, hourly, daily, weekly, and monthly means, long-term time-series; tide predictions; harmonic analyses/constants; tidal datums; tidal zoning; ancillary data, etc. These data have been used for nautical charting, marine boundary determination, navigation, dredging and harbor improvements, tsunami and storm surge warnings, environment management, climate and global change studies, international datum determination, and international treaty and regulations compliance. Users include U.S. governments (federal, state and local), marine navigation and shipping; surveyors and engineers; law firms; academia; private individuals; and foreign governments.

2. Products and Users of PORTS - The real-time environmental information are essential for safe and cost-effective navigation, hazardous material and oil spill prevention and response, search and rescue, and scientific research. These information are presented in tabulated form and charts. Users include harbor pilots, boat operators, marine traffic controllers, environment managers, and researchers.

3. Applications to Coastal Ocean Forecast System - A three-dimensional, baroclinc, primitive equation ocean model was jointly developed by the Princeton University and NOAA [4]. The model has been producing experimental daily 24-hour forecasts of water levels and three-dimensional temperature, salinity, and currents for the East Coast on an operational basis since August 1993 [1]. It is also used in finer grids to model the ocean dynamics in New York/New Jersey Harbor and Houston/Galveston Harbor.

The two NOS observation networks provided a great wealth of data for use in the model development. They have been used as initial boundary conditions and for model validations. Procedures for data assimilation are presently being developed. The following describes the basic model, examples of comparison with observations, and discussions of issues experienced in the model development.

A. Model Description. The Princeton Ocean Model was forced at the surface by forecast atmospheric pressure, heat and moisture fluxes, 10-m winds derived from a 29 kilometer resolution Eta atmospheric model [3]. Open boundary temperature and salinity are derived from Levitus' monthly and annual climatology, respectively [9]. Fixed mass transports from references [5,7,8] are prescribed at the open boundary. Tidal inputs at the open boundaries are optional.

A finite difference numerical formulation similar to the Gulf Stream System study [5] was used. The horizontal grid is a coast following, curvilinear orthogonal system. The grid resolution is approximately 6-10 km in coastal regions and 10-20 km in the deep ocean. A 15-level sigma coordinate is used in the vertical grid. The bottom topography is based on DBDB 5-degree resolution data except in coastal regions where the NOS 15-second topography is used for better resolution. The shallowest depth of the bottom topography in coastal regions is 10 m. The depth at deep ocean boundary is greater than 4000 m. The model domain, mass transports along the open boundary, and 12 NWLON stations are shown in Fig. 4.

The model was run continuously without re-initiation, with daily forecast starting at 00Z. The model outputs hourly subtidal water levels at locations closest to the NWLON stations along the East Coast.. The outputs at locations near the entrance of harbor/bay are used as open boundary conditions for the harbor/bay forecast models.

B. Comparison with Observations. Model simulations for the U.S. East Coast, Gulf of Mexico, Houston/Galveston and New York/New Jersey harbors have been made and results were compared with observations. The following shows examples of comparison for East Coast simulations during November 1995 through October 1996.

In these simulations, tidal inputs at the ocean boundary were not used. Results of subtidal water levels were compared with observations at 12 NOS NWLON stations from Portland, MN to Fort Pulaski, GA were made over the 12-month period. Fig. 5a, 5b and 5c show examples of the water level comparisons. On an average, the subtidal RMS difference between forecast and observation is about 14 cm, the correlation coefficient is about 0.7, and the forecasts have a success rate of about 55% at predicting high and low water events greater than two standard deviations.

C. Issues Regarding Data Comparison. Several issues have raised from the data comparison. These are:

a. Data quality - Since the observed data are considered as ground truth, good quality is of paramount importance. Common factors that could affected the data quality are:

. Data gaps. Backup measurements have shown to be very useful in this situation.

. Locations of observation stations. Majority of the NWLON stations are not directly exposed to the ocean (i.e. at the coastal boundary of the East Coast Ocean Model). This could cause differences in phase and amplitude of water level variations. Unless this problem is solved (e.g., a proof of the existence of these difference), the fitness of using the East Coast Ocean model outputs as open boundary conditions for the harbor/bay model exists. Presently method of using GPS technology to measure water levels from buoy stations at harbor/bay entrance are being developed to resolve this problem.

b. Initiation conditions - The experimental simulations of the East Coast Ocean model did not re-initialize for each daily run. This could affect the model performance. A restart procedure using nowcast results is being developed which shall improve the forecasts.

c. Data assimilation - Presently, SST data are being assimilated in the East Coast Ocean model. Procedures for assimilating altimeter-derived sea surface heights and NWLON water level measurements are also being developed. To implement the nowcast and data assimilation procedures, requirement of real-time data access is becoming increasingly important.

d. Optimal observation network - The question of what is the optimal network design has arisen due to increasing use of observation data in ocean forecast. This has been studied for meteorological networks [6]. The subject is currently being investigated at NOS.

e. Water current data - Up to now, efforts have been concentrated on the validation of water level predictions. Equally important to NOS applications is the verification of the model's capability in predicting currents. The amount and quality of current data required could be significant. To meet this challenge, NOS is working on the development of synoptic sensing technologies such as remote surface current mapping microwave radar and horizontal acoustic Doppler current profiling instrument.

IV. Conclusions

Observation data are used extensively in validating NOS coastal ocean forecast models. The use of data assimilation to improve the forecast is being developed. The existing two NOS observation networks have become important infrastructures for the development of these models.

Several issues arise from recent model validation efforts. The quality of observation data are critically important. Future demands from data assimilation also calls for innovative observation network design and more efficient measurement technology and method.

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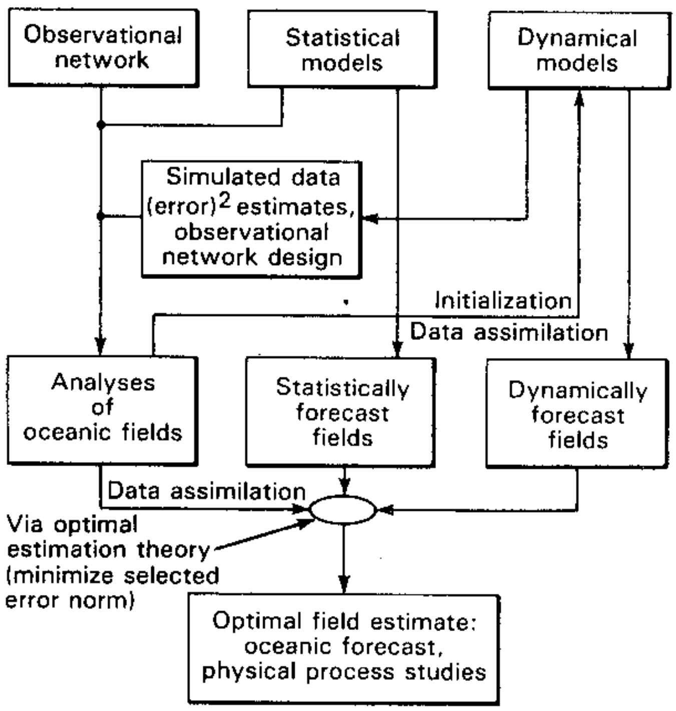

Fig. 1 Schematic diagram of an ocean forecast system [12]

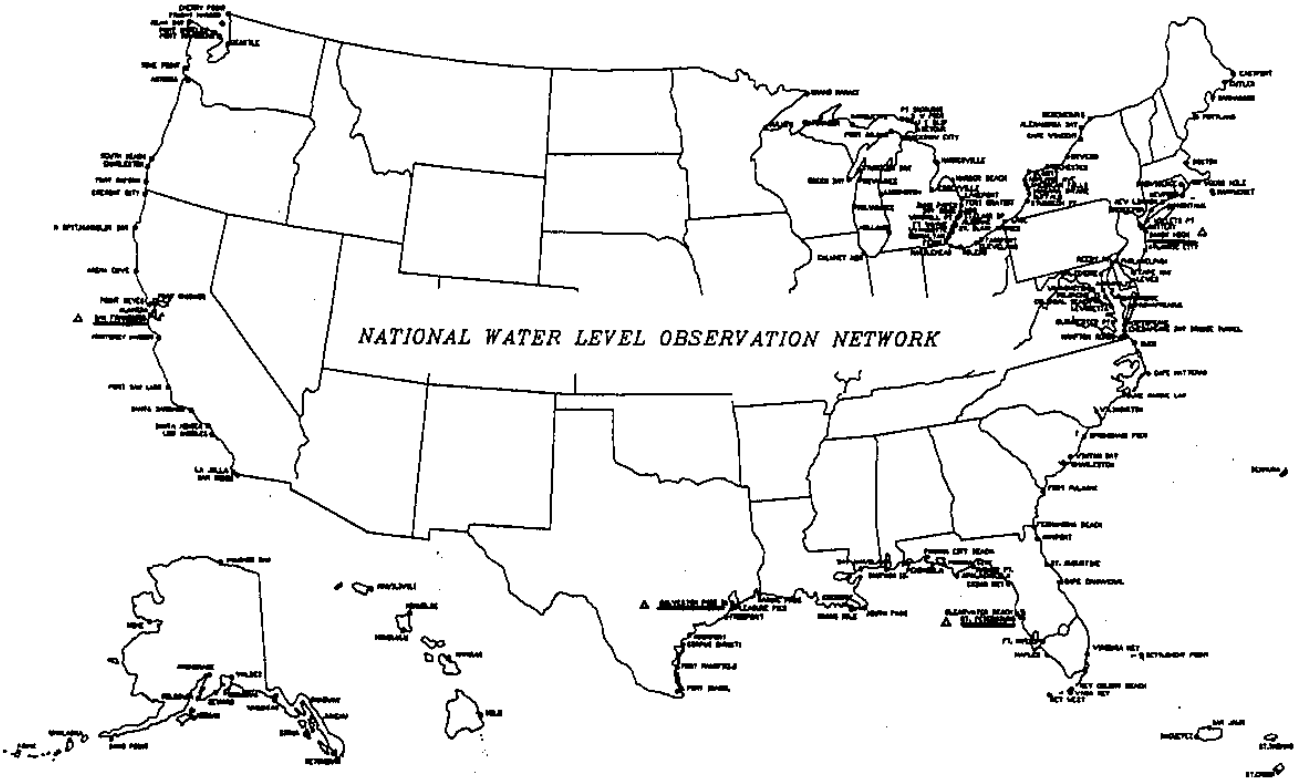

Fig. 2 Site locations of National Water Level Observation Network (NWLON) and Real-Time Physical Oceanography System network (PORTS, underlined sites marked by Δ)

Station	Sensor(s)
1	WV, V, C, M
2, 3	WL, M, ST
4, 9	C, V
5	M
6	C, M
7, 8, 10, 11	WL, M

(C: ADCP current meter
M: meteorological sensor
ST: salinity and temperature
V: visibility sensor
WL: water level
WV: wave)

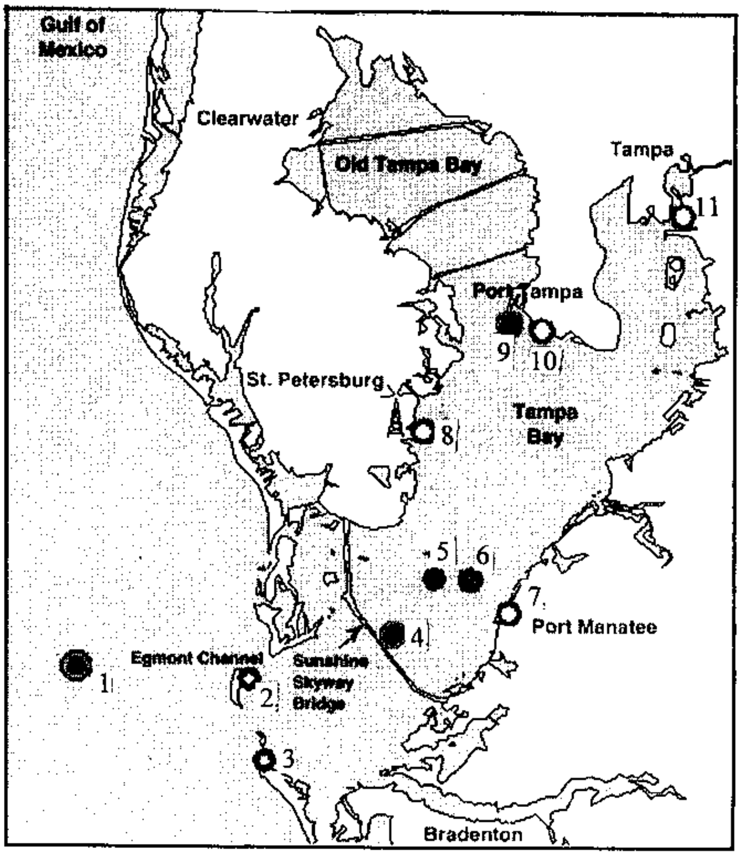

Fig. 3. Layout at the Tampa Bay PORTS observation site

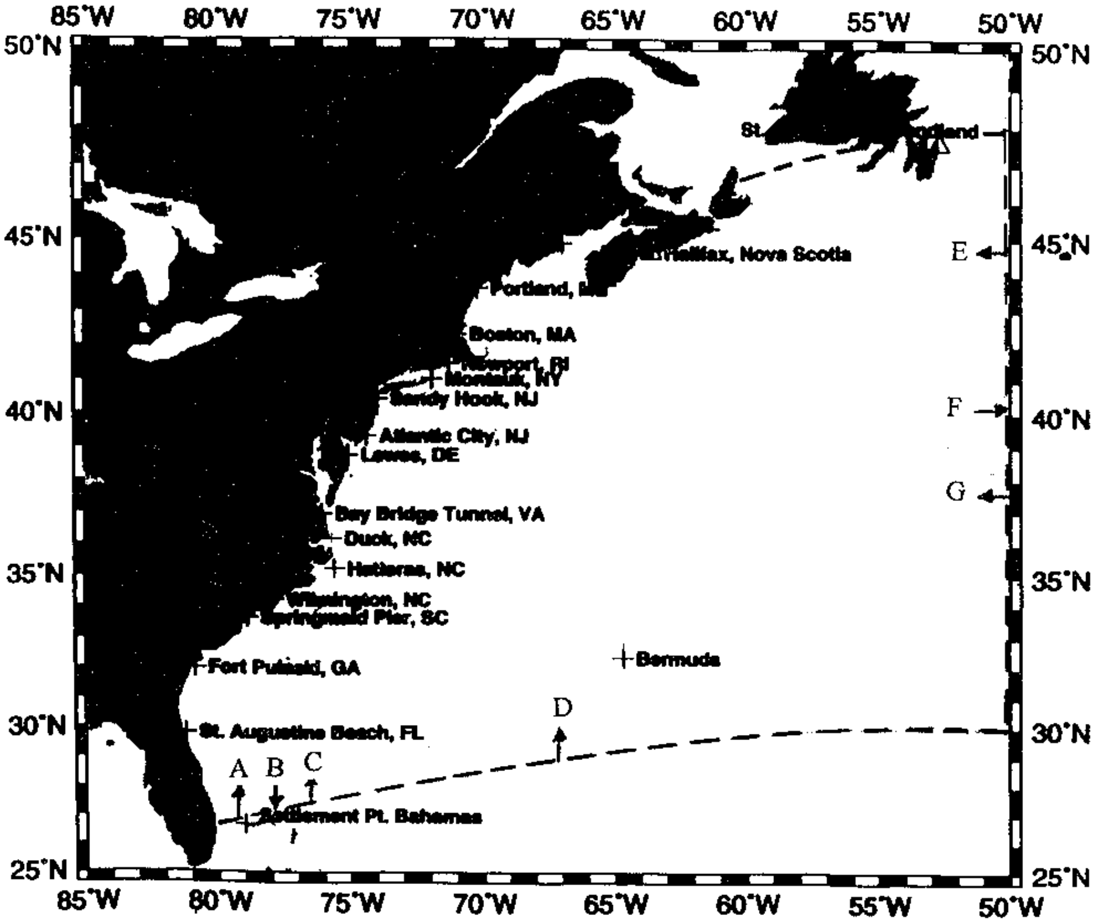

Fig. 4 Model domain and mass transports of the East Coast Ocean Forecast Model (Mass transports: A - 30 Sv, B - 38 Sv, C - 5 Sv, D - 33 Sv, E - 30 Sv, F - 90 Sv, G - 30 Sv, Coastal stations are those used in the water level comparison)

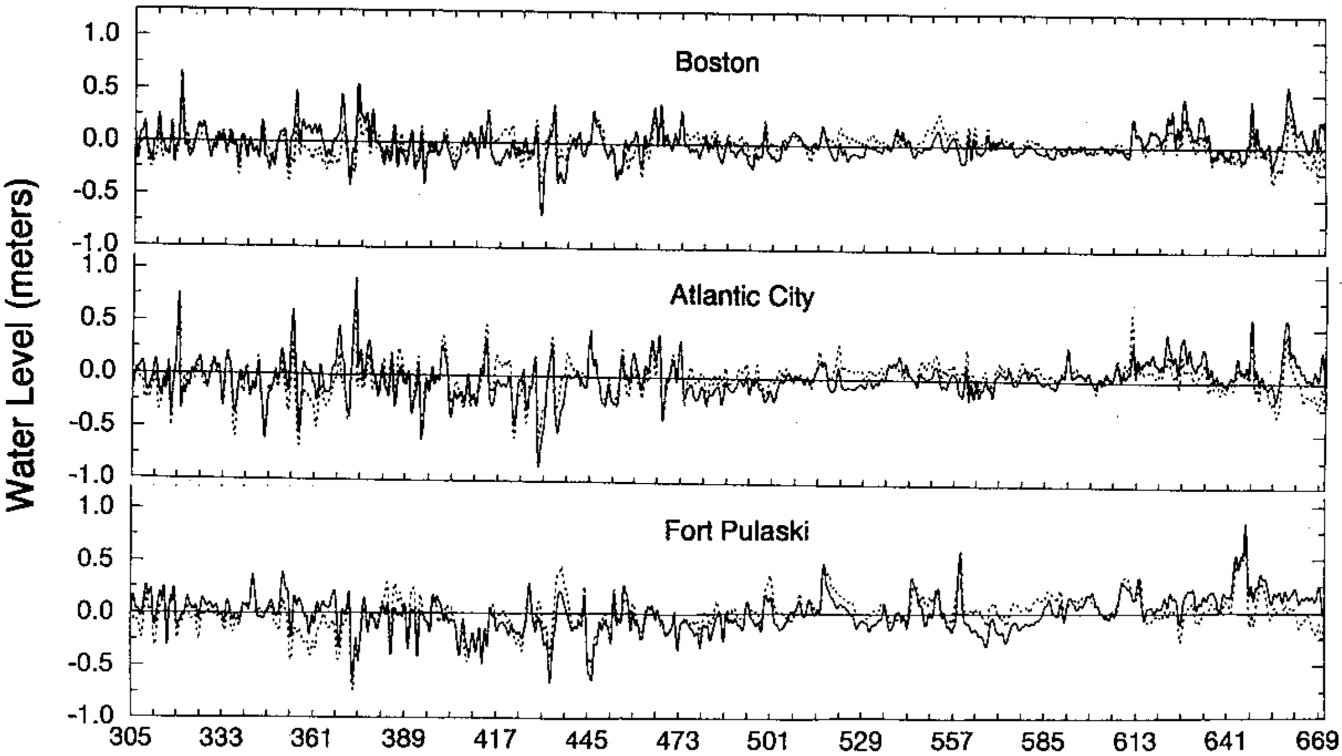

Fig. 5 Sample water level comparisons between model forecasts and observations (a. Boston, MA b. Atlantic City, NJ c. Fort Pulaski, GA, Time in days from Nov. 1, 1995 through Oct. 31, 1996)