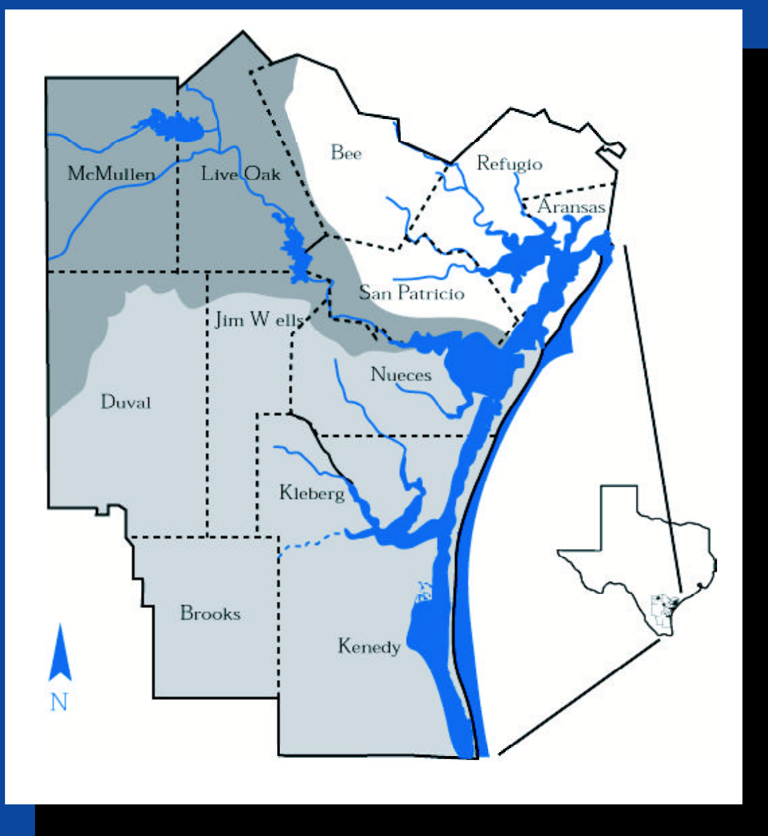
Effects of Structures and Practices on the Circulation and Salinity Pattern of the Corpus Christi Bay National Estuary Program Study Area



Corpus Christi Bay National Estuary Program

CCBNEP-19 • October 1997

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Effects of Structures and Practices on the Circulation and Salinity Patterns of the Corpus Christi Bay National Estuary Program Area, Texas

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CORPUS CHRISTI BAY NATIONAL ESTUARY PROGRAM

The Corpus Christi Bay National Estuary Program (CCBNEP) is a four-year, community based effort to identify the problems facing the bays and estuaries of the Coastal Bend, and to develop a long-range, Comprehensive Conservation and Management Plan. The Program's fundamental purpose is to protect, restore, or enhance the quality of water, sediments, and living resources found within the 600 square mile estuarine portion of the study area.

The Coastal Bend bay system is one of 28 estuaries that have been designated as an **Estuary of National Significance** under a program established by the United States Congress through the Water Quality Act of 1987. This bay system was so designated in 1992 because of its benefits to Texas and the nation. For example:

- Corpus Christi Bay is the gateway to the nation's sixth largest port, and home to the third largest refinery and petrochemical complex. The Port generates over $1 billion of revenue for related businesses, more than $60 million in state and local taxes, and more than 31,000 jobs for Coastal Bend residents.
- The bays and estuaries are famous for their recreational and commercial fisheries production. A study by Texas Agricultural Experiment Station in 1987 found that these industries, along with other recreational activities, contributed nearly $760 million to the local economy, with a statewide impact of $1.3 billion, that year.
- Of the approximately 100 estuaries around the nation, the Coastal Bend ranks fourth in agricultural acreage. Row crops -- cotton, sorghum, and corn -- and livestock generated $480 million in 1994 with a statewide economic impact of $1.6 billion.
- There are over 2600 documented species of plants and animals in the Coastal Bend, including several species that are classified as endangered or threatened. Over 400 bird species live in or pass through the region every year, making the Coastal Bend one of the premier bird watching spots in the world.

The CCBNEP is gathering new and historical data to understand environmental status and trends in the bay ecosystem, determine sources of pollution, causes of habitat declines and risks to human health, and to identify specific management actions to be implemented over the course of several years. The 'priority issues' under investigation include:

- altered freshwater inflow
- declines in living resources
- loss of wetlands and other habitats
- bay debris
- degradation of water quality
- altered estuarine circulation
- selected public health issues

The **COASTAL BEND BAYS PLAN** that will result from these efforts will be the beginning of a well-coordinated and goal-directed future for this regional resource.

STUDY AREA DESCRIPTION

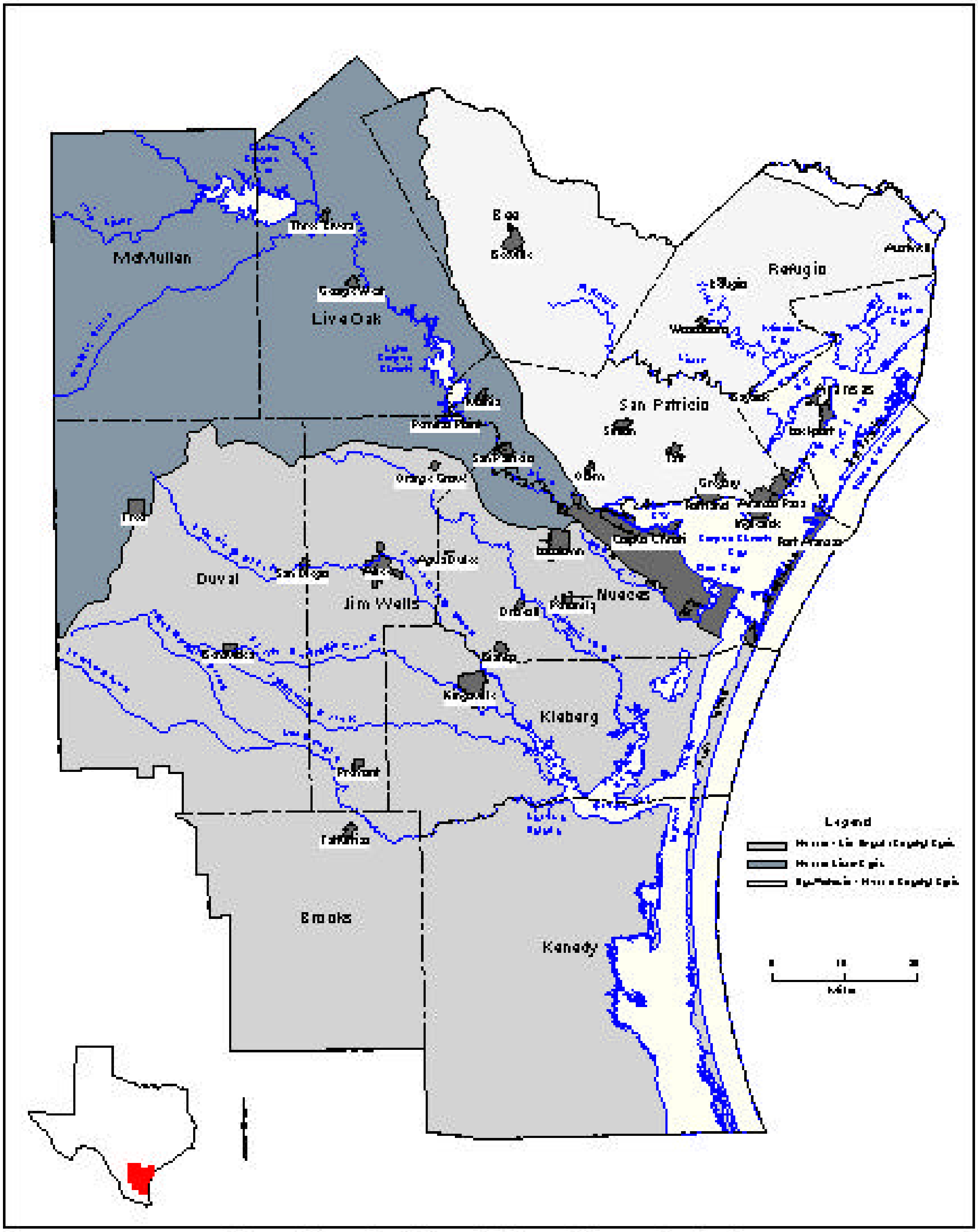
The CCBNEP study area includes three of the seven major estuary systems of the Texas Gulf Coast. These estuaries, the Aransas, Corpus Christi, and Upper Laguna Madre are shallow and biologically productive. Although connected, the estuaries are biogeographically distinct and increase in salinity from north to south. The Laguna Madre is unusual in being only one of three hypersaline lagoon systems in the world. The study area is bounded on its eastern edge by a series of barrier islands, including the world's longest -- Padre Island.

Recognizing that successful management of coastal waters requires an ecosystems approach and careful consideration of all sources of pollutants, the CCBNEP study area includes the 12 counties of the Coastal Bend: Refugio, Aransas, Nueces, San Patricio, Kleberg, Kenedy, Bee, Live Oak, McMullen, Duval, Jim Wells, and Brooks.

This region is part of the Gulf Coast and South Texas Plain, which are characterized by gently sloping plains. Soils are generally clay to sandy loams. There are three major rivers (Aransas, Mission, and Nueces), few natural lakes, and two reservoirs (Lake Corpus Christi and Choke Canyon Reservoir) in the region. The natural vegetation is a mixture of coastal prairie and mesquite chaparral savanna. Land use is largely devoted to rangeland (61%), with cropland and pastureland (27%) and other mixed uses (12%).

The region is semi-arid with a subtropical climate (average annual rainfall varies from 25 to 38 inches, and is highly variable from year to year). Summers are hot and humid, while winters are generally mild with occasional freezes. Hurricanes and tropical storms periodically affect the region.

On the following page is a regional map showing the three bay systems that comprise the CCBNEP study area.



Corpus Christi Bay National Estuary Program Study Area

TABLE OF CONTENTS

TABLES

FIGURES

Table of Contents

Effects of Structures and Practices on the Circulation and Salinity patterns of Corpus Christi Bay National Estuary Program Area, Texas

EXECUTIVE SUMMARY

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The objective of this project is to characterize the effects of existing structures and practices on the circulation and salinity patterns of the Corpus Christi Bay National Estuary Program (CCBNEP) study area. These structures and practices are those which would be expected to exert major influence on estuarine circulation and mixing processes, influencing the transport of salts, sediments, nutrients, and planktonic life within the estuary.

The Texas Water Development Board's (TWDB) hydrodynamic and conservative transport model, TxBLEND, was applied to five case studies: (a) the effect of recirculating large volumes of bay water used for cooling at electric power generating plants, (b) the effect of JFK Causeway on water exchange and circulation in the adjacent bay areas, (c) the effect of Corpus Christi's deep navigation channel on bay-wide circulation and salinity patterns, (d) the effect of the freshwater inflow diversions taken from the Nueces River, and (e) the effect of all impacts, the combination of the above four cases.

The CCBNEP study area is a complicated system of bays and waterways including three major estuarine systems. The Nueces Estuary consists of Nueces Bay, Nueces River, Oso Bay, Oso Creek, and Corpus Christi Bay. The Mission-Aransas Estuary consists of Copano Bay, Aransas Bay, St. Charles Bay, Mesquite Bay, Aransas River, Mission River, Copano Creek, Salt Creek, and Cavaso Creek. The upper Laguna Madre Estuary consists of upper Laguna Madre, Baffin Bay, San Fernando Creek, and Los Olmos Creek. The southern boundary of the study area is the Landcut of the Laguna Madre. The northern boundary is the northern edge of Mesquite Bay. The Corpus Christi Ship Channel is the main ship channel connecting Corpus Christi Bay to the Gulf of Mexico and Aransas Bay via Lydia Ann Channel. The Aransas Channel cuts through Redfish Bay from the entrance, and the Gulf Intracoastal Waterway (GIWW) runs north-south through the extent of the study area. The bathymetry is mainly shallow, three to five feet for the secondary bays, ten to fifteen feet for the primary bays. Navigation channels are deeper: the Corpus Christi Ship Channel is 45 feet deep and the GIWW is 15 feet in depth.

TxBLEND, a two-dimensional finite element model for simulating water circulation and salinity distribution in bays and estuaries, is based on the generalized wave continuity equation which

contains a numerical parameter G (or bigG) to enhance the mass conservation property. The model is computationally efficient and capable of simulating the wetting and drying process of tidal flats. Inputs to TxBLEND include data on the finite element grid, bathymetry, tides, wind, evaporation, precipitation, river inflow, and salinity. The finite element grid employed in this study consists of 4917 nodes and 8191 (linear triangular) elements, the finest grid used in TDWB estuary modeling to date. Baseline bathymetric information was collected from NOAA Nautical Charts. Adjustments in the upper Laguna Madre area incorporate findings of the 1995 survey of Laguna Madre conducted by the Corps of Engineers. Tides recorded at the Bob Hall Pier NOAA tide gage were used to drive the model. The tides recorded at gages inside the bays, part of the Texas Coastal Ocean Observation Network (TCOON) administered by the Texas General Land Office and the TWDB, were used to calibrate the model. Precipitation and wind data were compiled from the database developed by the National Climatic Data Center. Evaporation rates were estimated from temperature and wind speed. The combined inflow is the sum of gaged inflow, ungaged inflow, return flow and diversion. Ungaged inflows were estimated using a TWDB rainfall-runoff model. Diversion and return flow data were compiled from TNRCC records.

Data from years 1987, 1988, 1989, 1991, and 1992 were used for model calibration as well as for test cases. During 1987 there was a flood of the Nueces River in June; years 1988 and 1989 were dry years; 1991 and 1992 were wet years. The model was first calibrated to hydrodynamic data and then to salinity data. Data collected during the intensive inflow studies were used in model hydrodynamic calibration, including August 1987 Corpus Christi Bay Intensive Inflow Study (IIS), August 1988 Aransas Bay and Copano Bay IIS, June 1991 Laguna Madre IIS, and June 1994 Corpus Christi Bay IIS.

Salinity data from the TWDB DataSonde Program were used for salinity calibration because they constitute long-term series of frequently recorded values. Changes in salinity within a bay system typically take a much longer time to occur than do changes in velocities and tidal elevations. Thus, reliable salinity calibration requires simulation of longer periods. The 1987 DataSonde series of salinity data from mid Nueces Bay and Corpus Christi Bay was used to calibrate the CCBNEP model because salinity changes associated with the June flood and subsequent salinity recovery were captured clearly in this set. Other salinity data series contributing to calibration were from sites at the Copano Bay Causeway, mid Aransas Bay, at a site just below the JFK Causeway in the GIWW and at the mouth of Baffin Bay in the GIWW.

Model Application to Five Case Studies

The existing condition, which includes two structures and three practices, was used as a bench mark for comparative analysis of the effects of each and all of the structures and practices. In the first four scenarios, one structure or one or more practices was removed from the existing condition, allowing differences in circulation and salinity patterns to be examined. In the final scenario, all structures and practices were removed from the model and a comparison was made between the existing circulation and salinity patterns and those that may have existed before the structures and practices were constructed or begun. Two simulations of roughly two years duration, 1988-1989 representing dry period and 1991-1992 for wet period, were used for comparisons.

Scenario 1: Effect of Withdrawal of Seawater by Power Plants

The Barney Davis Power Plant withdraws seawater from Laguna Madre near Pita Island for cooling and releases it into Oso Bay. The average monthly plant discharge over the five year period from 1988 to 1992 was about 40 thousand ac-ft or 660 cfs. The Nueces Bay Power Plant takes seawater from the Corpus Christi Ship Channel for cooling and discharges it into Nueces Bay. The average monthly plant discharge over the same five-year period was about 30 thousand ac-ft or 500 cfs.

Simulation results show that the effect of power plant operation is to equalize salinities in the bay near the intake area and discharge areas. When Nueces Bay was fresh because of flooding by the Nueces River, the cooling water withdrawn from the ship channel and discharged into the Nueces Bay raised Nueces Bay salinity, because the salinity in the ship channel was much higher than the salinity of Nueces Bay. At mid Nueces Bay, the simulated salinity was as much as 6‰ lower under the 'no cooling water withdrawal' scenario in April 1992 — a very wet month — than was actually observed. When salinities were not extremely low but were less than normal marine conditions (35‰) in Nueces Bay, the effect of the cooling water discharge was to slightly raise salinity at the calculation point in Nueces Bay. Most of time the largest salinity differences in Nueces Bay were limited to the area immediately adjacent to the discharge point. When Nueces Bay became hypersaline, the salinity in the ship channel was lower than the salinity in Nueces Bay and power plant discharge lowered Nueces Bay salinity. This could be seen during the latter part of 1989, although the difference was small, less than 1‰.

At the middle of Corpus Christi Bay, during periods of lower salinity (less than 25‰), the effect of the Nueces Bay Power Plant cooling water circulation was to raise the salinity by less than 3‰. The effect diminishes as salinity level increased to 35‰. Under hypersaline conditions, the effect of the cooling water diversion was to slightly lower the salinity at the Corpus Christi Bay calculation node.

The same type of salinity amelioration effect occurred in Laguna Madre. When hypersaline conditions occurred in the Laguna Madre, withdrawal of cooling water was replaced by Corpus Christi Bay water which lowered the Laguna's salinity. Withdrawal by the Barney Davis Power Plant increased the flow from both north and south in the Laguna Madre, but the flow from Corpus Christi Bay was lower in salinity, and this reduced the Laguna Madre salinity near the power plant. The largest difference was 2.4‰ at the JFK Causeway site in June 1989. A similar effect occurs when Laguna Madre salinity was below about 30‰. In the 1992 wet period, the salinity at the JFK Causeway site was lower by as much as 1.7‰ if the power plant did not withdraw cooling water. Oso Bay salinity becomes independent of Laguna Madre salinity without power plant operation. The effect of power plant operation was also felt in Baffin Bay, but the magnitude was generally small, less than 1‰.

For 1988-1989 existing conditions, about 9000 ac-ft per day passed through the Humble-JFK/GIWW cross section toward the power plant area and about 5000 ac-ft per day flowed back to the north. Of the 4000 ac-ft difference, about 2000 ac-ft per day flowed further south toward Baffin Bay and was lost to evaporation. Most of the remaining flow probably went through the power plant. If the cooling water diversion had not been in operation in 1988-1989, about 8000 ac-ft per day would have flowed through the Humble-JFK/GIWW cross section southward and 6000 ac-ft per day would have flowed back to the north. The difference of about 2000 ac-ft per day would be lost to evaporation. Flows through the Humble-JFK/GIWW cross section simulated for the 1988-1989 period were similar to the 1991-1992 simulated flows, but the 1991-1992 evaporation (net evaporation) was close to zero.

Average flows for the Pita-GIWW section representing the flow across Laguna Madre south of the Barney Davis Power Plant showed nearly the same flows for the existing condition and for the ‘no power plant operation’ case. This suggests that on average most of the water for power plant operation comes from Corpus Christi Bay.

Except during very wet periods, the spatial extent of the effect of the withdrawal and discharge of seawater for Nueces Bay cooling water from the Corpus Christi Ship Channel into Nueces Bay was limited. There was virtually no effect in Corpus Christi Bay nor in the bays to the north. Even in Nueces Bay, the effect of the cooling water discharge was limited to the area adjacent to the discharge point. In contrast, the spatial effect of Barney Davis cooling water circulation was extensive in the upper Laguna Madre although the magnitude of the change was not great. During periods of hypersaline conditions, cooling water circulation reduced Laguna Madre salinity by 1‰ to 2 ‰ from the JFK Causeway to a point two-thirds of the way to Baffin Bay.

Residual vectors indicated that the net movement of water (or net flow) in the Corpus Christi Bay-Upper Laguna Madre part of the system was driven by power plant operation. The Corpus Christi Ship Channel carried water for the Nueces Bay Power Plant. This water returned to Corpus Christi Bay through the channel under the Nueces Causeway, then moved along the north shore of the bay and rejoined the ship channel near Ingleside. Net flow also traveled south, starting at the headway of the ship channel, along south shore of Corpus Christi Bay and entered Laguna Madre through the pass near the Naval Air Station and the GIWW. It moved further south through Humble Channel and the GIWW at JFK Causeway toward the Barney Davis Power Plant. Then, as the water was withdrawn by the power plant near Pita Island and discharged to Oso Bay, the net flow moved through Oso Bay toward Corpus Christi Bay. Another loop was formed with flow from the head of the ship channel toward mid Corpus Christi Bay south of the ship channel. It rejoined the ship channel near Ingleside. Thus there were two loops formed, one north and one south along the ship channel. The residual vectors in Laguna Madre and Oso Bay indicated that a major part of the water in that circulation comes from Corpus Christi Bay through both the GIWW and Humble Channel, and moved toward the intake site of the power plant.

Scenario 2: Effect of River Diversions

The purpose of Scenario 2 was to examine the effect of diversions taken from the Nueces River and associated return flows to areas in Corpus Christi and Nueces bays. The effect of these practices was tested through comparison with their simulated absence. Removal of these practices was simulated by increasing the river inflows during the model runs by the amounts of the diversions. A word of caution is necessary here. Most of the water diverted during the dry period was probably water released from Lake Corpus Christi specifically allocated for municipal and industrial uses and withdrawn at Calallen. Addition of this amount of water in the simulation was only to provide an amount of water for the purposes of the analysis. It does not imply that removal of the reservoir or cessation of upstream water uses would result in this quantity of water being restored to Nueces River flow in any specific month.

The inflows for the 'no diversion' scenario were computed by adding back to the river the diversions taken from Nueces River including withdrawals at Calallen for the City of Corpus Christi, San Patricio M.W.D., Koch Refinery, Hoechst Celanese, and Nueces County WCID #3, and not adding the return flows to Nueces Bay and Corpus Christi Bay. Over the five-year period, 1988 through 1992, 125 thousand ac-ft per year were diverted, and of that, 99 thousand ac-ft were for the City of Corpus Christi. A yearly average return flow over the same period was calculated to be 38 thousand ac-ft. Therefore, the average annual difference between the diversion and no diversion cases was 87 thousand ac-ft. On a monthly basis, the net diversion ranged from 4 thousand to 10 thousand ac-ft per month. This volume was not significant during wet periods but was very significant during dry periods like 1988 and 1989. For some months the diversions were as much as eight times the river inflow.

Results of comparative analysis showed the effect of freshwater diversion was limited only to Nueces Bay during both wet and dry periods. However, the influence was stronger during the dry period than the wet period, with salinities as much as 2.2‰ lower in the dry period at mid bay. The influence of the diversion on Corpus Christi Bay was very small, 0.2‰ in the dry period. The volume of water involved, roughly 8 thousand ac-ft per month, was not large enough to make a difference in Corpus Christi Bay but was large enough to influence Nueces Bay where the salinity was consistently 1 to 2‰ lower than in the main bay.

Scenario 3: Effect of the JFK Causeway

Contrary to expectations, the effect of JFK Causeway removal appeared to be minimal. With the simulated removal of this structure, salinity at the JFK Causeway site during the dry period of 1989 was as much as 0.9‰ higher than the existing condition, but no more than 0.4‰ higher in the wet period of 1992. In the dry years represented by the 1988-1989 simulation, the flows to the south at the NAS-GIWW section increased only 4%. The magnitude of the additional flow to the south (300 ac-ft per day) was approximately equal to the additional flow to the north (290 ac-ft per day), but the higher salinity of the water from the south resulted in a net salinity increase. The small increase in flows to the Laguna Madre was the cause of the small change in salinity at the site.

In the wet years represented by the 1991-1992 simulation, the flows to the south at the NAS-GIWW section increased about 4% without the Causeway. The magnitude of the additional flow to the south (340 ac-ft per day) was larger than the additional flow to the north (240 ac-ft per day). As a result, the larger volume of higher salinity water flowing from the north slightly increased the salinity.

The Pita-GIWW cross section did not show much salinity change during either wet or dry years. In wet years, the north and south flows balanced; in the dry years, the average daily flow to the north (190 ac-ft per day) was greater than the flow to the south (100 ac-ft per day), but the volume of the higher salinity water from the south must not have been great enough to significantly change the salinity.

The spatial extent of the salinity differences with respect to JFK Causeway removal for the August 1989 simulation showed that two areas were affected by the removal, the Laguna Madre area and Oso Bay. The salinity increase in Oso Bay was the result of the operation of the Barney Davis Power Plant which pumped water of slightly higher salinity (due to causeway removal) from Laguna Madre. The water was discharged into Oso Bay, thereby increasing Oso Bay salinity. Similarly to the dry period, the effect on salinity during the wet period was limited in magnitude, but more areas were shown to be affected. Corpus Christi Bay was 0.2 to 0.4‰ higher; Oso Bay was also higher by 0.5‰ or less.

Scenario 4: Effect of the Corpus Christi Ship Channel

The purpose of Scenario 4 was to examine the effect of the Corpus Christi Ship Channel. The effect was studied by changing the bathymetries of the channel (45 feet) to depths similar to the surrounding areas, mostly 10 to 12 feet.

The long-term salinity simulations for the 1988-1989 dry period showed that salinities in Nueces and Corpus Christi bays, at the JFK Causeway, and near the Naval Air Station and Pita Island were elevated 1 to 3 ‰ by removal of the channel. In Aransas Bay and Copano Bay salinity levels did not change significantly.

The 1991-1992 wet period salinities were generally slightly lower in all the bays with removal of the ship channel. The greatest effects were seen in Corpus Christi and Aransas bays where salinities in some months were more than 3‰ lower. The effect of the channel was noticeable as far away as Baffin Bay where salinities were as much as 2‰ lower without the channel. The effect of the Corpus Christi Ship Channel generally was to reduce the magnitude and duration of the high salinity periods and low salinity periods. Without the ship channel, the salinity during the 1989 dry period was 1‰ to 3‰ higher in bays other than Baffin and Aransas bays; during the 1992 wet period, salinity was lower in those areas by more than 3‰.

Decreasing depth of the Entrance Channel greatly reduced the flows in the Entrance Channel to about one-quarter of the existing volume**.** Flow volumes were decreased to one-sixth present levels at the Corpus Christi Ship Channel near Brown & Root, and to one-third the volume exchanged at the Nueces Causeway. Flows at Lydia Ann Channel were reduced to about half of present levels. Water exchange was also reduced by channel removal in the southern portion of the system. Flows were reduced to two-thirds to half at the NAS-GIWW, Humble-JFK/GIWW, and Pita-GIWW sections, with some asymmetry of inward and outward effect.

Scenario 5: All Impacts Removed
The purpose of Scenario 5 was to study the cumulative effect of all structures and practices, including fresh water diversions, power plant operations, the JFK Causeway, and the Corpus Christi Ship Channel. The effects were evaluated through comparison of present flows and salinities with 'naturalized' conditions simulated by putting the diverted flow back into the Nueces River, by not taking seawater for cooling, by removing the JFK Causeway, and by removing the ship channel in the model.

The effect of all structures and practices impacts was strongest on Nueces Bay. The compound effects of increased inflow due to the return of diverted water to the Nueces River and the reduced tidal exchange through the Nueces Causeway due to the removal of Corpus Christi Ship Channel caused large salinity differences. The salinity of mid Nueces Bay was lowered by 3‰ to 4‰ during the 1989 dry period, and by 5‰ to more than 11‰ during the wet period of 1992.

Compound effects were also seen at the JFK Causeway site at the GIWW. The 'no use of cooling water by power plant' scenario by itself raised salinity by 2.4‰ during June and July of 1989. Coupled with the reduction in tidal exchange of this scenario, salinity increased by 2.5‰ to 3.4‰ during the same period. Note that increased salinities occurred when the climatic regime set up generally hypersaline conditions (above 35‰). When salinities were moderate, mesohaline, the scenario with all structures and practices removed produced salinities slightly below existing salinities. During May 1992, a wet period, the 'all impacts removed' scenario lowered the salinity by as much as 5.0‰, which was greater than the combination of the 'no cooling water' case (lower by 1.7‰) and the 'no ship channel' case (lower by 2.6‰) taken together. The Naval Air Station and Pita Island stations showed the same patterns of elevated and decreased salinity as the JFK Causeway site.

In mid Corpus Christi Bay, scenario salinities were slightly higher than existing salinities when salinity conditions were above normal marine levels, and slightly below existing salinities when conditions were lower than normal marine salinities. This was the result of the reduced tidal exchange with the channel removal. During the August 1989 dry period, the effects of the scenario raised salinity by 0.8‰, while during the 1992 wet period it lowered the salinity by as much as 6.3‰.

The net flow patterns under the 'all impacts removed' case were very different from those of the existing condition. The magnitude of net movement was also much smaller than those of existing conditions. Flow enters Nueces Bay through a deeper part of the channel under the Nueces Causeway and exited through a shallow part of the same pass. It then traveled along the north shore of Corpus Christi Bay. Near the south end of the Nueces Causeway the net flow started moving south along the shore line, entered Laguna Madre through the pass near Naval Air Station, and traveled further south through Humble Channel. At about Pita Island the net flow diminished but the GIWW carried netflow back to Corpus Christi Bay.

Considering the impacts of structures and practices on the waters of the National Estuary Program area, the ship channel had the greatest single effect on water movement and salinity. Its effects were felt in the estuaries to the north and as far south as Baffin Bay. Of lower magnitude with respect to total area affected was the return of diverted water to Nueces Bay. While this practice had a big effect on Nueces Bay, the salinities of other nearby estuaries including Corpus Christi Bay were hardly affected by the diversion. The withdrawal of cooling water from the Laguna Madre for the Barney Davis Power Plant was next on the magnitude scale. The area of the upper Laguna Madre affected by the withdrawal was greater than the area of Nueces Bay, but the salinity change tended to be much smaller than that caused by river diversion. JFK Causeway had an even smaller effect on water movement and salinity. Its impact was largely limited to the area close to the causeway. The effect of power plant cooling water withdrawal and return on Nueces Bay and Corpus Christi Bay from the Nueces Bay Power Plant was localized and of small magnitude except during very wet periods.

I. INTRODUCTION

Background

There are issues concerning the bays and estuaries of the Coastal Bend Region which cannot be understood or resolved from an examination of empirical data or theoretical statements. Among the most important issues are the effects of natural and man-made perturbations on the circulation and salinity patterns of the associated estuarine ecosystems. A solution to the problem is possible through the development of computer models based on fundamental physical principals of water movement and mixing which can be used to simulate the hydrodynamics of bays and estuaries under conditions of interest to decision-makers. Computer models of estuarine water circulation are also valuable to scientists and engineers who need a better way of rigorously testing ideas and communicating results about estuarine ecosystems.

The initial effort at model development and use by the State of Texas focused on the influence of freshwater inflows on the Coastal Bend estuaries (TDWR 1981) and the need to analyze bay segment boundaries (TDWR 1982). These early models were coarse-grid, two-dimensional, finite difference, hydrodynamic and conservative mass transport models that were applied to show net circulation and salinity patterns under static monthly conditions. New modeling techniques are now available that utilize computationally fast, fine-grid, two-dimensional, finite element procedures to produce high-resolution, dynamic simulations of a year or more of estuarine conditions (Longley 1994).

A preliminary study employing one of the newer model formulations was conducted on one problem in Coastal Bend waterways by the Texas Water Development Board (Solis and Matsumoto 1991). The purpose of the study was to investigate the effects of a structure, the JFK Causeway, on local circulation. Although there was not enough hydrodynamic data available at that time to fully calibrate the model, an engineering interpretation of the hydrodynamic results suggested there would be minor increases in tidal exchange and estuarine circulation from elevation of the Causeway. The effect would be small because of the surrounding area's extreme shallowness and the presence of scattered spoil islands that block water exchange between the Laguna Madre and Corpus Christi Bay.

It is not the intent of this CCBNEP project to duplicate the earlier modeling exercises for comparison, but rather to use the additional hydrodynamic and water quality data collected since then to calibrate the Board's "third generation" models for the purpose of greatly expanding the characterization of impacts from existing structures and practices throughout the 550 square mile CCBNEP study area.

Objectives

The objective of this project is to characterize the effects of existing structures (transportation causeways, navigation channels, and Gulf passes) and practices (recirculation of bay waters for industrial cooling and diversion of freshwater inflows and wastewater return flows) on the circulation and salinity patterns of the CCBNEP study area. These structures and practices can potentially alter estuarine circulation and mixing processes, influencing the transport of salts, sediments, nutrients, and planktonic life within the estuary. Another objective of the project is to produce a high resolution, two-dimensional, hydrodynamic model for the entire CCBNEP study area, which can serve as a useful tool for investigating other water-related conditions of interest to decision-makers.

To objectively characterize the effects of structures and practices, the Board's hydrodynamic and conservative mass transport models were calibrated to simulate water movements and salinity gradients in the CCBNEP study area. These models were then applied to five case studies: (a) the effect of recirculating large volumes of bay water used for cooling of electric power generating plants, (b) the effect of JFK Causeway on water exchange and circulation in the adjacent bay areas, (c) the effect of Corpus Christi's deep navigation channel on bay-wide circulation and salinity patterns, (d) the effect of the freshwater inflow diversions taken from the Nueces River, and (e) the effect of all impacts in which the four cases are put together.

It would be appropriate to use a three-dimensional model to study the localized effects of the Corpus Christi Ship Channel in greater detail, to adequately represent the interaction of deep channel waters with shallow bay areas in the context of stratified flow and salinities. However, implementing a three-dimensional model would mean dramatically increased costs at the current stage of hardware and software development. In addition, more data collection would undoubtedly be required in order to calibrate the model. For a good first analysis and understanding of this very large estuarine system, the Board's two-dimensional model is more than adequate. For practical reasons, this analysis does not focus on a detailed study of the Corpus Christi Ship Channel's localized effects at this time; rather, this modeling study and analysis presents an overall picture of estuarine circulation and salinity patterns, based on a two-dimensional representation of the generally shallow, vertically well mixed, Coastal Bend region.

CCBNEP Study Area

The CCBNEP study area (Figure I.1) is a complicated system of bays and waterways including three major estuarine systems. The Nueces Estuary consists of Nueces Bay, where the Nueces River enters; Oso Bay, into which flows Oso Creek; and Corpus Christi Bay. The Mission-Aransas Estuary consists of Copano Bay, Aransas Bay, and St. Charles Bay. Copano Bay receives freshwater from the Aransas River, from the Mission River via Mission Bay, and from Copano Creek which drains into Copano Bay at the northern corner. Salt Creek and Cavaso Creek drain into St. Charles Bay. Both Copano Bay and St. Charles Bay are connected to Aransas Bay. Mesquite Bay lies between the Guadalupe Estuary and the Mission-Aransas Estuary. The upper Laguna Madre Estuary consists of the upper Laguna Madre, adjacent to Corpus Christi Bay, and Baffin Bay, which receives discharge from San Fernando Creek and Los Olmos Creek. The southern boundary of the study area is the Landcut of the Laguna Madre. The northern boundary is the northern edge of Mesquite Bay.

Waters of the study area are connected by channels and passes. The Corpus Christi Ship Channel is the main ship channel connecting Corpus Christi Bay to the Gulf of Mexico. Lydia Ann Channel connects Aransas Bay with the Entrance Channel. The Aransas Channel cuts through the Redfish Bay from the entrance. The Gulf Intracoastal Waterway (GIWW) runs throughout the study area from Mesquite Bay near the Aransas National Wildlife Refuge through Aransas Bay, Redfish Bay, Corpus Christi Bay, and continues south through the Laguna Madre. The bathymetry is mainly shallow, three to five feet for the secondary bays, ten to fifteen feet for the primary bays, but the Corpus Christi Ship Channel is 45 feet deep and the GIWW is 15 feet in depth (Figure I.2).

The Barney Davis Power Plant is located near Laguna Vista, withdraws cooling water from Laguna Madre and returns this water to Oso Bay. The Nueces Bay Power Plant is located near Nueces Bay, withdraws cooling water from the Corpus Christi Ship Channel in the harbor and returns it to Nueces Bay. The JFK Causeway is located in Flour Bluff, connecting the mainland and Padre Island.

Previous Studies

Duke (1990) provided a survey of historical information on the Laguna Madre and conducted a modeling study of the hydrodynamic implications of opening the JFK Causeway. From review of historical maps, he found deeper waters along the mainland shoreline and suggested the best place to open the causeway would be on the west side of the Humble Channel. He modeled area circulation to determine whether additional exchange would occur between the Laguna Madre and Corpus Christi Bay if additional openings were placed under the causeway. Duke used an early version of the TxBLEND two-dimensional finite element model, but reported difficulty with conservation of mass and stated doubts concerning results of the modeling study.

Solis and Matsumoto (1991) conducted a modeling study of the JFK Causeway opening. Solis investigated the question of the mass conservation raised by Duke and concluded the continuity errors were most likely due to use of an inadequate finite-element grid and suggested a more refined grid. Matsumoto studied the causeway openings by constructing a larger model which included the northern Laguna Madre, Baffin Bay, Nueces Bay, and Corpus Christi Bay. His analysis indicated a 4 to 5% increase in the flow exchange under various alternatives.

Brown, Militello, and Kraus (1995) studied the same JFK Causeway openings using a two-dimensional finite difference model, M2D. They compared differences in velocities with and without the project, and found the majority of differences to be in the range of 1 to 3 cm/s. This is significant because the ambient velocity of water movement is on the order of 5 cm/s. They recommended creating an opening in the causeway 5000 feet in width, near and including the Humble Channel.

Whitledge (1993) conducted an enhanced hydrographic survey of Nueces Bay. He monitored temperature, salinity, nutrients, and plant pigments in the area near the Central Power and Light

Company (CPL) cooling water discharge channel as well as in other parts of Nueces Bay. Monthly samples were collected from February 1991 through December 1991. He concluded that there is little, if any, effect of the CPL discharge on the circulation in the upper and central portions of Nueces Bay. The CPL discharge has salinity, temperature, dissolved inorganic nitrogen and phosphorus concentrations that are greater than ambient Nueces Bay levels. However, the area of enhanced concentrations is frequently very small and does not extend beyond the local area where the discharge occurs.

McArthur (1996) applied the SWIFT2D model, a two-dimensional hydrodynamic and transport model developed by USGS, to the upper Laguna Madre and compared the results with those simulated by TxBLEND. He found that simulated water surface elevations, velocities, and circulation patterns were comparable. On the basis of this application he also found TxBLEND is computationally more efficient. This is mainly because of the modeling restriction inherent in the finite difference models. If a modeler wants to model the GIWW in reasonable detail and the study area is as large as upper Laguna Madre, the number of computational cells becomes exceedingly large. McArthur used 200-meter grid cells and approximately 15,000 active computational cells. The TxBLEND model for CCBNEP covers more area than SWIFT2D-Laguna Madre model and yet is modeled by 8191 elements. (It should be noted that a simple comparison of grid size is not a complete measure of computational efficiency since the finite different scheme usually requires less computation per iteration.)

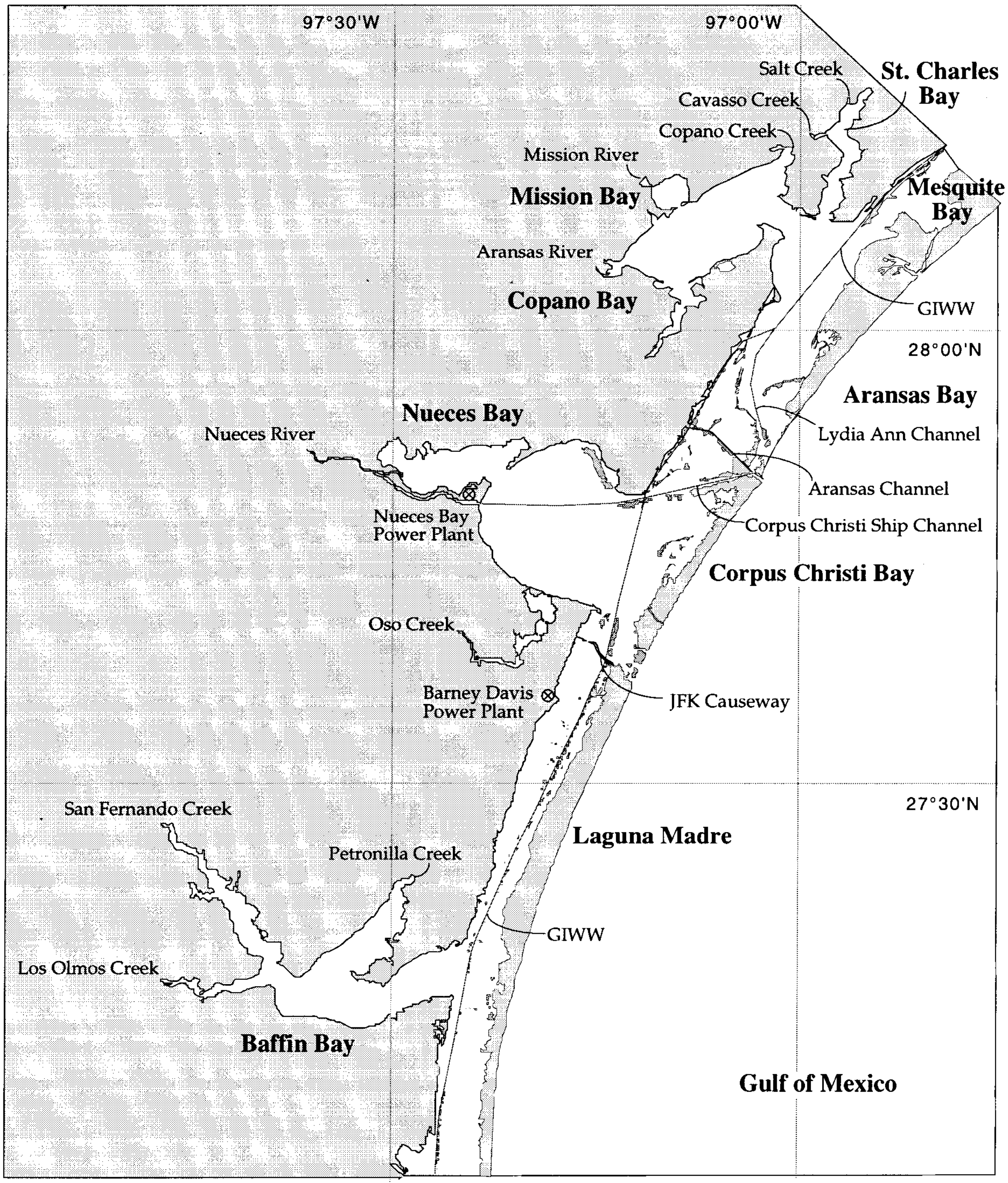


Figure I.1 The Corpus Christi Bay National Estuary Program Study Area

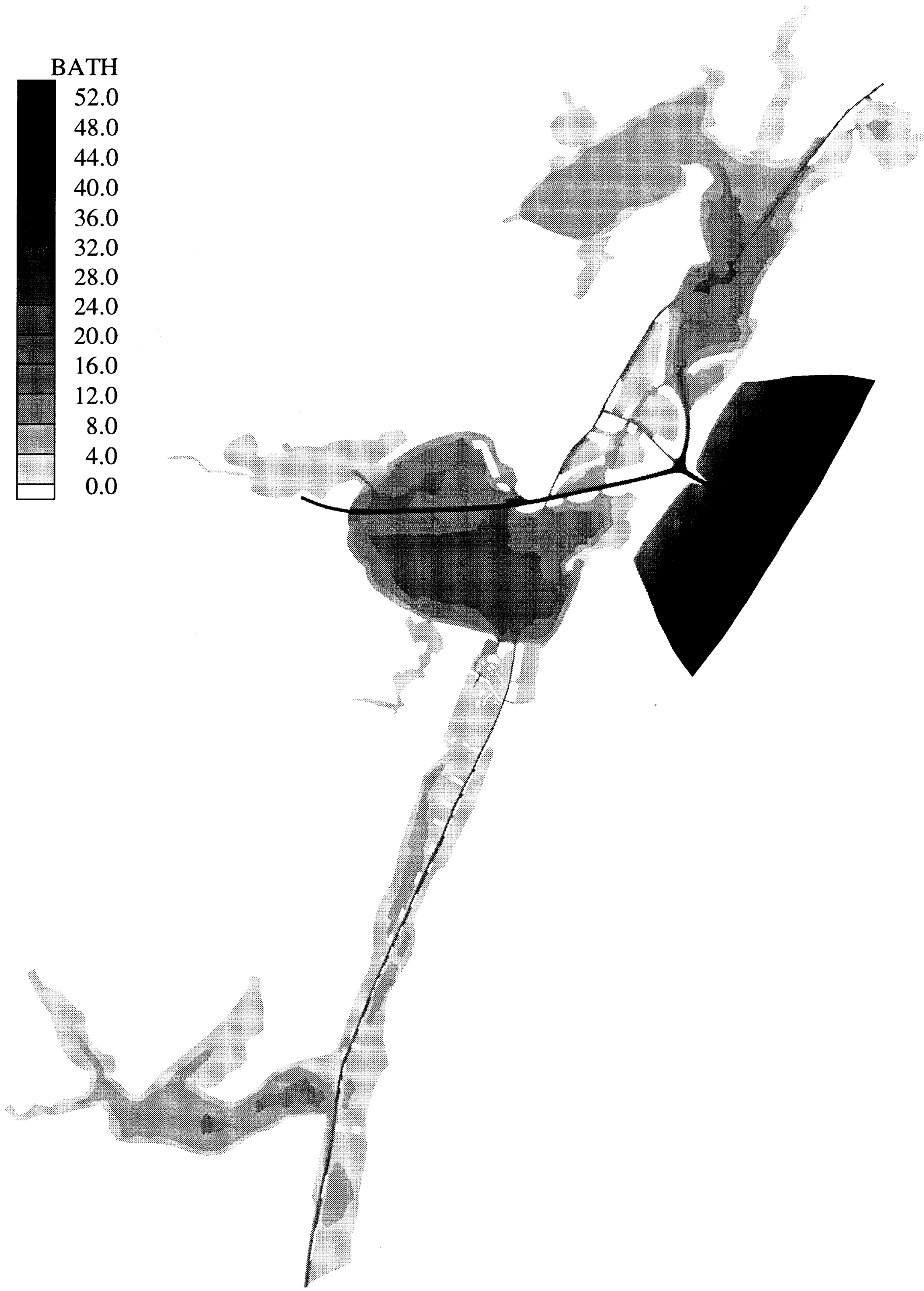


Figure I.2 Bathymetry (ft) of the CCBNEP study area

Table of Contents

II. TxBLEND MODEL AND INPUT DATA

TxBLEND Model

TxBLEND is a two-dimensional finite element model for simulating water circulation and salinity distribution in bays and estuaries. The model is a modification of the BLEND model developed by Dr. William Gray of Notre Dame University. BLEND is based on the wave continuity equation (Lynch and Gray 1979) with linear triangular elements. The wave continuity equation has particularly desirable characteristics that suppress numerical noise. The wave equation evolved into a generalized continuity equation (Kinnmark 1986; Kolar, et al. 1992) which contains a numerical parameter G (or bigG) to enhance the mass conservation property. TxBLEND is based on the generalized wave continuity equation, with various options and modifications added for estuarine application. One new feature is the capability to simulate the wetting and drying process of tidal flats. Another feature is computational efficiency mostly due to the use of linear triangular elements. It is our experience that TxBLEND runs an order of magnitude faster than the popular TABS model developed by the U.S. Army Corps of Engineers Waterways Experiment Station. With TxBLEND, a high resolution grid consisting of several thousand elements can be employed to represent bay regions and simulate an entire year with run times of 20 to 30 hours on a UNIX workstation. This model has been successfully used to simulate Texas bays and estuaries including San Antonio Bay (Longley 1994), Galveston Bay (Solis 1994), and JFK Causeway area between Corpus Christi Bay and northern Laguna Madre (Solis and Matsumoto 1991). A mathematical description of TxBLEND and numerical procedure are presented in Appendix I.

Input Data Preparation

Inputs to TxBLEND include data on the finite element grid and node coordinates, bathymetry, tides, wind, evaporation, precipitation, river inflow, and salinity. This section describes the sources of information used and how data were prepared.

Finite Element Grid

The finite element grid (Figure II.1) was prepared using a grid generation program, FastTABS. This produces an incidence list that describes the connectivity of the triangular elements, nodal coordinates, and bathymetries. The computational grid went through many modifications prior to final model application. The grid employed in this study consists of 4917 nodes and 8191 (linear triangular) elements. This is the finest grid used in Texas Water Development Board (TDWB) estuary modeling to date. It takes 51 CPU hours to simulate 15000 hours or approximately 21 months for 1991-1992 simulation on a SunSPARCstation 20. With this level of resolution, the Gulf Intracoastal Waterway (GIWW) — which is 125 feet wide at the bottom with a 14-foot design depth, plus 2-foot allowable over-depth — is well represented. However, there are still some things to be desired. Very small islands and channels — such as the ones seen in the Flour Bluff area — are not represented in detail, although the area was gridded by the smallest elements. However, the grid is adequate for the purpose of studying long-term effects due to structural and operational changes in this large estuarine system.

Bathymetry
Baseline bathymetric information was collected from NOAA Nautical Charts. Adjustments were made in the upper Laguna Madre area to incorporate findings of the 1995 survey of Laguna Madre conducted by the U.S. Army Corps of Engineers.

Tides
The Bob Hall Pier NOAA tide gage located on Padre Island records the Gulf tide. The tide gages inside the bays are part of the Texas Coastal Ocean Observation Network (TCOON) administered by the Texas General Land Office and the TWDB. Tide data from TCOON gages in the CCBNEP area were made available by the Conrad Blucher Institute for Surveying and Science (CBI), Texas A&M University-Corpus Christi. Observed tides were adjusted to the Mean Water Level by applying the values in Table II.1 (based on correspondence with CBI).

Table II.1 Correction factors to the mean sea water level (MWL)

Tide gage	Correction factor
Bob Hall Pier	21.5 feet
Port Aransas	4.9
Packery Channel	2.7
Bird Island	1.8
Yarborough	5.3
El Toro	3.5
White Point	1.4
CC Aquarium	4.6
Rockport	6.0
Copano Bay	4.0
Bayside	5.0

Tide data were examined for missing and anomalous data through visual inspection of tide plots and data records. In cases where missing portions were not extensive they were filled in by a graphical procedure. The El Toro tide record contains extensive missing portions. For 1991 and 1992, El Toro tides were filled in by a regression equation based on Yarborough data:

$$Tide(ElToro) = -0.437 + 0.766 \cdot Tide(Yarbo) \qquad \text{(II.1)}$$

Sample size for the regression is 7439, standard error is 0.23 feet, and the coefficient of determination (r^2) is 0.71. The graphical procedure was applied to the filled-in data to correct anomalous data. The fill-in and correction process was necessary because El Toro tides were used as a boundary condition for 1991-1992 simulation.

In the Bob Hall Pier tide record, there were extensive missing portions in March 1991 and September 1992. A regression equation was developed for the relationship between Bob Hall Pier tides and Port Aransas tides to form the basis for estimation of missing data:

$$Tide(BobH) = 15.341 + 1.222 \cdot Tide(PortA) \qquad \text{(II.2)}$$

Sample size in the regression is 12252, standard error is 0.24 feet, and r^2 is 0.89. The Bob Hall Pier tide is the major driving tide in the CCBNEP model and is used for 1987 simulation, 1988-1989 simulation and 1991-1992 simulation.

Wind and Temperature

Wind data were available from one source, the National Climatic Data Center (NCDC) in two different formats. One format is the SAMSON CD-ROM which contains the meteorological data in Texas from 1961 to 1990. The other is the meteorological data 1970 to August 1995 collected at the Corpus Christi Naval Air Station (NAS), which was specially ordered and purchased from the NCDC. Hourly data were extracted as inputs.

Precipitation

Precipitation data were obtained from a CD-ROM published by Hydrosphere, Inc. that contains the NCDC Summary of the Day - Climate data. Precipitation for the study area was based on data collected at the Corpus Christi Airport from 1948 to 1994.

Evaporation

Recorded daily evaporation data applicable to CCBNEP water areas is not available. Therefore, appropriate daily evaporation rates were estimated by the Harbeck equation as implemented by Brandes and Masch (1972),

$$Evap = N \cdot wspd \cdot (\phi_s - \phi_a) \qquad \text{(II.3)}$$

where *Evap* is evaporation in inches per day, *N* is a mass transfer coefficient, *wspd* is wind speed in miles per hour at some height above the water surface, ϕ_s is saturation vapor pressure in millibars, and ϕ_a is actual vapor pressure of air in millibars. Vapor pressure terms ϕ_s and ϕ_a are computed by

$$\phi_s = 3.28 \cdot \exp(0.0314 \cdot T_a - 0.0164) \text{ and } \phi_a = 3.28 \cdot \exp(0.0304 \cdot T_d) \qquad \text{(II.4)}$$

where T_a is air temperature and T_d is dew point temperature. The mass transfer coefficient is computed as

$$N = 0.00338 / A^{0.05} \qquad \text{(II.5)}$$

where *A* is the water surface area in acres. In application of the relationships to San Antonio Bay, Brandes and Masch used 0.00186 for *N*. Using the recorded evaporation data at Point Comfort, they calculated the monthly mass transfer coefficients to be 1.6, 1.4, 1.3, 1.3, 1.5, 1.8, 2.0, 2.1, 2.2, 2.2, 2.1, 1.9 (x10^{-3}) for months January through December, respectively.

Two evaporation files were prepared, one from NAS data for the CCBNEP Study area and the other from Victoria National Weather Service data representing San Antonio Bay. The evaporation data at NAS were initially generated by a constant *N* with the NCDC temperature and wind data. First, hourly evaporations were computed, and then they were averaged to compute daily evaporation. These daily values were tabulated to compute monthly evaporations and average monthly evaporations as well as yearly average evaporation. This yearly average value was compared with earlier estimates (TWDB, 1967) for the Corpus Christi area. The ratio of these annual averages was used to adjust the generated evaporation. In the second exercise, the mass transfer coefficient was varied as in Brandes and Masch (1972). Adjustments were made according to the annual averages as in the first exercise. However, since the monthly distribution of the second estimates was more pronounced than 1967 estimates and since the monthly distribution of the first estimates more closely resembled 1967 estimates, it was decided to take the first estimates as the input data for the CCBNEP model.

For San Antonio Bay, a similar exercise was performed with SAMSON temperature and wind data recorded at the Victoria National Weather Service Station. The result was also similar. The estimates by the constant N produced closer monthly distribution and therefore became the input evaporation data for the San Antonio Bay model that was used to compute the boundary conditions at the north end of the study area.

Figure II.2 illustrates the net evaporation at the Naval Air Station, or the difference of evaporation and precipitation.

River Inflow

Ungaged inflows were estimated using a TWDB rainfall-runoff model, TxRR (Matsumoto 1992). Diversion and return flow data were compiled from TNRCC records. The combined inflow is the sum of gaged inflow, ungaged inflow, return flow and diversion (which is treated as negative). The gaged inflows are the USGS streamflow data. For the Nueces River it is USGS Streamflow Gage 0821100 at Mathis.

Data from years 1987, 1988, 1989, 1991, and 1992 were used for model calibration as well as for test cases. Table II.2 lists the annual total inflows for the 1940-1994 period and the ranking from driest to the wettest years. Figures II.3(a) and II.3(b) show the inflows graphically. During 1987 there was a flood of the Nueces River in June, contributing to 1987's rank as a wet year. Years 1988 and 1989 were dry years, ranked 5th and 6th in the 55 year period; 1991 was 12th in the ranking, also a dry year. 1992 was a wet year, with annual flow grater than 1987, although no major flood event occurred. (The log scale in Figure II.3(b) reduces the emphasis of flood flows so that variation of moderate inflows can be seen.)

Salinity Data

Salinity data is an important tool for model calibration. Salinity data has been collected by TWDB, TDH, and TNRCC at sites within the study area over many years. The TPWD also collects salinity data at each location sampled for fisheries species biomass. Since 1987, through deployment of HydroLab DataSondes at strategic locations, TWDB has collected a fairly continuous record of environmental variables including salinity, temperature, dissolved oxygen, and pH. The 1987 salinity data from mid Nueces Bay and Corpus Christi Bay were used to calibrate the CCBNEP model. This data set is important because the salinity changes associated with the June flood and subsequent salinity recovery were captured clearly in this set. Other DataSonde salinity series contributing to calibration were taken from sites at the Copano Bay Causeway and mid Aransas Bay offshore from Rockport. A continuous salinity data series was also available through TWDB-funded monitoring by UTMSI at a site just below the JFK Causeway in the GIWW and in the GIWW at the mouth of Baffin Bay.

Table II.2 Nueces River inflows (ac-ft) 1940-1994

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total	Year	Flow	Rank	Year
40	1730	1520	3620	124700	77080	231700	311500	54950	17930	18640	46240	34180	923790	40	76390	1	62
41	6850	86310	17700	78620	645900	137600	95960	11850	219400	20780	9010	7300	1337280	41	79910	2	63
42	6190	1350	5580	6690	10110	9430	642000	8810	518900	50140	12490	4350	1276040	42	93720	3	84
43	2370	1960	2440	2350	3940	115900	32120	2560	19020	11490	4560	5830	204540	43	107640	4	83
44	5630	5370	14020	4460	76310	213500	10400	12940	375800	13730	5090	5690	742940	44	114560	5	88
45	3290	14250	18640	117000	44330	40760	4430	3990	2620	232200	3430	3920	488860	45	120620	6	89
46	3240	2890	10580	26510	158200	139000	6760	33280	317000	589500	14210	5150	1306320	46	127600	7	86
47	5430	4660	5120	9910	171800	40500	53790	15380	6010	5100	3880	2010	323590	47	129470	8	55
48	2440	1750	1910	2220	2410	2600	72180	2830	8030	31860	7600	1960	137790	48	136720	9	56
49	2450	2700	145800	200200	244500	108400	97800	39980	3990	28220	15090	18360	907490	49	137790	10	48
50	3860	2360	2420	2710	40070	116300	9000	4260	3720	13290	3550	2930	204470	50	160270	11	52
51	2610	2500	2620	2860	59640	137900	4120	4140	186000	19250	4120	2490	428250	51	182470	12	91
52	2720	3410	4630	9360	24510	82160	9520	4700	10440	3400	2710	2710	160270	52	186770	13	94
53	3150	2570	3250	4170	81150	4370	5070	23720	400200	65690	40890	2710	636940	53	201420	14	93
54	2730	3260	3710	3120	3710	55260	145300	5320	4630	4450	7650	3590	242730	54	204470	15	50
55	2980	3020	4260	4410	17260	15180	5550	6120	22930	41310	3660	2790	129470	55	204540	16	43
56	3200	3040	3630	2920	4310	6310	6790	11280	44030	39030	6440	5740	136720	56	209140	17	82
57	3710	3530	19710	158500	583000	484500	6720	6500	103300	125000	46410	5620	1546500	57	222680	18	78
58	307100	286800	269100	5190	5140	6170	10210	7240	39220	256300	200700	19980	1413150	58	242730	19	54
59	24240	8590	6810	5210	5860	6760	51960	8130	5860	267700	18900	6600	416620	59	250010	20	69
60	5860	7520	4500	5210	5270	13730	18300	54630	28580	155800	94260	61480	455140	60	276630	21	64
61	51460	64610	11160	17230	7490	81440	28100	28100	11870	6780	6250	6260	320750	61	298250	22	72
62	6570	6240	5880	6360	8180	6140	8200	7840	5400	6580	4970	4030	76390	62	320750	23	61
63	5430	4630	5540	6570	8950	7640	8810	9650	6440	6560	5070	4620	79910	63	323590	24	47
64	4640	3950	5080	6480	6360	7890	8160	9670	6890	190100	22870	4540	276630	64	331070	25	66
65	4250	69830	31650	6170	163200	52070	9690	8120	7340	5900	5670	5300	369190	65	352030	26	90
66	4700	5200	5950	7810	205700	53330	12840	8090	6840	7370	6870	6370	331070	66	358310	27	70
67	5810	4740	6620	8560	8620	9770	10510	9370	1484000	210200	20180	21530	1799910	67	363450	28	79
68	220300	39600	27470	6040	270500	32240	31480	6810	7790	18650	6090	6020	672990	68	369190	29	65
69	5820	5290	6020	6030	7740	9250	9970	10010	7270	60460	80810	41340	250010	69	373730	30	75
70	13920	9860	26990	7770	74870	179500	7730	10300	6120	8710	6600	5940	358310	70	389840	31	74
71	6200	6270	7640	6630	7320	8330	211100	618000	646000	913300	80890	25730	2537410	71	416620	32	59
72	19660	16940	6370	8180	154900	15240	7700	9200	34380	9890	8210	7580	298250	72	428250	33	51
73	7620	5810	6450	6380	8190	250700	103900	34820	67070	465900	65950	19830	1042620	73	455140	34	60
74	14710	14830	29340	13140	11930	10830	9530	69930	174600	9940	19330	11730	389840	74	469750	35	85
75	10730	19140	7980	5990	97470	119700	67310	14820	15340	6180	5140	3930	373730	75	488860	36	45
76	3320	3300	3980	3300	70390	8160	136200	57040	98620	158000	270800	115000	928110	76	528800	37	77
77	49410	28870	16040	276100	87910	32310	8510	5640	4660	6970	6180	6200	528800	77	562400	38	80
78	5890	5090	7200	6970	8410	46110	9430	54110	59580	7260	6580	6050	222680	78	636940	39	53
79	8090	5440	6500	47330	35440	205900	17810	8730	6330	7650	7200	7030	363450	79	672990	40	68
80	8650	6340	7570	8620	124600	36640	11190	304800	29140	11850	6950	6050	562400	80	742940	41	44
81	6220	5800	6750	7480	176700	446200	161700	13950	68420	104400	45090	13090	1055800	81	757310	42	87
82	10970	9250	8950	7940	100200	14370	11760	11010	9800	8850	7580	8460	209140	82	907490	43	49
83	8080	5990	7290	8770	10550	10720	10010	10650	8990	8360	8430	9800	107640	83	923790	44	40
84	8450	7850	8950	10760	10790	10630	8540	7060	5740	4530	4500	5920	93720	84	924900	45	92
85	6210	5830	6240	20240	99980	51140	48410	11170	7940	81090	114900	16600	469750	85	928110	46	76
86	6570	5520	7590	8140	7720	7700	11350	10200	8420	7520	8400	38470	127600	86	1042620	47	73
87	19840	19170	25700	8550	17350	488200	118000	16470	12740	10040	11330	9920	757310	87	1055800	48	81
88	8460	7880	8850	9020	9770	11030	12310	11950	9860	8610	8320	8500	114560	88	1276040	49	42
89	8170	7720	9040	8880	10510	9470	12180	12220	11680	11210	9620	9920	120620	89	1306320	50	46
90	9080	8010	8780	9260	38680	21580	97880	94160	27500	19110	8720	9270	352030	90	1337280	51	41
91	7830	7460	15030	17080	35020	23970	10040	11500	19080	15670	11000	8790	182470	91	1413150	52	58
92	73950	190250	81030	118420	188420	186010	14830	18310	16430	16390	10800	10060	924900	92	1546500	53	57
93	7170	6600	9750	11320	31010	21160	39020	14510	20540	18030	11280	11030	201420	93	1799910	54	67
94	8790	7680	9770	14980	29810	29640	16280	14280	20380	13960	9820	11380	186770	94	2537410	55	71
Mean	19068	19461	18095	27251	79985	81328	52545	33911	95833	80707	26605	12576	547365				

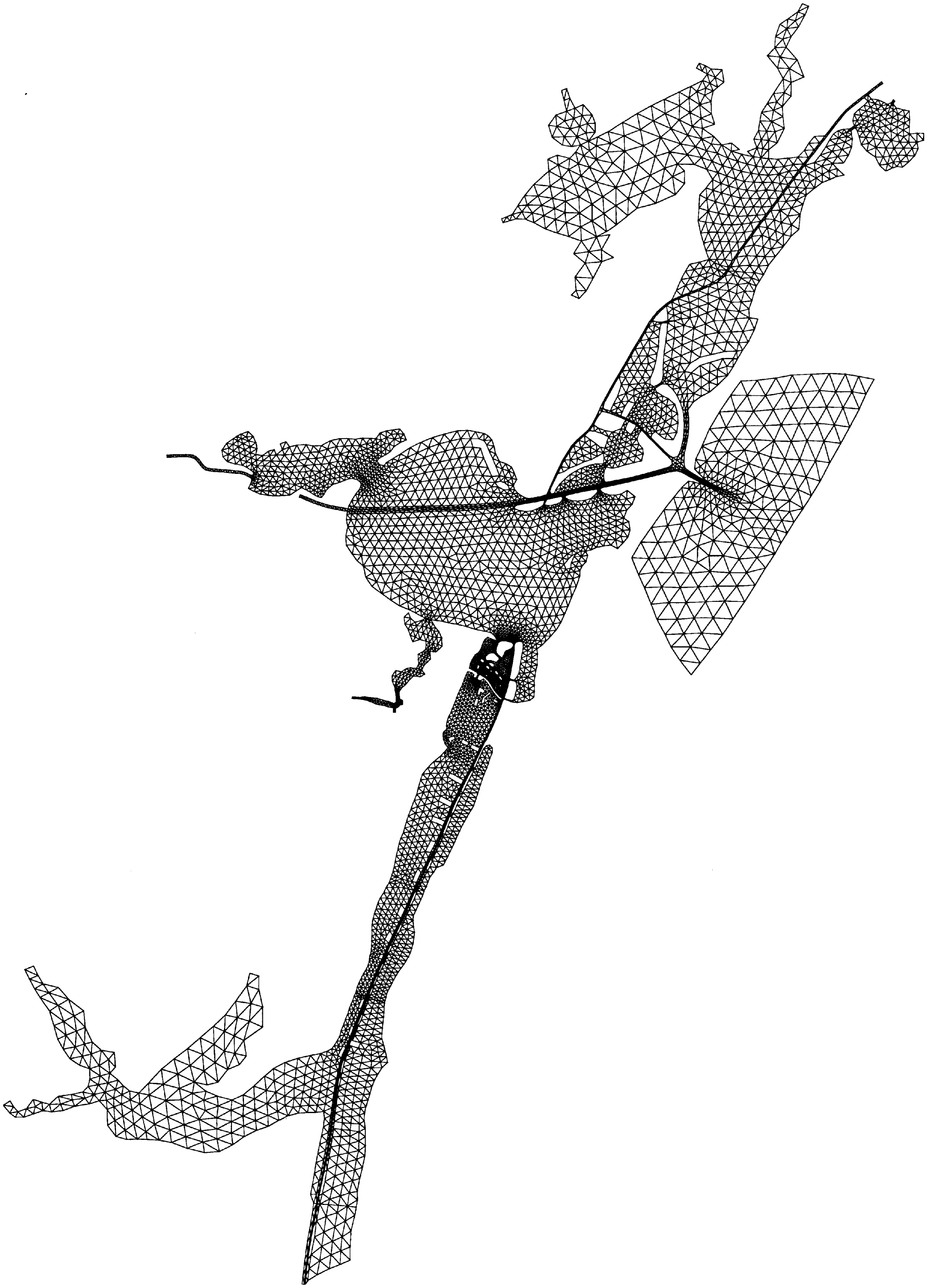


Figure II.1 Computational grid for the CCBNEP model

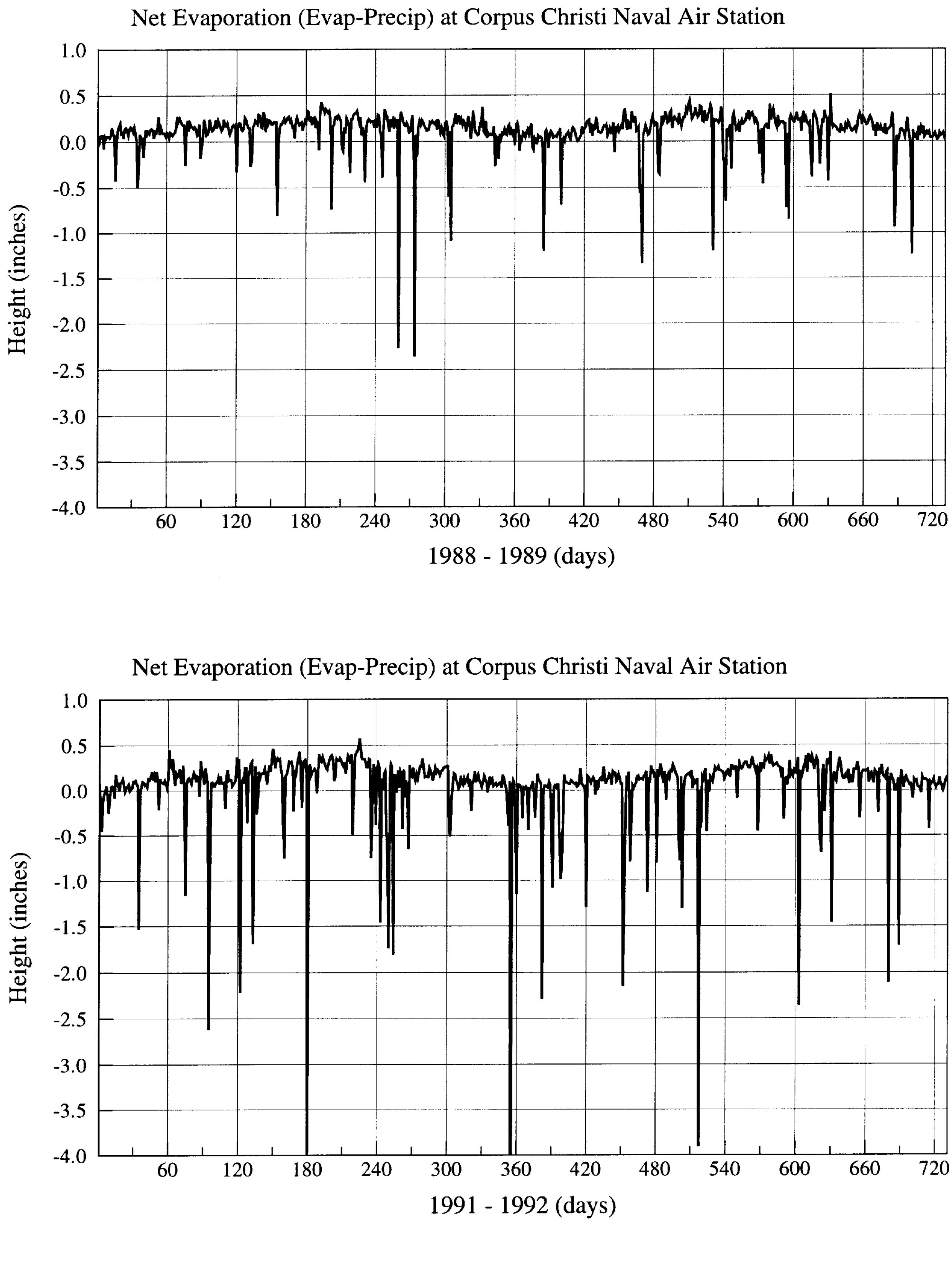
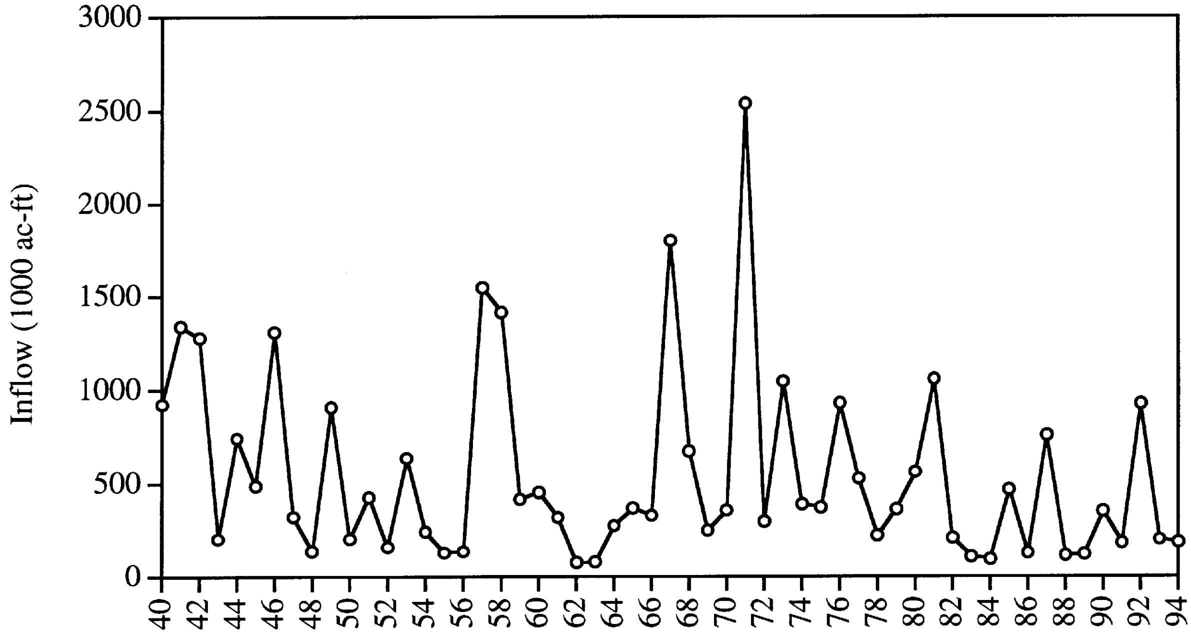


Figure II.2 Net evaporation at the Naval Air Station for 1988-1989 and 1991-1992

(a) Annual Nueces River Inflows



(b) Monthly Nueces River Inflows

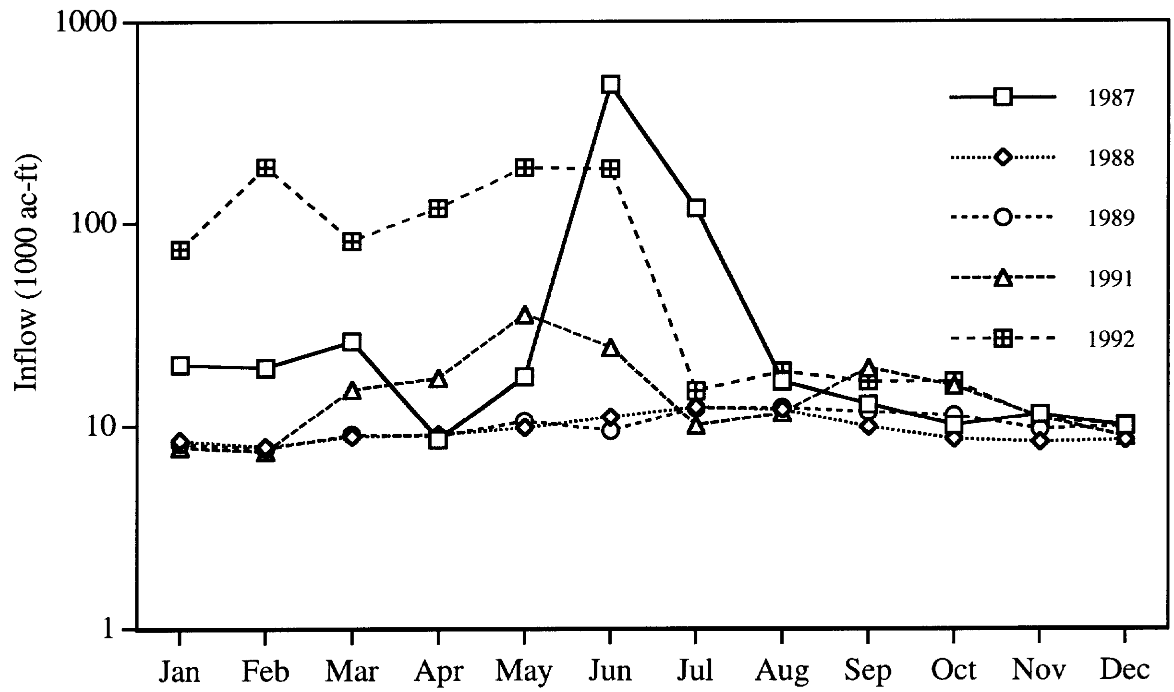


Figure II.3 Annual and monthly Nueces River inflows

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III. MODEL CALIBRATION

TxBLEND simulates hydrodynamics (or circulation patterns) and salinity distribution. The model was first calibrated to hydrodynamic data and then to salinity data. The data collected during the intensive inflow studies were used in model hydrodynamic calibration. Figure III.1 shows the intensive inflow survey sites used for velocity calibration and Figure III.2 shows the tide gages used to calibrate for tidal elevations. Salinity data from TWDB DataSondes were used for salinity calibration because salinities change much more slowly within a bay system than velocities and tidal elevations. The long-term salinity data supplied a time series long enough to realistically demonstrate model performance. Figure III.3 shows the DataSonde sites used for salinity calibration.

There is no established procedure for model calibration, but the essence of the process is the comparison of observed data and simulated data. By adjusting model parameters the user tries to make the model trace the observed values as closely as possible. For TxBLEND application to Texas bays, parameters for which adjustment is necessary to achieve calibration most often include bigG, dispersion, and Manning's n. The most important parameter for hydrodynamic calibration is Manning's n, representing bottom roughness. A larger n slows the water movement and vice versa. Similarly, the dispersion coefficient, which embodies physical mixing processes, is the key parameter for salinity calibration; the larger the parameter, the faster dissolved salt disperses. At a more structural level, the finite element grid often needs to be modified to better represent flow conditions in areas where shoreline geometry or bathymetry is complicated. In most cases, calibration involves a trial and error approach, the user modifying appropriate parameters until a point of diminishing returns is reached or until the means or room for improvement is exhausted.

August 1987 Intensive Inflow Study

TWDB conducted an intensive inflow study of Corpus Christi Bay and surrounding area from August 4 to August 7, 1987. Figure III.4(a) through Figure III.4(g) are the comparison plots of observed and simulated tidal elevations for that study. For this particular set, the observed tides are TWDB's; TCOON was not yet established. The model was run for 20 days prior to the last 10 days shown in the figures. This prior run-time was to produce appropriate system initial conditions and inertia prior to calibration. There are two factors to compare in tidal plots, phase and amplitude. In general these factors are matched well, but Figure III.4(c) and Figure III.4(f) show some discrepancies. Those could be due to mechanical problems with old tide recorders producing a series of bad values in the observed data. Since there were better calibration data sets, the model was not adjusted to attempt to match these discrepancies.

Figure III.5(a) to Figure III.5(n) show observed and simulated velocities at sites in the Aransas Study area. Velocities were measured at two-tenths, five-tenths, and eight-tenths of depth. TWDB made an effort to collect consistent and high quality data at major channels and passes, while at other sites data were collected sparsely as seen in Figures III.5(g), III.5(h), and III.5(i).

August 1988 Intensive Inflow Study

During August 7 through August 10, 1988, TWDB conducted an intensive inflow study of Aransas Bay and Copano Bay. Figures III.6(a) through III.6(f) display the tidal plots. Figure III.6(b) for the Entrance Channel at UTMSI indicates a disagreement with the observed tide. However by examination of the original data, it was found that the observed tide at UTMSI is actually a filled-in tide and therefore may not be reliable. Figures III.7(a) to III.7(n) show the velocity plots. In Figure III.7(k) for GIWW/Bludworth and Figure III.7(l) for Cedar Dugout, velocity plots indicate flow is in one direction only. This is due to a strong wind, near 30 mph, which prevailed during the study.

June 1991 Intensive Inflow Study

An intensive inflow study was made of Laguna Madre during June 10 through June 13, 1991. Figures III.8(a) to III.8(j) are the tidal comparisons from that data. Figure III.8(a) shows almost a perfect match because the Bob Hall tide was applied at the tidal boundary. Also the El Toro tide was applied at the south end of the CCBNEP grid. Figures III.9(a) to III.9(g) are the velocity comparisons. Generally, velocity is very small, less than a half foot per second in the Laguna Madre and this makes an accurate comparison difficult. However, overall comparisons appear reasonable.

June 1993 Tidal Comparison

Figures III.10(a) through III.10(l) exhibit tidal comparisons for June 1993. These comparisons were created to see how the model performs during a quickly rising, very high tide. The plots indicate the model works well.

June 1994 Intensive Inflow Study

Corpus Christi Bay and the surrounding area was a subject of another intensive inflow study during June 21 through June 24, 1994. Figures III.11(a) to III.11(i) show the tidal comparisons and Figures III.12(a) to III.12(t) the velocity comparisons. They are generally in good agreement with the exception of Figure III.11(I) for Bird Island. The observed data there may represent an instrument malfunction. Of particular importance in this intensive study is the deployment of an Acoustic Doppler Current Profiler (ADCP). This electronic instrument measures the velocity in three dimensions and the accompanying software automatically computes the flow volume across a cross-section. The velocities at ADCP sites used in the comparisons are the average velocities at the center of the channel recorded by the ADCP. A TWDB team covered the Entrance Channel, Corpus Christi Channel, Aransas Channel, and Lydia Ann Channel. A second team, the USGS, covered the GIWW near JFK Causeway and Humble Channel. Figures III.12(a), III.12(b), III.12(k), III.12(l), III.12(p), and III.12(q) are the velocity comparison plots at ADCP sites, which are in reasonable agreement. However, sites near the Entrance Channel show some discrepancies in phase and amplitude, indicating some limitation in the model's ability.

Long-term Tidal Comparison

To obtain more definitive information on the model performance, the two-year simulation of 1991-1992 and one-year simulation of 1993 were compared with the observed hourly tides. Figures III.13(a) and III.13(b) are the comparison plots for 1993 tides at the State Aquarium and Packery Channel. Linear regression equations were fitted through the observed data after anomalous data were excluded from the statistical analysis.

Table III.1 Observed and simulated tidal comparison statistics

Location	Year	Days	N_Data	R-squared	Stndrd_Error
Copano Causeway	91-92	626	2178	0.905	0.129
Bayside	91-92	626	3324	0.841	0.223
Packery Channel	91-92	626	7382	0.923	0.133
NAS	91-92	626	5725	0.698	0.295
White Point	91-92	626	7309	0.432	0.450
Port Aransas	91-92	626	7342	0.956	0.151
Riviera Beach	91-92	626	7252	0.769	0.213
State Aquarium	91-92	626	7488	0.631	0.311
Copano Causeway	1993	338	3874	0.707	0.236
Bayside	1993	338	3876	0.700	0.272
Packery Channel	1993	338	4040	0.770	0.200
NAS	1993	338	3450	0.661	0.288
White Point	1993	338	3245	0.662	0.340
Port Aransas	1993	338	3904	0.744	0.274
Riviera Beach	1993	338	4022	0.709	0.222
State Aquarium	1993	338	4028	0.739	0.239

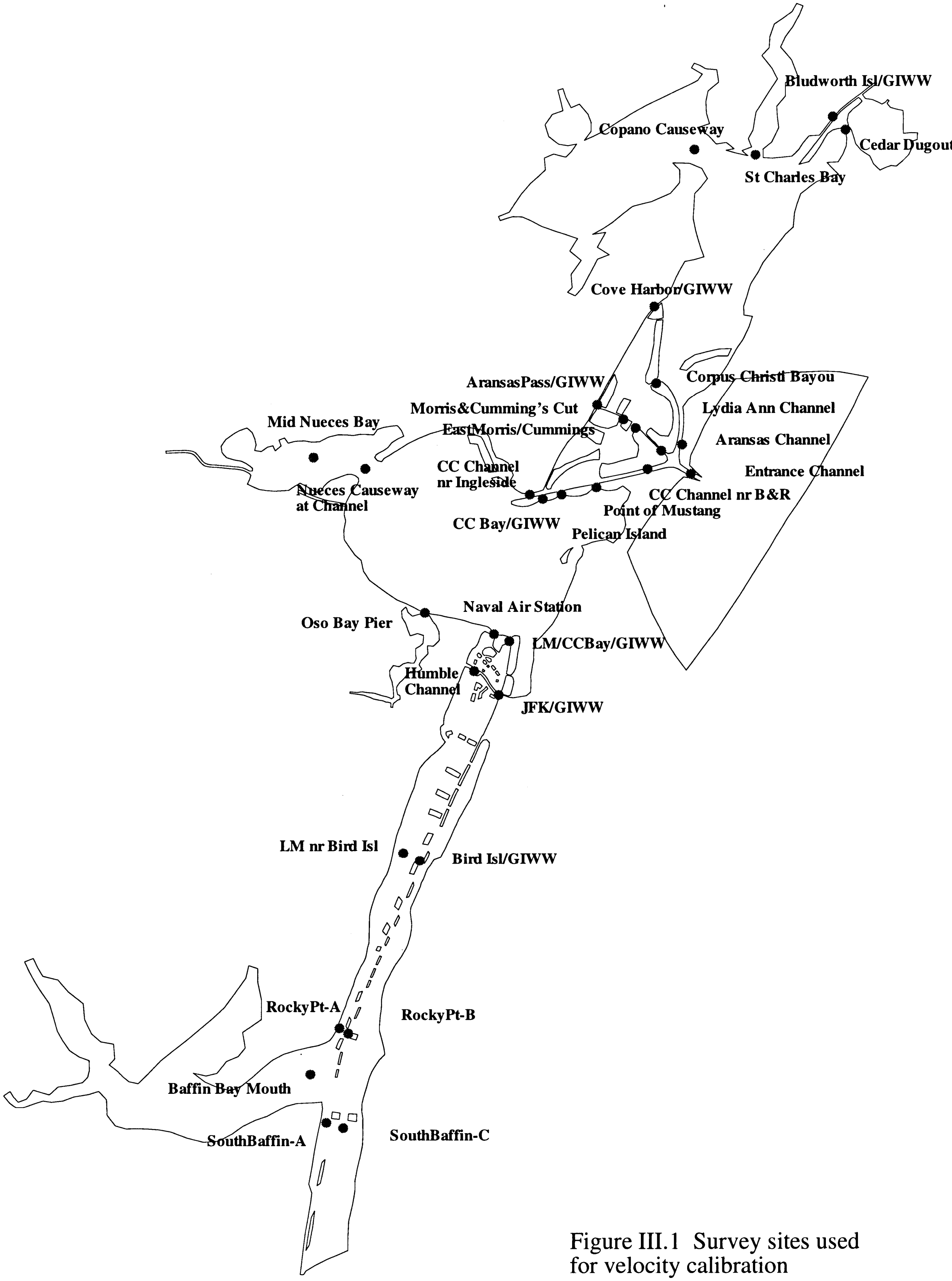


Figure III.1 Survey sites used for velocity calibration

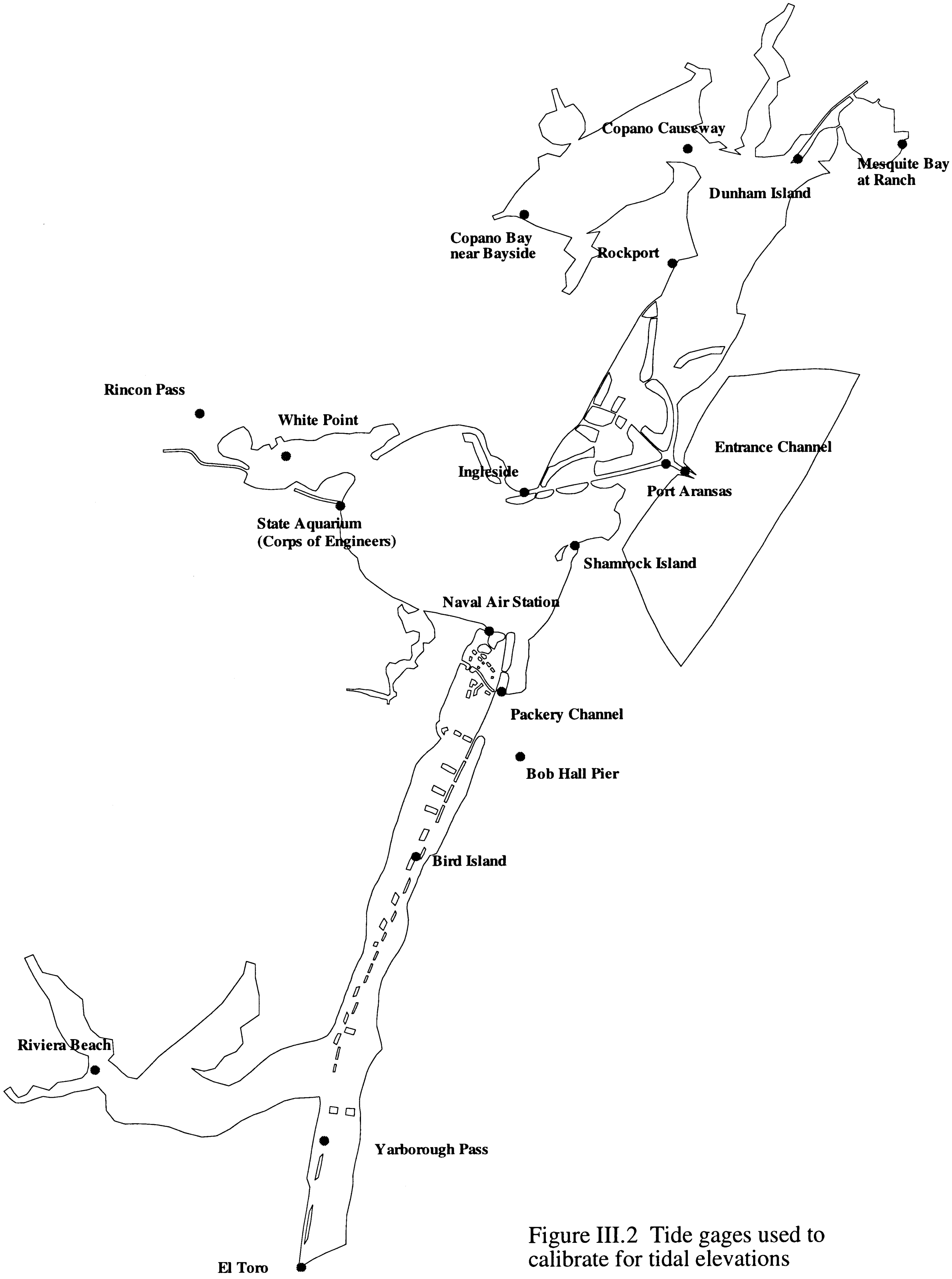


Figure III.2 Tide gages used to calibrate for tidal elevations

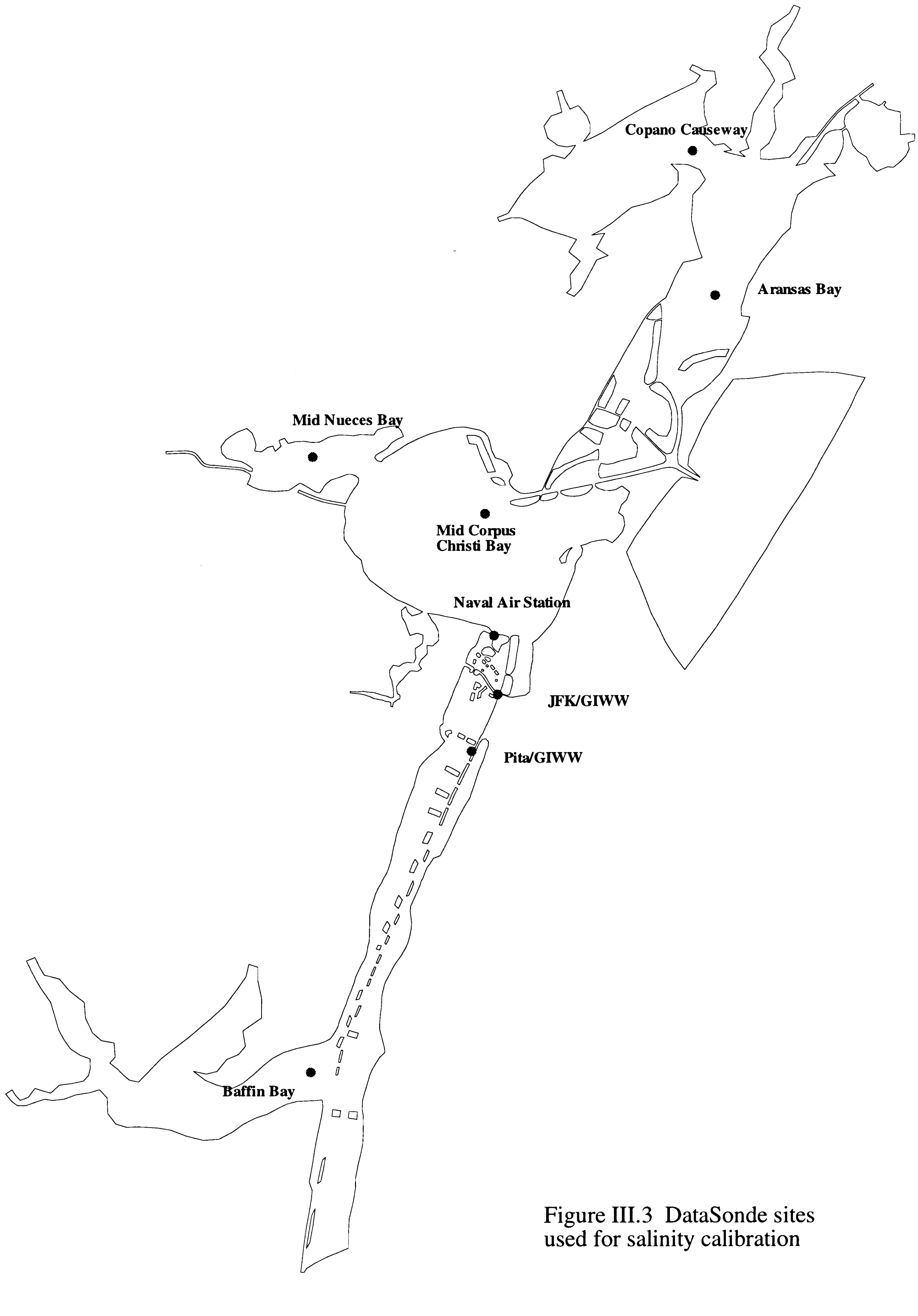


Figure III.3 DataSonde sites
used for salinity calibration

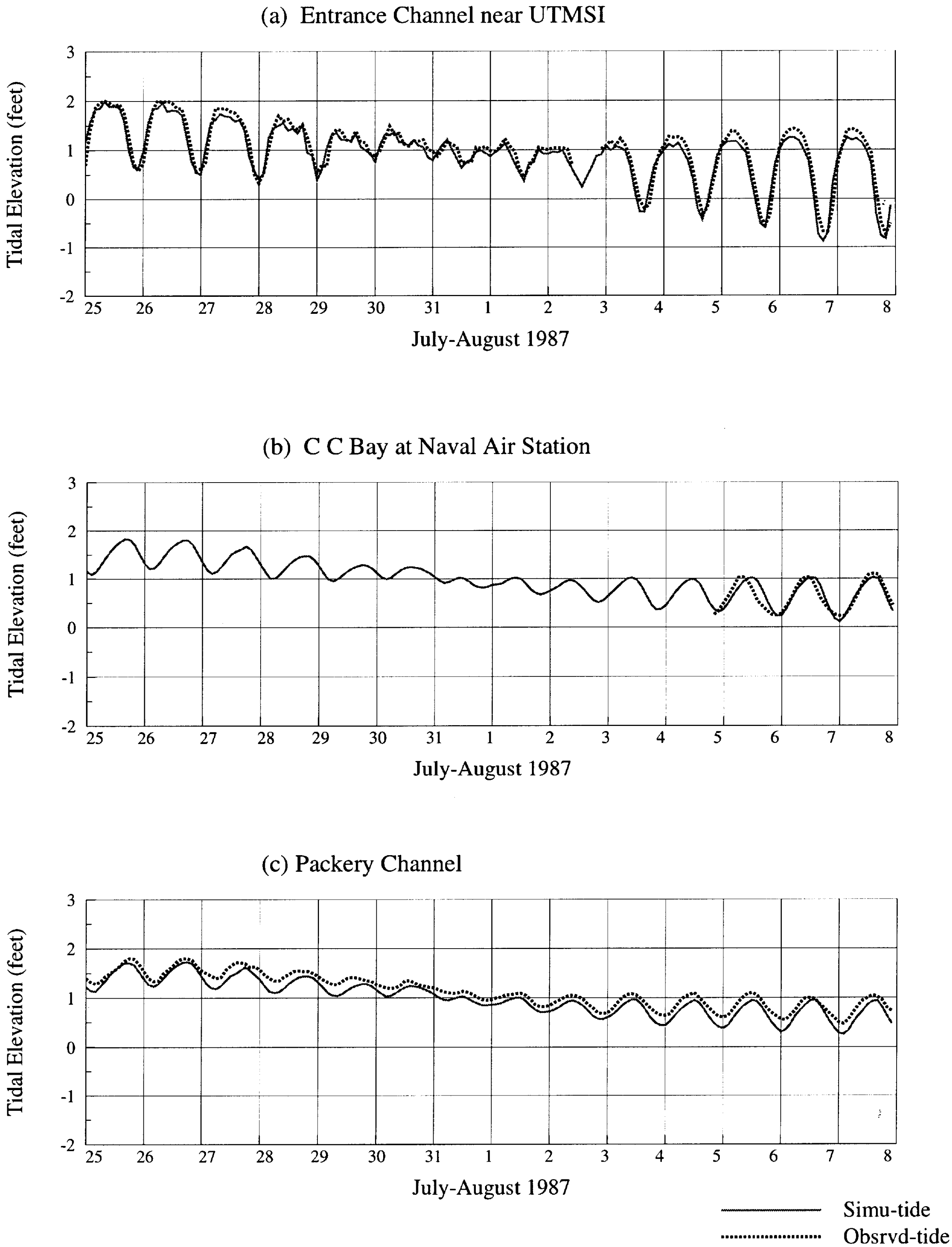


Figure III.4 Simulated and observed tides in July and August 1987

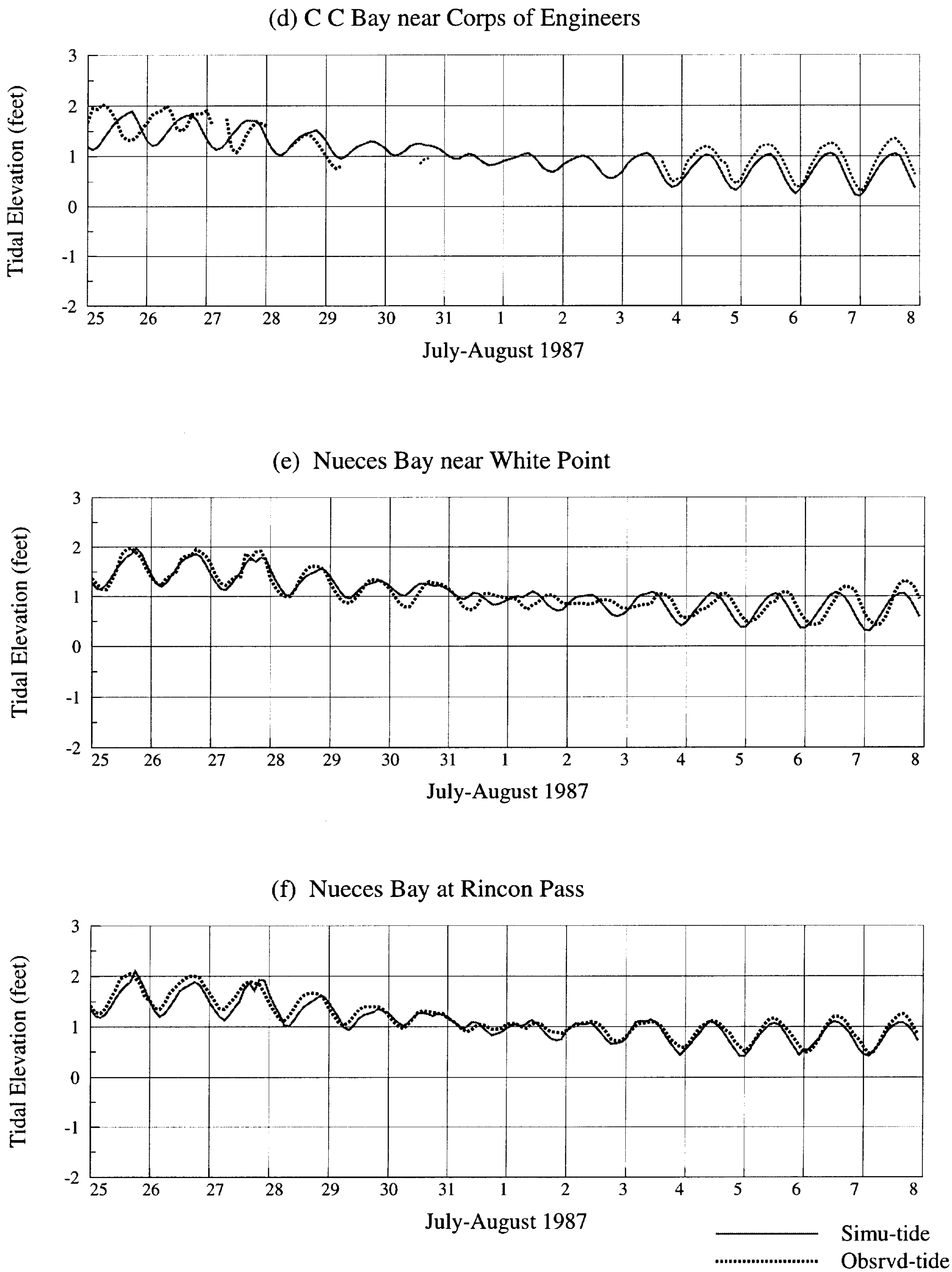


Figure III.4 Simulated and observed tides in July and August 1987

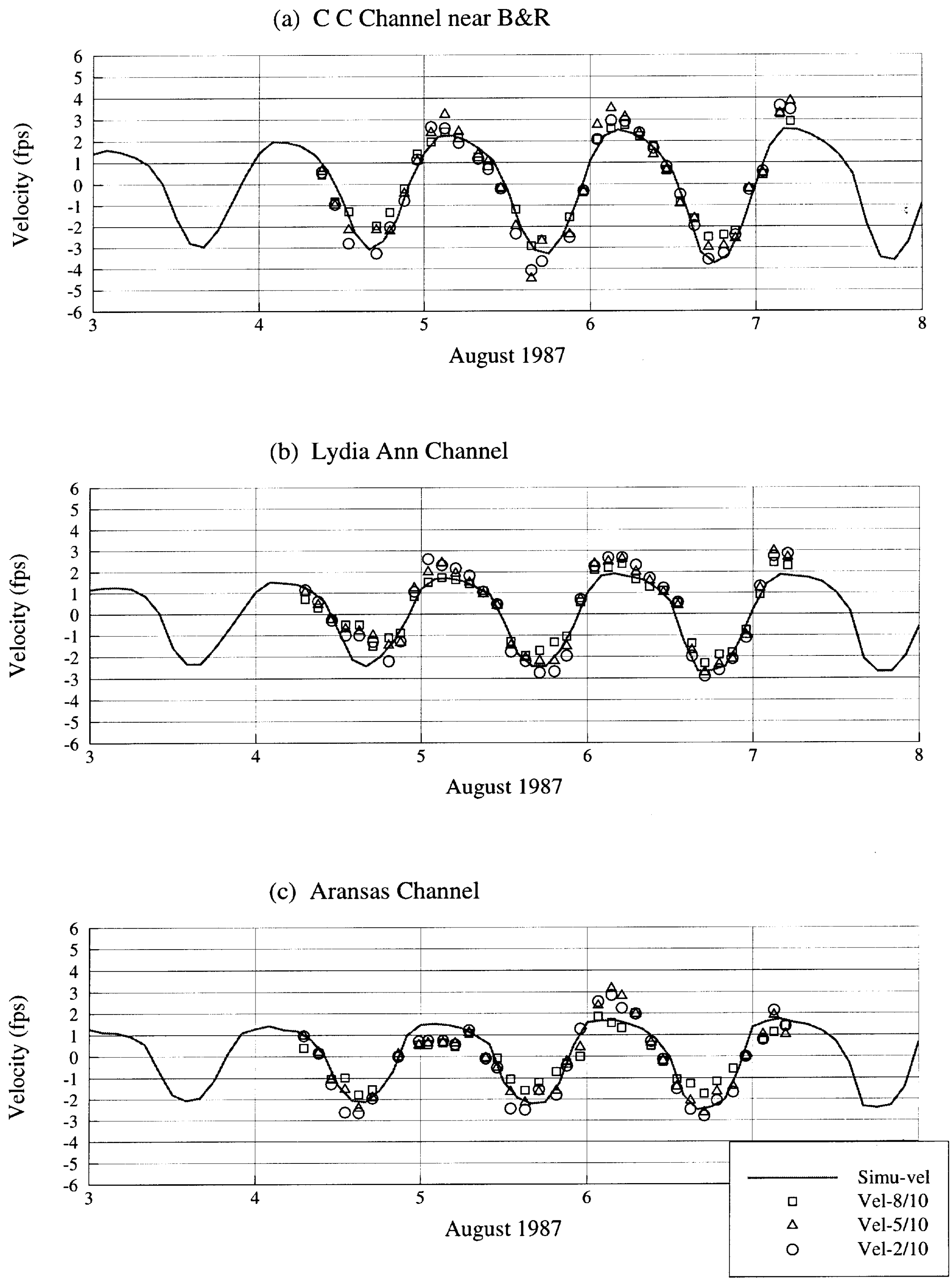


Figure III.5 Simulated and observed velocities in August 1987

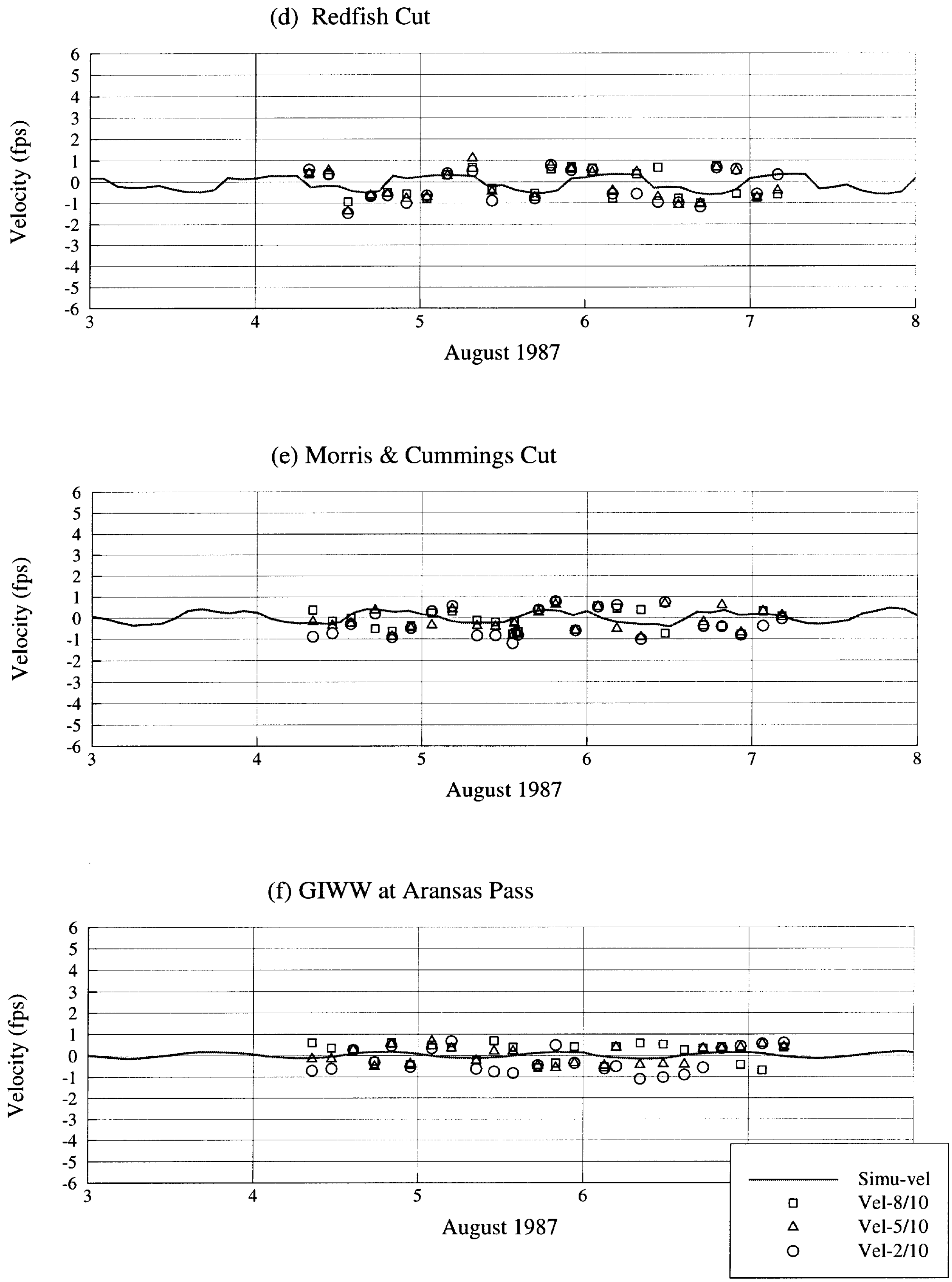


Figure III.5 Simulated and observed velocities in August 1987

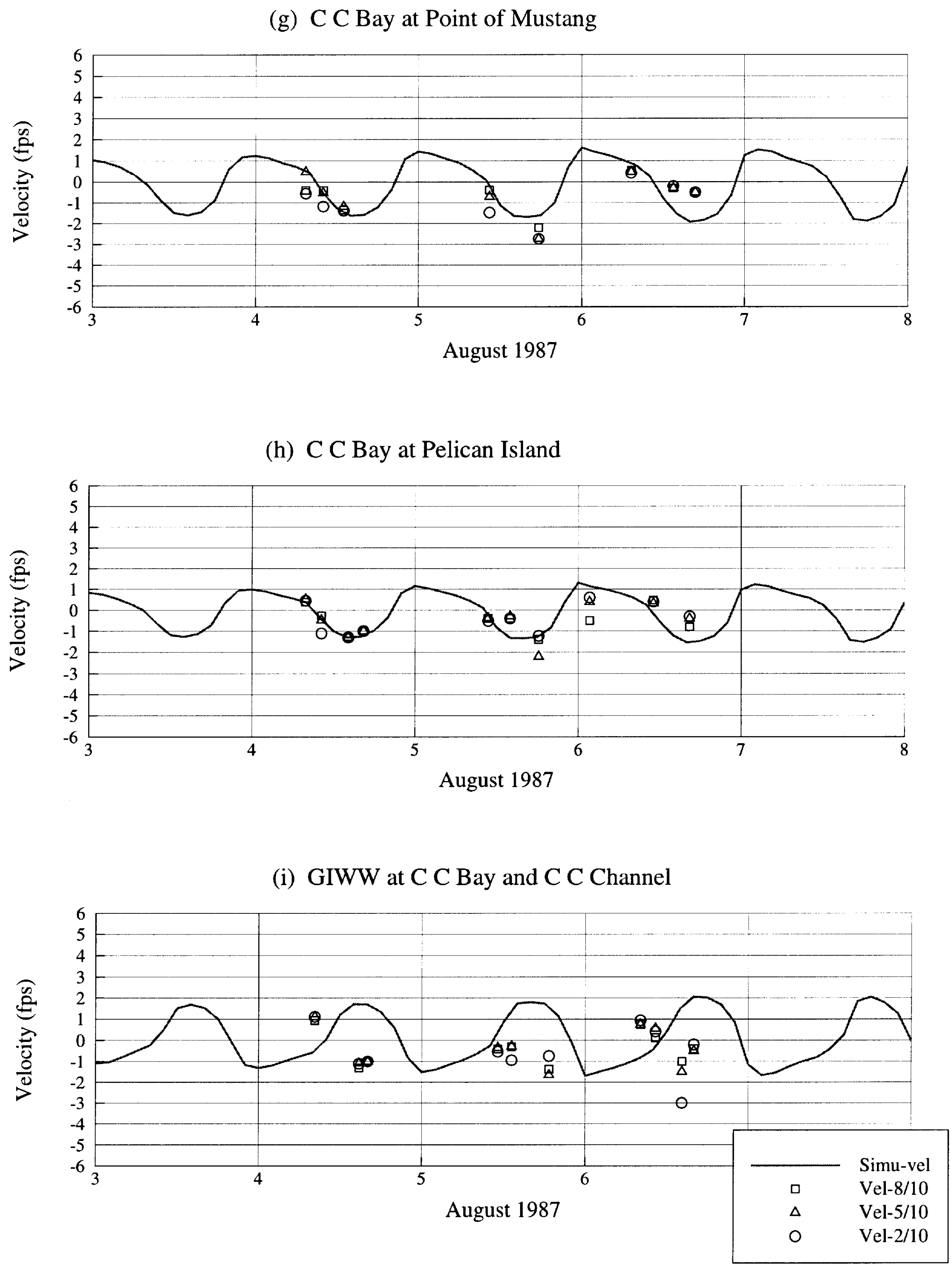
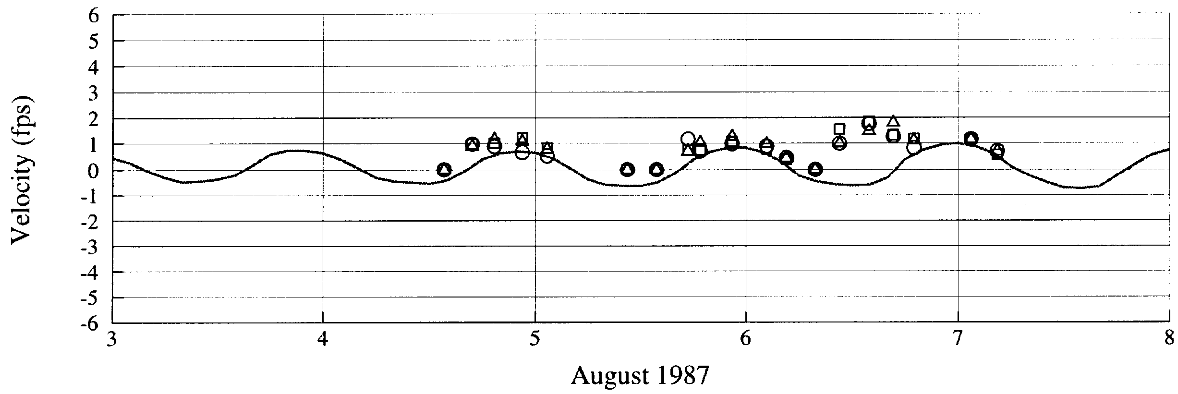
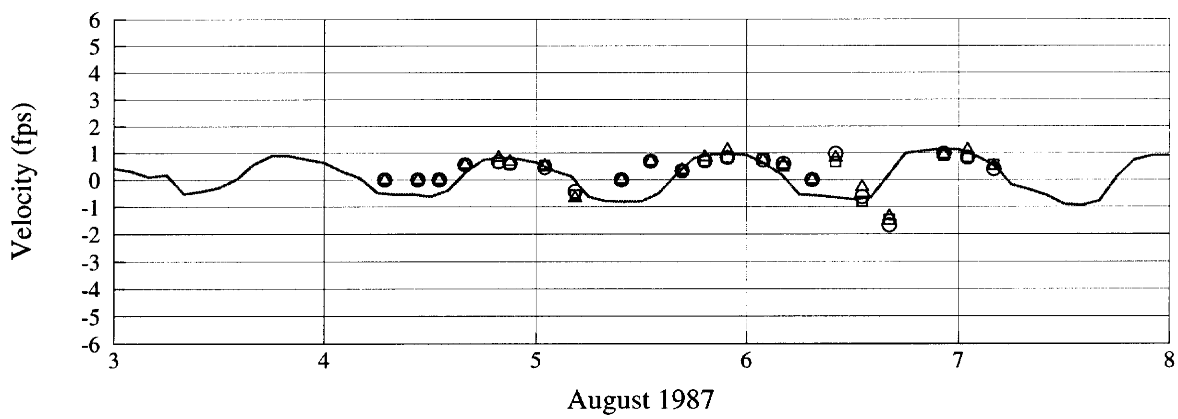


Figure III.5 Simulated and observed velocities in August 1987

(j) GIWW at JFK Causeway



(k) Humble Channel



(l) Oso Bay Pier

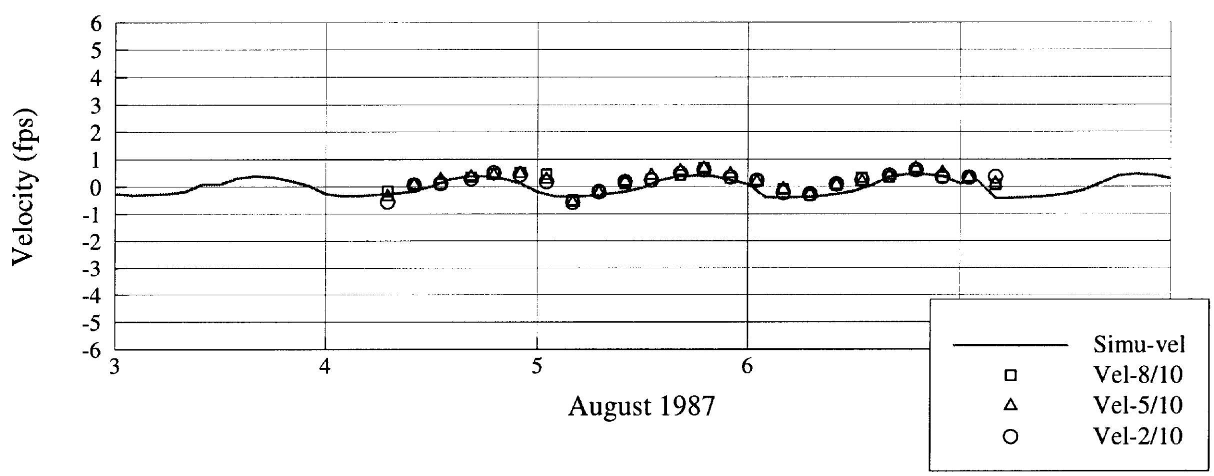


Figure III.5 Simulated and observed velocities in August 1987

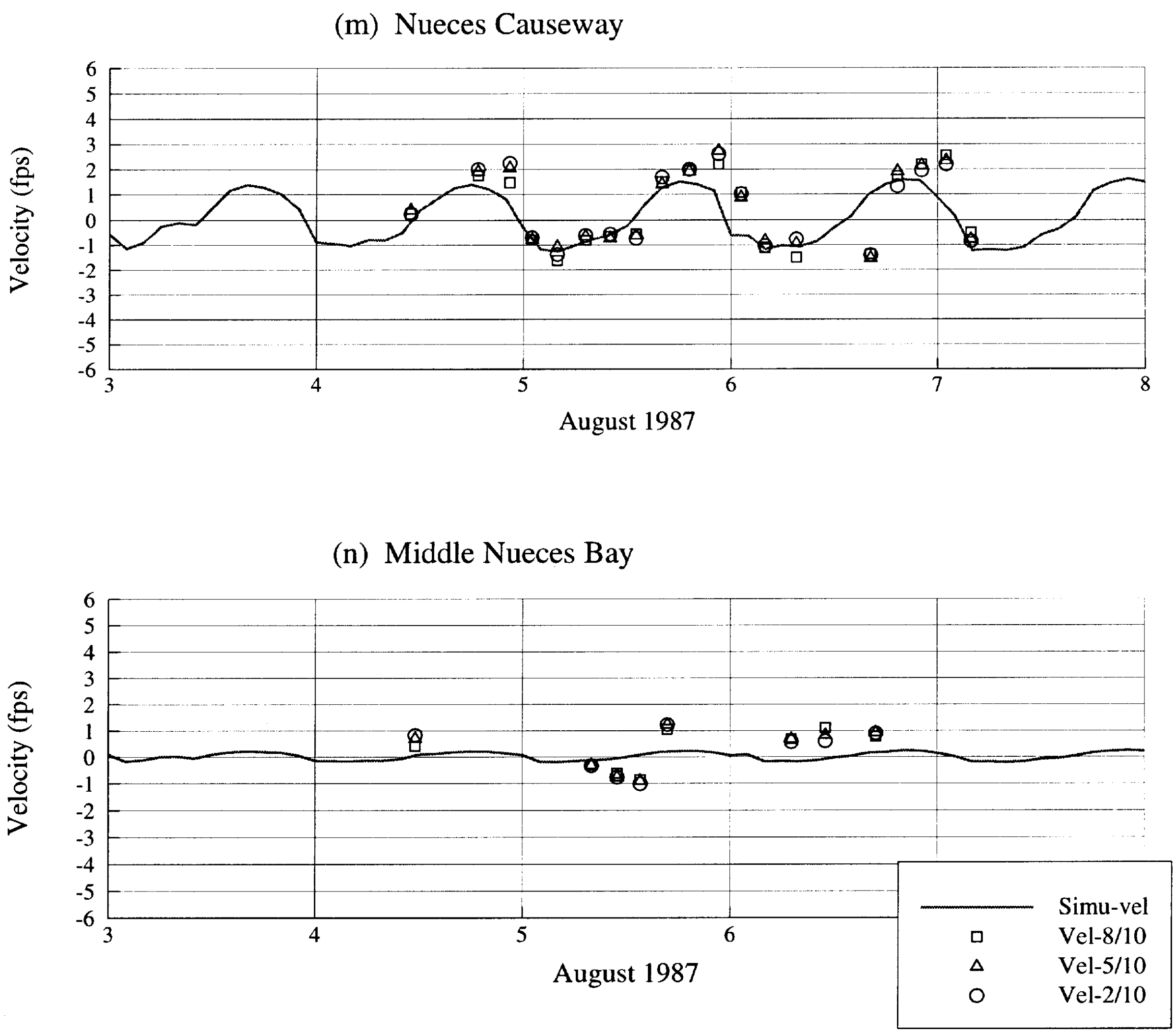


Figure III.5 Simulated and observed velocities in August 1987

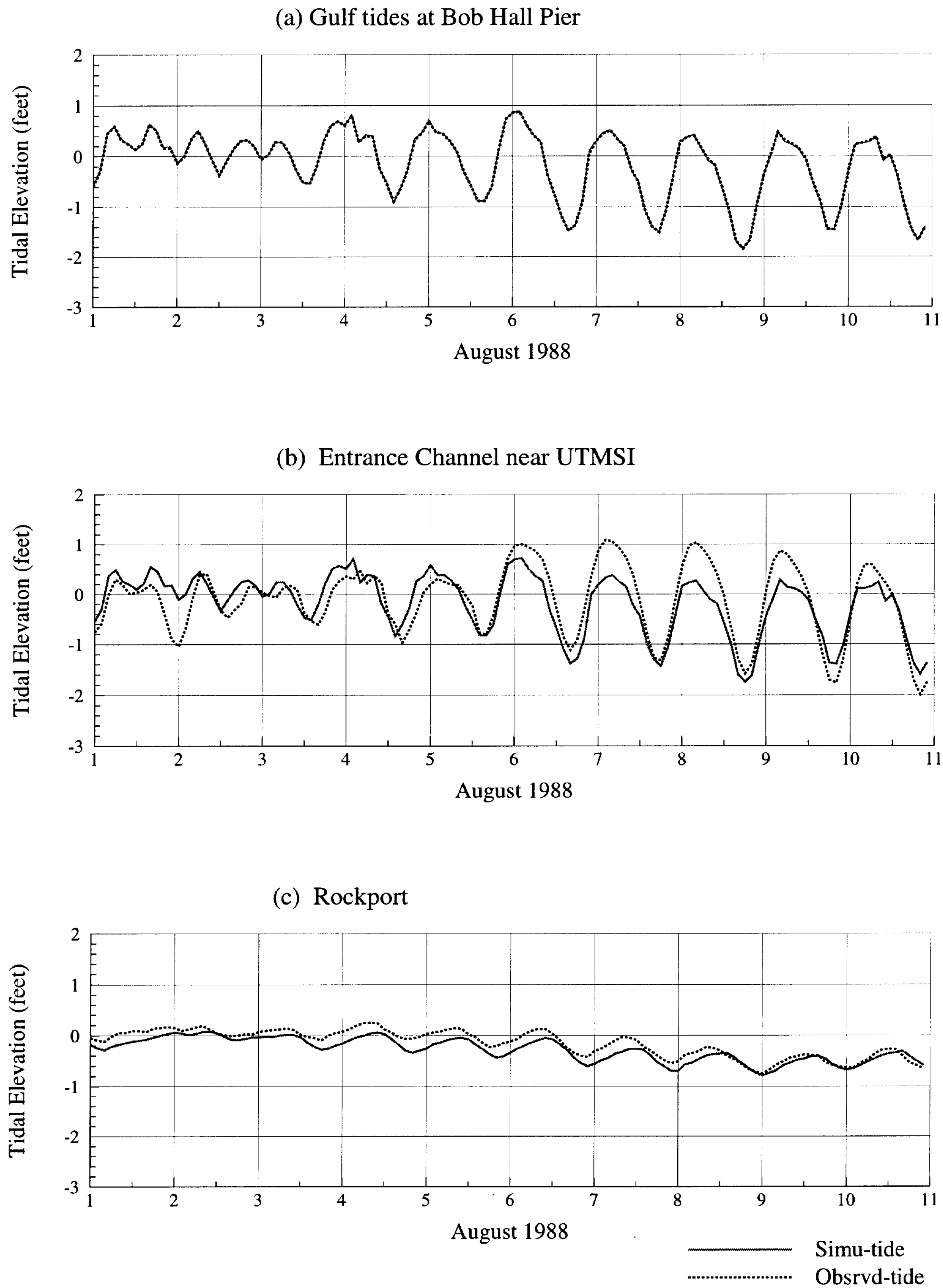


Figure III.6 Simulated and observed tides in August 1988

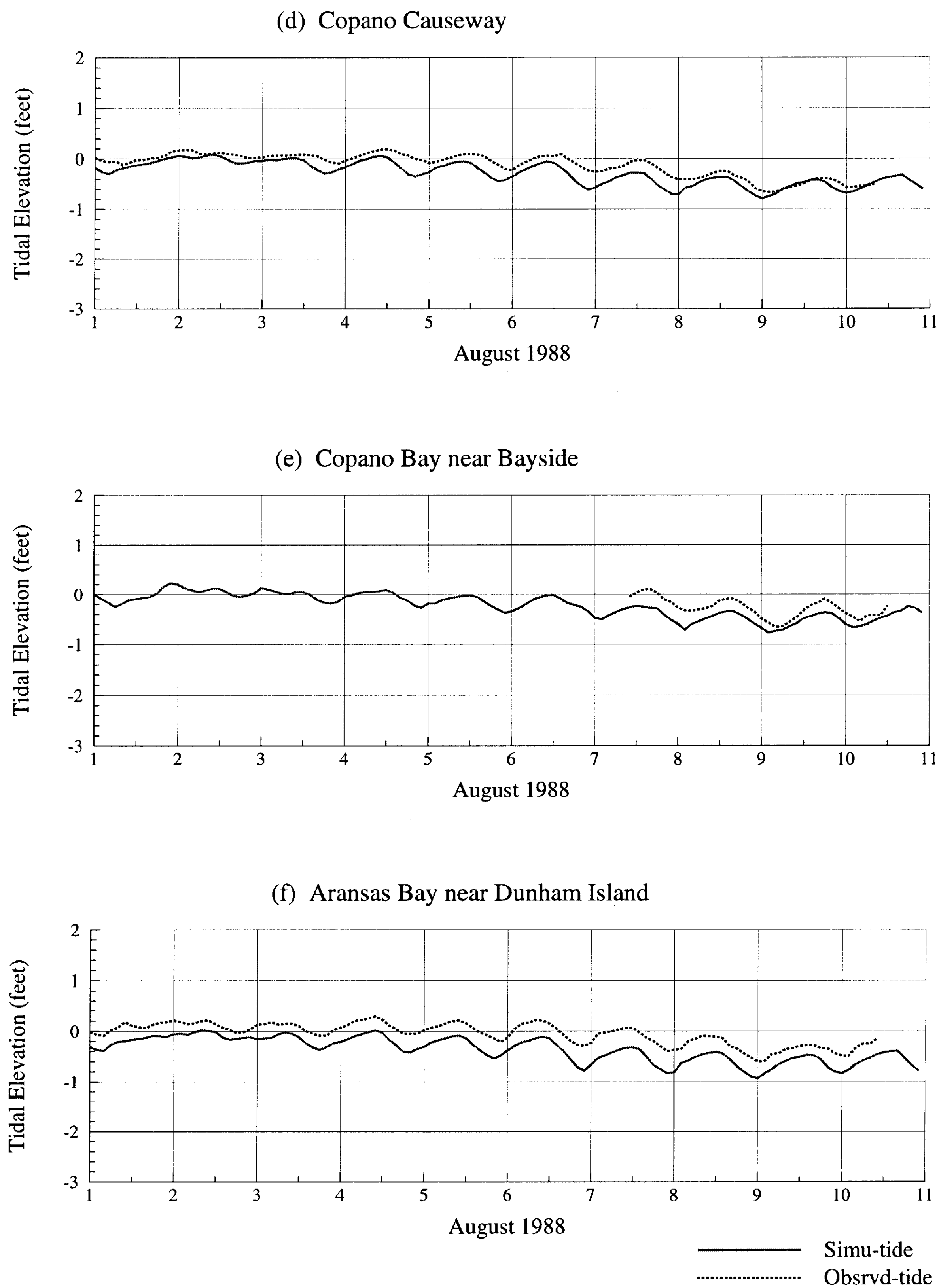


Figure III.6 Simulated and observed tides in August 1988

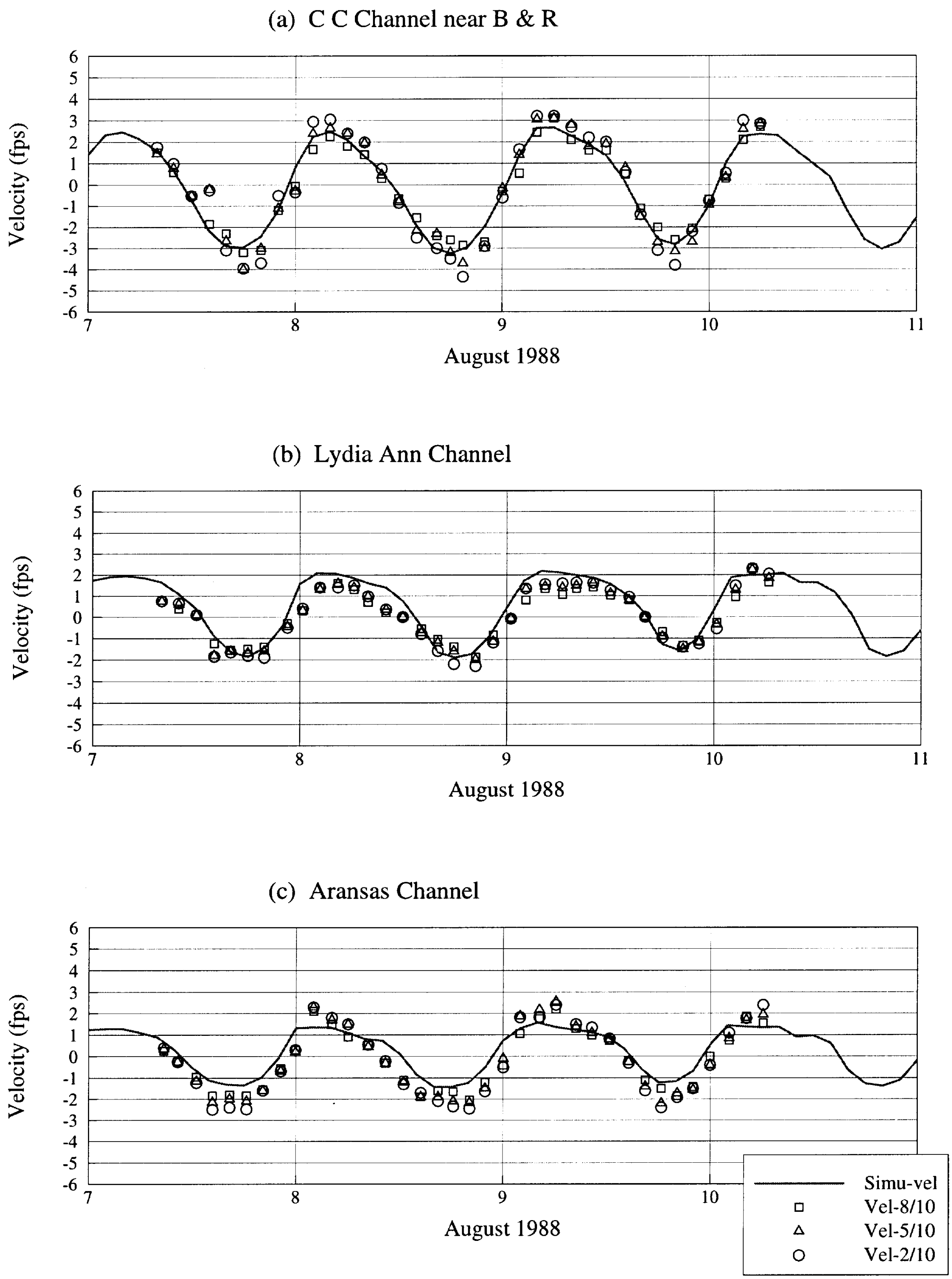


Figure III.7 Simulated and observed velocities in August 1988

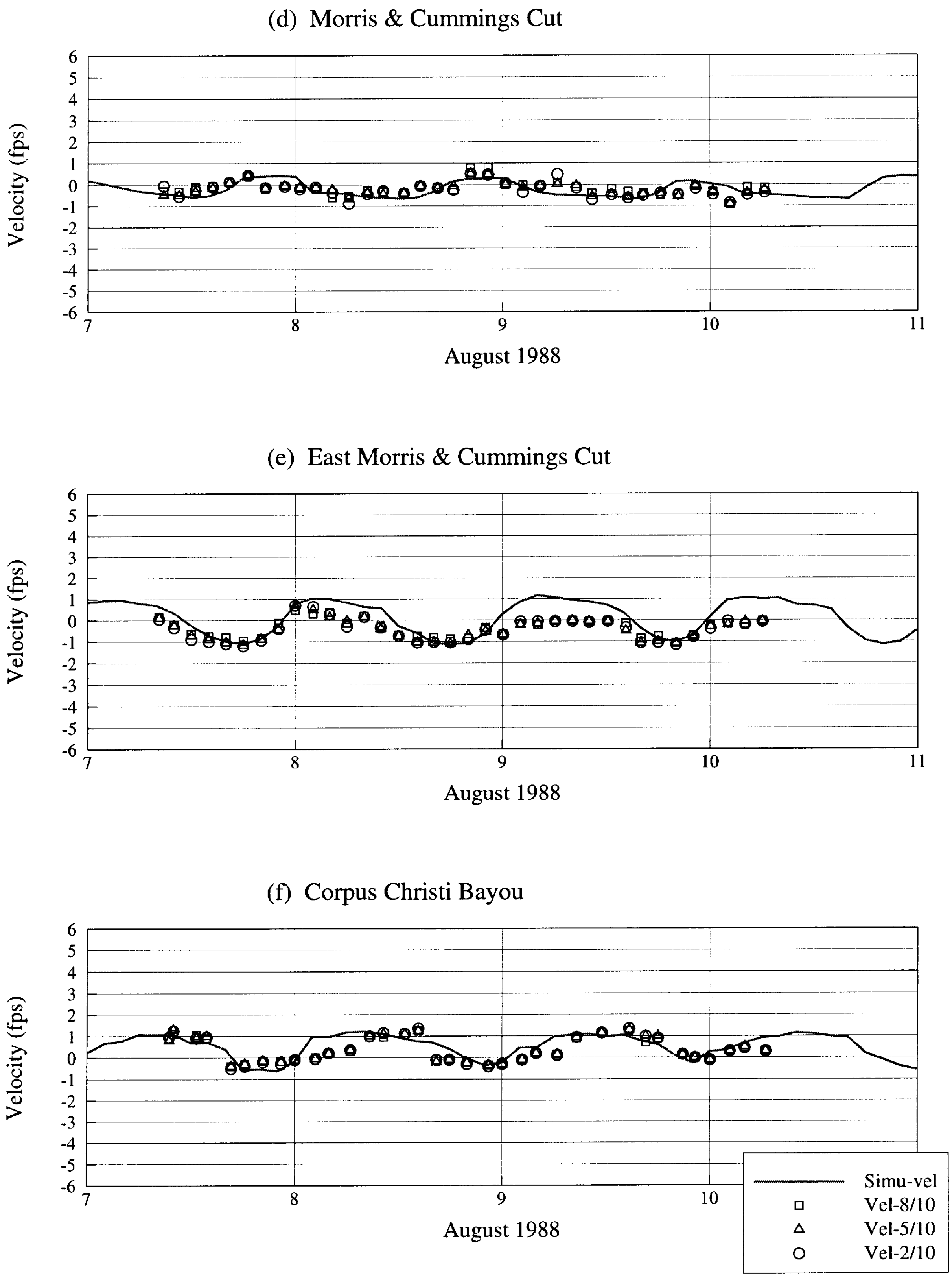


Figure III.7 Simulated and observed velocities in August 1988

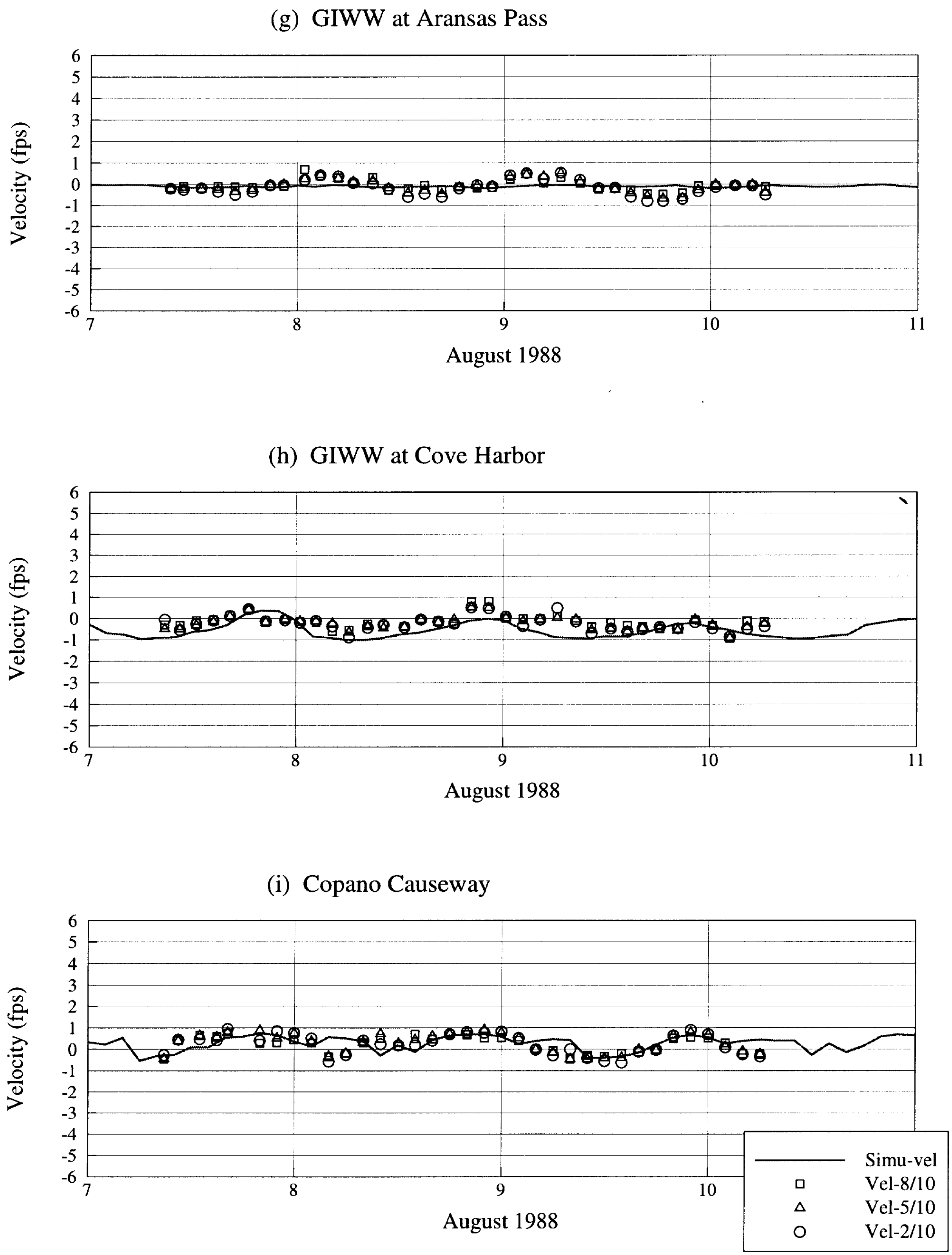


Figure III.7 Simulated and observed velocities in August 1988

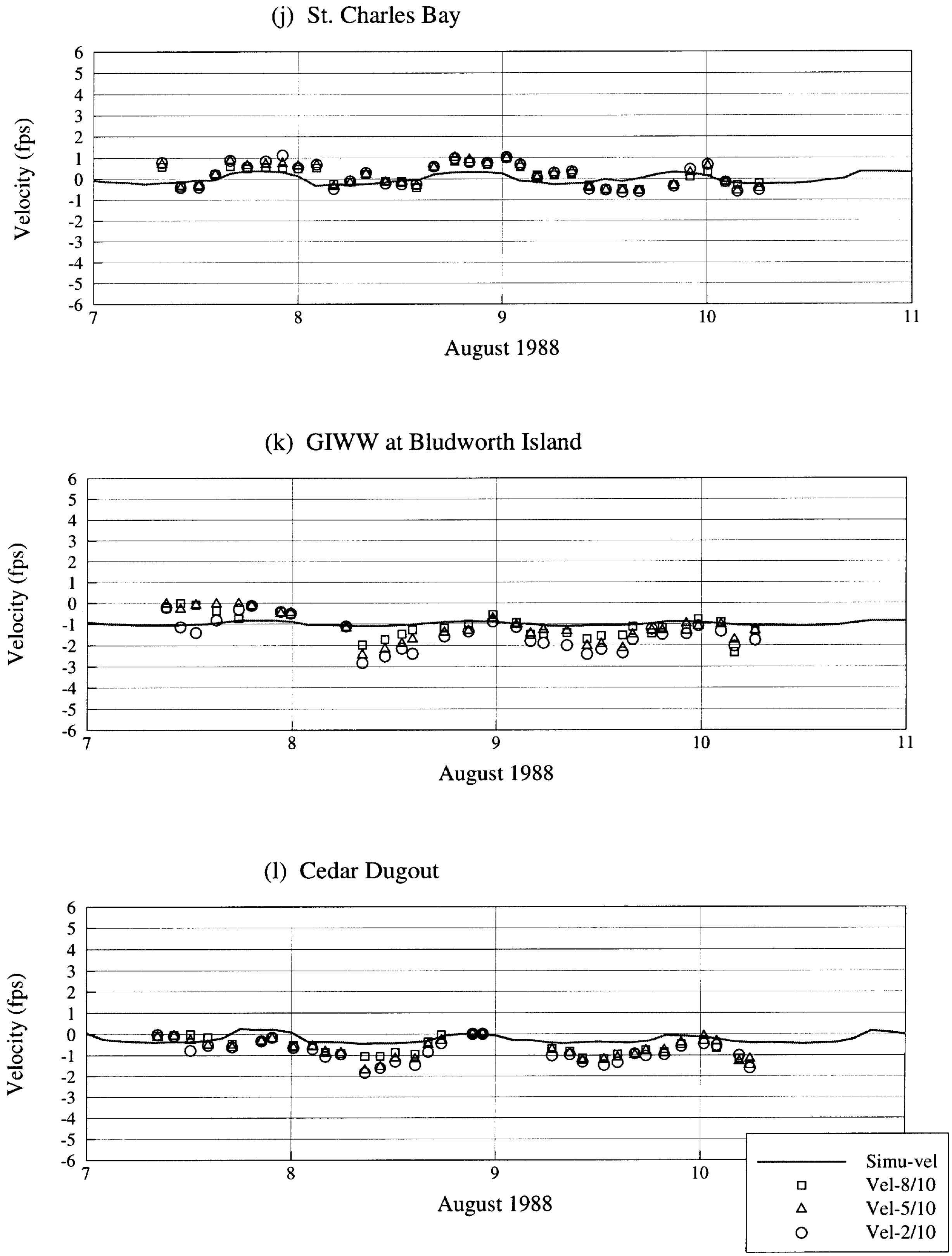
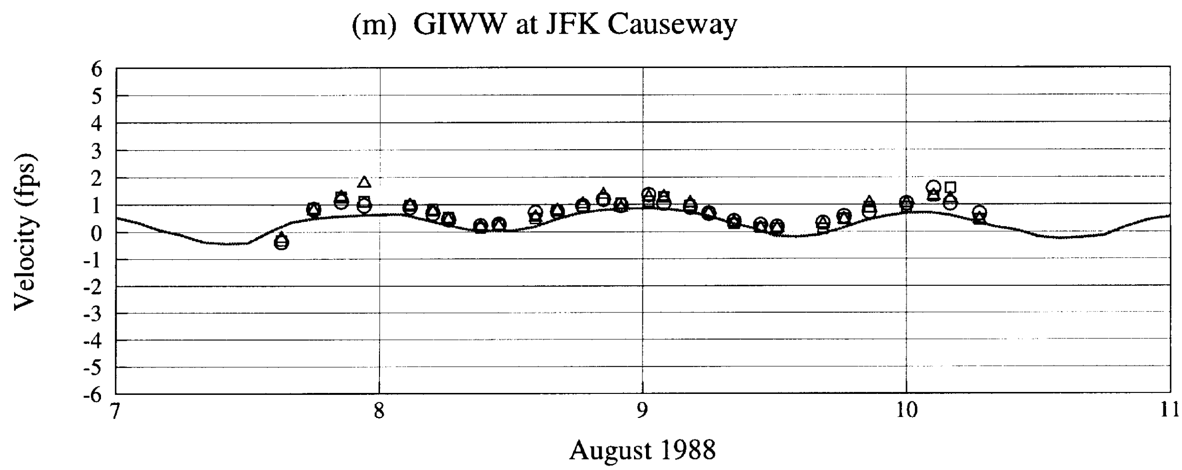


Figure III.7 Simulated and observed velocities in August 1988



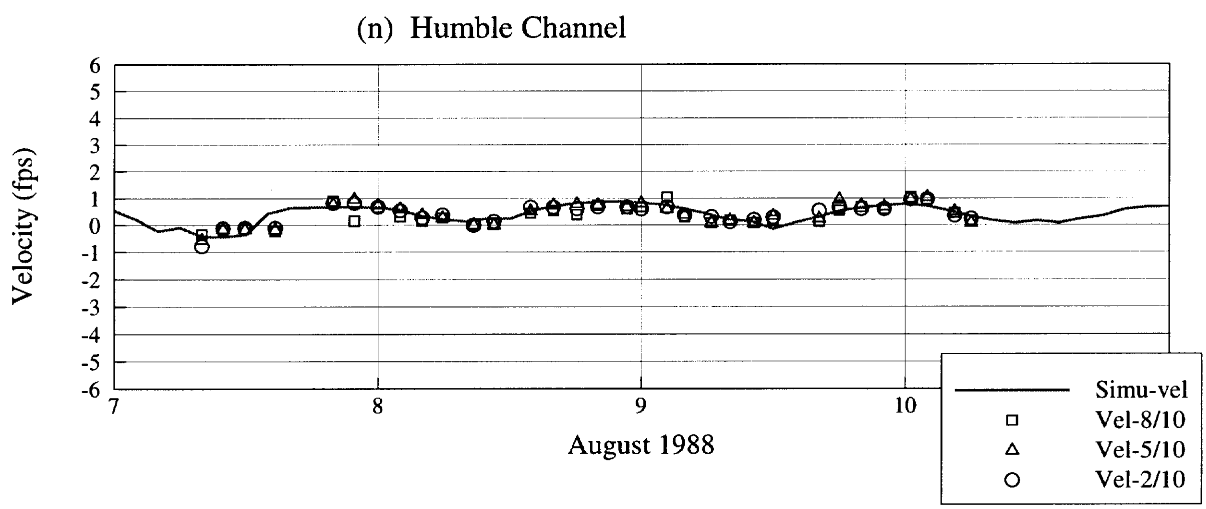


Figure III.7 Simulated and observed velocities in August 1988

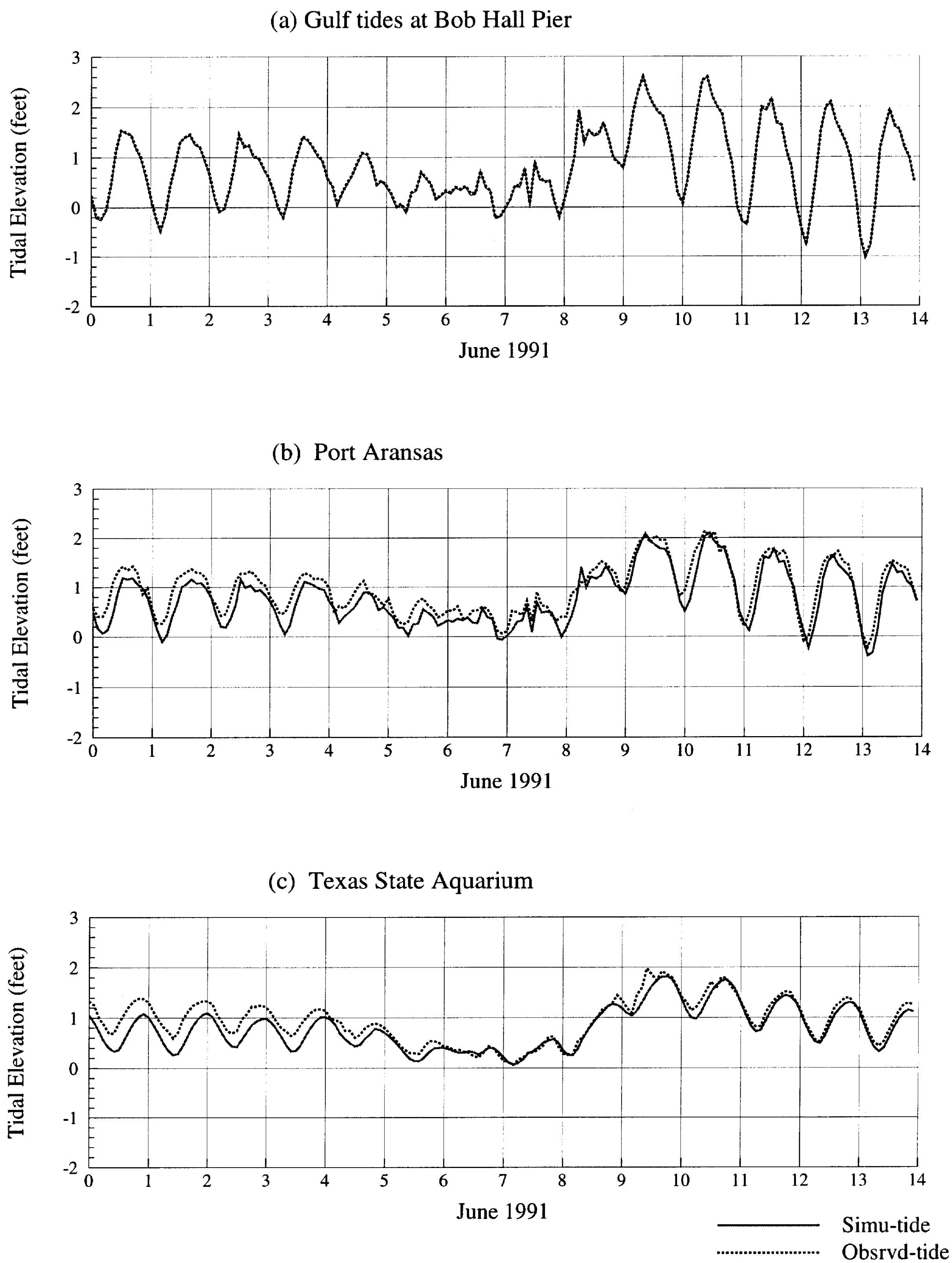


Figure III.8 Simulated and observed tides in June 1991

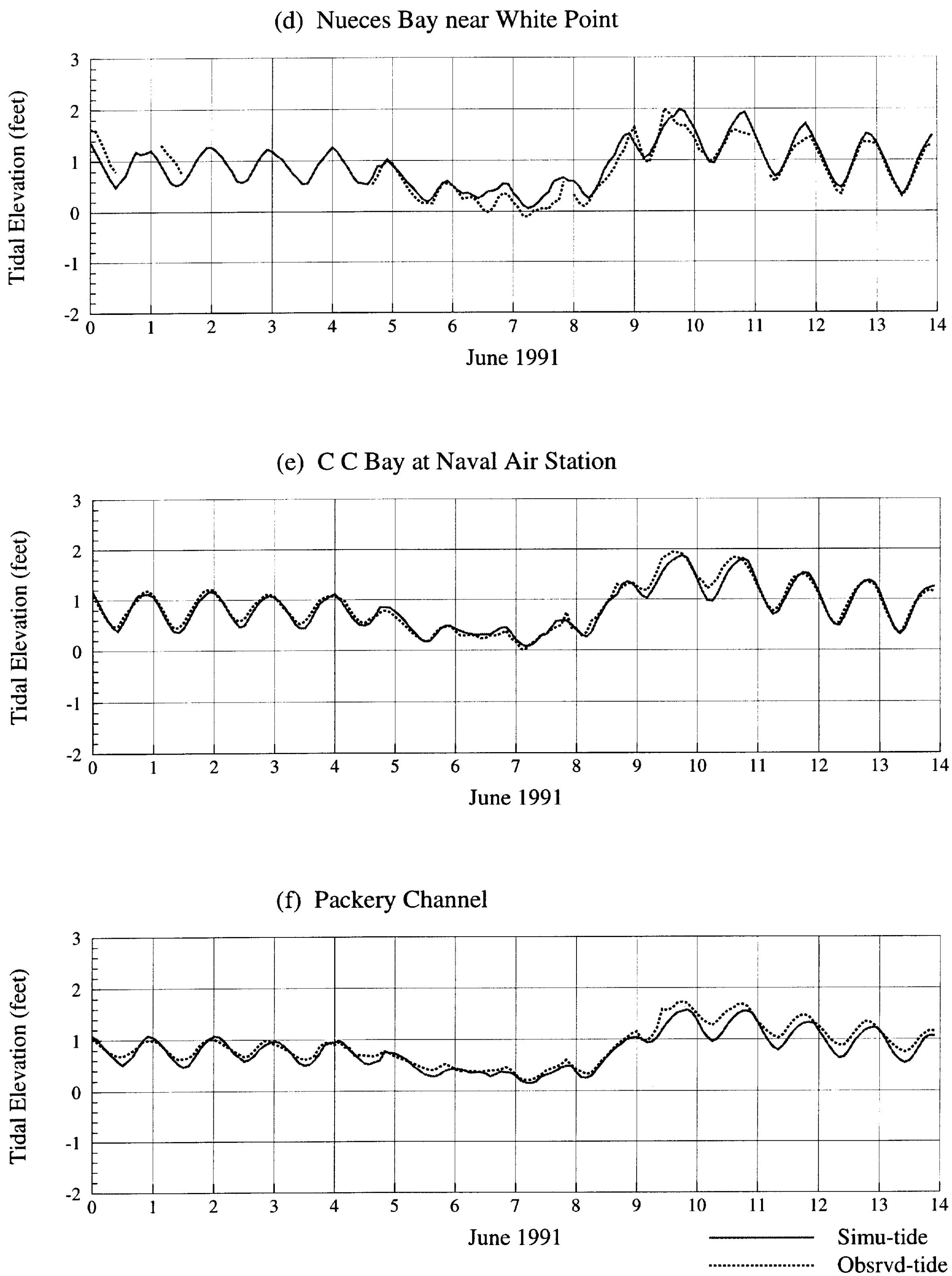


Figure III.8 Simulated and observed tides in June 1991

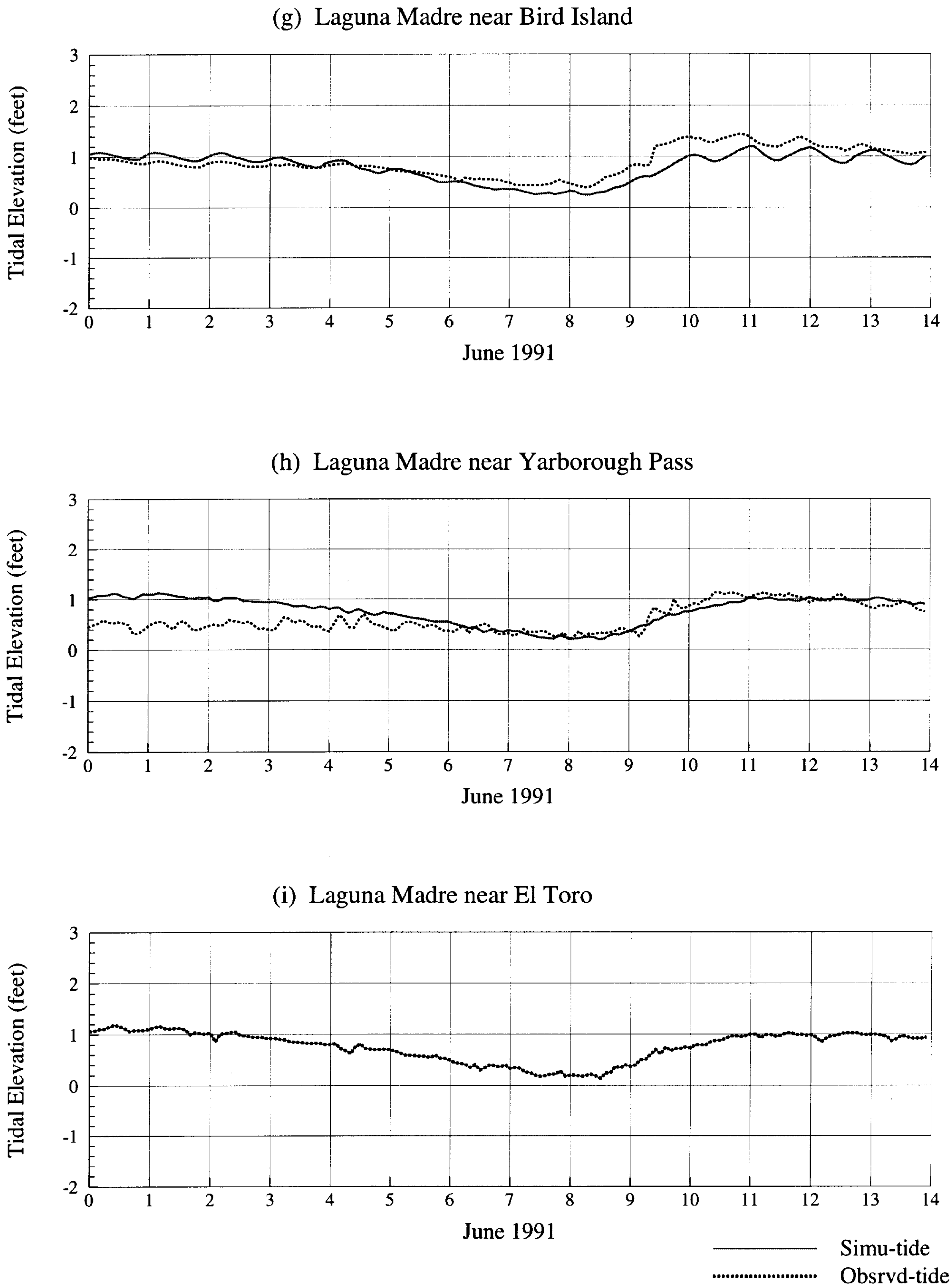


Figure III.8 Simulated and observed tides in June 1991

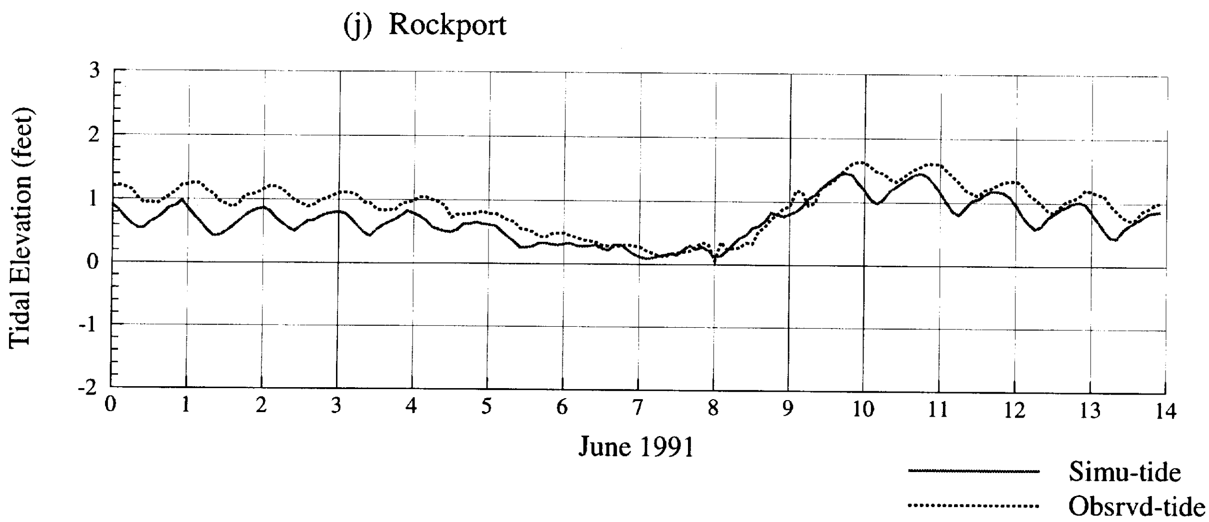


Figure III.8 Simulated and observed tides in June 1991

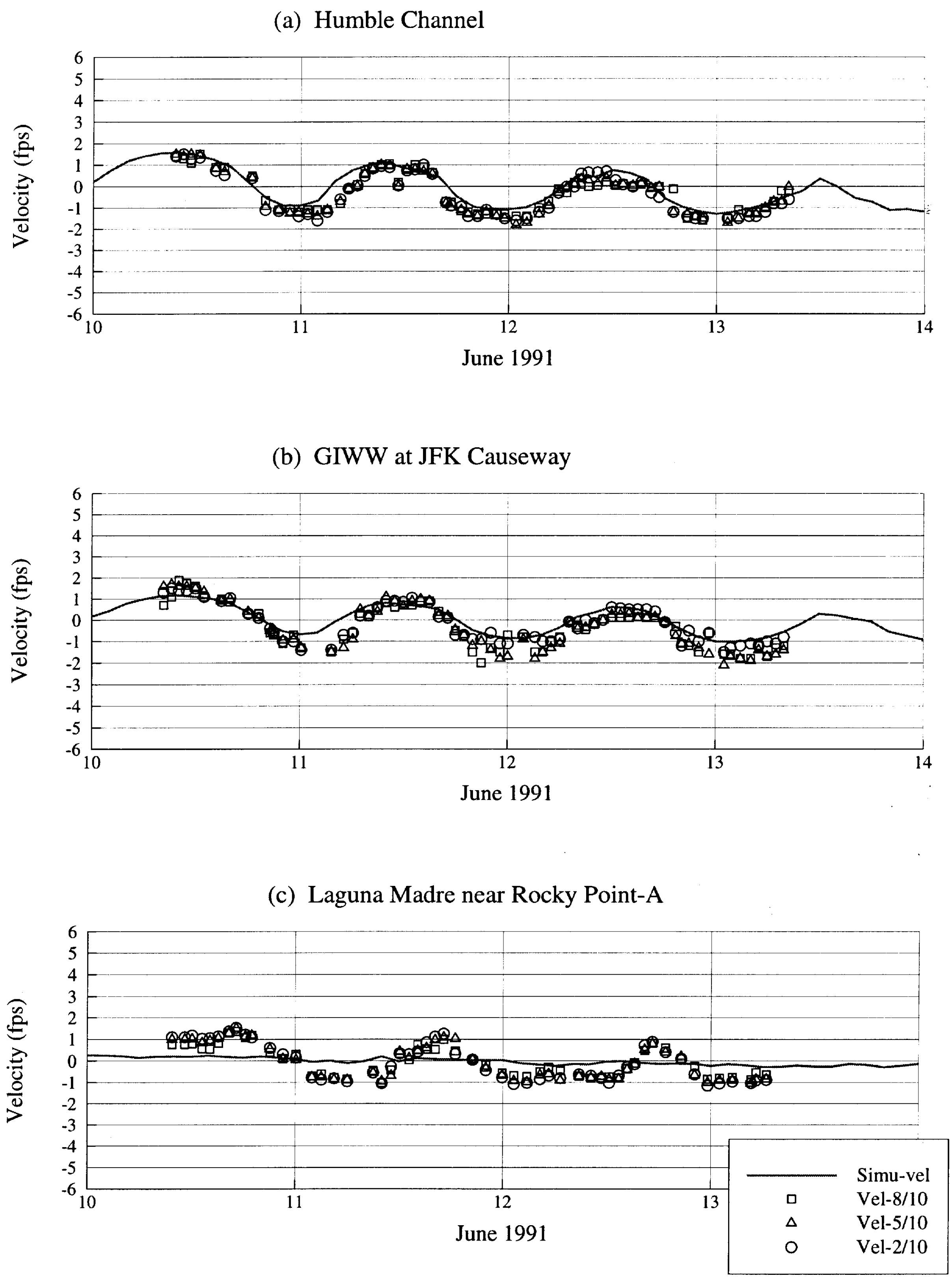


Figure III.9 Simulated and observed velocities in June 1991

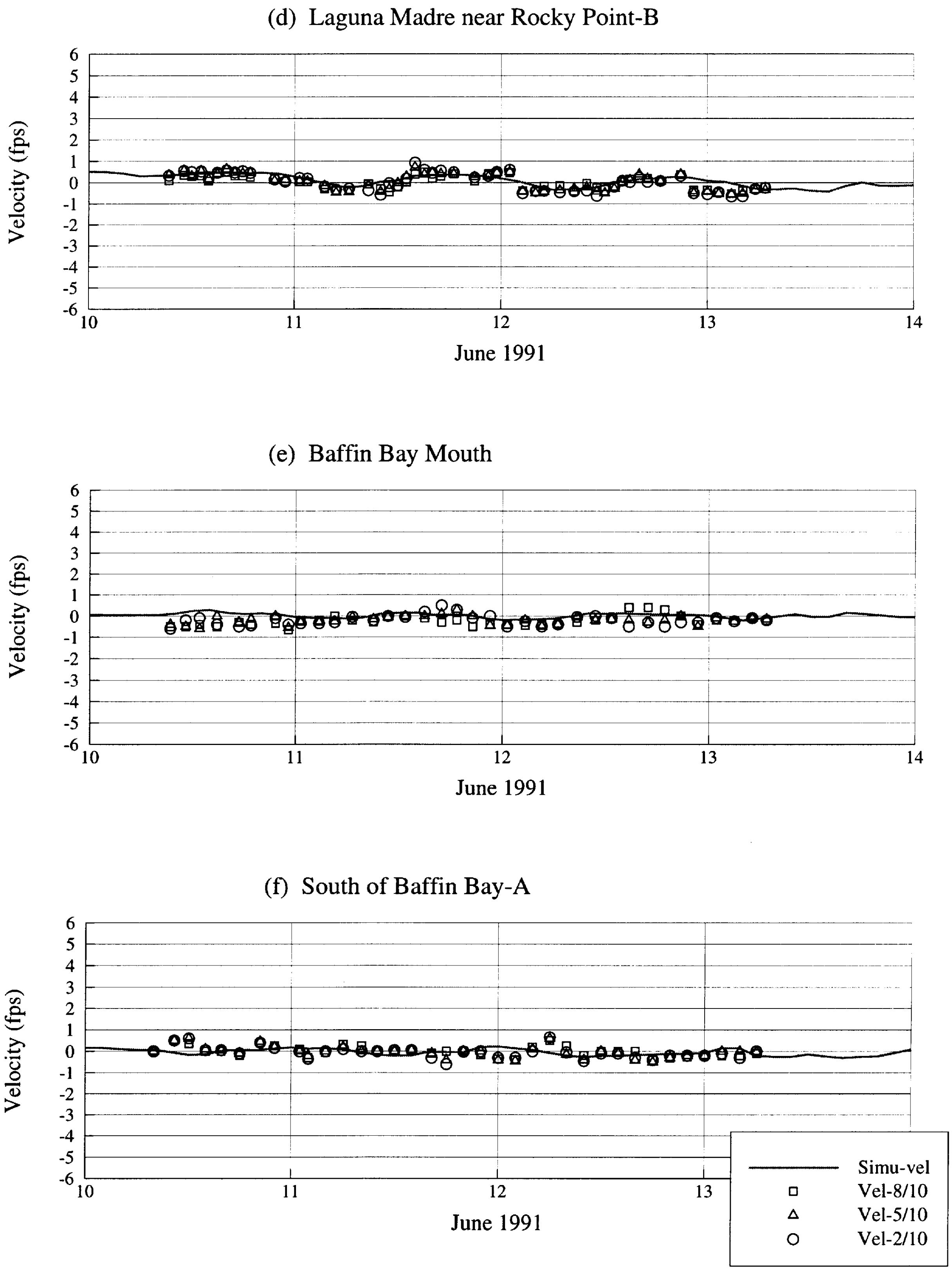


Figure III.9 Simulated and observed velocities in June 1991

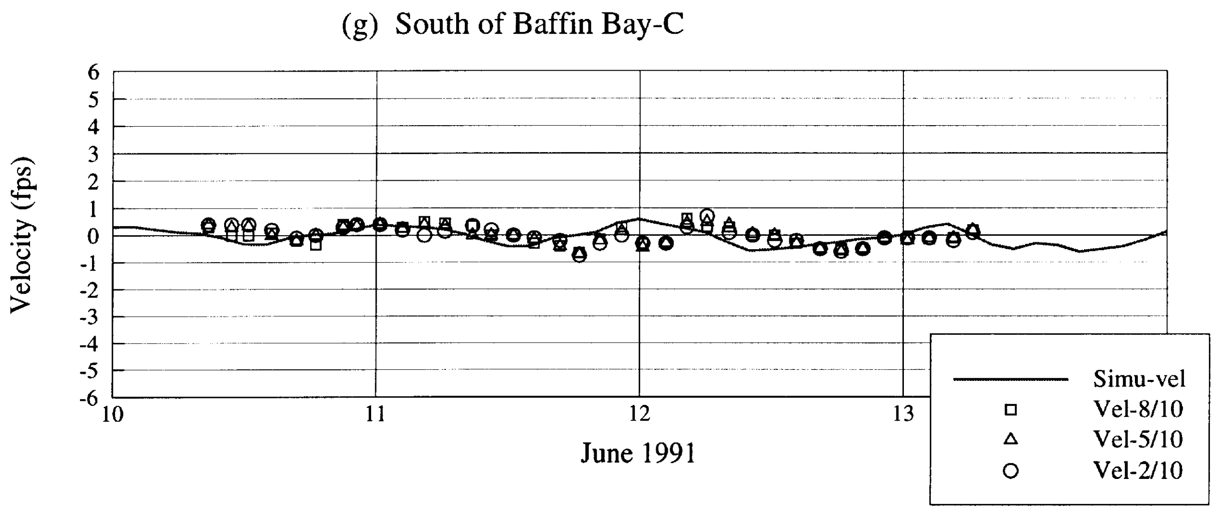


Figure III.9 Simulated and observed velocities in June 1991

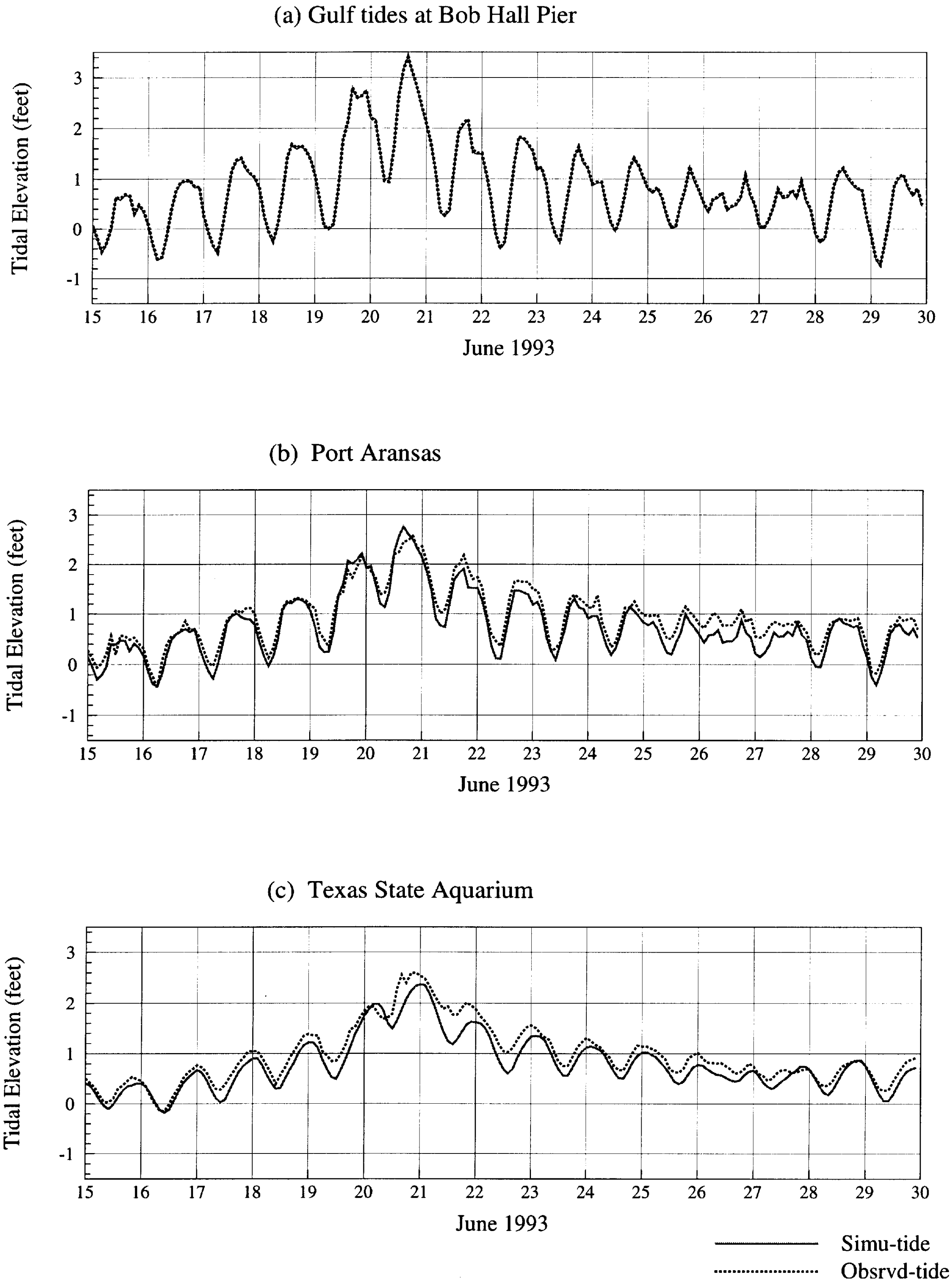
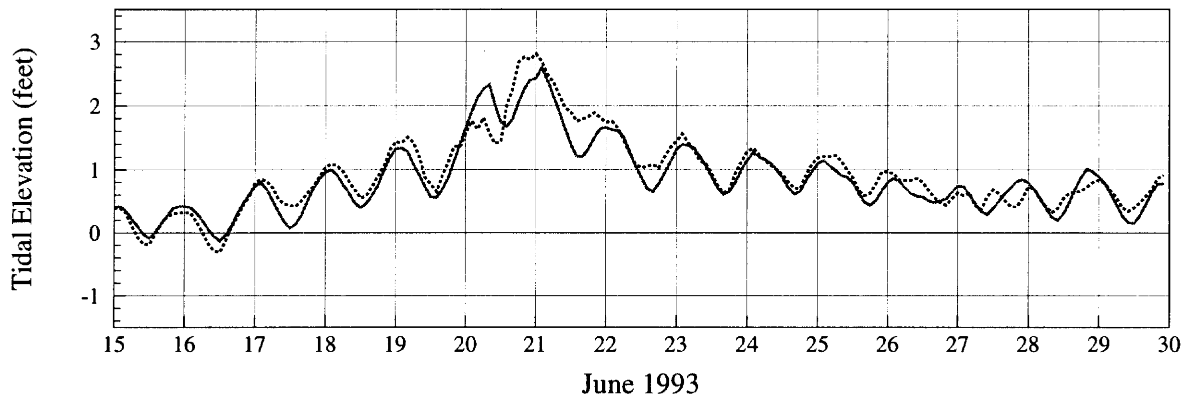
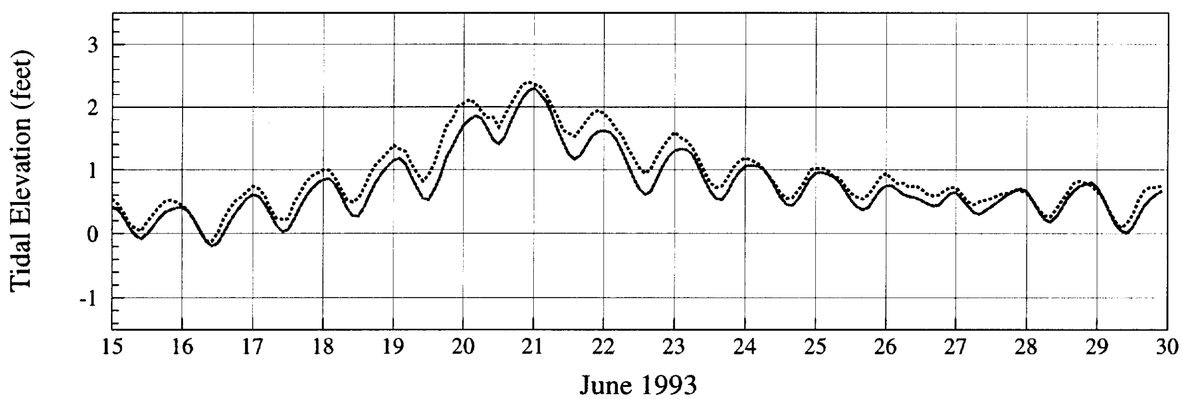


Figure III.10 Simulated and observed tides in June 1993

(d) Nueces Bay near White Point



(e) C C Bay at Naval Air Station



(f) Packery Channel

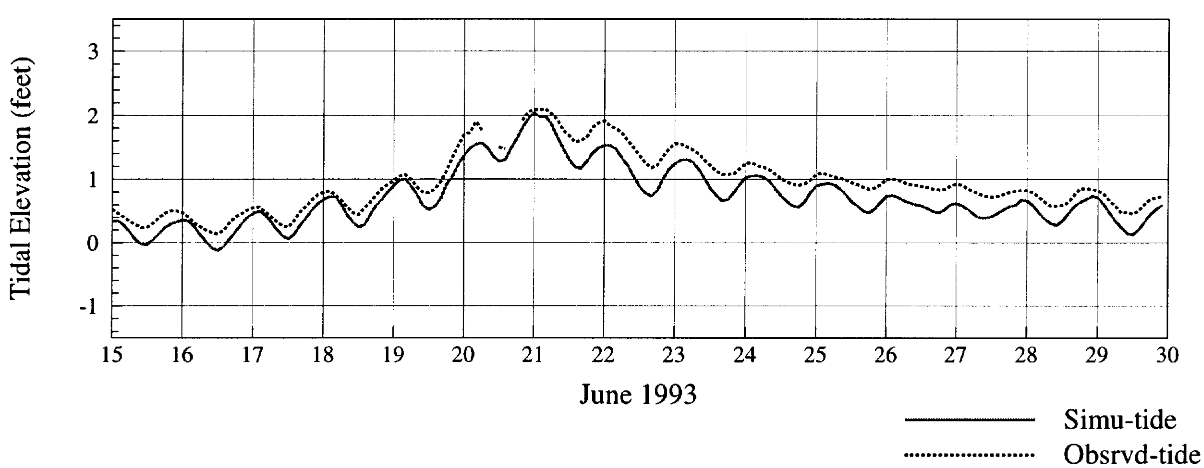


Figure III.10 Simulated and observed tides in June 1993

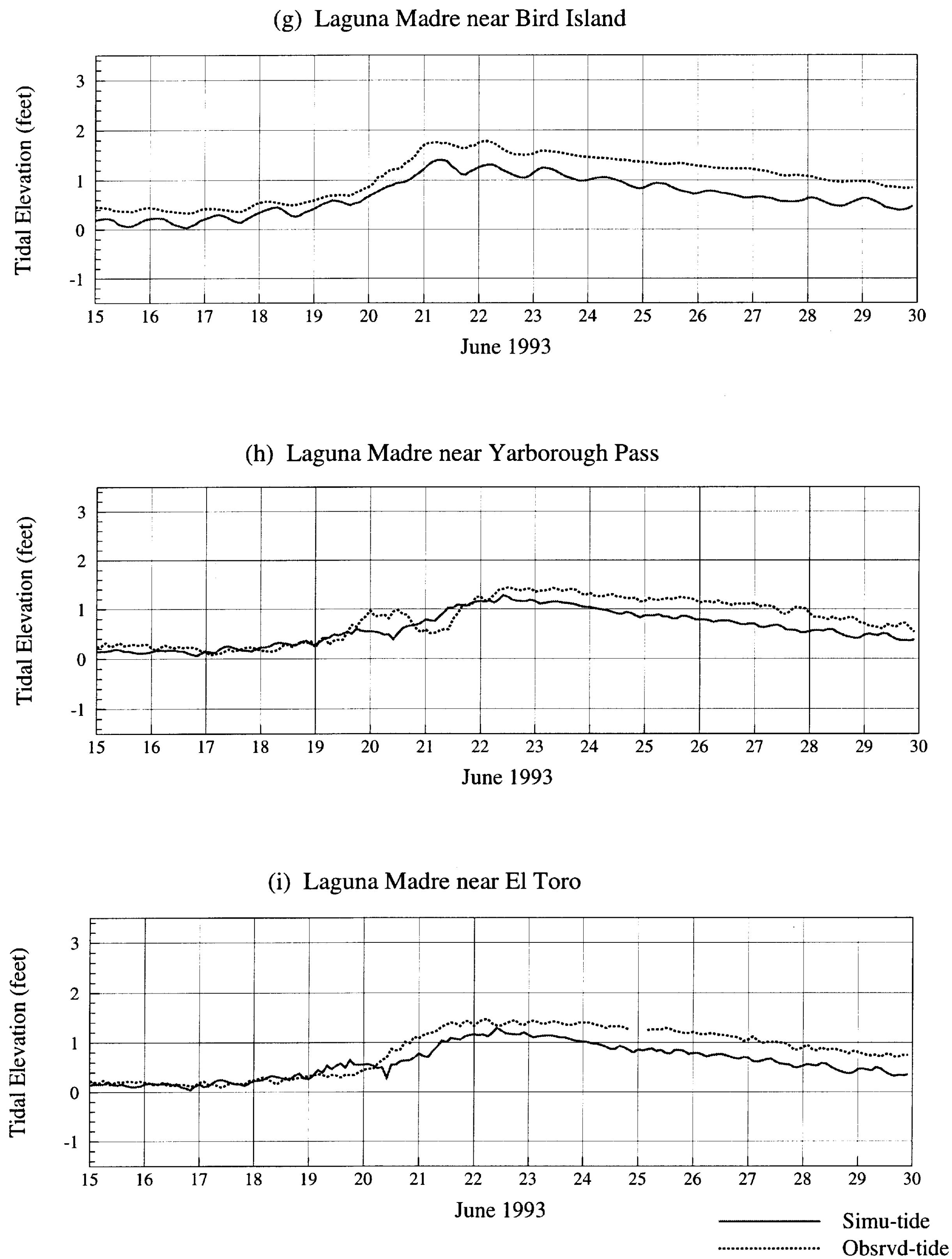
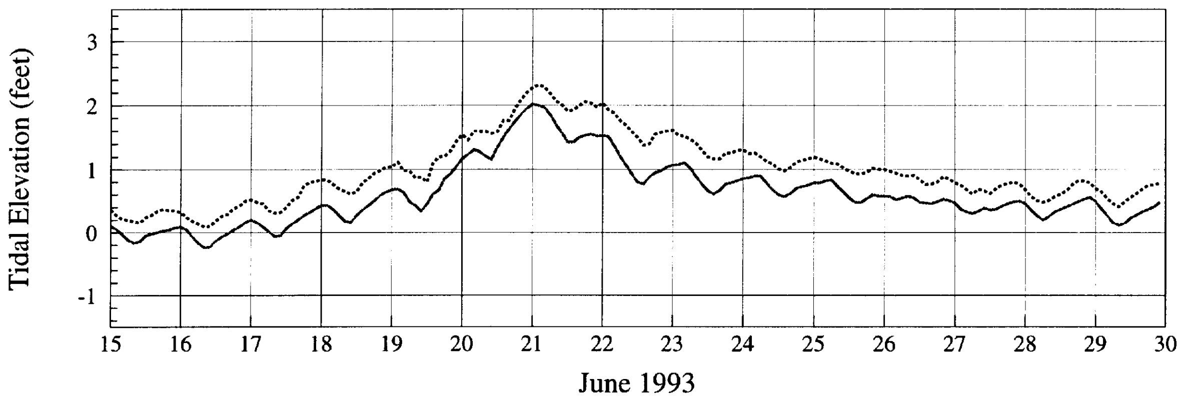
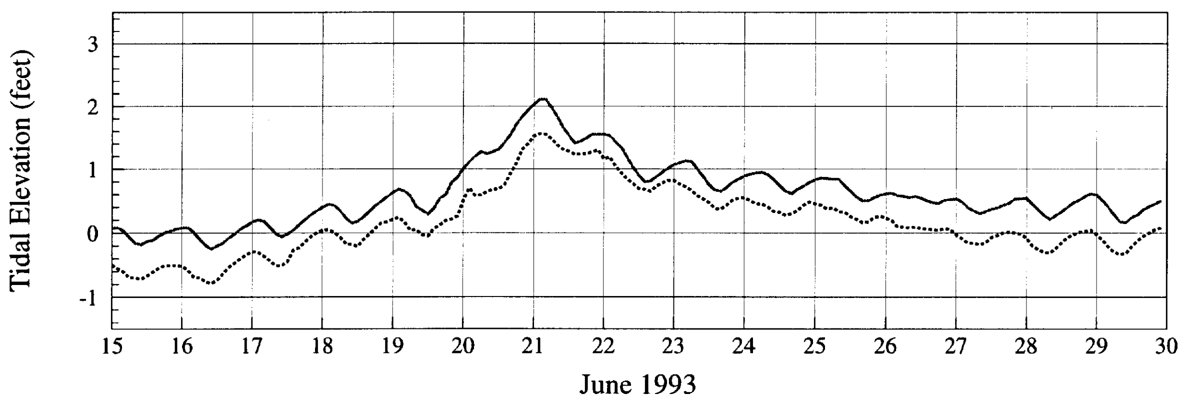


Figure III.10 Simulated and observed tides in June 1993

(j) Rockport



(k) Copano Causeway



(l) Copano Bay near Bayside

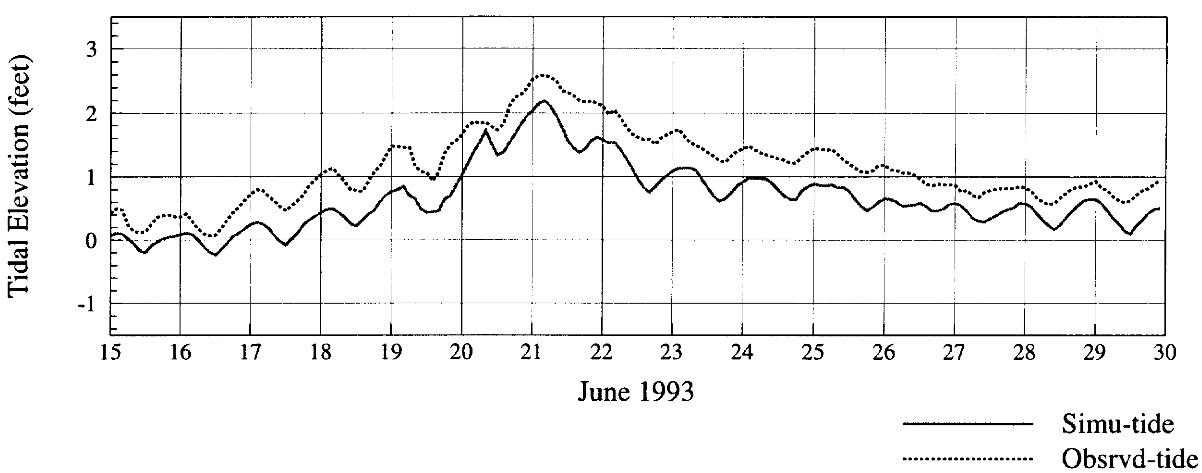


Figure III.10 Simulated and observed tides in June 1993

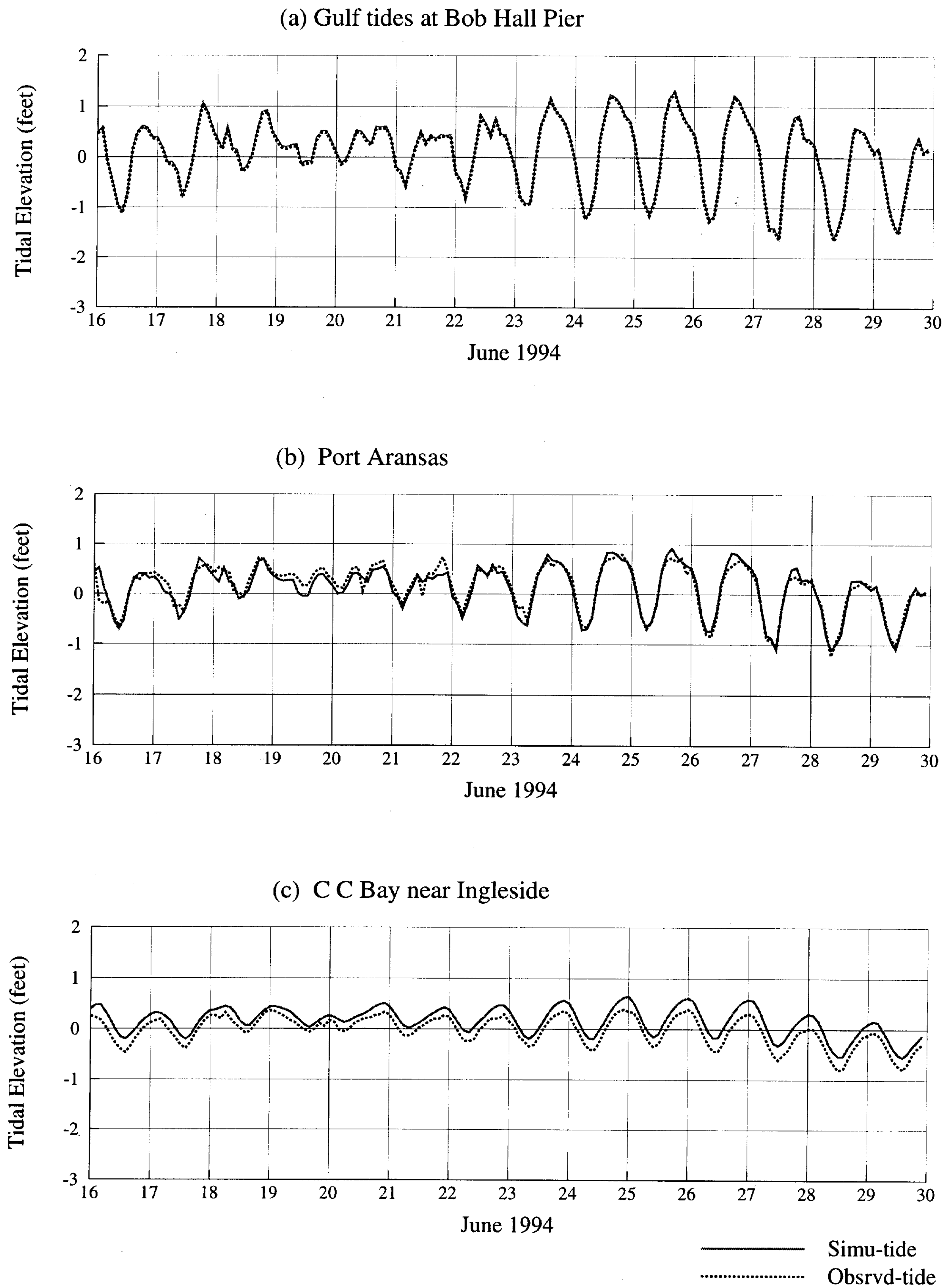


Figure III.11 Simulated and observed tides in June 1994

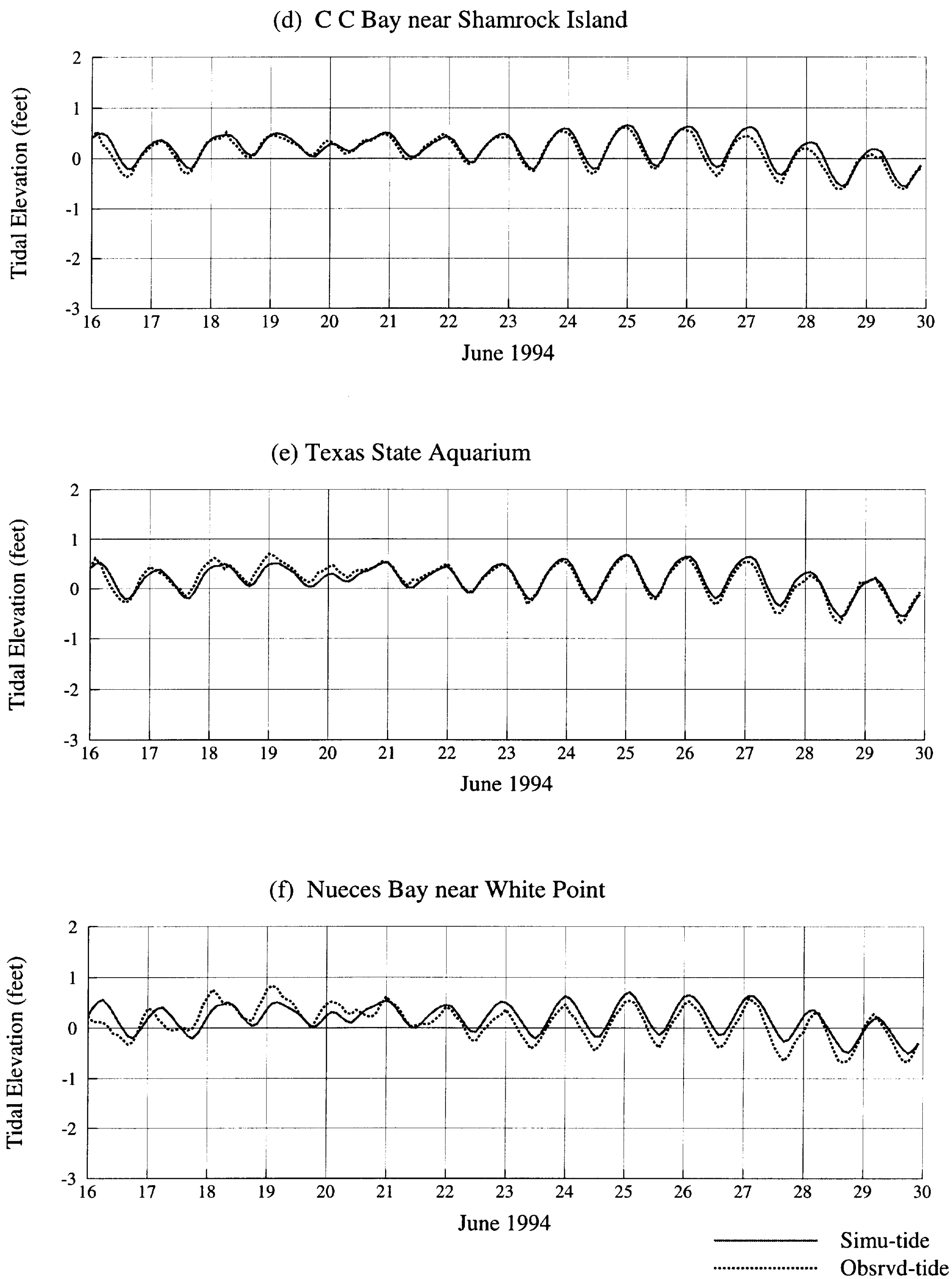
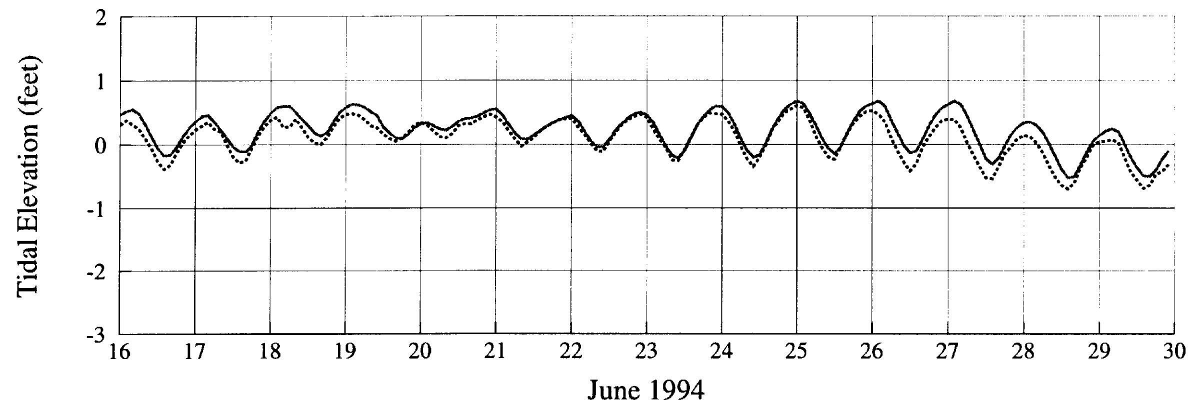
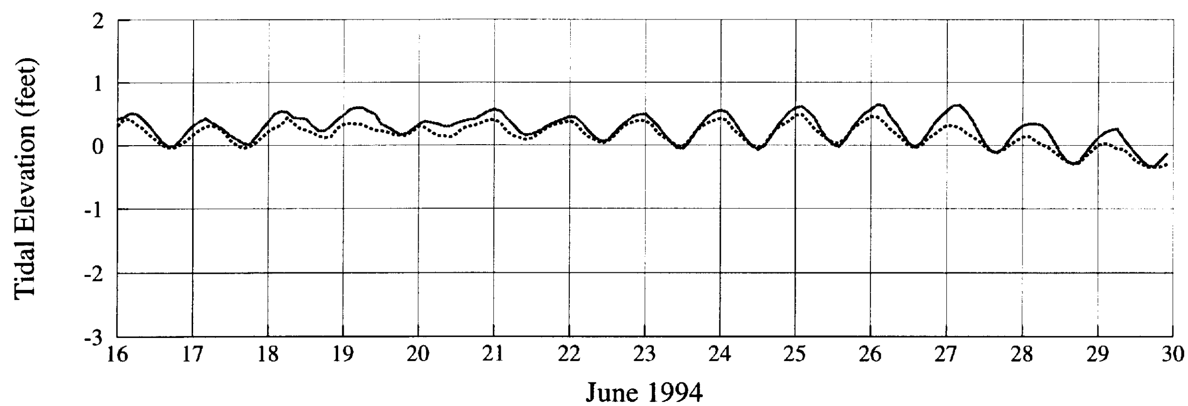


Figure III.11 Simulated and observed tides in June 1994

(g) C C Bay at Naval Air Station



(h) Packery Channel



(i) Laguna Madre near Bird Island

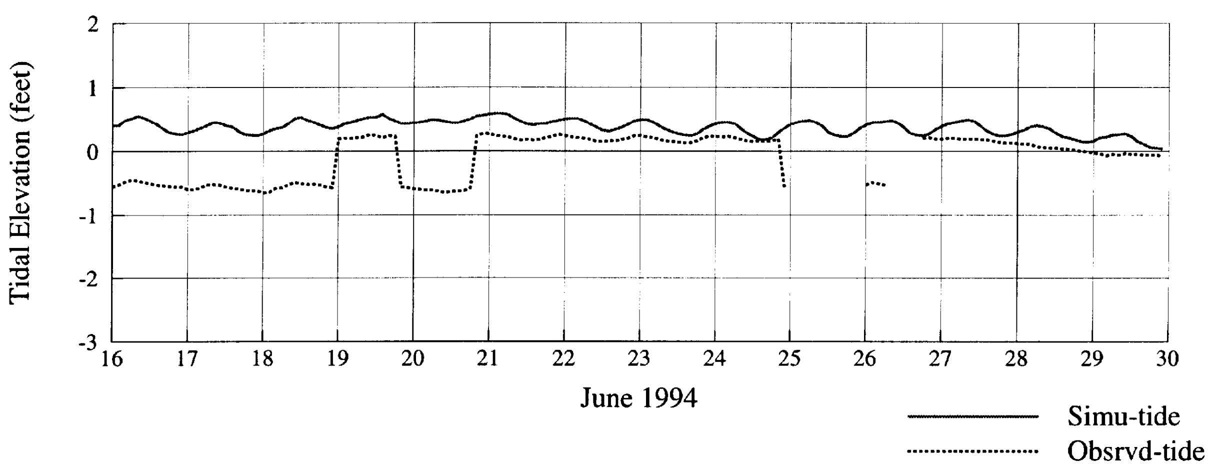


Figure III.11 Simulated and observed tides in June 1994

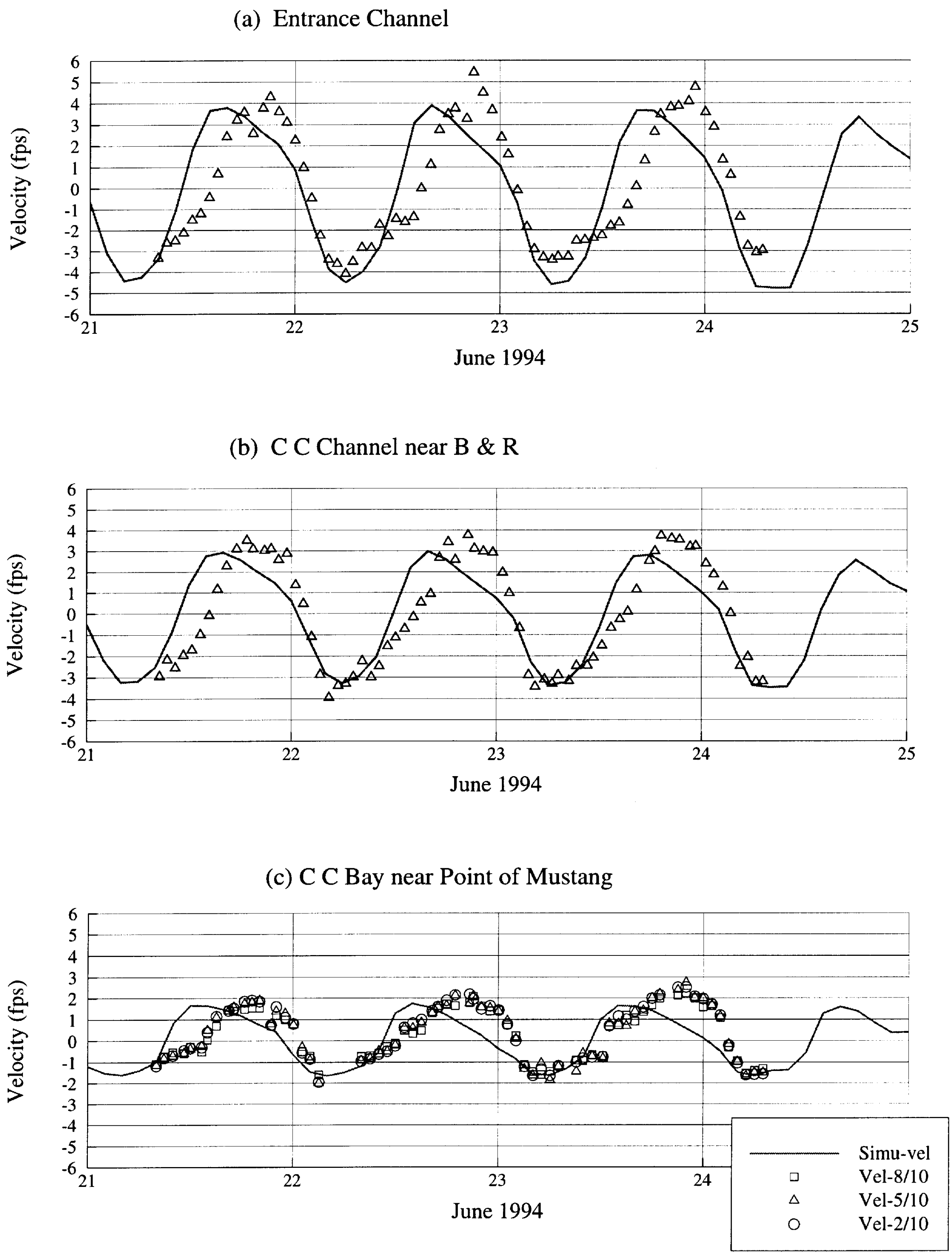
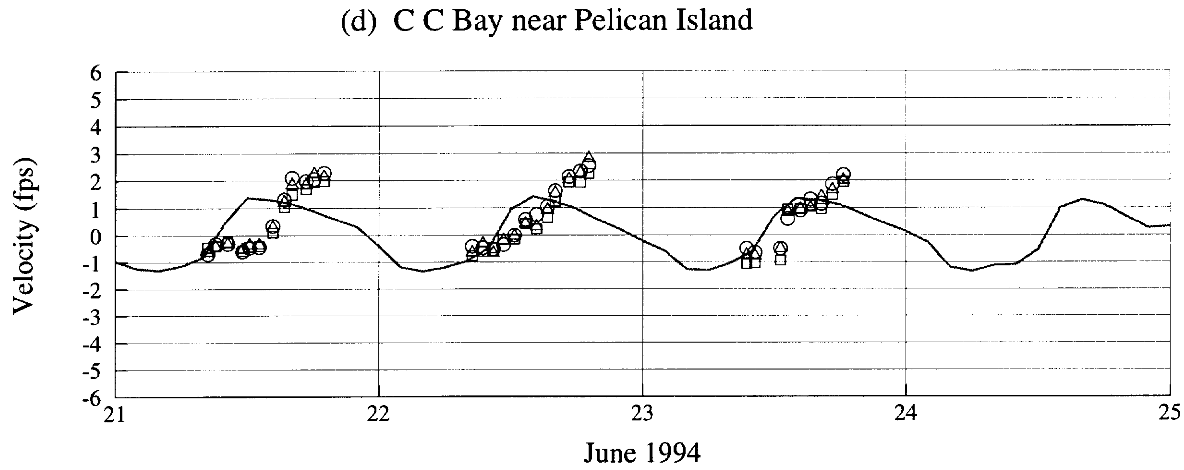
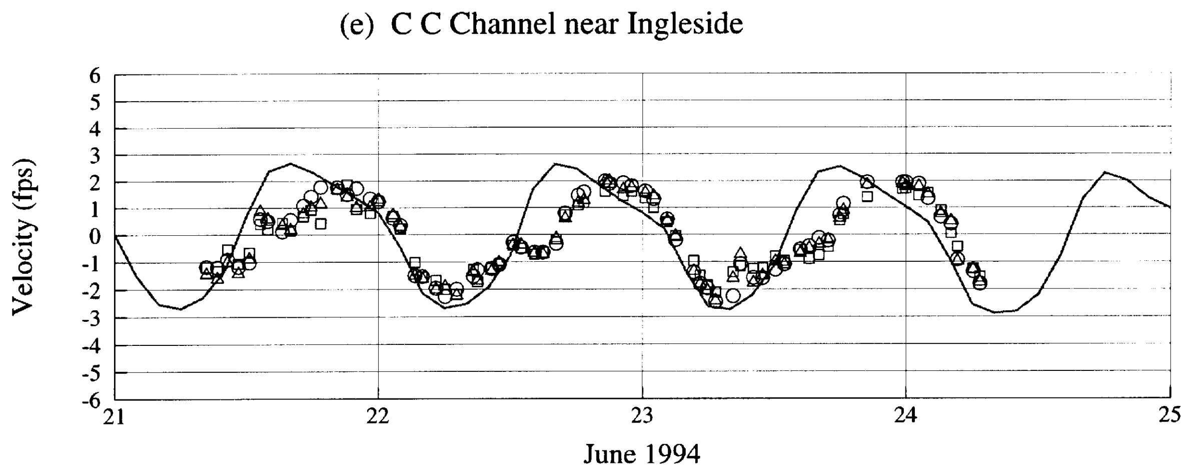


Figure III.12 Simulated and observed velocities in June 1994





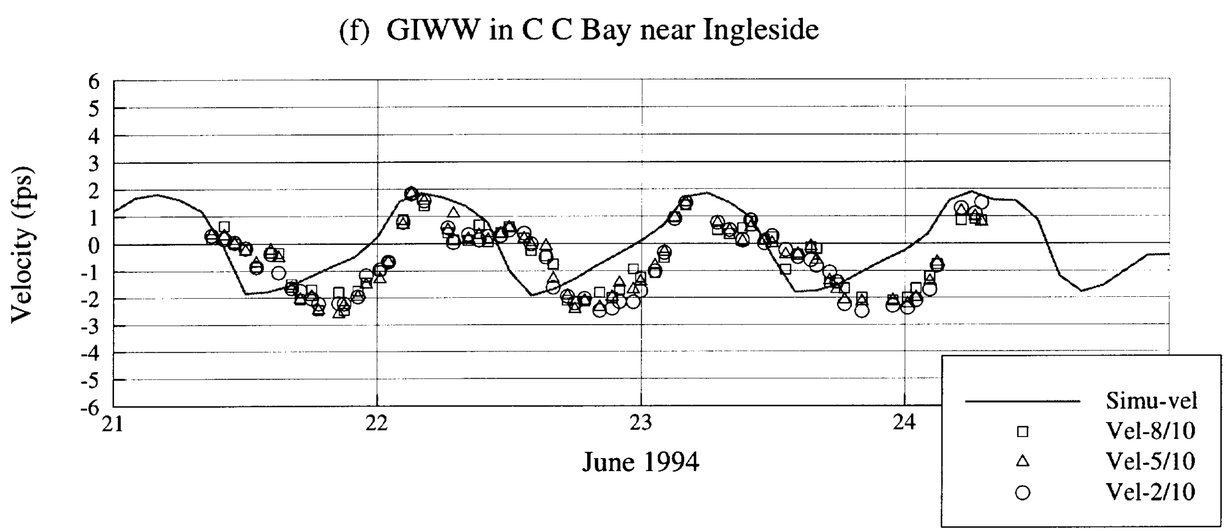


Figure III.12 Simulated and observed velocities in June 1994

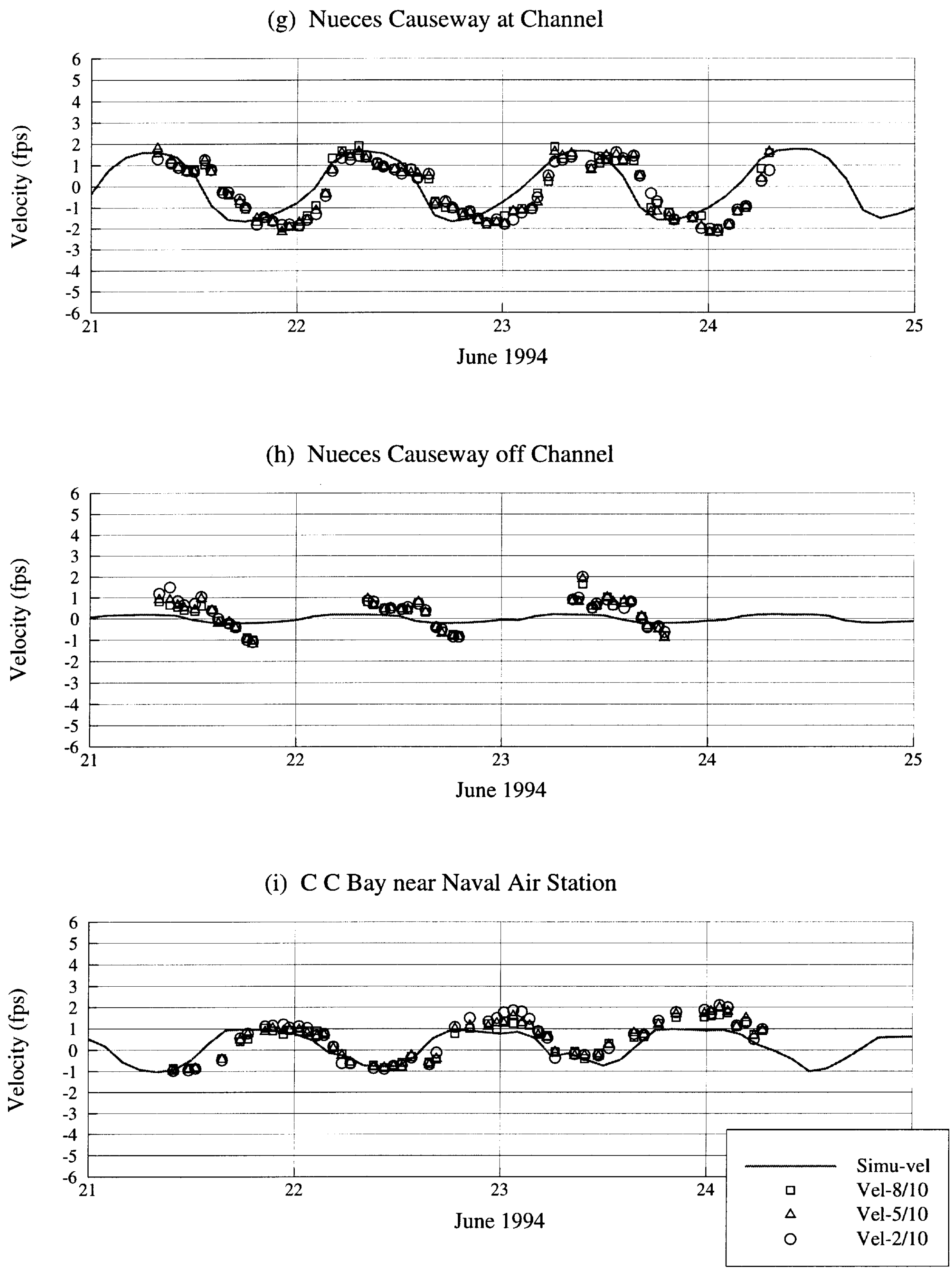


Figure III.12 Simulated and observed velocities in June 1994

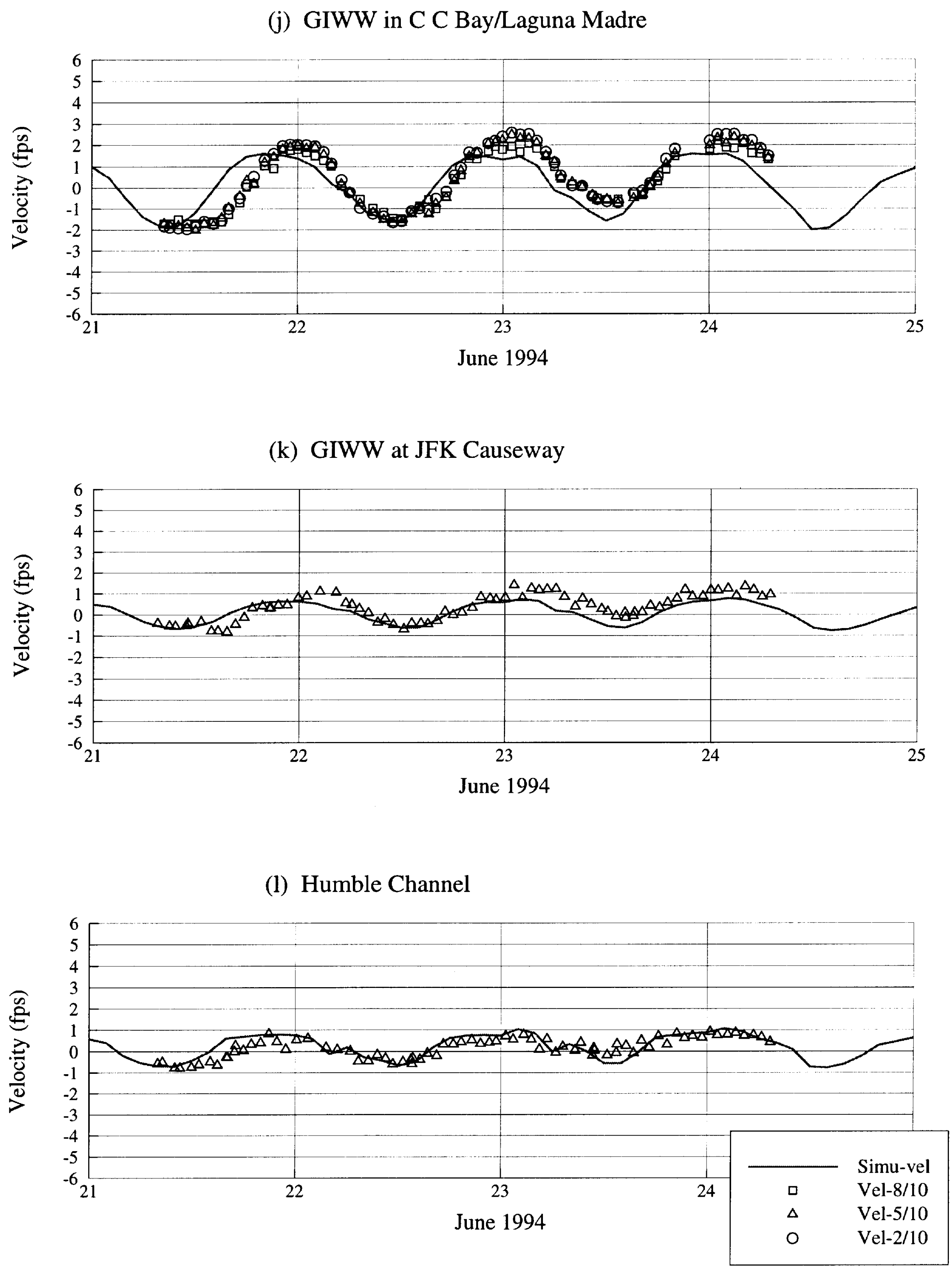


Figure III.12 Simulated and observed velocities in June 1994

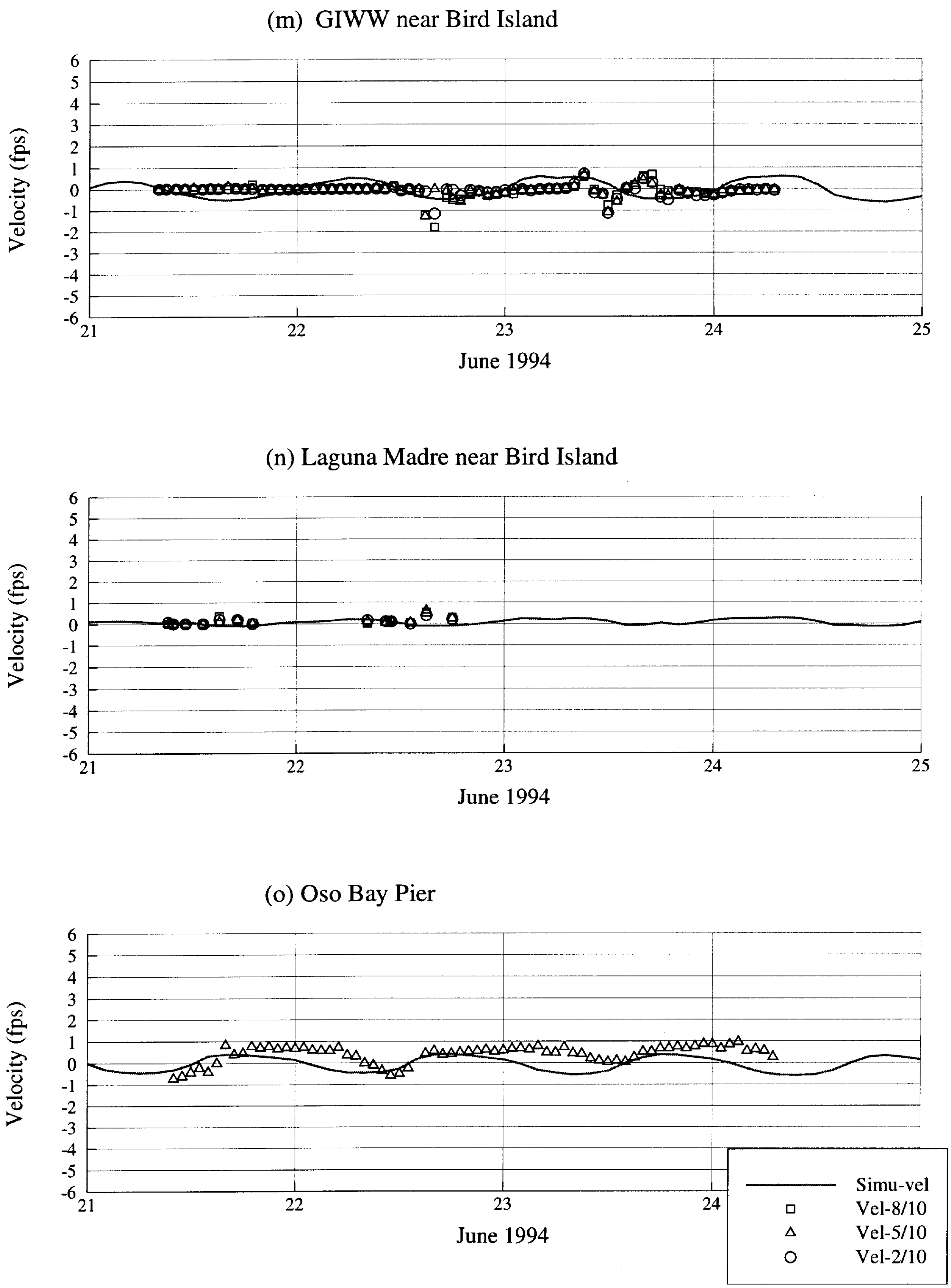


Figure III.12 Simulated and observed velocities in June 1994

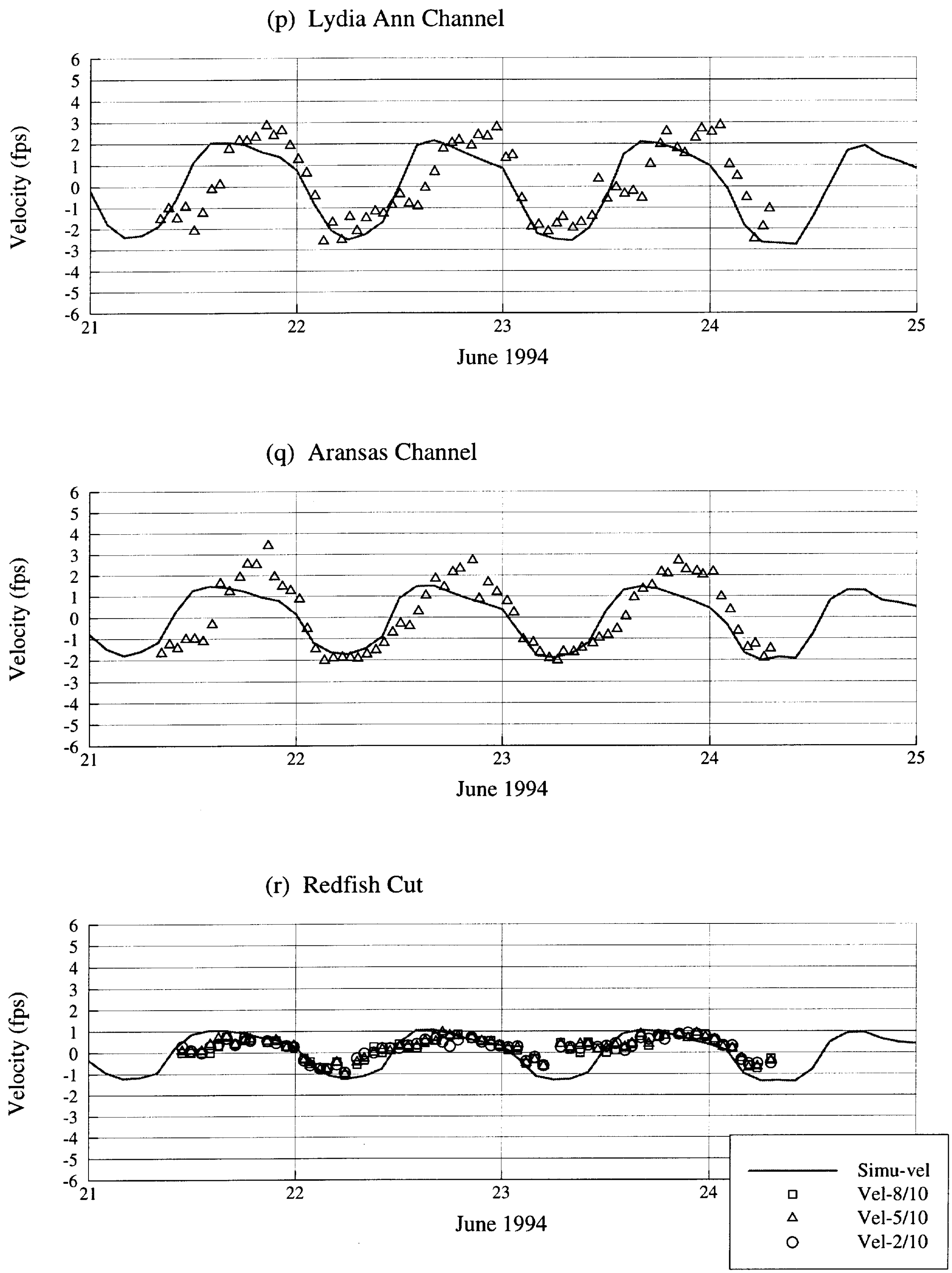
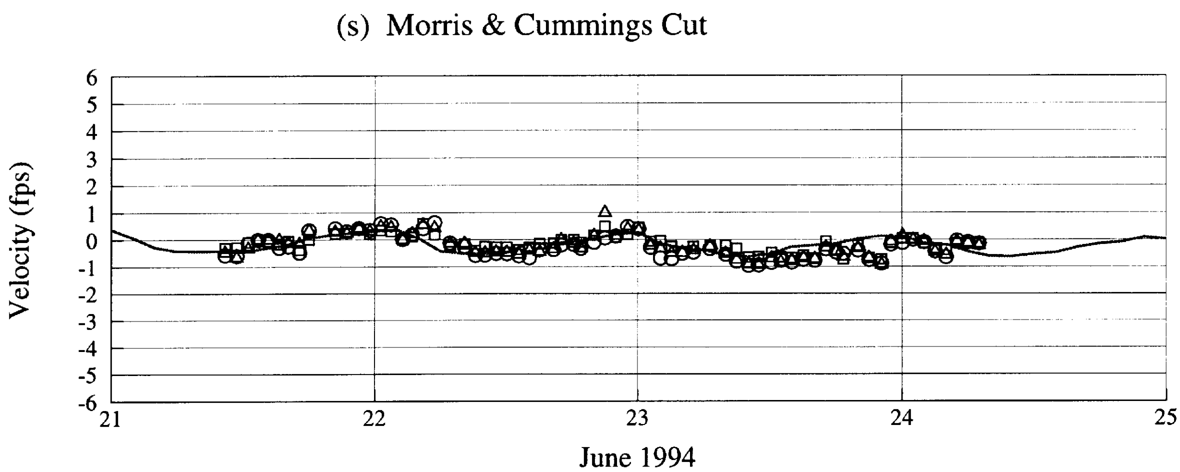


Figure III.12 Simulated and observed velocities in June 1994



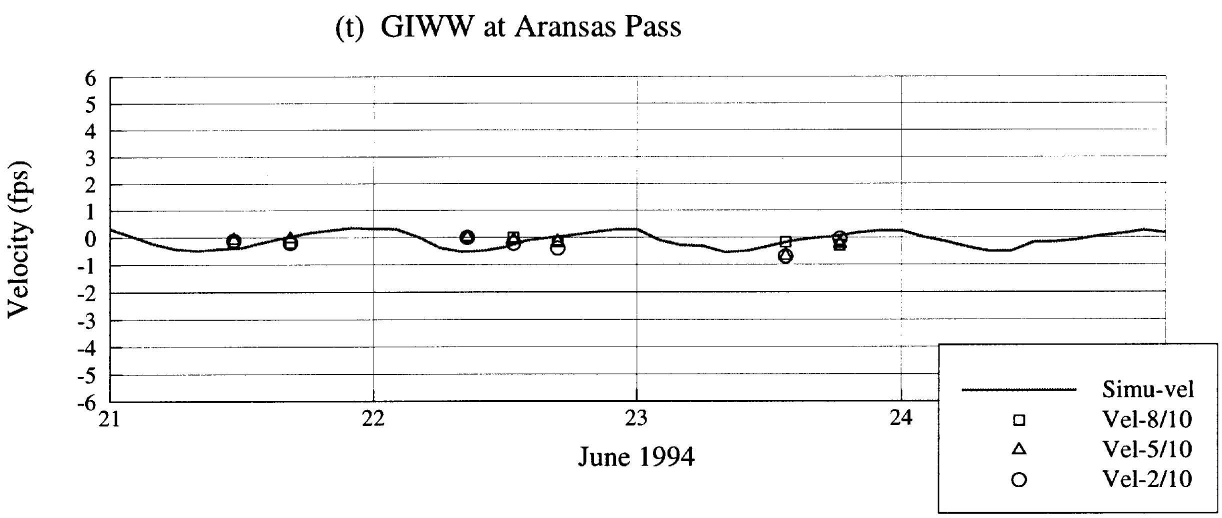
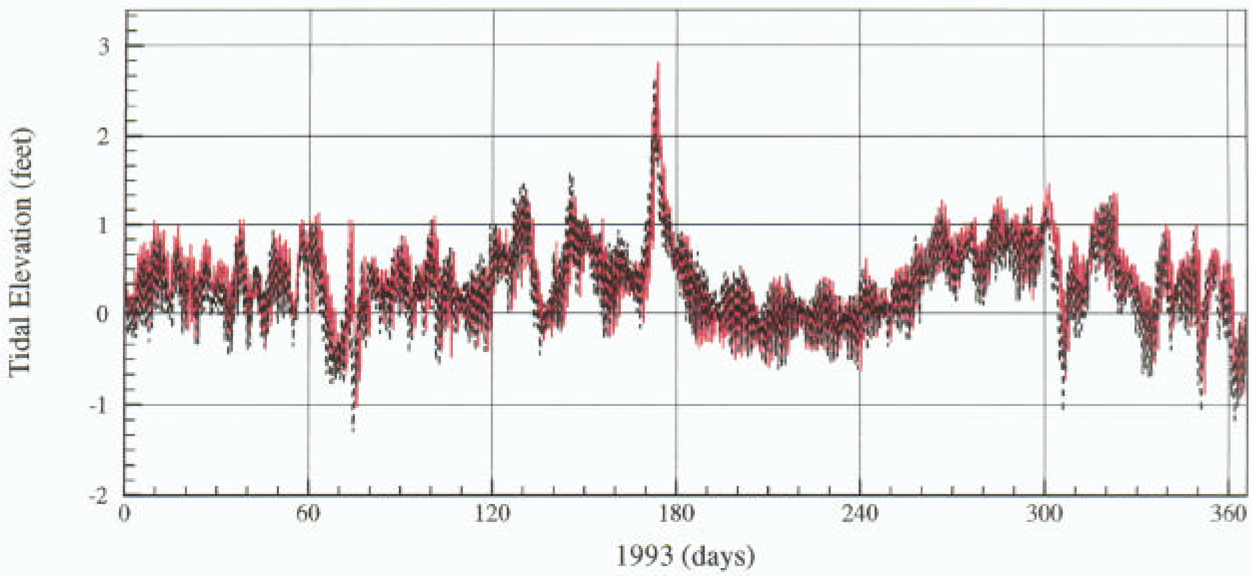


Figure III.12 Simulated and observed velocities in June 1994

(a) Texas State Aquarium



(b) Packery Channel

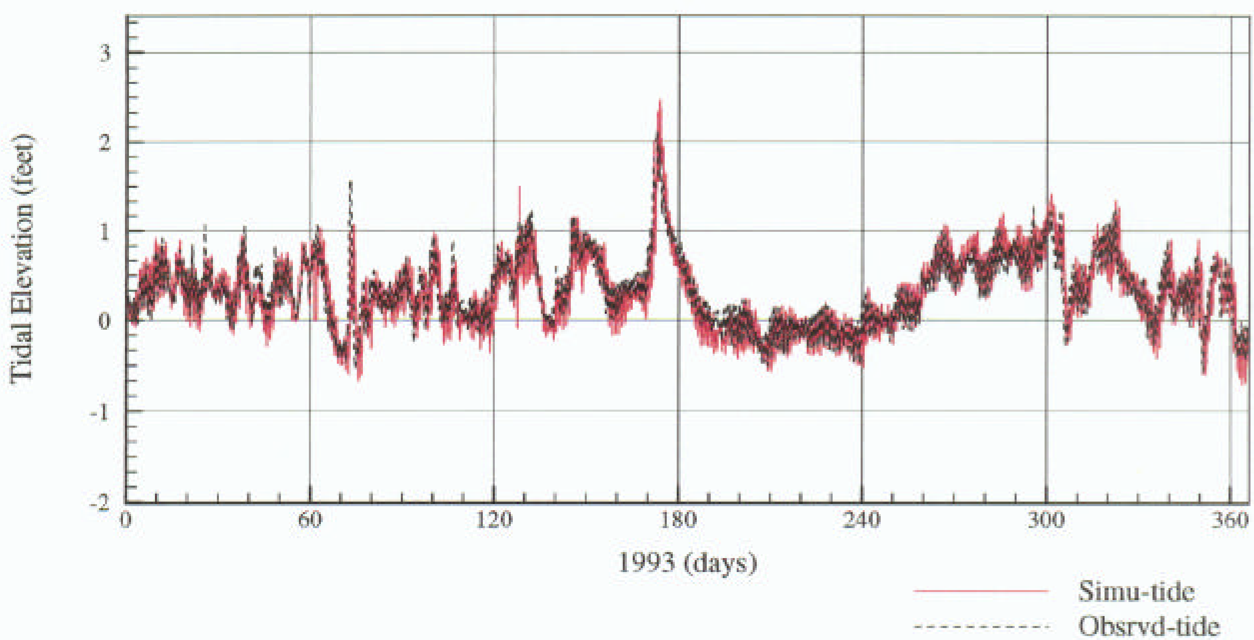


Figure III.13 Simulated and observed tides in 1993

Next Page