1982

SLOSH - A HURRICANE STORM SURGE FORECAST MODEL

Chester P. Jelesnianski, Jye Chen, Wilson A. Shaffer, and Amikam J. Gilad*

Techniques Development Laboratory
Office of Systems Development
National Weather Service, NOAA
Silver Spring, Maryland 20910

Abstract

The National Weather Service has developed a hurricane storm surge model, SLOSH, for real-time surge forecasts as a hurricane threatens. The model is being applied to 22 basins, covering most of the Gulf of Mexico and Atlantic coastal areas of the United States. Recently, the model has been used as a tool for hurricane evacuation planners to delineate areas of potential hurricane flooding.

1. Introduction

SLOSH--which stands for Sea, Lake, and Overland Surges from Hurricanes--is a numerical-dynamical computer model designed to forecast hurricane storm surges. The model was designed in the National Weather Service's Techniques Development Laboratory for "real-time" hurricane forecasting. The storm surge--a significant increase in water level accompanying a storm--has long been known as the major threat to life from a hurricane. In one incident alone, storm surge from the 1900 hurricane resulted in from 5000 to 6000 deaths in the Galveston storm.

Tide gage observations taken during a hurricane's passage show that the storm surge lasts, typically, about 6 hours. A sample tide gage report taken during a hurricane event is shown in Fig. 1 with the forecast astronomical tide removed. Of course, a very large, slow-moving hurricane will produce significant surges for a much longer period of time. To emphasize the threat posed by the surge, consider that the surge from Hurricane Camille in 1969 reached 24 feet!

A 5-year program to adapt the SLOSH model to 22 basins--or areas of coverage--along the Gulf of Mexico and Atlantic coasts began in FY 1981. The basins, shown in Fig. 2, were developed roughly in their order of vulnerability to hurricane storm surges.

2. The SLOSH Model

The SLOSH model is two-dimensional, covering part of the continental shelf, inland water bodies

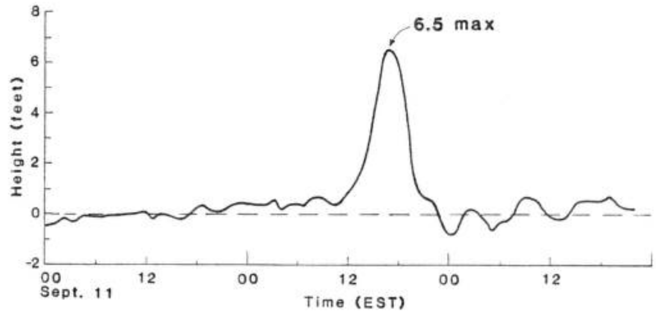

Figure 1. Typical storm surge record, formed by removing predicted tides from a tide gage record. The record shown was taken during Hurricane Donna, 1960, at Buzzards Bay, Massachusetts.

and terrain. The equations of fluid motion are solved numerically, incorporating finite amplitude effects but not the advective terms from the equations of motion. SLOSH uses a time-history bottom stress (Platzman, 1963; Jelesnianski, 1967), corrected for finite amplitude effects. At any given point, the computed surge is designed to reproduce the time-history of a long-period gravity wave--the surge as shown in a tide gage hydrograph or stage record. Short period phenomena, such as wind waves and their associated "run-up", are ignored.

With the exception of the Lake Okeechobee basin, all of the SLOSH basins use a polar grid, such as the one shown for the Lake Pontchartrain/New Orleans basin in Fig. 3. This polar grid allows a fine mesh in the primary area of interest. One advantage of this grid is that boundary conditions are imposed far from the area of interest.

On each of the model's gridpoints, a value of terrain height or water depth is supplied, thus tailoring the model to a specific basin area. Literally hundreds of maps (USGS quadrangle maps, NOS bathymetric charts, and various types of plats) are used to specify these values. The model allows for the overtopping of barriers or impeding the flow of water. Such barriers, significant with respect to grid size, include dunes, levees, spoil areas, natural ridges, reefs, and various man-made structures. The model also treats sub-grid size flow through cuts between barriers; channel flow; and chokes and expansions along rivers.

*Mr. Gilad is employed by Marine Environments Corporation and works under contract with the National Weather Service.

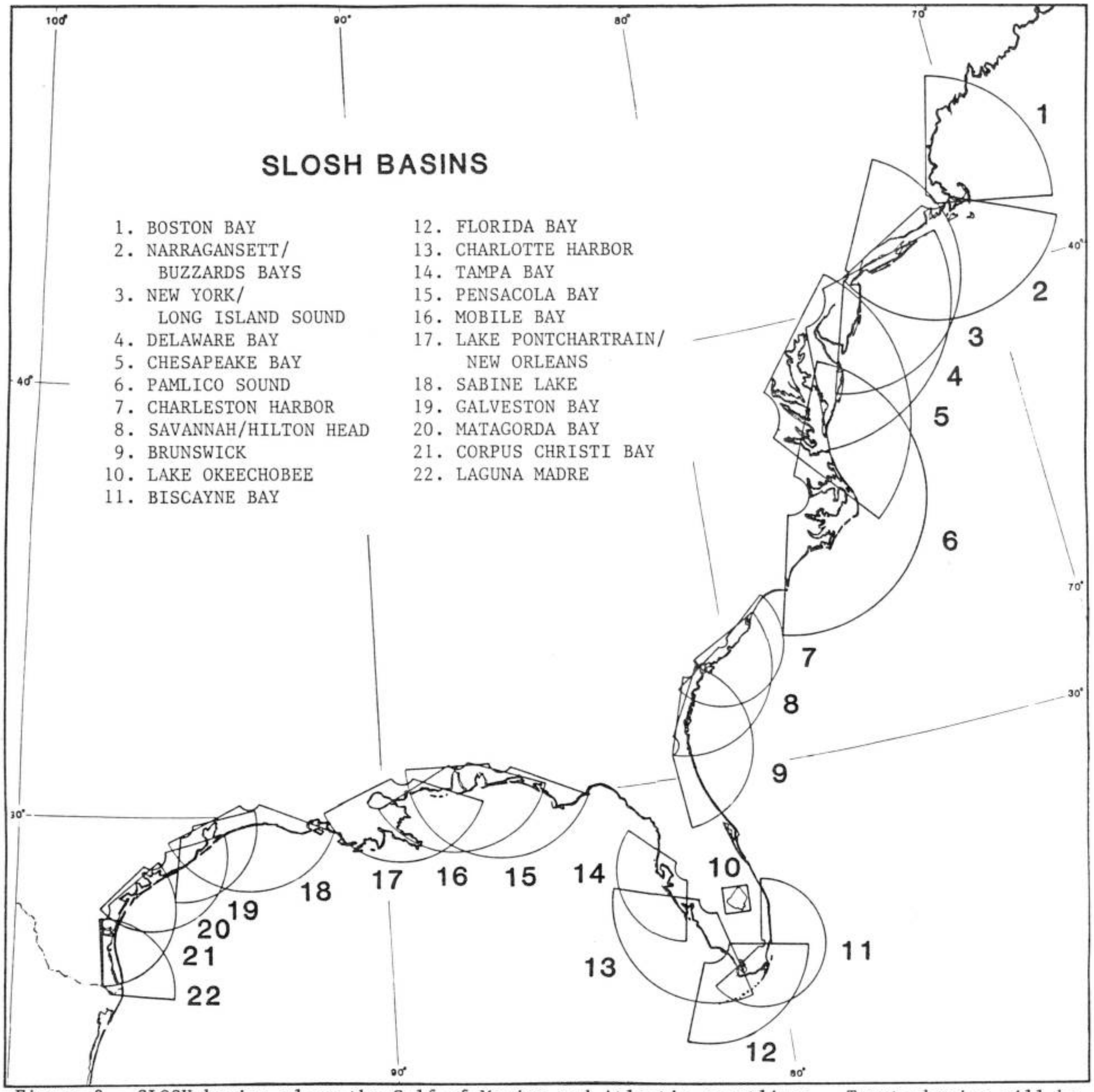

Figure 2. SLOSH basins along the Gulf of Mexico and Atlantic coastlines. Twenty basins will be completed by the end of this fiscal year. Basins 8 and 9 will be completed during 1985.

As the forecast proceeds, if water overtops barriers, then water spills into and is stored in areas behind the barriers. Model computations are turned on for newly wetted grid squares. Likewise, as water recedes after the storm, computations are turned off on dried grid squares. Water penetrates inland until impeded by other barriers or naturally rising terrain. It is possible for a hurricane to produce massive inundation across low lying terrain, extending many miles inland.

Imbedded within SLOSH is a hurricane wind model. For a computational run of SLOSH for a given hurricane event, the user must supply simple, time-dependent meteorological parameters. These are: position (latitude and longitude) of the hurricane, central pressure, and storm size (distance from storm center to the maximum wind). These inputs are entered at 6-hour intervals, beginning 48 hours before landfall and ending 24 hours after landfall. In the event the hurricane does not make landfall, the time of the storm nearest to the basin's defined origin is used instead of landfall time. Note that wind is not an input parameter. The SLOSH wind model produces a vector wind field throughout the basin by balancing forces according to the meteorological input parameters.

3. Model Accuracy

We attempt to simulate flooding from historical hurricanes that affected a basin, to verify the SLOSH model. This is done wherever sufficient observational data are available to define the hurricane to the needed precision and

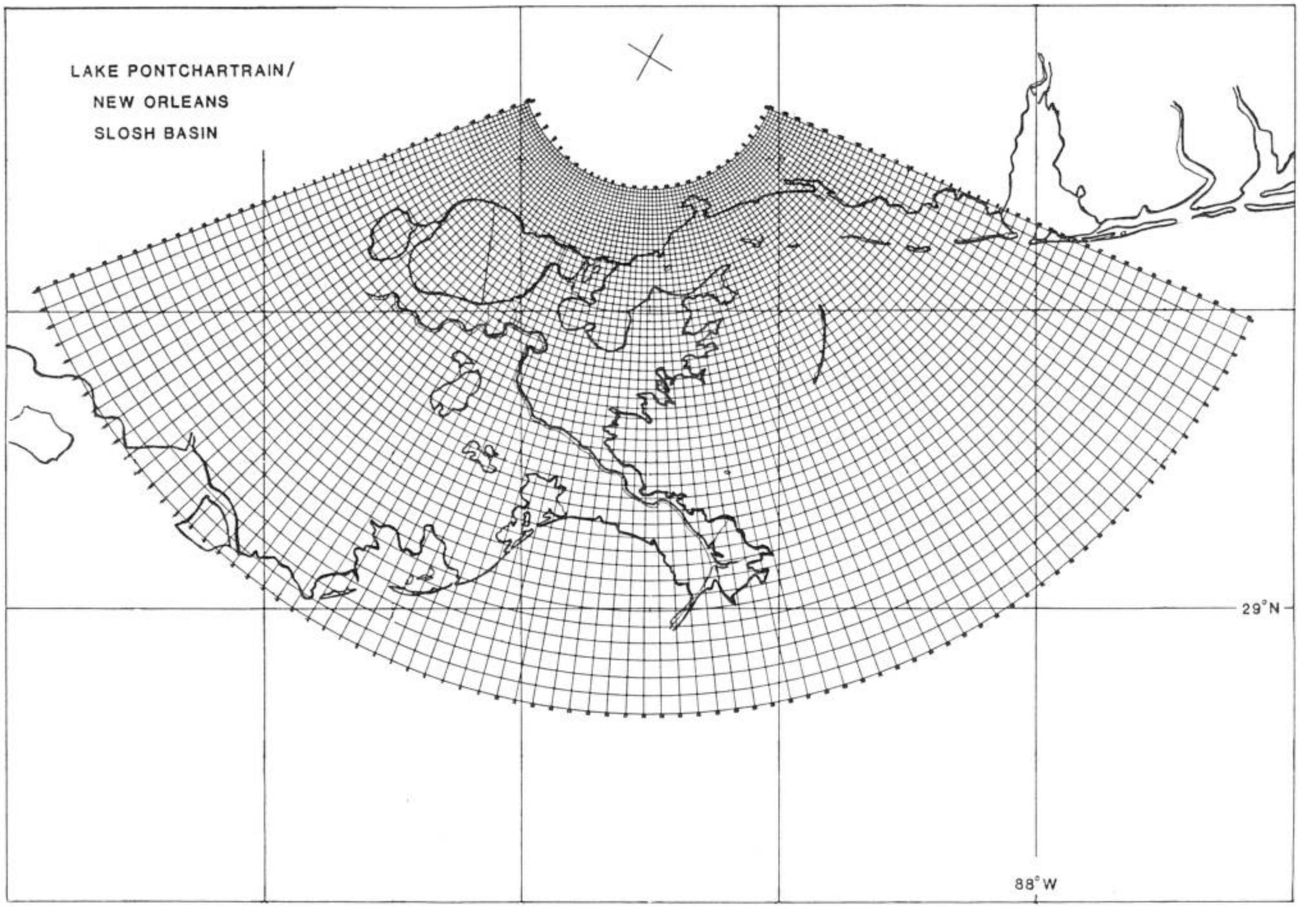

Figure 3. Example of the polar grid used by SLOSH, allowing fine resolution in the area of interest. The region of coverage is the Lake Pontchartrain/New Orleans area.

to adequately describe the storm surge at various locations within the basin. Surge data consist of tide gage observations, staff records, and high water marks. High water marks are the least accurate due to contamination by wave action and inadequate damping or overdamping of the water levels by the structure. Often high water marks vary by 20% for two locations separated by less than a mile.

Before a SLOSH simulation, the hurricane's track is determined as precisely as possible. We've found published "best fit" tracks are frequently not sufficiently accurate to pinpoint the hurricane's track and landfall. Even after a meticulous study, there are often ambiguities and imprecise data which compromise the desired level of detail. In addition to the track, we estimate, as precisely as the data allow, a hurricane's radius of maximum wind and its central pressure. These are the same parameters required to make a real-time forecast using the SLOSH model.

In Fig. 4, we show the combined results of several simulations done for several basins. The error is generally within ± 20% for the significant surges, with a few observations falling outside that range. A total of 542 surge observations were used to develop this figure. These observations were taken throughout the area affected by the surge--around the maximum surge, at the storm's periphery, and along inland water bodies. Note that the tide gage data is limited to the lower observed heights; tide gages frequently fail during major surge events.

The SLOSH model is not "tuned" for a particular geographic location, but uses "universal" specifications for such constants as the model's drag coefficient, bottom stress, etc. This allows us to adapt SLOSH to any geographical location, whether or not it has ever experienced a hurricane, and if verification data is non-existent, and have confidence in the model's computations.

4. Extended Uses of SLOSH

Although SLOSH originated as a forecast model, it has recently been used as a tool to delineate areas of potential hurricane flooding along the coast. With this information, an evacuation planner can identify areas for evacuation, determine which highways can be used for evacuation routes, and site shelters in areas not flooded or cut off by a hurricane.

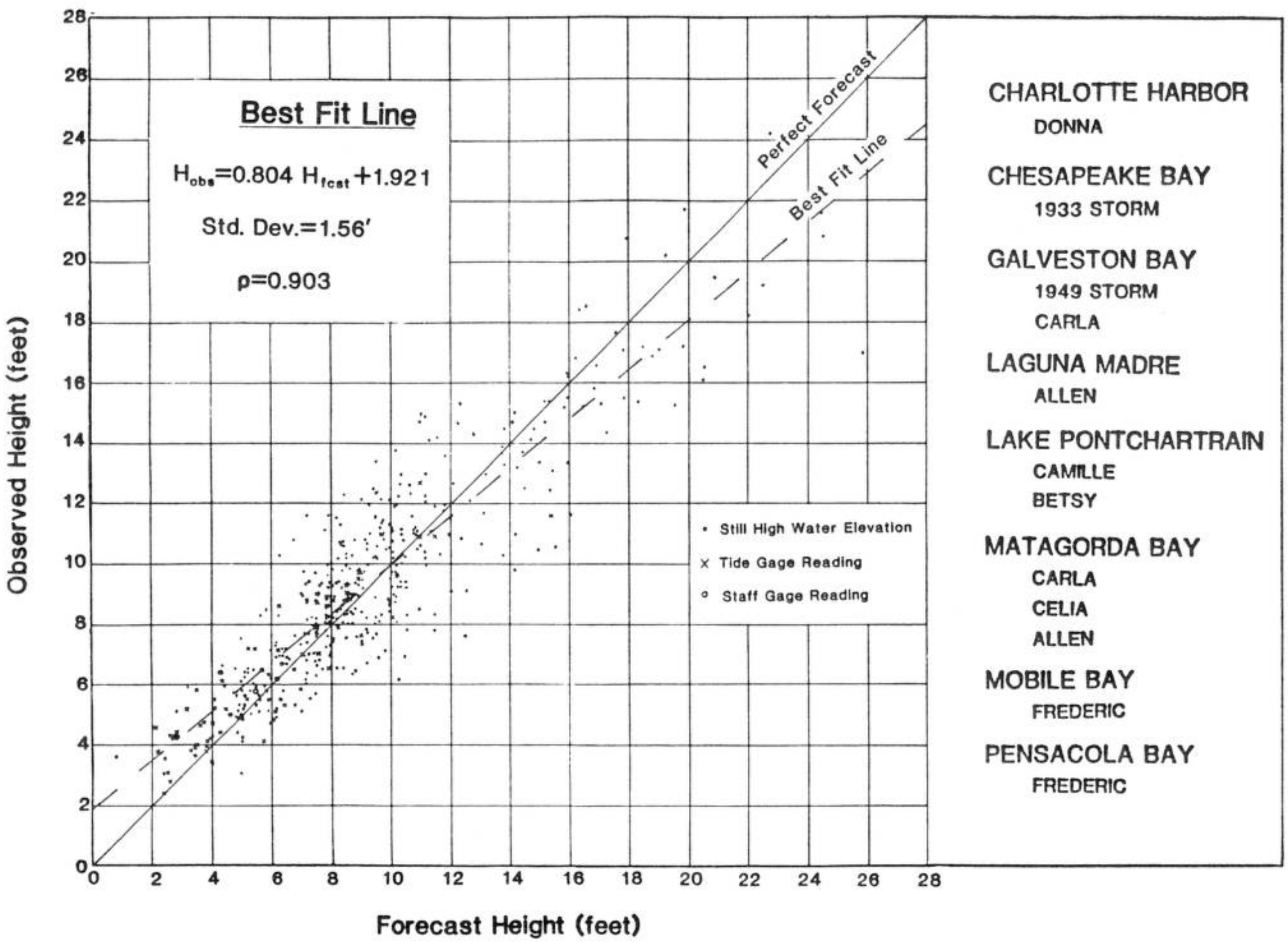

Figure 4. Observed surge heights versus surge heights forecast by the SLOSH model for nine storms in eight basins. A total of 542 tide gage, staff gage, and high water mark observations are shown with the corresponding SLOSH forecast. Generally, the model is within ± 20% for significant surge heights.

To find a region's potential for storm surge flooding, a large number of hypothetical storms are simulated to impact the area, with the flooding due to each one archived. These storms are varied in intensity, size, and landfall point along climatologically likely tracks. Typically, 300 such storms are simulated in a basin. This number is sufficient to highlight critical hurricane paths that may pose excessive flooding in an area.

A spinoff of the simulations is an "atlas" of flooding within a basin. This atlas comprises displays of flooding for each storm run for the vulnerability analysis. As a hurricane threatens the coast, a National Weather Service forecaster can turn to the atlas, match his forecast hurricane (path, size, and intensity) to one already in the atlas, and get an approximation of the flooding due to that storm. However, it is unlikely that any simulated hurricane will match precisely the track of the approaching storm. By using several analogue hurricanes from the atlas, bounds on the expected flooding can be obtained.

The atlas also contains various composites of flooding which are of use to the forecaster. For example, areas flooded by a hurricane coming from a given direction, regardless of its landfall point, and having a given hurricane intensity, may be combined. This composite aids the forecaster by pointing out critical regions where flooding may be extreme.

4. References

Jelesnianski, C. P., 1967: Numerical computations of storm surges with bottom stress. Mon. Wea. Rev., 95, 740-756.

Platzman, George W., 1963: The dynamical prediction of wind tides on Lake Erie. Meteorological Monographs, Amer. Met. Soc., 4, 44 pp.