SLOSH Planning and Mitigation

WMO WORKSHOP 2019
National Hurricane Center Mission

- Support coastal community preparedness and resiliency through storm surge vulnerability and risk analysis (Stafford Act)
  - National Hurricane Program
  - Evacuation planning, modeling, and mapping
  - Training and technical assistance

- Provide accurate real-time storm surge forecasts during tropical cyclone events (Weather Service Organic Act)

- Support post-landfall response and recovery (Stafford Act and Coastal Act)
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Storm Surge Hazard Maps
Motivation

- High-demand for a seamless view of storm surge inundation using the SLOSH products
- A new product to increase awareness of storm surge hazard through education and outreach to reduce loss of life and property
- Eliminate confusion for our partners about SLOSH basin overlap for planning purposes/analyses
- Numerous benefits for federal, private, academic, and public organizations
• About 7.4 million people vulnerable to storm surge
• Roughly 4,600 miles of evacuation route becomes inundated or cut off
• Almost 3.9 million housing units vulnerable to surge
SLOSH Model MOMs and MEOWs

- Fundamental data that is used by the National Hurricane Program to create hurricane evacuation zones from Texas to Maine

- Based on climatology, tens of thousands of hypothetical hurricanes are simulated in SLOSH each basin, and the storm surges are calculated

- **MEOWs** — represent the maximum storm surge resulting from hypothetical storms of varying forward speed, radius of maximum wind (RMW), intensity (categories 1–5), landfall location, initial water level, and storm direction

- **MOMs** — are an ensemble product of maximum storm surge heights and are created by compositing all the MEOWs, separated by category and initial water level anomaly, and retaining maximum value in each grid cell
Storm Surge Hazard Maps

- Seamless high-resolution storm surge inundation maps:
  - Texas to Maine
  - Puerto Rico
  - U.S. Virgin Islands
  - Hawaiian Islands
  - **Hispaniola**
- Updated DEM (new LIDAR)
- Improved inundation mapping techniques (same as potential storm surge flooding map)
- GIS data available for download

SLOSH Grids Used

[Map of storm surge hazard maps]
New NHC Webpage and Data Download

- New NHC webpage is currently being developed along with ArcGIS online map services
- Comprehensive metadata will be provided to describe the data and its limitations
- Data will be available on NHC website in GeoTIFF format in 8-bit unsigned integer raster (most likely 1 ft inundation bins)

What’s New with November 2018 update to Version 2
- Reprocessed Puerto Rico at an improved grid cell size
- Added USVI, Hawaii, and Hispaniola to Storm Maps and data download
- No updates at this time for U.S. East and Gulf Coast storm surge hazard data

Interactive Map Viewer

Technical Description

Introduction

The National Oceanic and Atmospheric Administration (NOAA), specifically the National Weather Service’s (NWS) National Hurricane Center (NHC), utilizes the hydrodynamic Sea, Lake, and Overland Surges from hurricanes (SLOSH) model to simulate storm surge from tropical cyclones. Storm surge information is provided to federal, state, and local partners to assist in a range of planning processes, risk assessment studies, and operational decision-making. In regards to the former, tens of thousands of climatology-based hypothetical tropical cyclones are simulated in each SLOSH basin (or grid), and the potential storm surges are calculated. Storm surge composites – Maximum Encroachment of Water (MEOWs) and Maximum of MEOWs (MOM5s) – are created to assess and visualize storm surge risk under varying conditions. While MEOWs and MOM5s provide a local assessment of storm surge risk, they do not provide a seamless perspective of the hazard owing to the many discrete SLOSH grids. This section briefly describes the scientific techniques used to create the seamless inundation maps for Category 1-5 hurricanes using the SLOSH MOM product as well as a description of the datasets and map viewer available to the public.
Hispaniola
Hispaniola Storm Surge Inundation

This national depiction of storm surge flooding vulnerability helps people living in hurricane-prone coastal areas along the U.S. East and Gulf Coasts, Puerto Rico/USVI, Hawaii, and Hispaniola to evaluate their risk to the storm surge hazard. These maps make it clear that storm surge is not just a beachfront problem, with the risk of storm surge extending many miles inland from the immediate coastline in some areas. If you discover via these maps that you live in an area vulnerable to storm surge, find out today if you live in a hurricane storm surge evacuation zone as prescribed by your local emergency management agency. If you’re in such an evacuation zone, decide today where you will go and how you will get there, if and when you’re instructed by your emergency manager to evacuate. If you don’t live in one of those evacuation zones, then perhaps you can identify someone you care about who does live in an evacuation zone, and you could plan in advance to be their inland evacuation destination - if you live in a structure that is safe from the wind and outside of flood-prone areas.

How this map was created:
The SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model is a numerical model used by NWS to compute storm surge. Storm surge is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tides. Flooding from storm surge depends on many factors, such as the storm, intensity, size, and forward speed of the hurricane and the characteristics of the coastline where it comes ashore or passes nearby. For planning purposes, the NHC uses a representative sample of hypothetical storms to estimate the near worst-case scenario of flooding for each hurricane category.

SLOSH employs curvilinear polar, elliptic, and hyperbolic telescoping mesh grids to simulate the storm surge hazard. The spatial coverage for each SLOSH grid ranges from an area the size of a few countries to a few states. The resolution of individual grid cells within each basin ranges from tens to hundreds of meters to a kilometer or more. Sub-grid scale water features and topographic obstructions such as channels, rivers, and cuts and dikes, barriers, and roads, respectively, are parameterized to improve the modeled water levels.

The NHC provides two products based on hypothetical hurricanes: MOWs and MOMs. MOWs are created by computing the maximum storm surge resulting from up to 100,000 hypothetical storms simulated through each SLOSH grid of varying forward speed, radius of maximum wind, intensity (Categories 1-5), landfall location, tide level, and storm direction. A MOW product is created for each combination of category, forward speed, storm direction, and tide level. SLOSH MOWs products exclude Category 5 storms north of the NHCIA border. For each storm combination, parallel storms make landfall in 5 to 10 mile increments along the coast within the SLOSH grid, and the maximum storm surge footprint from each simulation is composited, retaining the maximum height of storm surge in a given basin grid cell. These are called MOWs and no single hurricane will produce the regional flooding depicted in the MOWs. SLOSH MOMs are an ensemble product of maximum storm surge heights. SLOSH MOMs are created for each storm category by retaining the maximum storm surge value in each grid cell for all the MOWs, regardless of the forward speed, storm trajectory, or landfall location. SLOSH MOMs are available for mean tide and high tide scenarios and represent the near worst-case scenario of flooding under ideal storm conditions. A high tide initial water level was used for the storm surge hazard maps.
CIFDP-C
Hispaniola Demonstration
Project Overview
WMO CIFDP-C

- Coastal Inundation Forecasting Demonstration Project (CIFDP) initiated by Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM)

- At the 5th meeting of the CIFDP Program Steering Group (May 2014, Geneva), the previous Sub-Project for Dominican Republic (CIFDP-DR) was re-scoped for a Caribbean/regional approach and denoted CIFDP-C

- CIFDP-C will be initially demonstrated and tested for the Dominican Republic and Haiti

- Developed SLOSH products for planning, preparedness, and forecasting

- RSMC Miami will provide the leading technical contribution, in collaboration with the PSG and other partners

- Fully funded by USAID (1.2 Million U.S. Dollars)
WMO CIFDP-C Participants

RSMC Miami
Jamie Rhome CIFDP-C System Developer/Project Manager
Ethan Gibney CIFDP-C Grid Builder

NWS Environmental Modeling Center
Andre Van der Westhuysen and Dongming Yang CIFDP-C Modelers

Florida International University
Keqi Zhang CIFDP-C DEM and Grid Builder
Almost 50% of the deaths are due to storm surge.

Over 80% of deaths are due to water.

Wind causes less than 10% of deaths.

## CIFDP-C Demonstration Project Plan

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### Project Scoping and Preparation:

- **Definitive National Agreement (DNA), training, and initial data inventory**

### Project Planning and Design:

- Stakeholder workshop, establish National Coordination Team (NCT), regional buy-in, initial project design/setup (Mexico demo)

### System Development:

- Digital elevation model (DEM), SLOSH/wave grid creation and quality control, and model development
- Develop Training modules

### System Validation:

- MOMs/MEOB creation, QA/QC, and model validation
- Deploy online training modules

### System Integration and Training:

- System implementation, project evaluation, specialized training workshop
- Project evaluation and recommended application to region (RA-IV)

**NHC_Surge**

hurricanes.gov/surge @NHC_Surge
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Phase 0: 2013-2014
Phase 1: 2015
Phase 2: 2016
Phase 3: 2017
Phase 4: 2018

@NHC_Surge hurricanes.gov/surge
Specialized Storm Surge Training

- First-ever international storm surge modeling workshop held at NHC/FIU in January 2015, funded by the WMO

- Students consisted of various Nations from the WMO RA-IV region plus participants from the Philippines (PAGASA) and JMA

- Specialized training focused on setting up, running, and analyzing SLOSH model results and required data sets necessary for properly setting up and validating a storm surge modeling system

- NHC gathered feedback from workshop participants to lay foundation for CIFDP-C system design and implementation in member Nations
CIFDP-C Project Kickoff and NCT Meeting in Dominican Republic
**CIFDP-C Demonstration Project Plan**

**Phase 0**  
*2013-2014*

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SLOSH + Waves Development
Coastal Inundation Forecasting Demonstration Project

- Fully funded by USAID (1.2 Million U.S.)

- Implement a coupled storm surge and wave modeling system
  - SLOSH hydrodynamic model
  - Wave model recommended by IOOS modeling testbed (parametric)

- Develop products for planning, preparedness, and forecasting
  - SLOSH MOMs and MEOWs
  - Same display system as employed by RSMC-Miami (SLOSH Display Program)

- Provide specialized training programs on how to use the storm surge products for planning and preparedness
  - Project completed in 2018
2nd Gen (Parametric) Wave Model

- An efficient parametric wave model to couple with SLOSH (within P-Surge)
- Parametric models that reduce full solution space N(t,x,y,\sigma,\theta), to e.g. M(t,x,y) (Schwab et al. 1984).

\[
\frac{\partial \vec{M}}{\partial t} + \vec{v} \cdot \nabla_{x,y} \vec{M} = \vec{\tau}_w
\]

\[
\vec{\tau}_w = 0.028 \rho_a D_f |\vec{U} - 0.83C_p|(\vec{U} - 0.83C_p)
\]

\[
\sigma^2 = 6.23 \times 10^{-6} \left( \frac{f_p U}{g} \right)^{-10/3} \frac{U^4}{g^2}
\]

- Simplified physics, but significantly cheaper than SWAN or WW3
- More suitable to couple with SLOSH

SLOSH basin and wave model grid mesh
TanDEM-X Project

WMO Coastal Inundation Forecasting Demonstration Project (CIFDP) – for the Caribbean (C)
Funded by USAID

- TDX global DEM developed by German Aerospace Center
  - Relative vertical accuracy (2m slope < 20%); (4m > 20%)
  - Absolute vertical accuracy (10 m)
  - 0.4 arc second resolution in latitudinal direction (12m)
  - Resolution varies in longitudinal direction (0.4-4 arc seconds)
- Vertical datum – EGM2008 (Pavlis et al. 2012)
- Filtered DEM using the Morph Method

Scatter plot of TDX DEM vs GPS measurements at Pedernales, Samana, and Sanchez in The Republic of Dominica (Zhang et al. 2018 – under review)
Hispaniola Demonstration Project

Storm Surge Hazard Mapping
National Hurricane Center
Punta Cana, Dominican Republic

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