Development and application of a continental scale compound flood modeling system in a complex coastal flood plains

Henok Kefelegn[1], Hassan Mashriqui[2], Js Allen[1], Jason Ducker[1], Ryan Grout[1], Richard Gibbs[3], Julio Zyserman[1], Saeed Moghimi[4], Yuji Funakoshi[4], Ali Abdolali[5], Andre Van der Westhuysen[5], Trey Flowers[1], and Edward Clark[1]

[1]NOAA Office of Water Prediction, National Water Center, Tuscaloosa, AL, United States
[2]National Oceanic and Atmospheric Administration (NOAA), Office of Water Prediction, National Weather Service (NWS), Silver Spring, United States
[3]University of Alabama, Tuscaloosa, AL, United States
[4]NOAA National Ocean Service, Silver Spring, MD, United States
[5]NOAA Environmental Modeling Center, College Park, MD, United States

November 22, 2022

Abstract

We present a high-resolution continental-scale compound flood modeling system. It aims to quantify inland flooding resulting from the composite effects of riverine discharge and surface runoff and storm surge, in the inland-coastal zone during significant riverine and coastal storm events. This is achieved by coupling three continental models: the National Water Model (NWM) for the hydrology component, the Advanced Circulation Ocean Model for the coastal storm surge component, and the WAVEWATCH III model for the surface wave component with a detailed inland-coastal inundation model as the mediator between coastal and inland hydrology module. The inundation model, Delft3D FM, D-Flow Flexible Mesh (D-Flow FM), uses a high quality 2D unstructured grid with high-resolution (˜100 m) near coastal features and lower-resolution in other areas to resolve the geometry of the study area. The coastal features are collected from NWM streamlines, National Hydrography Dataset, US medium shorelines and bathymetric features from the United States Army Corps of Engineers . The D-Flow FM model is forced by time-varying water levels and riverine discharges applied at its offshore and inland boundaries, respectively, by spatially- and time-varying wind and pressure fields and incorporates the contributions of surface and subsurface runoff to the total discharge in rivers, channels and streams. We conducted model validations for the following four major flooding events across the US coast: Hurricanes Ike (2008), Sandy (2012), Irma (2017), and Florence (2018). The results highlight the importance of including composite effects of compound flooding to accurately predict water levels during combined river flooding and extreme storm surge events.

Development and application of a continental scale compound flood modeling system in a complex coastal flood plains

Henok Kefelegn[2], Hassan Mashriqui[1], Js Allen[2], Jason Ducker[2], Ryan Grout[2], Richard Gibbs[2], Julio Zyserman[2], Saeed Moghimi[3], Yuji Funakoshi[3], Ali Abdolali[4], Andre Jaco Van der Westhuysen[4], Trey Flowers[2], Edward Clark[2]

[1]NOAA-OWP, Silver Spring, MD, [2]NOAA-OWP, National Water Center, [3]NOAA Coast Survey Development Laboratory, [4]IMSG at NOAA Environmental Modeling

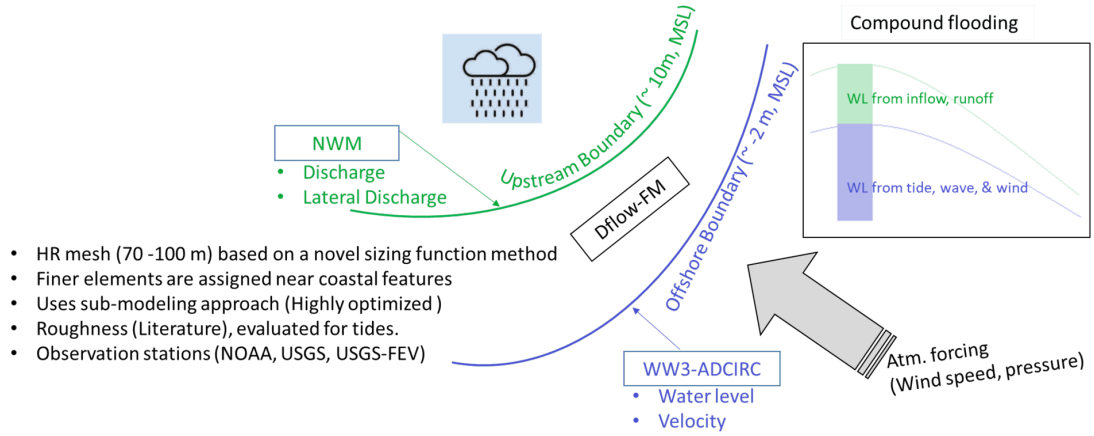
OWP OFFICE OF WATER PREDICTION

PRESENTED AT:

Frontiers in Hydrology

INTRODUCTION

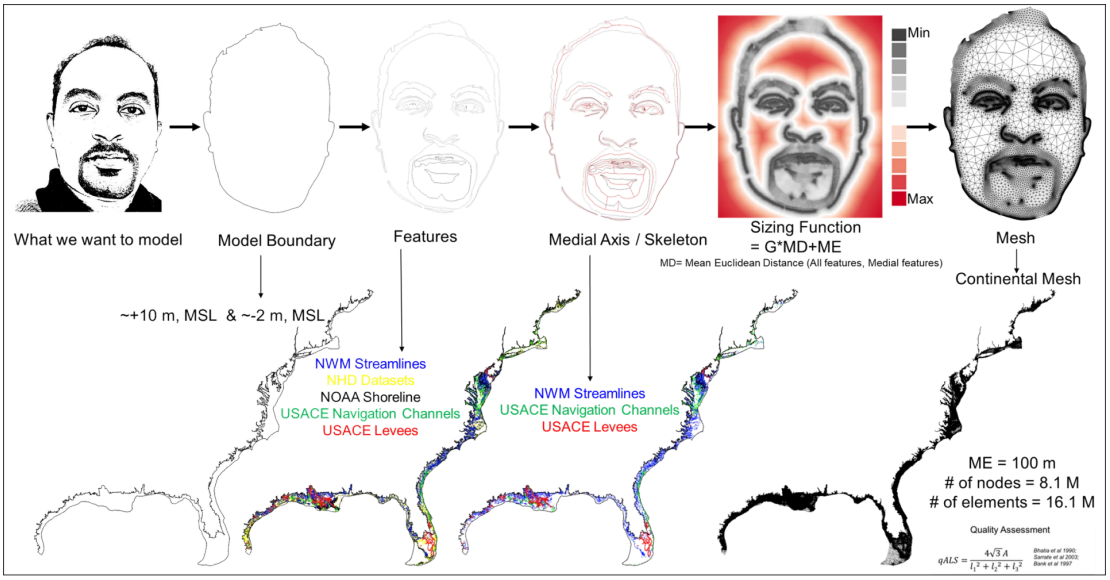
Compound flooding happens when two or more extreme events occurring simultaneously or successively.

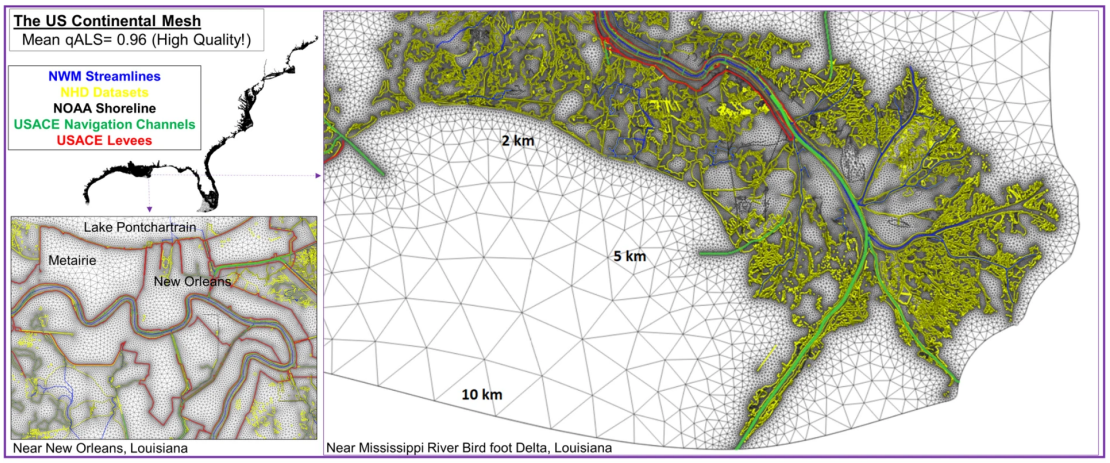


This study investigates the compound effect of inflow from rivers, rainflall runoff and oceanic surge for four named storms (Irma, Florence, Ike, and Sandy)

GULF-ATLANTIC CONT. MESH

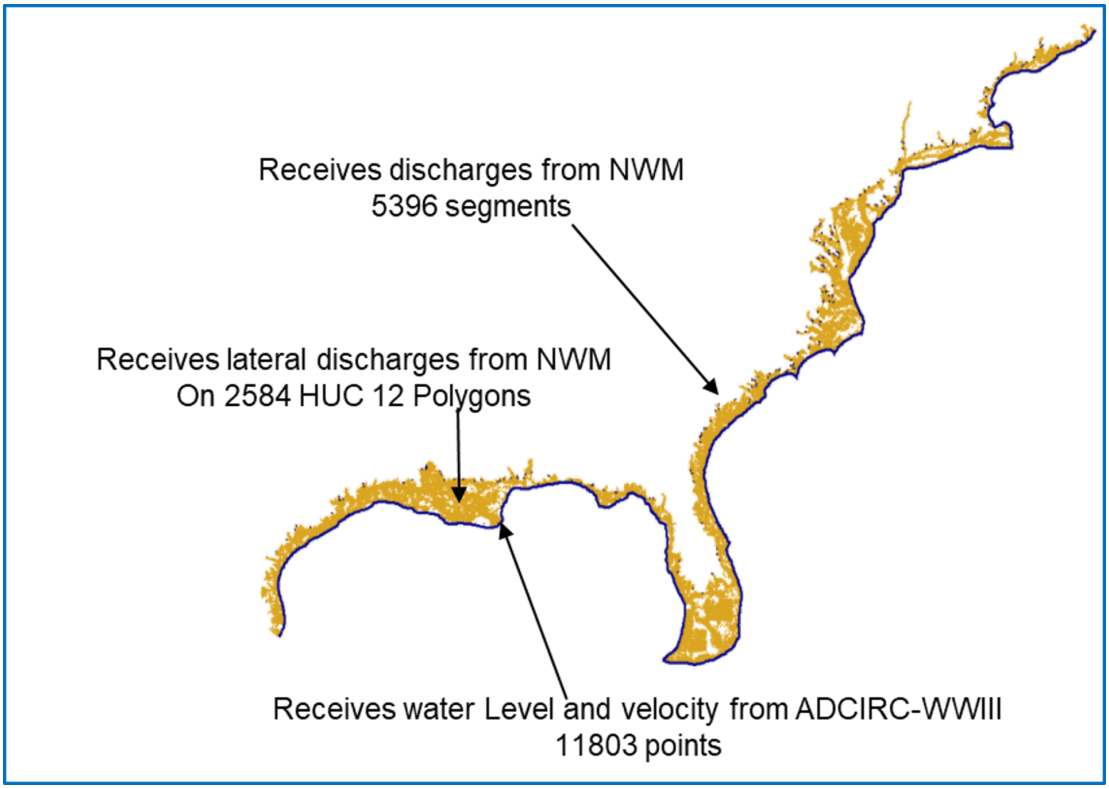
Methodology for the mesh development





MODEL FEATURES

Boundary conditions



Model allows sub-setting approach

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1654648958/agu/39-68-4A-5E-96-42-4D-11-3D-20-F3-FA-54-1B-FE-70/Video/Subsetting_animation_uq63zv.mp4

Levees are represented with polylines

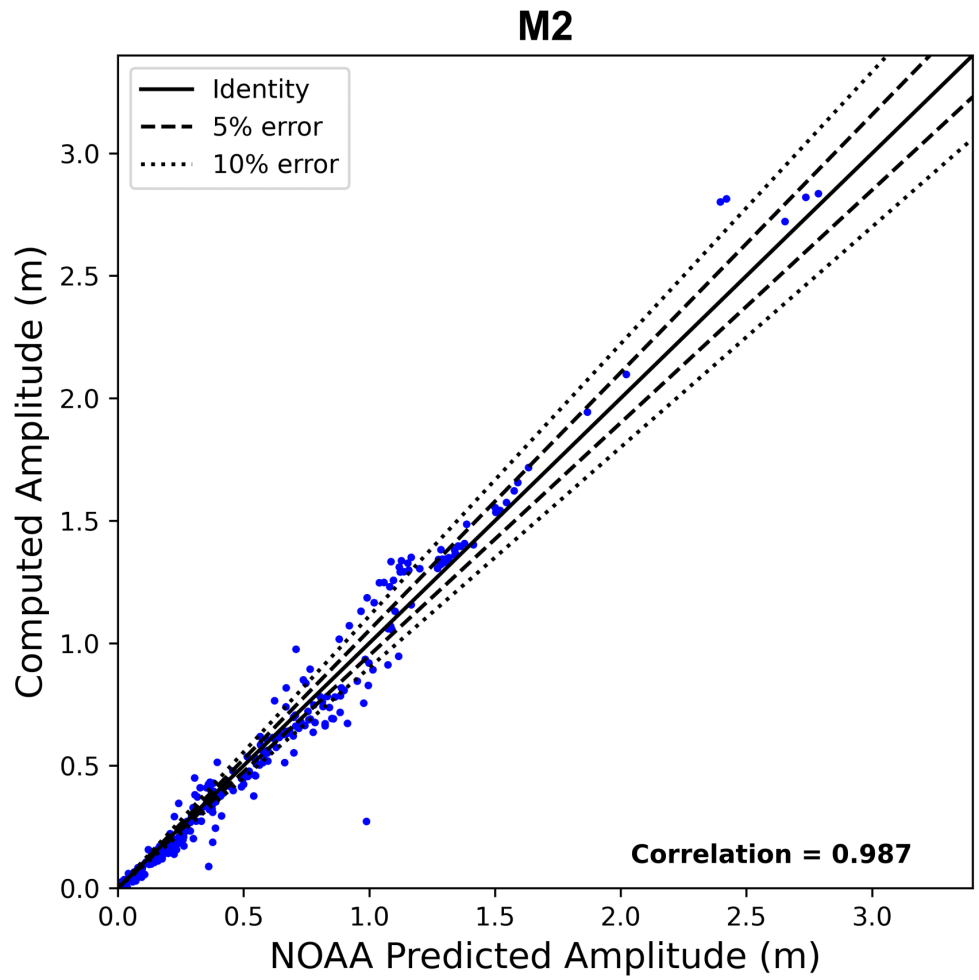
[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1654659041/agu/39-68-4A-5E-96-42-4D-11-3D-20-F3-FA-54-1B-FE-70/Video/Levees_kl3ihs.mp4

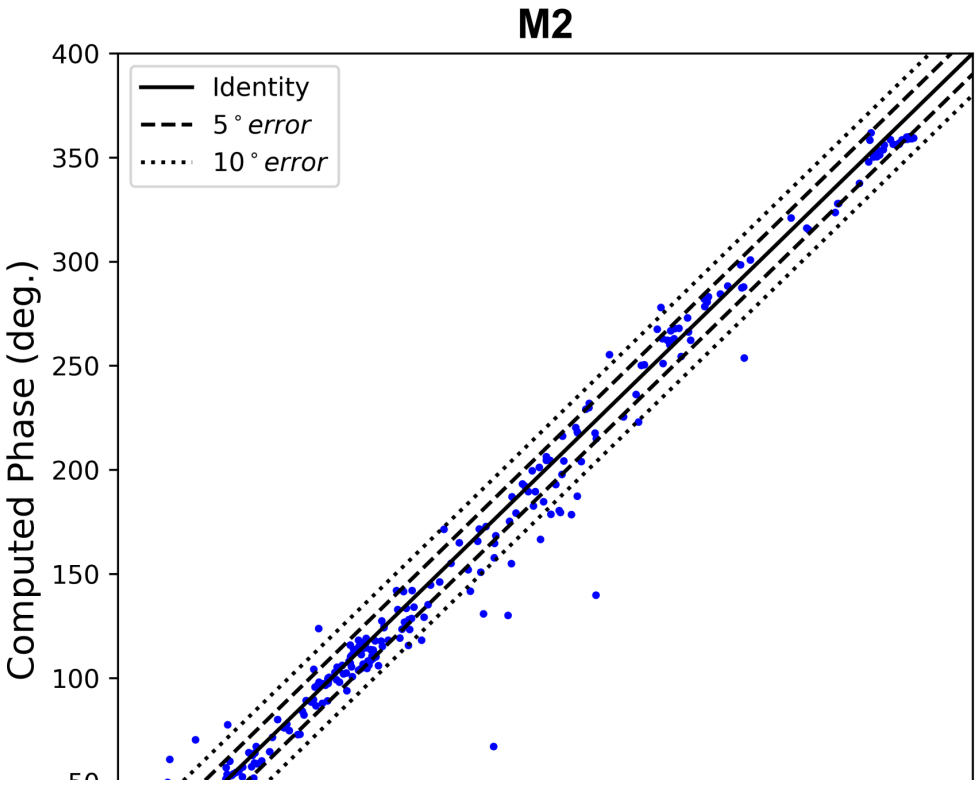
Channels are represented with finer elements

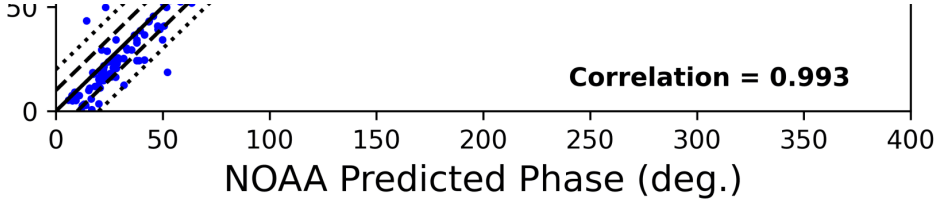
[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1654659142/agu/39-68-4A-5E-96-42-4D-11-3D-20-F3-FA-54-1B-FE-70/Video/navigation_channel_animation_ww3ynh.mp4

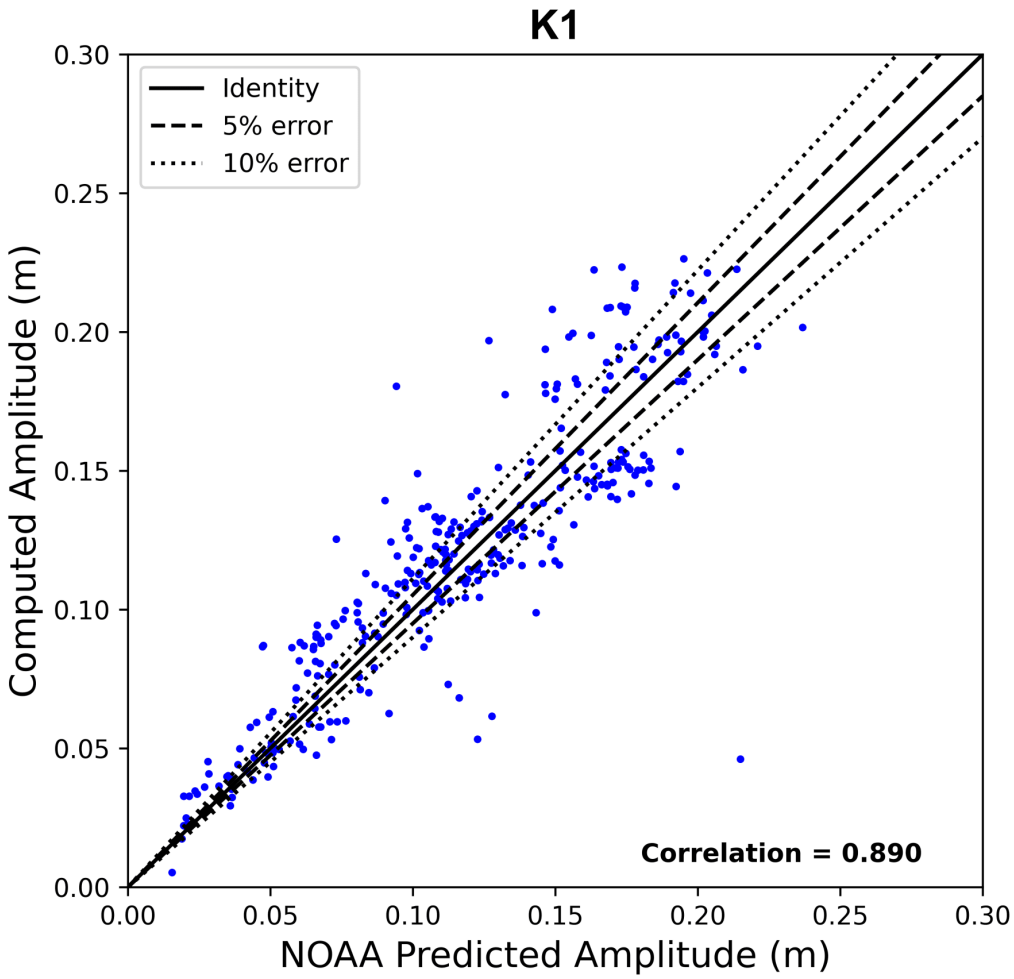
TIDAL EVALUATION

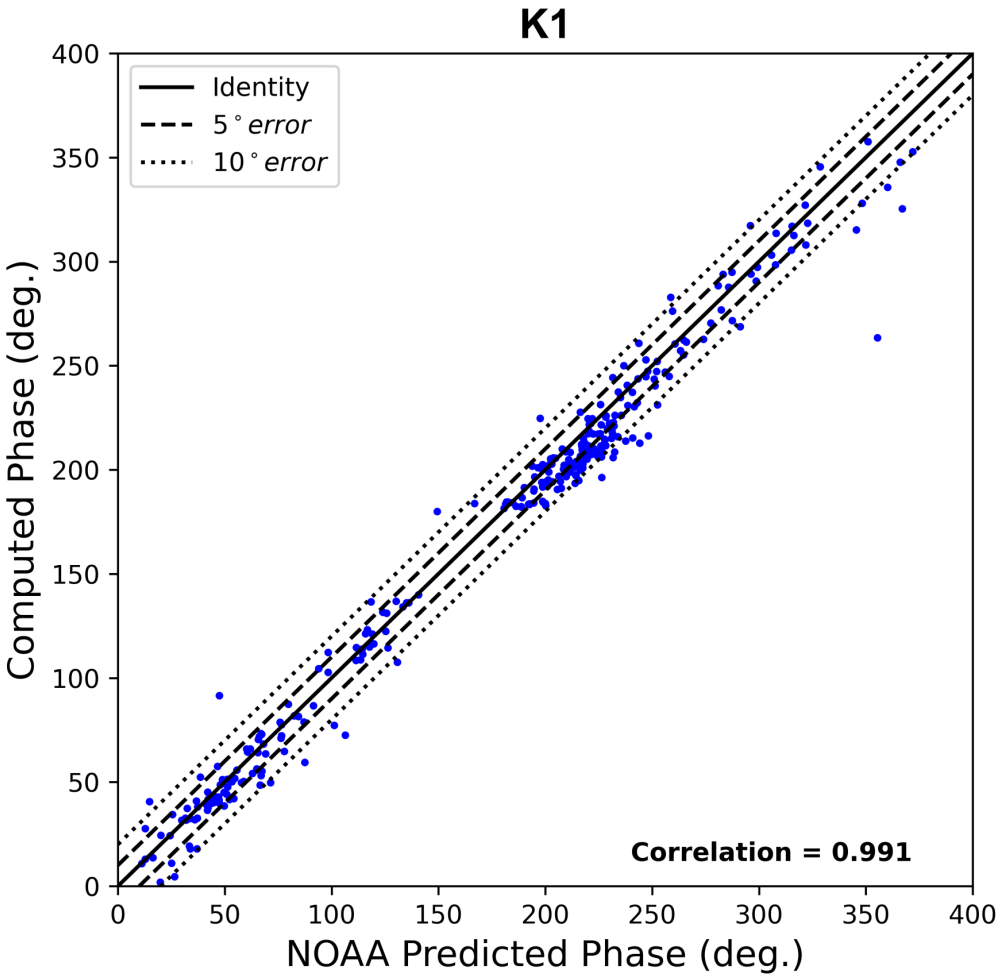
Model was evaluated at 320 NOAA tidal stations.


M2
Identity
5% error
10% error
Computed Amplitude (m)
NOAA Predicted Amplitude (m)
Correlation = 0.987
0.0
0.5
1.0
1.5
2.0
2.5
3.0


M2
Identity
5 ° error
10 ° error
Computed Phase (deg.)
100
150
200
250
300
350
400


50
0
0
50
100
150
200
250
300
350
400
Correlation = 0.993
NOAA Predicted Phase (deg.)


K1
Identity
5% error
10% error
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Computed Amplitude (m)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Correlation = 0.890
NOAA Predicted Amplitude (m)


K1
Identity
5 ° error
10 ° error
Correlation = 0.991
Computed Phase (deg.)
NOAA Predicted Phase (deg.)
0
50
100
150
200
250
300
350
400

CONTRIBUTION OF RAINFALL RUNOFF AND INFLOW TO THE TOTAL WATER LEVEL

IRMA

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1654667091/agu/39-68-4A-5E-96-42-4D-11-3D-20-F3-FA-54-1B-FE-70/Video/Irma_Surge_Inflow_Runoff_vs_Oceanic_Surge_wl_diff_video_kxv9bo.mp4

FLORENCE

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1654667198/agu/39-68-4A-5E-96-42-4D-11-3D-20-F3-FA-54-1B-FE-70/Video/Florence_Surge_Inflow_Runoff_vs_Oceanic_Surge_wl_diff_video_azmeo9.mp4

IKE

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1654699912/agu/39-68-4A-5E-96-42-4D-11-3D-20-F3-FA-54-1B-FE-70/Video/Ike_wl_diff_gxxgoc.mp4

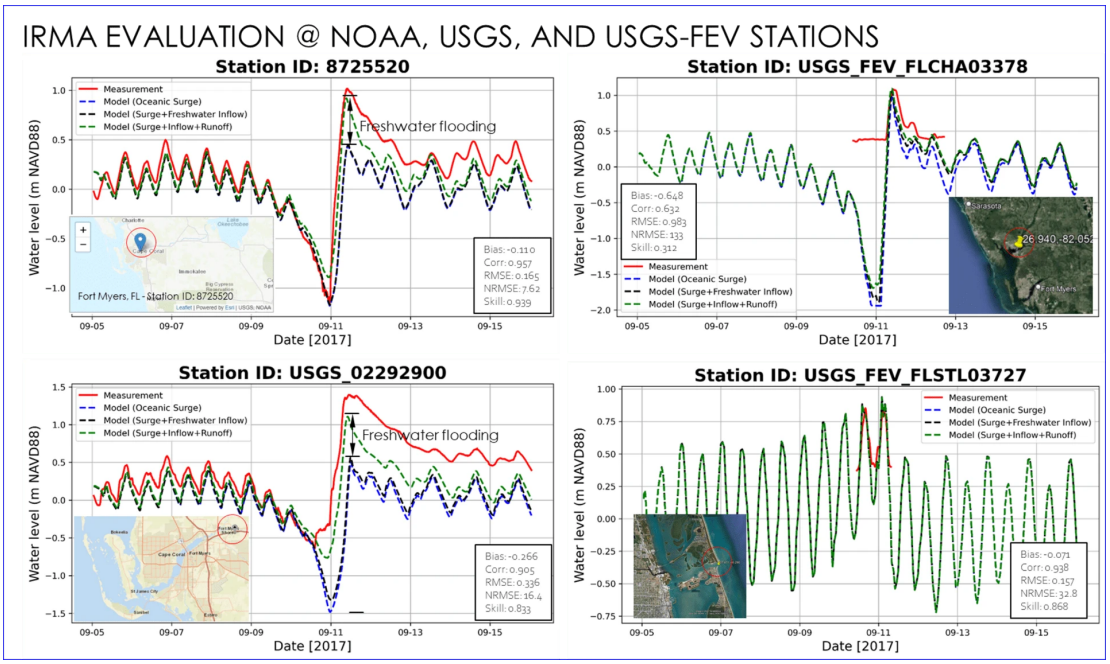
FLORENCE

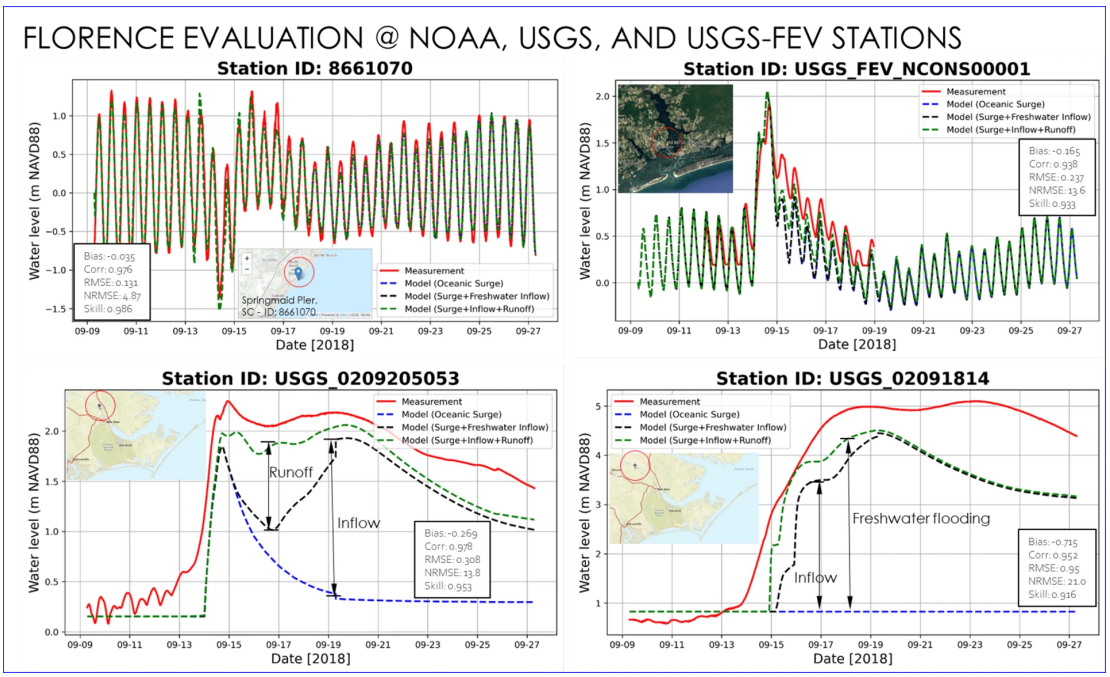
[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1654667230/agu/39-68-4A-5E-96-42-4D-11-3D-20-F3-FA-54-1B-FE-70/Video/Ike_Surge_Inflow_Runoff_vs_Oceanic_Surge_wl_diff_video_tudydd.mp4

SANDY

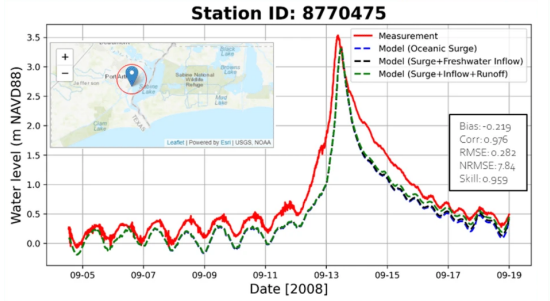
[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1654667252/agu/39-68-4A-5E-96-42-4D-11-3D-20-F3-FA-54-1B-FE-70/Video/Sandy_Surge_Inflow_Runoff_vs_Oceanic_Surge_wl_diff_video_yaqmeb.mp4

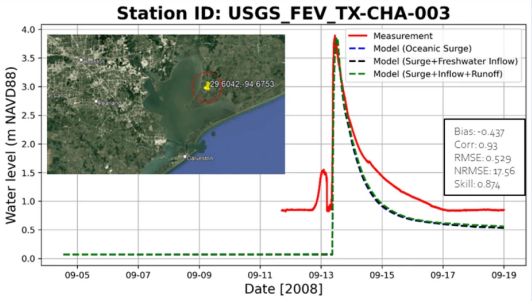
INCLUDING THE COMPOUND EFFECTS OF RIVER-INFLOW, RAINFALL-RUNOFF AND SURGE IS CRUCIAL FOR ACCURATE DETERMINATION OF COASTAL FLOODING!

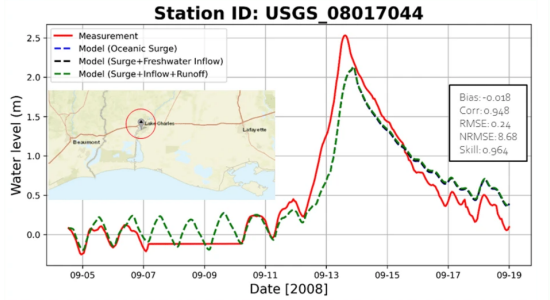


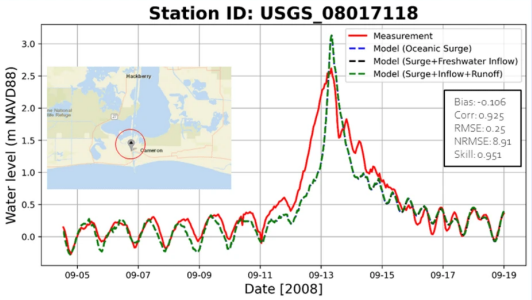


IKE EVALUATION @ NOAA, USGS, AND USGS-FEV STATIONS

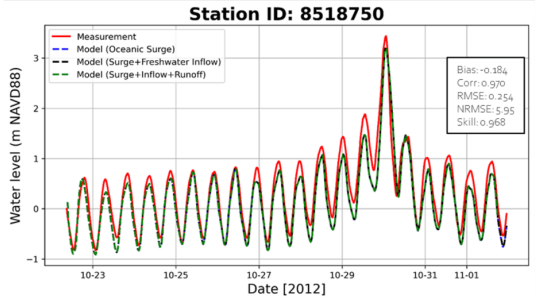


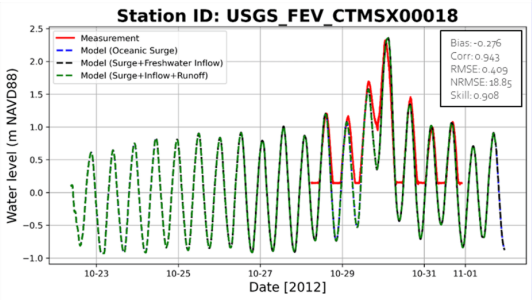


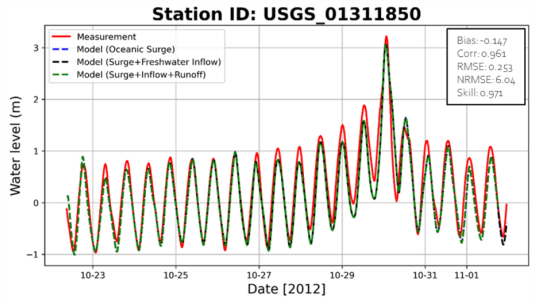


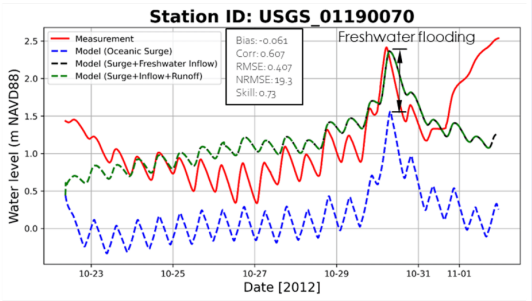


SANDY EVALUATION @ NOAA, USGS, AND USGS-FEV STATIONS









CONCLUSION

Including the effect of compound flooding is crucial for accurate determination of coastal flooding.

The effect of compound flooding is more prone in the inland region of coastal areas where the hydologic flood intersects the oceanic surge.

Not all storms exhibit the compound effects of storm surge, inflow and runoff. In our study Ike and Sandy lacks the compound effect from inflow and runoff in contrast, Irma and Florence can be considered compound flood events.

ABSTRACT

We present a high-resolution continental-scale compound flood modeling system. It aims to quantify inland flooding resulting from the composite effects of riverine discharge and surface runoff and storm surge, in the inland-coastal zone during significant riverine and coastal storm events. This is achieved by coupling three continental models: the National Water Model (NWM) for the hydrology component, the Advanced Circulation Ocean Model for the coastal storm surge component, and the WAVEWATCH III model for the surface wave component with a detailed inland-coastal inundation model as the mediator between coastal and inland hydrology module.

The inundation model, Delft3D FM, D-Flow Flexible Mesh (D-Flow FM), uses a high quality 2D unstructured grid with high-resolution (~100 m) near coastal features and lower-resolution in other areas to resolve the geometry of the study area. The coastal features are collected from NWM streamlines, National Hydrography Dataset, US medium shorelines and bathymetric features from the United States Army Corps of Engineers . The D-Flow FM model is forced by time-varying water levels and riverine discharges applied at its offshore and inland boundaries, respectively, by spatially- and time-varying wind and pressure fields and incorporates the contributions of surface and subsurface runoff to the total discharge in rivers, channels and streams.

We conducted model validations for the following four major flooding events across the US coast: Hurricanes Ike (2008), Sandy (2012), Irma (2017), and Florence (2018). The results highlight the importance of including composite effects of compound flooding to accurately predict water levels during combined river flooding and extreme storm surge events.