COASTAL FLOODING DUE TO EPISODIC SEA LEVEL ELEVATION AND IMPACT ASSESSMENT OF INUNDATED URBAN AREAS IN MIAMI (SOUTH FLORIDA, USA)

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INTRODUCTION

The variability of nearshore Sea Level Elevation (SLE) is a key indicator of global-scale climatic changes with significant impacts on low-lying coastal areas. As such, South Florida (USA) is one of the most vulnerable regions worldwide to episodic coastal inundation due to extreme sea levels caused by tropical storms and hurricanes. Specifically, the natural and urban coastal environment in and around Miami (FL) is a hotspot for climate-related adverse effects (Kourafalou et al., 2024).

Severe storm surge has impacted the study region's low-land littoral areas in the past by inundating coastal floodplains and exposed urban settings. Especially when storm surge coincides with high tides (storm tides) enhanced further by the recent mean Sea Level Rise (SLR), it can cause land loss, coastal erosion, damages on onshore infrastructure and properties, human casualties, degradation of coastal ecosystems, etc.

In this paper, we present recent developments of a numerical modelling system for coastal inundation (Makris et al., 2023a) induced by extreme SLE due to storm surge, intensified by high astronomical tides and SLR that was set up for the Mediterranean Sea's coasts (Androulidakis et al., 2023a); it is hereby expanded to fit the needs for our investigation in the Miami study area.

SCOPE OF RESEARCH

The scope of the study is to evaluate the interannual spatial variability of impacts from coastal inundation due to seawater flooding over characteristic important areas of Miami. The study period refers to the recent 30-years period of 1994 to 2023. We aspire to identify in high detail all the important environmental and socioeconomic implications that are recognized as important factors in the sustainability of coastal environments.

In this work, we also validate an updated version of the CoastFLOOD model (Makris et al., 2023a) for littoral inundation and apply it in very high resolution (dx=1-2m) (Makris et al., 2023b) throughout the densely populated urban area around Biscayne Bay, including the more exposed Miami Beach. We further investigate the long-term variability and trends of measured SLE by tide-gauge records and the respective behavior of coastal inundation patterns over coastal low-land areas.

The main motivation of the study is to contribute to the better understanding of climatic impacts along the exposed coastal areas, by examining the increasing sea level trends of coastal Total Water Level (TWL). This can be potentially useful to research about the implications to public plot-holdings' and individual properties' prices and insurance fees.

METHODOLOGY (MODEL AND FIELD DATA)

Our methodology incorporates continuous long-term field data from in situ tide-gauge observations for SLE/TWL and numerical simulations for coastal flood hydraulics (Androulidakis et al., 2023b).

The evolution of daily SLE maxima (based on NAVD88 datum) is investigated. SLE was derived from several locations including the Virginia Key tide-gauge station, during the 1994-2023 period. Post-processing for the definition of extreme cases over certain thresholds (e.g., double the standard deviation, 2σ) and their occurrence frequencies, statistically significant trends (Sen's Slopes), residuals of Empirical Mode Decomposition (EMD), and annual maxima are derived (Figure 1). The Pettit Homogeneity Test (PHT) confirmed a clear shift in the evolution of SLE, together with analyses about the correlation of low Sea Level Pressure barometric systems and high winds with extreme SLEs. The most important hurricanes of the broader Miami area are further investigated.

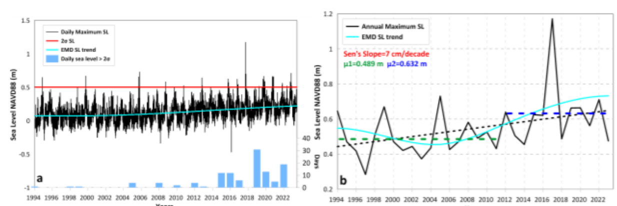

Figure 1 – (a) Evolution of daily SLE maxima at Virginia Key tide-gauge station during the 1994-2023 period (with annual frequencies over the 2σ threshold, red line; trend residual, light blue line) by EMD. (b) Annual SLE maxima and respective Sen's Slope and EMD trend), including μ1 (green) and μ2 (blue) means (PHT).

CoastFLOOD is a high-resolution, O(dx)=1m, raster-based, storage-cell hydraulic model for mass balance floodwater flow based on decoupled 2-D Manning-type equations (Skoulikaris et al., 2021). It is applied locally (domain scale: O(x)=20km) at lowland coastal areas with both natural floodplains and complex urban settings. It is forced by the aforementioned 30-years SLE timeseries, implemented for several scenarios of TWL maxima.

We include a very detailed representation of terrain Manning roughness (bottom friction) based on open access Land Use – Land Cover (LULC) data of the USGS's National Land Cover Database (NLCD). Verification of the model is performed by comparisons against output from NOAA's bathtub SLR map viewer (https://coast.noaa.gov/digitalcoast/tools/slr.html; Figure 2; with Goodness-of-Fit>80%). The model domain's land elevation data are derived from NOAA's Digital Coast Digital Elevation Model (DEM; NAVD88 datum) for the Biscayne Bay study area in a 2m spatial resolution.

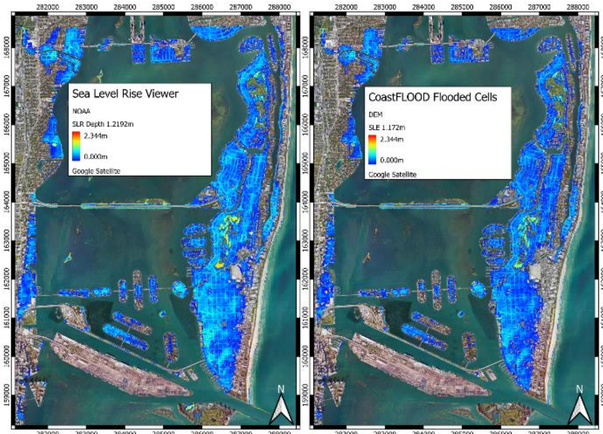

Figure 2 – Validation of (a) CoastFLOOD model results against (b) NOAA's SLR Viewer output, based on maps of flooded areas for SLE and SLR = 1.2m (~4ft) along the coastline. Color maps refer to floodwater height.

COASTAL FLOOD MODEL APPLICATION

CoastFLOOD performs modeling of seawater uprush on the shoreline and highly detailed flood routing over complex urban terrain. Typical results are presented in Figure 3. Furthermore, several issues are discussed about the proper inclusion of coastal structures, port infrastructure, beach formations, and rocky shores in the model grid, considering the inclusion or exclusion of past and future Miami-Dade County (MDC) projects and their influence on protection against coastal hazards.

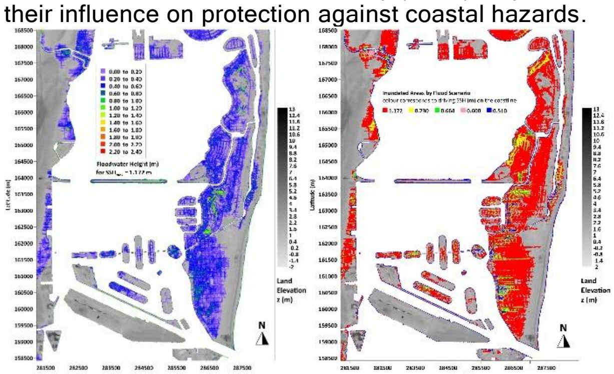

Figure 3 – Maps of flooded areas portraying the inundated study region of southcentral Miami based on simulations with CoastFLOOD model for (a) TWL maximum (color map for floodwater depth), (b) 5 scenarios of SLE maxima (color map showing different overlaid flood extents).

Extreme SLEs are shown to cause severe impacts to inhabited urban spaces and built infrastructures with the maximum inundation area exceeding the value of 1400 acres in a study region of 70 Km^2. The urban area has further been divided according to the actual boundaries of individual plot holdings provided by the open-data GIS app of the MDC about properties. Figure 4 shows the impact of coastal flooding as percentage of inundated area within each discrete plot property during the 30-years period.

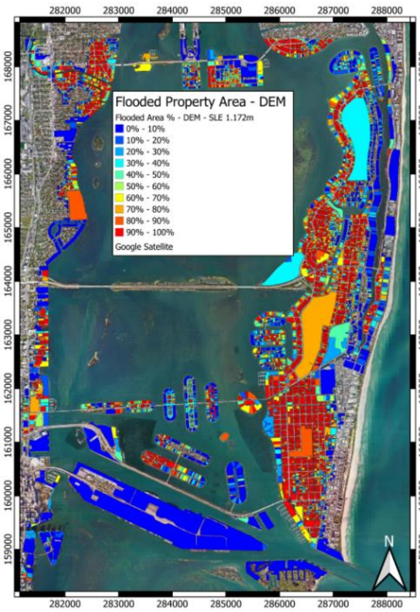

Figure 4 – Map of flooded properties as percentage of inundated area within each discrete plot holding over the study region of southcentral Miami topography domain for the maximum SLE=1.172m during the 1994-2023 period.

CONCLUSIONS

The spatial variability of seawater flood impacts on inundated civil properties is investigated in detail, based on simulations of coastal flooding with robust applications of CoastFLOOD model during 1994-2023.

REFERENCES

Androulidakis, Makris, Mallios, Krestenitis (2023a): Sea level variability and coastal inundation over the northeastern Mediterranean Sea. Coastal Engineering Journal, TAYLOR & FRANCIS.

Androulidakis, Makris, Mallios, Pytharoulis, Baltikas, Krestenitis (2023b): Storm surges and coastal inundation during extreme events in the Mediterranean Sea: the IANOS Medicane. Natural Hazards, SPRINGER, vol. 117, pp. 939-978.

Kourafalou, Androulidakis, Makris, Mallios (2024): Climate impacts on the coastal environment of South Florida: Marine Heat Waves and Coastal Flooding. Proceedings of 2024 Ocean Sciences Meeting, AGU.

Makris, Mallios, Androulidakis, Krestenitis (2023a): CoastFLOOD: A High-Resolution Model for the Simulation of Coastal Inundation Due to Storm Surges, Hydrology, MDPI, vol. 10(5), pp. 103.

Makris, Mallios, Androulidakis, Krestenitis (2023b): CoastFLOOD: fine-resolution modelling of flood inundation due to storm surges in the coastal zone. Proceedings of 2nd DMPCO, AUTH, vol. 1, pp. 26-30.

Skoulikaris, Makris, Katirtzidou, Baltikas, Krestenitis (2021): Assessing the vulnerability of a deltaic environment due to climate change impact on surface and coastal waters: the case of Nestos River (Greece). Environmental Modeling & Assessment, SPRINGER, Vol. 26, pp. 459-486.