Coupled Coastal Town Risk Framework to Evaluate Management Decisions

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INTRODUCTION

Past research has shown feedback between natural and human decision systems in coastal areas influence the efficiency of management actions. To capture these feedbacks, a coupled coastal town risk framework was developed (Karanci et. al., 2017) which uses storms and sea level rise as exogenous drivers and simulates the evolution of the morphological landscape, implementation of soft-engineered coastal protection measures and household's occupation/abandonment decisions through the years.

Employing scenario analysis, the framework can be used to illustrate and explore the ramifications of coastal management decisions and policies. Numerous scenarios with diverse conditions can be considered by varying natural (storm frequency, SLR) and socio-economic conditions (insurance rates, flooding risk perception, costs of prevention measures).

The utilization of the process-based model XBeach (1-D) to determine the coastal response and inundation depths due to storms enables the framework to accurately estimate the morphological response (Roelvink et al., 2009). However, it also imposes steep computational time requirements when conducting scenario analysis which call for numerous XBeach simulations (~2100 simulation runs for a single scenario of 50-year time frame). Additionally, the implementation of XBeach requires broad knowledge of coastal processes and modeling skills which constrains the potential user community.

To overcome this challenge, a Bayesian network (BN) was created to act as a surrogate for XBeach simulations in the framework. This study describes the surrogate storm impact estimation BN and demonstrates its integration to the framework through a scenario analysis study.

COUPLED COASTAL TOWN RISK FRAMEWORK

The coupled coastal town risk framework integrates geospatial, process-based and probabilistic methods with complex system dynamics that can represent human decisions and natural systems (Figure 1). The framework has three main components:

i) Geospatial analyses: The environment in the model upon which the households interact has been designed to represent properties of the cadastral and physical coastal landform conditions. A topographic layer represents the coastal landform conditions (i.e. dune height beach width). A cadastral layer contains the areas that households inhabit and is generated from cadastral geographic data. Cadastral parcels can be either empty or occupied and have varying attributes that reflect their current physical and economic properties (i.e. parcel value, structure height from ground, structure distance to shore). The environment is created using geospatial analysis using diverse data such as building databases, shoreline maps, and topography.

ii) Storm impact evaluation: Each year, if a storm exists, framework modifies the topographic layer and assigns damage to structures in the cadastral layer according to the estimated morphological change and inundation at buildings. To predict the influence of the storm the framework employs a BN which connects offshore hydraulic boundary conditions and subaerial morphology of the beach to storm impacts such as dune erosion and inundation depth.

The BN is created using a XBeach simulation database, which contains a suite of 1-D XBeach simulations with varying morphology and hydraulic boundary conditions. Once generated the BNs response is instantaneous and can be used as a surrogate for XBeach in the framework.

iii) Coastal town agent based model (ABM): The main processes considered in this part of the framework are natural evolution of coastal landforms, implementation of soft engineered coastal projects, and trading of residential properties and cadastral parcels. For each time step, the coastal features are updated using user specified erosion and sea level rise rates. If triggered, the coastal features are further modified by coastal protection projects (beach nourishment or dune replenishment). The households' occupation and abandonment decisions in each yearly cycle consists of several phases: relocation decision of homeowners and transformation of these agents into seller agents, decision to move into the coastal community by buyers, selection of the best affordable housing alternative by buyers, and determination of seller agent with whom to trade. Decision rules governing these processes include theories and parameters produced by engineering, social science, economy and planning disciplines. Details about these processes can be found in Karanci et al., 2017.

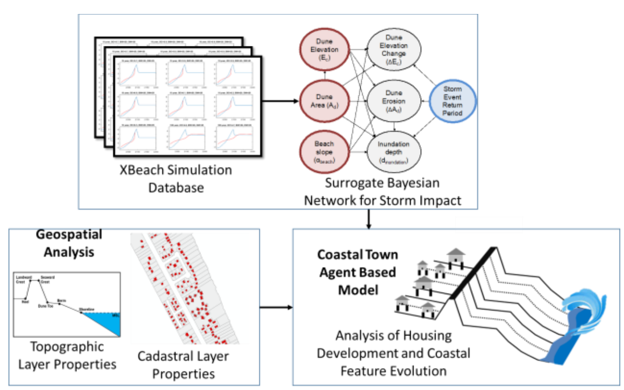

Figure 1 – Coupled Coastal Town Risk Framework

CASE STUDY and RESULTS

This framework was used to simulate evolution of housing and coastal dynamics in the Town of Nags Head located in the Outer Banks of North Carolina, under varying soft engineered coastal protection design alternatives.

25 design combinations were generated by varying design storm for dune replenishment and design beach width for nourishment projects. The influence of design alternatives was explored by analyzing the final community occupancies after each 50 years of simulation.

Heat map of the normalized final occupancy numbers is presented in Figure 2. Columns represent beach nourishment design width options and rows are the design storm used for dune replenishment. Cells are colored based on final number of occupied households at the end of the 50 year simulations. Dark colors represent higher occupancy numbers and light colors indicate lower numbers.

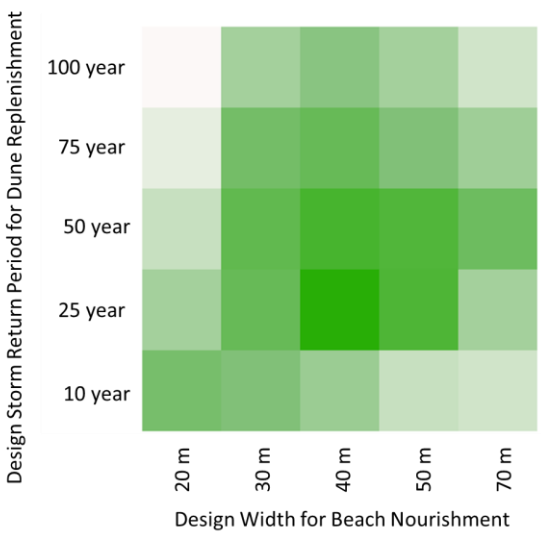

Figure 2 – Heat map of the normalized final occupancy.

The simulations for the Town of Nags Head indicate that maintaining a balance between wide beaches that enhance recreation and mitigate erosion, and large dunes for storm protection is crucial. For example, although the practice of appropriating town's coastal management funds solely to establish wide beaches have enhanced tourism and increased property prices, it also led to substantial structural damage after storms due to the absence of protective dunes. Conversely, having narrow beaches exposed foredunes to chronic erosion or even did not allow its construction due to space constraints. In essence, the allocation of the community's coastal management funds for large beach nourishment and dune replenishment designs reduces the community's ability to undertake other beach management projects that might be required in the future.

In addition, analysis of occupancy with soft-engineering design alternatives suggests that population in Nags Head maximizes when economic benefits and protection from both, dunes and beaches, are balanced.

CONCLUSIONS

A framework that simulates interactions between human and natural systems by integrating geospatial, process-based and probabilistic methods with complex system dynamics has been applied to study occupation dynamics in the coastal community of Nags Head, NC. This model constitutes a novel management tool built to enrich the understanding of human-nature systems by predicting coupled behavior under different forcing scenarios and management strategies. The framework can provide valuable insights into the town system that can ultimately be used by decision-makers to employ management measures that reduce risk and increase resilience.

REFERENCES

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