Modeling the Impacts of Sea Level Rise and Climate Change on Coastal Forests and Hydrology

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Sea-level driven land conversion and the formation of ghost forests

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Ghost forests created by the submergence of low-lying land are one of the most striking indicators of climate change along the Atlantic coast of North America. Although dead trees at the margin of estuaries were described as early as 1910, recent research has led to new recognition that the submergence of terrestrial land is geographically widespread, ecologically and economically important, and globally relevant to the survival of coastal wetlands in the face of rapid sea level rise. This emerging understanding has in turn generated widespread interest in the physical and ecological mechanisms influencing the extent and pace of upland to wetland conversion. Choices between defending the coast from sea level rise and facilitating ecosystem transgression will play a fundamental role in determining the fate and function of low-lying coastal land.
Introduction

Fig. 1 | Geographic distribution of sea-level driven land conversion in North America. a, Red spruce ghost forest and buried stumps, New Brunswick, Canada. b, Atlantic white cedar ghost forest in New Jersey (indicated by dashed line). c, Salt damaged agricultural field in Virginia, where white and grey areas indicate bare ground, and yellow-red colours represent stressed crops. d, Palm tree ghost forest in Florida. Credit: David Johnson (a), Kenneth W. Able (b), USDA Farm Service Agency (c) and Amy Langston, Virginia Institute of Marine Science (d)

Kirwan and Gedan, Nature Geoscience, 2019
Fig. 3 | Stages of ghost forest creation. a–c. Photos show forest-to-marsh conversion in the Chesapeake Bay region (MD, USA) characterized by (a) death of tree saplings, (b) opening of canopy and invasion of *Phragmites* and shrubs, and (c) adult tree death and conversion to marsh, indicated by stumps in foreground and ghost forest in background. Image in c courtesy of Lennert Schepers, UAntwerpen.
Introduction

• Study the coastal forest variations by analyzing satellite datasets coupled with hydrological models

• Results can be used in assessment and resource management decisions
01 Introduction

**LandSat 7**

**Launch Date:** April 15, 1999  
**Sensors:** Enhanced Thematic Mapper Plus (ETM+)  
**Altitude:** 705 km  
**Orbit:** polar, sun-synchronous  
**Equatorial Crossing Time:** nominally 10 AM  
(± 15 min.) local time (descending node)  
**Repeat Coverage:** 16 days  
**Swath:** 183km

Source: NASA
01 Introduction

LandSat 7 NDVI Data

\[ NDVI = \frac{NIR - R}{NIR + R} \]

where NIR is the reflectance in the near-infrared band and R is the reflectance in the red band

01 Introduction

LandSat 7 NDVI Data

**Duration:** 1999-07-21 to 2014-12-21  
**Time Interval:** 16 days  
**Spatial Range:** NC coastal wetland  
**Spatial Resolution:** 30m  

Source: NASA
02 Issues

Missing Data
02 Issues

Cloud

NDVI
High: 0.76863
Low: 0

NDVI
High: 0.80392
Low: 0
02 Issues

Discontinuous
03 Solutions

Monthly Mean

Two-month Mean

Three-month Mean

1999-07

1999-07 to 1999-08

1999-07 to 1999-09
All data have been downloaded and analysis is going on.
01 Introduction of Sentinel Data

**Sentinel 2**

**Sensors:** Multispectral Instrument (MSI)

**Repeat Coverage:** 5 days
Each single satellite revisit time is 10 days.
Two satellites (Sentinel 2A and 2B)

**Swath:** 290 km

**Coverage limits:** 56° S to 84° N

Source: ESA
The process-based model have been successfully applied to the Alligator River and the SE US to

- Understand coastal wetland hydrology at a regional scale
- Understand the hydrologic resilience of coastal wetland due to climate variability & sea level rise
Understanding coastal wetland hydrology with a new regional-scale, process-based hydrological model

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(Zhang et al. 2018, Hydrological Processes)
Understand Coastal Wetland Hydrology

- A regional scale, spatial distributed, physically based, hydrologic model

- Using semi-discrete finite volume method and TINs (Triangular Irregular Network)
\[
\begin{align*}
\frac{d\psi_{\text{canopy}}}{dt} &= vFrac \times (1 - sFrac) \times P - E_c \\
\frac{d\psi_{\text{snow}}}{dt} &= sFrac \times P - SM \\
\frac{\partial \psi_{\text{surf}}}{\partial t} &= TF - \nabla q_{sw} - I - E_s \\
\frac{d\psi_{\text{unsat}}}{dt} &= I - R - E_g - E_{gt} \\
\frac{\partial \psi_{\text{sat}}}{\partial t} &= \nabla q_{gw} + R - E_{sat} - E_{tsat} \\
\frac{\partial \psi_{\text{salt}}}{\partial t} &= \nabla q_{salt}
\end{align*}
\]
Boundary Conditions

1) Tide and Sea level rise

The hydrological processes are subject to change due to the coastal processes, like tides and sea level rise.

\[ q_{SW}(x) = \frac{[\psi_{surf}(x)]^5}{\text{ns} + (S)^2} \frac{\psi_{surf}(x) + z - h_{sea}}{L} \quad \forall x \in \partial \Omega \quad \text{model domain } \Omega \subset \mathbb{R}^n \]

2) Saltwater intrusion

We assume that 1) the fresh and salt water are immiscible by ignoring the dispersion between the interface, and 2) the flow is Dupuit flow where the hydraulic head along a vertical direction is constant.

\[ q_{gw}(x) = -K \frac{\partial (\psi_{sat}(x) + \psi_{salt}(x) + z_B)}{\partial x} \quad \forall x \in \partial \Omega \]

\[ q_{salt}(x) = -K \frac{\partial [\frac{\sigma_f \psi_{sat}(x)}{\sigma_s} + \psi_{salt}(x)]}{\partial x} \quad \forall x \in \partial \Omega \]
(Zhang et al. 2018 Hydrological Processes)
From 2007 to 2016, frequency ranging from 5% (rarely occur) to 100% (always occur) each year.
Two-thirds of these occurrences had a frequency higher than 50%.

(Zhang et al. 2018 Hydrological Processes)
Hydrologic resilience to sea level rise

Difference of saltwater table under extremely dry and wet periods

- Area with highest difference is 400 m from the coastlines
- Least resilient region to water availability

(Zhang et al. 2018 Hydrological Processes)
Summary

- Remote sensing technology used to study Ghost Forests: Challenges
- Hydrological model (PHIM-wetland) model: Validation
- Integrated assessment of SLR and climate variability (including hurricane activities) over the SE US
- Coupling projections of SLR and climate variability