

# Climate change impacts on freshwater resources in southern Florida

*As climate changes and sea levels rise, saltwater intrudes into the groundwater that sustains humans and natural ecosystems. These changes are often analysed using complex and highly detailed models analogous to weather forecast models. In this work, Dr Joseph Park and colleagues used a simpler, holistic approach: an agent-based model reflecting the response of different vegetation types to changing environmental conditions. In the area of southern Florida modelled for the study, the research predicts transformation of freshwater coastal marshes into mangroves and new estuaries, and details the associated reduction in available freshwater resources in response to sea level rise.*

As the climate changes and sea levels rise, coastal environments can be affected by saltwater encroachment, resulting in reductions in freshwater availability and changes to vegetation and ecosystems. The scientific consensus is that sea level rise will accelerate throughout the next century, so it is important to understand the impact on people and the wider environment. Localised modelling studies provide a way of helping us understand the impacts of sea-level rise in particular regions.

Southern Florida has a subtropical climate and is home to several areas of natural beauty including the Biscayne, Everglades and Dry Tortugas National Parks, as well as the Big Cypress National Preserve. The region hosts a range of natural ecosystems and wildlife as well as a human population of over 6.5 million. The region's low elevation and flat landscape make it particularly sensitive to the impacts of sea level rise. In fact, southern Florida is ranked

ninth globally in terms of urban areas with human populations exposed to coastal flooding from sea-level rise, and first in terms of exposed economic assets. Future water availability is a key issue. The aquifers and reservoirs that people currently rely on for their water supply are diminishing in capacity due to saltwater infiltration as a result of rising sea levels, prompting local governments to make plans addressing water availability in the future.

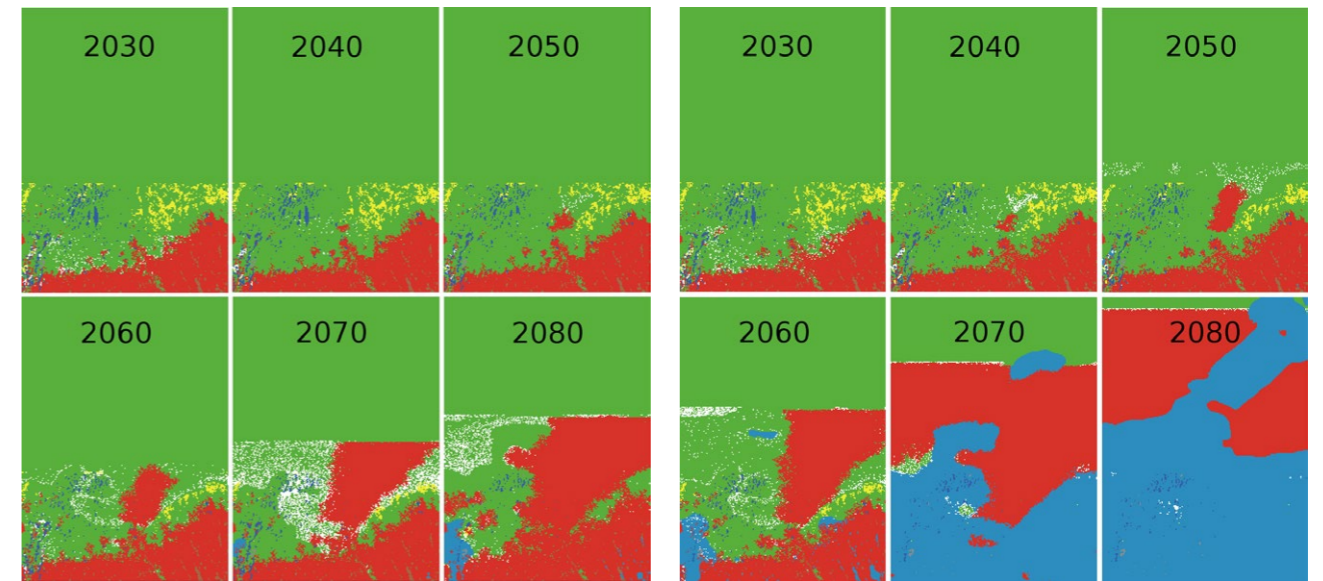
## PROJECTED SEA LEVEL RISE IN SOUTHERN FLORIDA

Dr Joseph Park and colleagues have carried out computer modelling studies looking at sea level rise in South Florida, focusing on low-elevation natural areas at the southern end of the peninsula under two scenarios: high and low sea level rise. The researchers first produced projections for sea level rise specific to southern Florida, and then carried out modelling work to assess changes to the landscape, ecosystems and ecology of the area.

The researchers used global sea level rise projections informed by the Intergovernmental Panel on Climate Change models, selecting the business-as-usual greenhouse gas emissions scenario – which they deemed to be reasonable given current levels of progress towards emissions reductions. The high and low projections for sea level rise are both based on this business-as-usual emissions scenario and represent the uncertainty about the response of the climate to these emissions. The researchers note that the higher sea level rise projection is consistent with the effects of an expected collapse of the Antarctic ice sheet. Sea level rise for southern Florida was based on local tide gauge corrections to the global sea level rise projections.



The freshwater ecosystems in Florida provide key habitat for wildlife such as egrets.



Images of model domain output (vegetation coverage) under low sea level rise conditions (left panel) and high sea level rise conditions (right panel). Green: freshwater sawgrass; red: saline water mangroves; blue: open water.

Dr Park and a team of researchers mapped the projected inundation of sea onto the land across southern Florida for the years 2025, 2050, 2075 and 2100 using high resolution digital data for the topography of the landscape. Over the next ten years, the researchers found that sea level is expected to rise by 7-10 cm, resulting in more tidal inundation along coastal regions, and by 23-36 cm by 2050. By 2100 with predicted sea levels 74-156 cm higher than today, both scenarios show significant expansion of the region below mean sea level. Under the high emissions scenario, the mean sea level boundary extends from the southwestern peninsula to the northeast corner of the Everglades National Park.

In further analysis, the team found that northern Florida Bay has already begun the process of transitioning from a freshwater marsh estuarine environment towards a marine environment over the last two decades. This was measured using the Marsh-to-Ocean transformation index, an index designed to measure the gradual transformation of freshwater coastal marshes into saltwater marshes and eventually into submarine basins.

## HOW DOES THIS AFFECT COASTAL ECOSYSTEMS?

As saltwater intrudes into coastal aquifers and moves inland, saltwater ecosystems such as mangrove marshes also move inland. Dr Park and colleagues carried out additional computer modelling to create projections of the extent of this

transformation in southern Florida over the 21st century. Modelling studies of this type have frequently been carried out using equation-based models.

## As sea levels rise, Florida Bay will expand into the Everglades and South Florida establishing new estuarine and marine habitats.

These are based on solving equations governing the relevant physical and biological processes or on probabilistic descriptions of the processes. They have advanced our understanding of coastal processes. However, it is difficult to

simulate the so-called emergent effects of nonlinear feedbacks in these models. In general terms, emergent properties are behaviours or results that arise from

interactions between components of a complex system, behaviours that cannot be produced from the components themselves acting in isolation. In order to resolve this issue, Dr Park and colleagues used a so-called agent-based modelling

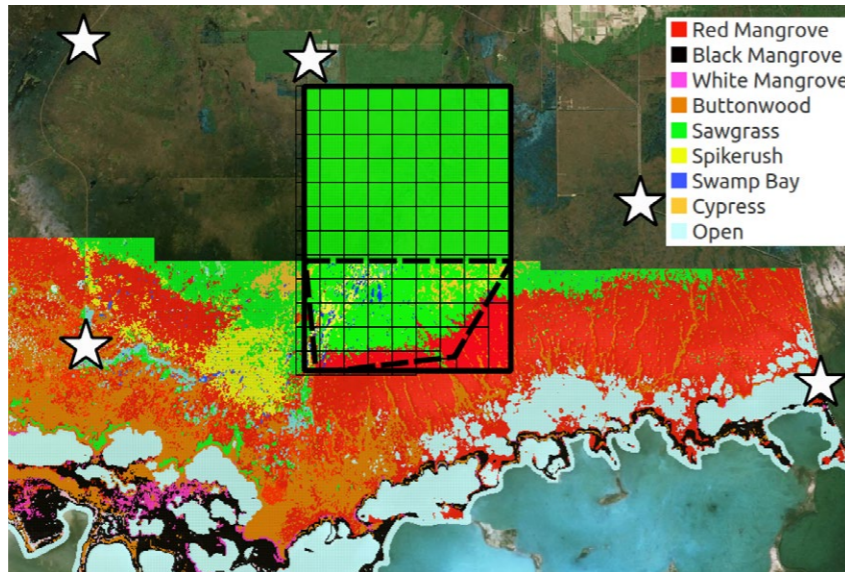


The Big Cypress National Preserve is one of Florida's many areas of natural beauty.

G. Gardner/National Park Service



Satellite image of South Florida with the model domain highlighted by the small rectangle in the lower part of the image.



The model domain overlaid on satellite imagery with a color-coded vegetation map. The large rectangle is the model domain. White stars are geotechnical exploratory wells that define the aquifer depth.

approach, based on modelling the actions and interactions of 'agents' (such as vegetation types) with a view to assessing their effects on the system as a whole. The effects of nonlinear feedbacks are automatically incorporated into these models.

The researchers focused on a 14,382 hectare area spanning a mangrove/freshwater ecotone (zone across which ecosystems transform from one to another) in southern Florida. They modelled changes in the vegetation coverage and the freshwater content of the aquifers from 2015 to 2100, having first calibrated the model using data from the period 1973-2015. The researchers represented the current vegetation coverage using data from field observations and aerial photography. Data representing land surface elevation, marsh freshwater levels and sea level rise was also input. The model assessed the vitality of vegetation types – whether they had been stressed enough to die as a result of saltwater encroachment for example – and then calculated their propagation by assessing vacant patches and working out whether vegetation in surrounding patches could propagate into the vacant patch based on the updated environmental conditions.

The results indicate continued equilibrium between fresh and saltwater species until 2050, after which there is eventual replacement of fresh groundwater with saline water and freshwater species with salt tolerant ones, ultimately transitioning into new marine habitat.

Under the low sea level rise scenario, the model projects that a mangrove stand will emerge in the south-central section of the region by 2050, before expanding northward. By 2080 a significant part of

### The South-Dade agricultural areas and Florida Keys wellfields may see a reduction in freshwater resources.

the region is projected to be transformed to mangroves, with a small region in the southwest of the domain transformed into open water. Under the high sea level rise scenario, large parts of the domain gradually transform to mangrove or open water: by 2070, the model projects open water to make up over one third of the domain, and by 2080 the modelled region is almost entirely made up of mangrove swamp or open water.

#### THE IMPACT ON FRESHWATER RESOURCES OVER THE 21<sup>ST</sup> CENTURY

The model projects that freshwater resources in the domain will be reduced from 28.6 million cubic metres in 2015 to

8.7 million cubic metres by 2100 under the low sea level rise scenario, and that freshwater resources would be depleted entirely in the model domain by 2085 under the high sea level rise scenario. This suggests that the nearby South-Dade agricultural areas and Florida Keys Aquaduct Authority well-field providing water for 70,000 residents are likely to see a reduction in freshwater resources by the end of the century. According to the modelling work detailed here, adaptation is necessary in order to cope with

reduced freshwater resources: the researchers conclude that the avoidance of extreme low water events

from droughts and generally higher water levels in the Everglades are key to prolonging the viability of freshwater resources.

This work provides key information about projected freshwater availability and landscape transformation by the end of the current century. This will be a key part of developing a climate change adaptation strategy for southern Florida, and will help inform the Comprehensive Everglades Restoration Plan, which is aimed at restoring, protecting and preserving water resources in the region. The researchers also note that this methodology can be applied to similar coastal regions around the globe.



# Behind the Research

## Dr Joseph Park

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### Research Objectives

Dr Joseph Park has carried out computer modelling studies of the effects of sea level rise on water resources and ecosystems in southern Florida.

### Detail

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### Bio

Dr Joseph Park has a broad spectrum of operational, managerial, research, communication, and pedagogical experience in engineering and science. Current and prior posts include the U.S. Department of Interior, Software Literacy Foundation, Scripps Institute of Oceanography, Salk Institute, NOAA, University of Hawaii and Florida Atlantic University.

### Collaborators

- Dr Jed Redwine
- Dr Troy D. Hill
- Mr Kevin Kotun



### References

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### Personal Response

#### What do you think is the key message from your work for local farmers and the Florida Keys Aqueduct Authority?

South Florida farmers and the Florida Keys Aqueduct Authority have keen insights and close connections to the environment and freshwater resources. Our results suggest that by the end of the century the surficial aquifers used by these interests will have reduced freshwater capacity. Long term planning for alternative sources of water or alternative agricultural strategies will eventually be needed.

