FINAL REPORT

Southeast Climate Adaptation Science Center (SE CASC)
Award G19AC00083
Project 038

Improving Scenarios of Future Patterns of Urbanization, Climate Adaptation, and Landscape Change in the Southeast

1. ADMINISTRATIVE

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Cooperator/Partner: Dr. Georgina Sanchez (Research Scholar, Center for Geospatial Analytics, NC State University) and Dr. Adam Terando (Research Ecologist, U.S. Geological Survey Southeast Climate Adaptation Science Center)
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Project cost: $323,040

2. PUBLIC SUMMARY

One of the most significant and lasting changes humans can make to the environment is converting natural and rural areas into urbanized areas. As the population continues to grow, there is an increasing demand for urban spaces. In the Southeast U.S., which is known for its favorable climate and strong economy, rapid population growth has been observed in recent decades. However, this region is also highly vulnerable to climate change, particularly along its extensive coastline where many people live. Rising sea levels and increased flood risks pose significant challenges to coastal communities, potentially leading residents to relocate to safer areas at higher elevations and latitudes.

This study aims to understand how current population dynamics in the Southeast U.S. interact with the potential movement of people away from vulnerable coastal and flood-prone areas. To achieve this, we have developed a unique land change model called FUTURES 3.0. This model can simulate urban growth, increases in flood hazard due to climate change, and human adaptive response to flooding in a spatially interactive manner, meaning that what happens in one location can affect others. FUTURES 3.0 is freely accessible, allowing researchers and decision-makers to use it for their own analyses. Furthermore, we have created comprehensive scenarios that depict future population redistribution and urbanization patterns across the Southeast U.S. These "what-if" scenarios provide valuable information for natural resource decision-makers, regulatory agencies, and land managers. They help us understand and anticipate the tradeoffs between different paths of urbanization, which is crucial for wildlife and habitat management efforts. By proactively protecting and conserving valuable ecosystems and species of concern, we can better manage the impacts of urbanization. Additionally, this information can support land use planning and decision-making by providing estimates of future flood exposure for built infrastructure.

3. TECHNICAL SUMMARY

The conversion of non-urban and rural land into urban and highly modified areas is a significant and long-lasting impact of human activities (Theobald, 2013). Understanding and simulating the spatial patterns of these conversions in regions experiencing rapid population growth and urbanization are crucial for adaptive planning efforts by natural resource managers (Terando et al., 2014; Dorning et al., 2015). This need is particularly relevant in the Southeastern United States, which has seen a substantial influx of people due to its favorable winter climate (Rappaport, 2007). However, the Southeast is also highly vulnerable to the impacts of sea-level rise, as a significant portion of its population, approximately 27%, resides along the coast and in low-lying areas. Previous modeling studies have highlighted the potential for sea-level rise to drive coastal residents towards higher-elevation inland locations (Hauer, 2017; McAlpine & Porter, 2018). However, these studies have not fully considered the spatially explicit outcomes of population redistribution from flood-prone areas, nor the influence of additional socio-economic factors that affect communities' ability to respond to flood risk.

The primary goal of this project was to improve land change modeling by examining the interaction between global climatic change and human mobility in shaping the extent and spatial distribution of developed areas. To achieve this, we developed advanced modeling techniques and spatially explicit scenarios that provide a deeper understanding of urbanization patterns in the Southeastern U.S. Our approach involved introducing a new version of the FUTure Urban-Regional Environment Simulation (FUTURES; Meentemeyer et al., 2013) modeling framework, which now integrates human responses to flood risk and incorporates the key components of flood risk: exposure, hazard, and vulnerability (Haer et al., 2019). By considering these factors, we can better inform adaptive planning and decision-making processes. Flood risk is influenced by urban development patterns, which determine the exposure of infrastructure to potential flood damage. The likelihood and intensity of floodwaters, known as the hazard, are also influenced by factors such as rising sea levels and climate change-induced riverine flooding. Additionally, the vulnerability of a population plays a role in their ability to reduce exposure and mitigate hazards through adaptive responses, such as the implementation of nature-based solutions or the relocation of homes from hazardous areas. The resources and capacity of a population dictate their ability to implement these measures.

By projecting human mobility and shifts in development patterns in response to future flooding, while considering the three components of flood risk, our modeling framework provides valuable insights for natural resource managers and stakeholders. It contributes to the Department of the Interior's Secretarial Priority 1, "Creating a conservation stewardship legacy second only to Teddy Roosevelt." By understanding the potential impacts of urban growth on regional species, ecosystems, and habitats of concern, we can support more effective conservation and natural resource management efforts.

3.1. Major research accomplishments

We developed FUTURES 3.0, an advanced version of the open-source land change model. FUTURES 3.0 can now probabilistically project new urban development while also simulating human migration and other adaptation measures in response to flood hazard from climate change. It integrates dynamic flood event modeling and human adaptive response to project spatially interactive patterns of urban growth via population redistribution and adaptation in the face of future urbanization and climate change. The software is available on GitHub (https://github.com/ncsu-landscape-dynamics/GRASS_FUTURES) with the identifier doi:10.5281/zenodo.6607097. We have submitted a description of the new modeling methods in

FUTURES 3.0 for review in *Scientific Reports* (Sanchez et al., in review). We have published two data releases presenting spatially-explicit scenarios of urbanization patterns. The first release utilizes FUTURES 3.0 and focuses on the Southeastern U.S. (Petrasova et al., 2023a), while the second release utilizes FUTURES 2.0 and focuses on the Conterminous U.S. (Petrasova et al., 2023b).

We have developed a modeling framework that allows us to understand the underlying drivers of flood damage and estimate the probability of such damage for each 30-meter pixel across the Conterminous U.S. (CONUS). The findings of our study have been summarized in a research manuscript published in *Environmental Research Letters* (Collins et al., 2022a). We have published a data release, making the data and code used in our study publicly available (Collins et al., 2022b).

4. PURPOSE AND OBJECTIVES

Our research and data products have proven to be highly relevant to key stakeholders such as the U.S. Fish and Wildlife Service (FWS) Region 4 managers, Southeast Conservation Adaptation Strategy (SECAS) conservation partners, Florida Natural Areas Inventory analysts, and other interested parties. These stakeholders have actively sought access to our data products and documentation, recognizing their value in informing conservation planning and decision-making processes. Additionally, some stakeholders have provided additional funding to further leverage the findings from our project, indicating their strong interest and investment in the outcomes (PI: Bardon, B.; Co-PIs: Sanchez, G.M. et al. 2019-2021. Amount: $206,272. Spaces Between the Bases: The North Carolina Strategic Plan for Sustaining Military Readiness Through Conservation Partnerships. Sponsor: U.S. Fish & Wildlife Service). The collaboration and support from these stakeholders demonstrate the practical significance and applicability of our research in addressing conservation challenges and supporting informed management actions.

The project successfully accomplished the three initially conceived research objectives, as well as an additional objective that emerged during the development of the project. The objectives were as follows:

Objective 1: *Using an existing high-resolution land change model, incorporate important macro-factors and forcings that affect the amount and distribution of people in the Southeast U.S*. This objective was successfully achieved through the development of the new CLIMATE FORCING submodel in FUTURES 3.0. This submodel integrates various data sources, including current and future flood probability and flood depth data, to estimate the probability of flood damage and the likely adaptation response in developed locations. The adaptive response is determined based on factors such as flood probability, level of damage, and local estimates of adaptive capacity. Additionally, the submodel predicts the destinations of displaced residents within or between counties. By incorporating these factors and forcings, the CLIMATE FORCING submodel enhances the modeling capabilities of FUTURES 3.0 and provides valuable insights into the potential impacts of flood events on urban areas and the adaptive responses of the population.

Objective 2: *Develop spatially explicit scenarios that explore social-environmental tradeoffs in areas of high climate risk*. The flexibility of FUTURES 3.0 accommodates creating different scenarios that capture the adaptation inclinations of various communities and the influence of policies. This objective was successfully achieved through the implementation of two “what-if” policy interventions and flood response scenarios (Petrasova et al., 2023a). The "Reactive" scenario assumes that residents respond to flood threats on an individual basis, adapting as the events occur. This scenario does not involve any specific incentives or policies that would directly influence the outcomes. It represents a reactive approach where residents take adaptive actions based on their own adaptive capacity. The "Managed Retreat" scenario involves policymakers implementing incentives to encourage the conversion of at-risk developed land into undeveloped land, effectively abandoning the areas. In this scenario, residents at all levels of adaptive capacity are encouraged to relocate to safer locations. The goal of this scenario is to proactively reduce exposure and vulnerability to flood hazards by strategically managing the retreat from high-risk areas.

Objective 3: *Explore the potential for tipping points that could slow or even reverse the rate of in-migration to the region as the climate warm*s. To showcase the capabilities of FUTURES 3.0, we chose a specific test case location in the Southeast U.S. consisting of three counties near the rapidly growing Charleston Metropolitan Area in the coastal South Carolina Lowcountry. This region is highly susceptible to flooding and has been proactive in implementing climate adaptation measures. It serves as an ideal case study for evaluating the effectiveness of the new modeling framework. We conducted a comparison analysis to examine the tradeoffs between different modeling assumptions and scenarios of growth and adaptive response to flooding. Specifically, we assessed (Sanchez et al., in review) the extent of developed land area that is projected to be exposed to future flooding under various modeling scenarios. Our findings indicated that of the interventions studied, only managed retreat showed a reduction in projected exposure compared to the baseline conditions.

[Added] Objective 4: *Analyze the contributing factors that lead to flood damage and develop a predictive model*. As part of this project, we recognized the need for a comprehensive understanding of the spatial distribution of flood damage probability. By leveraging machine learning, geospatial predictors, and reports of flood damages, we have successfully generated the first spatially complete map of flood damage probability for the Conterminous U.S. (Collins et a., 2022a; 2022b). This map offers valuable information regarding the likelihood of flood damages across the entire country, empowering stakeholders to more effectively assess and manage flood risks.

5. ORGANIZATION AND APPROACH

The research team held weekly meetings to collaboratively discuss and address research and development tasks related to this SE CASC funded project. Each team member contributed their unique skills and expertise to advance specific tasks within the project. Co-PI Sanchez served as project manager, responsible for coordinating, overseeing, and leading the research and development efforts of the team.

5.1. Data collection and processing

In line with our commitment to open science, we made use of publicly available geospatial datasets whenever possible. Additionally, we leverage this project to establish a data sharing agreement with First Street Foundation, enabling us to access their cutting-edge flood risk data products.

5.2. Model development, validation, and upscaling of simulations

The research team conducted a comprehensive literature review to explore existing modeling methods used to project human mobility and development patterns in response to climate stressors. The findings revealed that previous studies have mainly focused on one or two components of flood risk, lacking integration of all three (exposure, hazard, and vulnerability). Furthermore, existing modeling methods were often limited in terms of accessibility, scalability, and generalizability. Leveraging our knowledge of the FUTURES modeling framework and the state-of-the-science, we developed new modeling mechanisms that integrate dynamic flood event modeling and human adaptive response. Through iterative evaluation and modifications, we finalized FUTURES 3.0. The model was implemented in the Charleston Metropolitan Area, South Carolina, an area prone to flooding and at the forefront of adaptation efforts. We upscaled FUTURES 3.0 simulations across the Southeast U.S. using NC State's high-performance computing (HPC) cluster after thorough model validation.

5.3. Scenario development

Using the FUTURES 2.0 model, we conducted simulations for a "Status Quo" growth scenario across the entire CONUS (Continental United States). This scenario represents a continuation of urban growth without considering human’s adaptive responses to increasing flood hazards. Using the advanced FUTURES 3.0 model, we computed simulations for two additional scenarios specifically focused on the Southeast U.S. region. The first scenario, named "Reactive," assumes that residents respond to flood threats individually, adapting as events occur without any specific incentives or policies to reduce exposure or damage. The second scenario, called "Managed Retreat," involves policymakers implementing incentives to encourage the conversion of at-risk developed land into undeveloped land, effectively abandoning those areas. The objective of this scenario is to proactively reduce exposure and vulnerability to flood hazards by strategically managing the retreat from high-risk areas. We performed 20 stochastic iterations for each scenario, spanning from 2020 to 2100 with annual time steps. Probability layers were generated for each decade throughout this timeframe.

6. PROJECT RESULTS

According to our findings for the "reactive" scenario, a significant amount of land in the test case location is projected to experience new development in flood-prone areas by 2050 (approximately 121 km^2, SD = 29 km^2). Therefore, it will be crucial to implement measures to protect this additional development from potential flood damage. By 2050, a substantial portion of the existing and future development in the area will either need to be protected (125 km^2, SD = 43 km^2) or abandoned (11 km^2, SD = 13 km^2) to adapt to future flood hazards. Localities that are unable to protect, armor, or retreat will remain vulnerable (trapped) to subsequent flood events (31 km^2, SD = 3 km^2). The majority (~76%) of residents expected to retreat from the test case location will likely resettle within the same area. Among the approximately 24% projected to leave the area, most are expected to resettle in other parts of South Carolina (27%) or nearby states, particularly Florida (12%), Georgia (10%), North Carolina (10%), and Virginia (9%). However, a total of 42 states, including distant states such as Washington and Oregon, are likely to receive residents who are retreating.

In addition to the "reactive" response function, we parameterized four other response scenarios in the test case location, named "managed retreat," "resist," "polarized population," and "trapped population." These parameterizations allowed us to evaluate the impact of different adaptive response scenarios on simulated outcomes. Among these response scenarios, "managed retreat" showed the lowest levels of developed land exposed to future flooding compared to both baseline conditions and other modeled scenarios, particularly in areas with higher flood probabilities (e.g., the 100-year floodplain). It was the only scenario that predicted a decrease in the total amount of developed land in flood-exposed areas over time. Additionally, "managed retreat" resulted in a greater number of census tracts demonstrating some level of retreat, indicating a regional pattern. On the other hand, the "resist" scenario showed the highest percentage increase in developed land exposed to future flooding. However, there were specific census tracts where residents experiencing significant flood damage were likely to retreat. With the "polarized population" scenario, the probability of retreat was greater than the "resist" scenario but lower than the "reactive" scenario. The exposure estimated for a polarized population fell between these two scenarios, and the spatial pattern of exposure closely resembled that of the "resist" scenario. The "trapped population" scenario resulted in lower levels of exposure across all hazard zones compared to all scenarios except "managed retreat." In this scenario, the probability of retreat was concentrated in highly resilient census tracts, including those situated in waterfront areas.

7. ANALYSIS AND FINDINGS

Our approach in developing FUTURES 3.0 aligns with the global demand for flexible and transferable modeling frameworks that integrate all three components of flood risk: exposure, vulnerability, and hazard. These components are crucial for informed decision making. By simultaneously modeling urban growth, climate change-induced increases in flood hazard, and human adaptive response to flooding, we were able to anticipate future hotspots of urbanization and human mobility. This provides valuable insights for natural resources managers to consider potential threats to ecosystems and their services, as well as for land use planners to evaluate the potential flood exposure of built infrastructure. Our open science approach enhances the reliability and applicability of FUTURES 3.0, enabling it to address the complex challenges associated with flood risk management and resources management.

8. CONCLUSIONS AND RECOMMENDATIONS

Scenario-based models that accurately project future risks play a crucial role in proactive planning efforts. These models enable us to anticipate and mitigate the potential impacts of development and make informed decisions to protect vulnerable areas. Additionally, they can be used strategically in conjunction with conservation efforts to prevent future risky development and preserve valuable natural resources. By incorporating various scenarios and assessing their outcomes, decision-makers and resources managers can evaluate different courses of action and identify the most effective strategies to minimize risks and maximize benefits. This approach enables proactive planning that takes into account the long-term consequences of development, avoids costly interventions, and promotes sustainable and resilient communities. Through the use of scenario-based models, we can enhance our understanding of the potential risks associated with different development patterns and make informed decisions that balance economic, social, and environmental considerations.

9. MANAGEMENT APPLICATIONS AND PRODUCTS

Ongoing collaborations with key stakeholders, including the USGS Southeast Climate Adaptation Science Center, U.S. Fish and Wildlife Service, Florida Natural Areas Inventory, city planning departments, and researchers from federal agencies and academic institutions, have demonstrated the wide-ranging utility of FUTURES projections in informing forward-thinking planning, management decisions, and research. These projections provide valuable insights into the potential threat of urban growth to natural lands, facilitating the preservation and management of green spaces in rapidly expanding urban areas. Additionally, FUTURES projections enhance our understanding of the interactions between increased flooding and human exposure, enabling decision-makers to develop effective flood risk management strategies. End users of FUTURES projections can utilize this data to assess the tradeoffs between different growth pathways. They can incorporate this factor into their research and other modeling efforts, such as hydrologic disturbances and wildfire risk analysis. By doing so, they offer insights to guide stakeholders towards environmentally conscious choices and effective planning for a resilient future.

9.1. Stakeholders’ quotes

- “*The Southeast Conservation Adaptation Strategy (SECAS) partnership uses the FUTURES urban growth projections as a threat layer in the online viewer and automated reporting for the Southeast Conservation Blueprint. Having a consistent CONUS-wide model that simulates the spatial patterns of urbanization helps Blueprint users understand a key driver of landscape change in the Southeast. Combining the Blueprint priorities with future threat predictions provides important context about the urgency of conservation action in different parts of the region and the potential demand for* *expanded outdoor recreation opportunities in growing urban areas. Blueprint users and SECAS staff use the FUTURES models to inform strategic decisions about where to focus conservation efforts, and to help make a stronger case for bringing new funding to the Southeast region,*" said Hilary Morris, User Support and Communications, with the Southeast Conservation Blueprint at U.S. Fish and Wildlife Service.

- "*Having comparable urban growth projections in Puerto Rico & U.S. Virgin Islands to what we currently have for CONUS [FUTURES projections] would be enormously useful to us and our partners and help address data inequities in the Caribbean, which is a high priority for the SECAS [Southeast Conservation Adaptation Strategy] initiative,*" said Hilary Morris, User Support and Communications, with the Southeast Conservation Blueprint at U.S. Fish and Wildlife Service.
- "*The FUTURES projections dataset will be useful as a decision-support map overlay in the Longleaf Sustainability Analysis, a spatial conservation prioritization analysis. The long-term ability to prevent land conversion of extant longleaf pine sites as well as the long-term persistence of restoration investments is a critical piece to landscape sustainability. Individual longleaf pine practitioners will be able to decide the best strategy to mitigate the threat of potential conversion. For example, if an area is projected to be a high priority for restoration and predicted to be developed in the future, a practitioner could decide to advocate for a new (or extension of a current) protected area/conservation easement and then restore it. Alternatively, a practitioner could decide that the limited funding should be spent elsewhere and would not invest in restoring the area,*" said Carly Voight, GIS Analyst with the Florida Natural Areas Inventory at Florida State University.

10. OUTREACH AND COMMUNICATION

10.1. Publications

10.1.1. *Peer reviewed scientific publications (including in review)*

- Sanchez, G.M., Petrasova, A., Skrip, M., Collins, E., Lawrimore, M., Vogler, J.B., Terando, A., Vukomanovic, J., Mitasova, H., Meentemeyer, R.K. Spatially interactive modeling of land change identifies location-specific adaptations most likely to lower future flood risk. In review. *Scientific Reports*.
- Lawrimore, M.A., Sanchez, G.M. Cothron, C., Tulbure, M.G., BenDor, T.K., Meentemeyer, R.K. Creating Spatially Complete Zoning Maps Using Machine Learning. In review. *Landscape and Urban Planning*.
- Hutchens, L., Kupfer, J., Gao, P., Sanchez, G.M., Meentemeyer, R., Terando, A., Hiers, J. Long-term, large-scale human influences on the spatial and functional persistence of a threatened pine savanna ecosystem. In review. *Conservation Science and Practice*.
- Collins, E., Sanchez, G.M., Terando, A., Stillwell, C., Mitasova, H., Sebastian, A., Meentemeyer, R. K. (2022a). Predicting flood damage probability across the conterminous United States. *Environmental Research Letters*, 17, 034006, https://doi.org/10.1088/1748-9326/ac4f0f.

10.1.2. Scientific publications in preparation

- Sanchez, G.M., Lawrimore, M.A., Petrasova, A., Vogler, J.B., Collins, E., Petras, V., Harper, T., Butzler, E., Meentemeyer, R.K. Exploring the impact of the 100-year floodplain on development patterns and future flood exposure across the United States. In preparation for submission to *Global Environmental Change*.
- Petrasova, A., Petras, V., Sanchez, G.M., Mitasova, H. Parallelization approaches in complex geoprocessing workflows for urban growth modeling. In preparation for submission to *Environmental Modelling & Software*.

10.1.3. Data and software releases

- Petrasova, A., Sanchez, G.M., Skrip, M.M., Collins, E.L., Lawrimore, M.A., Vogler, J.B., Terando, A., Vukomanovic, J., Mitasova, H., and Meentemeyer, R.K. (2023a). FUTURES v3: Scenarios of Future Patterns of Urbanization in Response to Sea Level Rise and Frequent Flooding Across the Southeast United States from 2020 to 2100: U.S. Geological Survey data release, https://doi.org/10.5066/P9BD5V4B.
- Petrasova, A., Sanchez, G.M., Lawrimore, M.A., Vogler, J.B., Collins, E.L., Petras, V., Harper, T., Butzler, E., and Meentemeyer, R.K. (2023b). FUTURES v2: Status Quo Projections of Future Patterns of Urbanization Across the Conterminous United States from 2020 to 2100: U.S. Geological Survey data release, https://doi.org/10.5066/P94N3ICH.
- Lawrimore, M.A., Sanchez, G.M., Cothron, C., Tulbure, M.G., BenDor, T.K., Meentemeyer, R.K. (2023). Predicted spatially complete zoning map of North Carolina. Zenodo. https://doi.org/10.5281/zenodo.8136886.
- Collins, E.L., Stillwell, C.C., Terando, A.J., Sanchez, G.M., Mitasova, H., Sebastian, A., and Meentemeyer, R.K. (2022b). Data and Code for Predicting Flood Damage Probability Across the Conterminous United States: U.S. Geological Survey data release, https://doi.org/10.5066/P954TTQN.
- Petrasova, A., Petras, V. (2022). ncsu-landscape-dynamics/GRASS_FUTURES: FUTURES v3.0.0. Zenodo. https://doi.org/10.5281/zenodo.6607097.

10.2. Presentations

10.2.1. Conference presentations

- Lawrimore, M.A., Sanchez, G.M., Cothron, C., Meentemeyer, R.K. (March 2023). Creating spatially continuous zoning maps using machine learning. NCSU's College of Natural Resources Graduate Research Symposium. Raleigh, NC. Poster presentation.
- Lawrimore, M.A., Sanchez, G.M., Meentemeyer, R.K. (November 2022). Smart zoning for coastal flood resilience and adaptation. The North Carolina Coastal Conference. Raleigh, NC. Poster presentation.
- Sanchez, G.M., Petrasova, A., Skrip, M., Collins, E., Lawrimore, M., Vogler, J.B., Terando, A., Vukomanovic, J., Mitasova, H., Meentemeyer, R.K. (September 2022). Improving forecasts of societal responses to sea level rise and frequent flooding. 2022

Southeast Climate Adaptation Science Symposium. Gulf Shores, AL. Poster presentation.

- Lawrimore, M., Sanchez, G.M., Petrasova, A., Skrip, M., Collins, E., Vogler, J.B., Terando, A., Vukomanovic, J., Mitasova, H., Meentemeyer, R.K. (September 2022). Forecasting scenarios of human mobility and shifts in development patterns driven by future flood hazard conditions. 2022 Southeast Climate Adaptation Science Symposium. Gulf Shores, AL. Poster presentation.
- Petrasova, A., Petras, V. (August 2022). Tips for parallelization in GRASS GIS in the context of land change modeling. FOSS4G 2022. Florence, Italy. Oral presentation.
- Terando, A., Sanchez, G.M., Petrasova, A., Collins, E., Vogler, J.B., Petras, V., Vukomanovic, J., Mitasova, H., Meentemeyer, R.K. (December 2021). Forecasting land change in response to sea-level rise and frequent flooding. American Geophysical Union. New Orleans, LA. Poster presentation
- Petrasova, A., Sanchez, G.M., Petras, V., and Meentemeyer, R.K. (February 2021). FUTURES v2: Urban Growth Modeling at Scale. NCGIS. Virtual poster presentation, DOI: 10.13140/RG.2.2.11830.22081
- Collins, E.L., Sanchez, G.M., and Meentemeyer, R.K. (January 2021). Urban areas at great risk from flood damage. National Council for Science and the Environment Drawdown Conference. Virtual poster presentation.

10.2.2. Webinars and invited presentations

- Petrasova, A. (July, 2023). Scaling up Urban Growth Projections with FUTURES. Speaker at the Science Seminar Series. Organized jointly by the USGS Southeast Climate Adaptation Science Center and the U.S. Fish and Wildlife Service Southeast Conservation Adaptation Strategy. Raleigh, NC.
- Sanchez, G.M. (March, 2023). Improving projections of societal responses to sea level rise and frequent flooding. Invited talk prepared for the Iowa Flood Center at the University of Iowa. Iowa City, IA.
- Sanchez, G.M. (February, 2023). Future scenarios of societal responses to sea level rise and frequent flooding. Invited talk prepared for the NCSU's Vice Provost for University Interdisciplinary Programs Office. Raleigh, NC.
- Sanchez, G.M. (November, 2022). Improving forecasts of societal responses to flooding. Speaker at the Science Seminar Series. Organized by the USGS Southeast Climate Adaptation Science Center. Raleigh, NC.
- Sanchez, G.M. (September, 2022). Southeast Climate Adaptation Science Symposium. Plenary speaker. Session: Visualizing Change in the Southeast. Gulf Shores, AL.

10.3. Media coverage

- *Sun Sentinel*, Fort Lauderdale, FL. Saunders, J. (2022, November 8). Federal flood maps in Florida fall short, researchers say as Tropical Storm Nicole approaches. Available at https://www.sun-sentinel.com/news/florida/fl-ne-nsf-florida-flood-maps-weaknesses-20221108-wlwor3qyvjgtfgfifbcr5egeqi-story.html

- *Newsy "The Why"*. Host: Magarino, L.; Producer: Kintisch, E. (2022, September 26). Why the United States is ill-prepared for devastating floods. Available at https://video.snapstream.net/Play/TZN40OJMrv6jJXWumreAs?accessToken=b903hkeofdzg2
- *CNN Investigates*. Tolan, C. (2022, August 15). 'We thought we were safe': Kentucky disaster shows how US is ill-prepared and under-insured for devastating floods. Available at https://www.cnn.com/2022/08/15/us/fema-kentucky-flood-insurance-climate-change-invs/index.html
- *WNCT Channel 9 On Your Side*, Greenville, NC. Molle, C. (2022, March 9). New research from NC State suggests many more may be at risk for flooding than FEMA says. Available at https://www.wnct.com/weather/new-research-from-nc-state-suggests-many-more-may-at-risk-for-flooding-than-fema-says/
- *WUNC 91.5 NC Public Radio (NPR)*, Raleigh, NC. Debruyn, J. (2022, March 7). FEMA flood maps underestimate damage risks, according to NC State research. Available at https://www.wunc.org/environment/2022-03-07/fema-flood-maps-underestimate-damage-risks-according-to-nc-state-research
- *NC News & Observer*, Raleigh, NC. Wagner, A. (2022, March 3). NC State study: More than a million square miles of US at risk of flood damage. Available at https://www.newsobserver.com/news/state/north-carolina/article258936393.html
- *NC Sea Grant Coastwatch Magazine*, Raleigh, NC. Moore, A. (2021, June). Mapping the Future: Climate Change and Flooding in Coastal North Carolina. Available at https://ncseagrant.ncsu.edu/coastwatch/current-issue/summer-2021/mapping-the-future/

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Meentemeyer, et al. FUTURES: multilevel simulations of emerging urban–rural landscape structure using a stochastic patch-growing algorithm. Annals of the Association of American Geographers, 103(4):785-807 (2013).

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Terando, A. et al. The Southern Megalopolis: Using the Past to Predict the Future of Urban Sprawl in the Southeast U.S. PLoS ONE 9(7): e102261. doi:10.1371/journal.pone.0102261 (2014).
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