Supporting Regional Implementation of Integrated Climate Resilience Consortium for Climate Risk in the Urban Northeast (CCRUN) Phase II

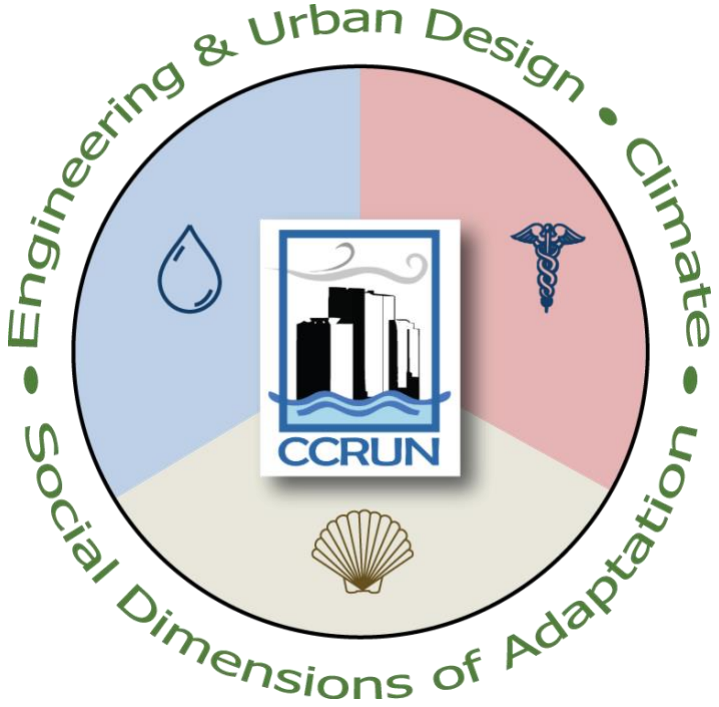
NA15OAR4310147
NA20OAR4310147A

Research Highlights, June 1, 2020 – May 31, 2021

Boston

New York City

Philadelphia



CCRUN's Mission

CCRUN conducts stakeholder-driven research that reduces climate-related vulnerability and advances opportunities for adaptation in the urban Northeast

Columbia University
In the City of New York

Stevens
Institute of Technology
The Innovation University

University of Massachusetts Amherst

Boston University

Drexel University

Hunter
The City University of New York

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*Indicates new team member over the past year

Stakeholders and Partners

100 Resilient Cities
AKRF Environmental Services Group
All Hazards Consortium
American Littoral Society
Baltimore City Department of Public Works
Beacon Institute for Rivers & Estuaries
Boston Environmental Department
Boston Public Health Commission
Camden County Municipal Utilities Administration
City of Cambridge (MA) Public Health Department
City of New Rochelle NY
City of Stamford CT
City of Yonkers NY
Connecticut Water
Consolidated Edison, Inc.
Delaware River Basin Commission
Delaware Valley Regional Planning Commission
Eastwick Friends and Neighbors Coalition
Environmental Protection Agency
ESIP Federation
F.P. Clark Associates
Groundwork Hudson Valley
Hudson River Foundation
Hudson River Watershed Alliance
Hudson Valley Initiative
Interstate Commission on the Potomac River Basin
Jamaica Bay-Rockaway Parks Conservancy
Javits Center in Manhattan
Jersey City Division of Planning
Jersey City Office of Sustainability
Massachusetts Department of Conservation and Recreation
Massachusetts Department of Environmental Protection
Massachusetts Department of Fish and Game
Massachusetts Executive Office of Energy and Environmental Affairs
Massachusetts Water Resources Authority
National Institute for Coastal & Harbor Infrastructure
National Oceanic and Atmospheric Administration, National Ocean Service
National Oceanic and Atmospheric Administration, National Weather Service
National Oceanic and Atmospheric Administration, Office of Coastal Management
Natural Resources Defense Council
The Nature Conservancy
Neptune Township, New Jersey
Newark Office of Sustainability
New England Climate and Health Network
New Jersey Department of Environmental Protection
New Jersey Sea Grant Consortium
New York City Department of City Planning
New York City Department of Environmental Protection
New York City Department of Health and Mental Hygiene
New York City Department of Parks and Recreation
New York City Geographic Information System and Mapping Organization
New York City Mayor's Office of Recovery and Resiliency
New York City Mayor's Office of Sustainability
New York City Office of Emergency Management
New York City Urban Field Station
New York-New Jersey Harbor Estuary Program
New York State Department of Environmental Conservation
New York State Department of Health
New York State Department of State
New York State Energy Research and Development Authority
New York State GIS Association
Philadelphia Office of Sustainability
Philadelphia Parks & Recreation
Philadelphia Water Department
Port Authority of New York and New Jersey
Providence Water
Regional Plan Association
Riverkeepers
Rockaways Waterfront Alliance
Rockland County NY Dept. of Planning
Sage Services LLC
Scenic Hudson
Science and Resilience Institute at Jamaica Bay
StormCenter Communications, Inc.
The Trust for Public Land
Town of Cortland NY
Town of Groton CT
US Army Corps of Engineers
Urban Climate Change Research Network
US Forest Service
US National Park Service
University of Connecticut
University of Massachusetts Boston
University of Pennsylvania
Village of Mamaroneck NY
Village of Nyack NY
Village of Tarrytown NY
Waterfront Alliance
Westchester County NY GIS and Department of Planning

Adapting and Responding to Changing Stakeholder Needs

Rapidly responding to stakeholder needs has always been a focal point of CCRUN research, with the research agenda crafted to deliver weather and climate risk information to a variety of audiences with evolving needs. Presented here are two examples of how CCRUN advanced efforts to address next-user demands while integrating emerging research topics as they came to the forefront.

New climate model data has become available as part of the Coordinated Model Intercomparison Project (CMIP6). These outputs align with efforts by stakeholders to update the climate risk assessments and reports they develop for previous CMIP iterations. This also reflects changing stakeholder needs, as they'll often ask for new information based on their own assessments. A strong co-generation process has long been established with CCRUN and New York State Research and Development Authority (NYSERDA), which allows our team to quickly respond to new requests or make changes as the science becomes available. As the release of the data is occurring in real time, CCRUN has frequently been asked by stakeholders to consider how to bring new climate science into ongoing research. Working with NYSERDA, CCRUN's Climate Science Team (PI-Horton) is updating the climate projections of record for New York State with this data, and these projections will inform a broader risk and adaptation assessment. With more models and emissions scenarios coming online as the research continues, modifications have been made to the scope of work to incorporate new climate variables (e.g., heat and humidity) identified as important by community groups and infrastructure stewards. (NA15OAR4310147)

The past reporting period occurred entirely amid the COVID-19 pandemic. At the same time, events occurring across the United States brought to the forefront issues related to justice, equity, diversity, and inclusion (JEDI). A major accomplishment of this reporting year has been CCRUN's flexibility to respond to these events in real time, providing regional stakeholders with timely and context-specific support. A number of our research teams investigated topics at the intersection of the pandemic and environmental justice, such as the CCRUN Public Health Team (PI-Kinney), the CCRUN Engineering and Urban Design Team (PI-Montalto), and the CCRUN Social Science Team (PI-Madajewicz) (see New Areas of Focus for additional details). CCRUN has always maintained strong relationships with community groups, allowing us to partner with vulnerable communities and deliver stakeholder-driven research that addresses their needs. (NA20OAR4310147A)

New Areas of Focus and Partnerships

CCRUN's research identified two primary areas of new focus and partnership over the reporting period. CCRUN team members are now participating in the New York City Panel on Climate Change (NPCC4), which reconvened while CCRUN was working on updating the climate projections for New York State. In addition, CCRUN more fully integrated emerging themes of justice, equity, diversity, and inclusion (JEDI) into the team's research agenda.

Justice, Equity, Diversity, and Inclusion

CCRUN's research took on a greater focus on topics related to JEDI over the past year. There are multiple examples of how our research team incorporated these themes into the work over the reporting period.

CCRUN's Engineering and Urban Design Research Team (PI-Montalto) is working to design cooling structures to be deployed on residential blocks in the Hunting Park neighborhood of Philadelphia, Pennsylvania. This community, in North Philadelphia is heat-vulnerable, with a largely non-English speaking, low income, elderly population and sparse tree canopy. The COVID-19 pandemic and associated stay-at-home orders forced the closure of cooling centers traditionally used by these residents during extreme heat events.

CCRUN's Public Health Team (PI-Kinney), partnering with the Department of Environmental Health in Boston, Massachusetts, is working on the C-HEAT project, a study to build heat resilience capacity in the Mystic Creek communities of Chelsea and East Boston. A high percentage of the residents living in these communities have low household income, live in older housing, rent their home, and speak English as a second language, adversely affecting their access to resources and opportunities.

Environmental justice was one of three themes around which the CCRUN seminar series was organized. The presentations on this topic included one focused on the PES Refinery in Philadelphia, another on addressing air quality in North Brooklyn, and a third with examples from a community-university relationship in Massachusetts.

The City University of New York (CUNY) - Hunter College, one of the institutions that is part of CCRUN (PI-Solecki), is a Minority Serving Institution (MSI). CCRUN's Data Science Team (PI-Chen) has established a working agreement with the Department of Earth, Environmental, and Geophysical Sciences at Lehman College, part of CUNY, to support development of built infrastructure data for flood hazard assessment using machine learning approaches. The current project involves training and mentoring four Lehman graduate students in data development efforts. (NA20OAR4310147A)

New York City Panel on Climate Change

As New York State was advancing updates on their climate science projections, the City of New York, another long-time CCRUN stakeholder, started to consider updates to their climate resilience risk information as well. CCRUN has strong relationships with the Mayor's Office in New York City and many CCRUN team members have contributed to the technical research that forms the basis for the city's resiliency efforts. This past year, the city reconvened the NPCC4, an advisory panel that synthesizes scientific information on climate change and advises City policymakers on local resilience and adaptation strategies. Several members of the CCRUN team (PI-Horton, PI-Montalto, PI-Orton, PM-Bader) were appointed to serve and selected to participate in this effort, with responsibilities including leading some of the NPCC's working groups. (NA15OAR4310147)

Research Highlights

Climate

CCRUN, through the Climate Science Team (PI-Horton), has become a leader in assessing and preparing for connected extreme events, which can be defined as a) multiple-variable events such as extreme heat accompanied by extreme humidity, b) sequences of extreme events in a given region such as a tropical storm followed by a cold snap, or c) simultaneous extreme events in multiple regions such as fires in the western U.S. while a major hurricane occurs in the eastern U.S. During the past year, CCRUN conducted important climate research on this topic, including (Kornhuber et al. 2020 and Raymond et al. 2020; Figure 1). Recent research focused on important event combinations (e.g., coastal flooding and rainfall, heat, and air pollution). Individual sectors were also examined from impact and adaptation perspectives, such as Health, Infrastructure, and Insurance. (NA15OAR4310147)

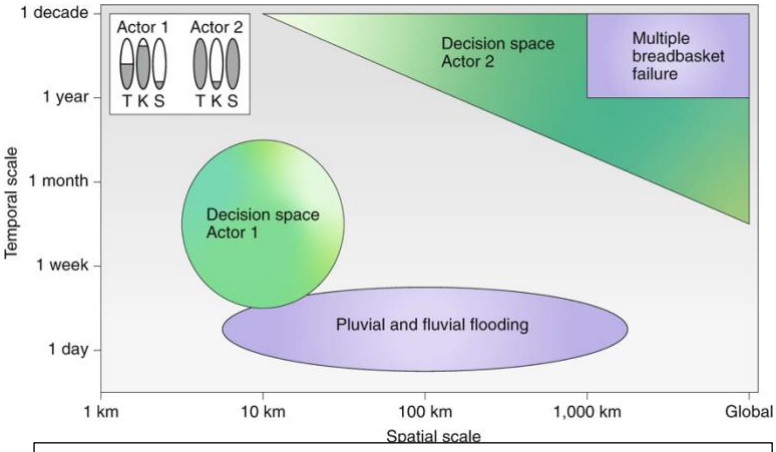

Figure 1. Generalized diagram of the spatiotemporal scales associated with connected extremes (across both physical and societal aspects) compared against the typical spatiotemporal scales of the decision-making that affects the societal response to them, for two example events and two example actors.

Also, CCRUN's Climate Science Team (PI-Horton) has partnered with University of Massachusetts-Amherst researchers on an assessment of differences in warming trends between the Northeast's populous coastal zone and the interior regions. The work revealed that warming trends have been greater in the populous coastal zone than in interior regions, especially during the warm-season months when populations are most vulnerable to heat. The team linked the rapid coastal land warming during the warm season to the rapid warming of coastal waters in the CCRUN regions. The work also revealed that climate models are not able to reproduce the observed coastal warming pattern, raising the prospect that prior assessments may have underestimated warming potential in the Northeast's most populous regions. This work has been re-submitted to Nature Climate Change after revisions. (NA20OAR4310147A)

Coasts

Gated storm surge barriers are being studied by the United States Army Corps of Engineers (USACE) for coastal storm risk management for the New York City metropolitan area. Surge barrier gates are only closed when storm tides exceeding a specific "trigger" water level might occur in a storm. Gate closure frequency and duration both strongly influence the physical and environmental effects on enclosed estuaries.

In Chen et al. (2020), CCRUN researchers use historical observations to represent future storm tide hazard and superimpose local relative sea-level rise (SLR) to study the potential future changes

to closure frequency and duration. Researchers account for the effects of forecast uncertainty on closures, using a relationship between past storm surge and forecast uncertainty from an operational ensemble forecast system. A concern during a storm surge is that closed gates will trap river streamflow and could cause a new problem with trapped river water flooding. Similarly, the research evaluates this possibility using historical data to represent river flood hazard, complemented by hydrodynamic model simulations to capture how waters rise when a hypothetical barrier is closed. The results show that SLR causes an exponential increase of the gate closure frequency, a lengthening of the closure duration, and a rising probability of trapped river water flooding. The USACE has proposed to prevent these SLR-driven increases by periodically raising the trigger water level (e.g., to match a prescribed storm return period). However, this alternative management approach for dealing with SLR requires waterfront seawalls to be raised at a high, and ongoing, additional future expense. For seawalls, costs and benefits will likely need to be weighed on a neighborhood-by-neighborhood basis, and in some cases retreat or other non-structural options may be preferable. (NA20OAR4310147A)

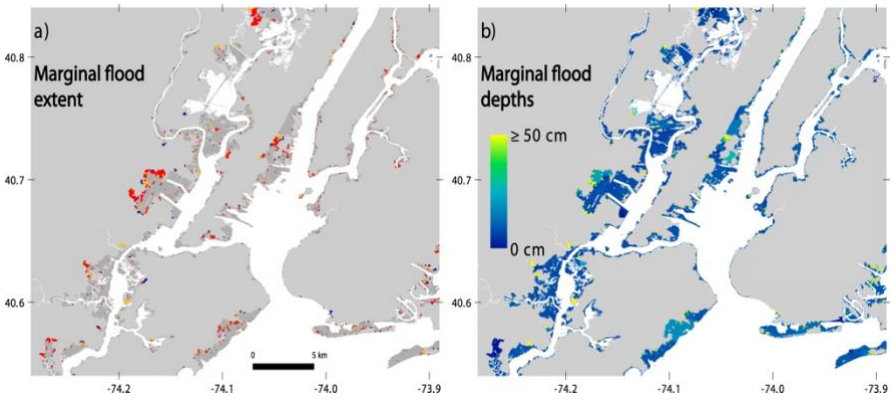

Figure 2. This figure shows the additional flooding for a range of 4 (blue), 10 (blue+orange) or 20cm (blue+orange+red) of past anthropogenic sea level rise. This is the central estimate (10cm) and 95% confidence range. The central estimate causes 71000 additional people to be flooded across the entire Sandy-affected area. Source: Strauss et al., 2021

CCRUN's Coasts Team (PI-Orton) collaborated with Climate Central, the US Army Corps of Engineers, and others, to demonstrate a new ensemble framework for attribution of anthropogenic climate change effects on hurricane coastal flooding (Strauss et al. 2021). This was the first study to quantify the costs of storm damage caused by sea level rise driven specifically by human-induced climate change. The potential influence of climate change on Hurricane Sandy itself has been debated, but sea level rise driven by anthropogenic climate change more clearly contributed to damages (Figure 2). To quantify this effect, researchers simulated water levels and damage both as they occurred and as they would have occurred across a range of lower sea levels corresponding to different estimates of attributable sea level rise. They found that approximately $8.1B ($4.7B–$14.0B, 5th–95th percentiles) of Sandy's damages are attributable to climate-mediated anthropogenic sea level rise, as is extension of the flood area to affect 71 (40–131) thousand additional people. The same general approach demonstrated here may be applied to impact assessments for other past and future coastal storms. (NA20OAR4310147A)

Data Science

CCRUN's Data Science team is working on a manuscript (MacManus et al.) titled "Estimating Population and Urban Areas at Risk of Coastal Hazards, 1990-2015: How data choices matter". The accurate estimation of population living in the Low Elevation Coastal Zone (LECZ), and at heightened risk from sea level rise, has improved considerably since it was first estimated that 10%

of the world's population, and an even greater share of the urban population, lived in the LECZ (McGranahan et al., 2007). Updates to those initial estimates with newer, improved inputs provide a range of estimates, along with sensitivity analyses that reveal the importance of understanding the strengths and weaknesses of the underlying data. This research estimates that between 750 million to nearly 1.1 billion persons globally, in 2015, live in the ≤ 10 m LECZ, with the variation depending on the elevation and population data sources used. The variations are considerably greater at more disaggregated levels, when finer elevation bands (e.g., the ≤ 5 m LECZ) or differing delineations between urban, quasi-urban and rural populations are considered. Despite these variations, there is general agreement that the LECZ is disproportionately home to urban dwellers, and that the urban population in the LECZ has grown more than urban areas outside the LECZ since 1990. This research has relevance to CCRUN's region in the urban Northeast as a significant amount of the population lives within proximity to the coast. (NA15OAR4310147)

Engineering and Urban Design

Smalls-Mantey et al., (2021) evaluated effectiveness of the nearly 27,500 m2 green roof at the Jacob K. Javits Convention Center (JJCC) located in New York City, one of the largest extensive green roofs in the United States. CCRUN researchers examined three years of fine scale microclimate data collected at the JJCC green roof and its potential ability to reduce the urban heat island intensity (UHII). The results indicate that the temperatures of the air above the green roof, and its exterior surface are different (e.g., lower) than those measured above and on, respectively, the black roof that preceded it. Differences in the maximum daytime air and surface temperature between the black and green roof were 1.80 ◦C and 18.4 ◦C, respectively. Installation of the green roof increased evapotranspiration, modifying the roof's surface energy balance, and reduced the median summer nighttime UHII (compared to the pedestrian level station) by 0.91 ◦C. Though microclimatic conditions on two sections of the green roofs vary somewhat, the research findings generally support the statement that green roofs are a moderately effective strategy for mitigating the UHI effect. (NA15OAR4310147)

Across the world, cities are spending billions of dollars to manage urban runoff through decentralized green infrastructure (GI). Recent CCRUN research uses an agent-based model to explore some of the physical, social, and economic consequences of one such urban GI program. Using the Bronx, NY, as a case study, two alternative approaches to GI application are compared. The first (Model 1) mimics NYC's current GI program by opportunistically selecting sites for GI within the city's priority combined sewer watersheds; the second (Model 2) features a more spatially flexible approach to GI siting, in which the city attempts to maximize opportunities for co-benefits within the geographic areas considered in Model 1. (NA15OAR4310147) (NA20OAR4310147A)

The CCRUN team began using ENVI-met to simulate urban microclimates. The team completed two projects over the past year. The first was a simulation of the west side of Manhattan (e.g., Hudson Yards). The purpose of this analysis was to quantify the extent to which new skyscrapers modified the microclimate of that part of the city. The second was a simulation of the microclimate of a single block in the Hunting Park neighborhood of North Philadelphia. The ENVI-met modeling activities have concluded, and manuscripts are in preparation. (NA20OAR4310147A)

Public Health

To inform heat adaptation planning, information is needed on the extent to which available adaptation strategies, such as reflective and green roofs, could result in significant reductions in heat exposure and health benefits. CCRUN's public health team is examining urban heat island reduction scenarios and their potential benefits in terms of reduced temperature-related mortality in the urban Northeast.

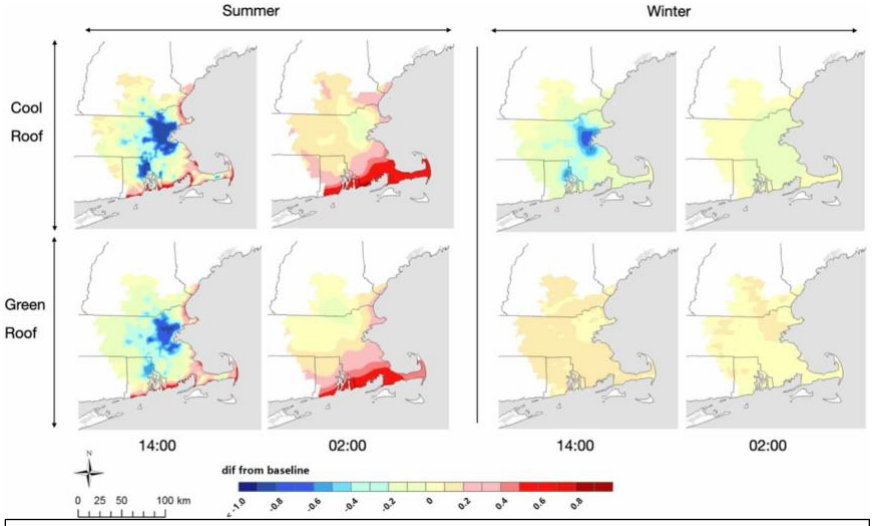

Figure 3. Summertime and wintertime 2 m temperature changes caused by cool roof and green roof strategies across the GBA. Source: He et al., 2020

Using the Weather Research and Forecasting (WRF) model, the team analyzed the impact of green and cool (reflective) roofs on the urban heat island (UHI) and temperature-related deaths in the Greater Boston area (GBA) and New England area (NEA) in summer and winter (Figure 3). In the GBA, green and cool roofs reduced summertime population-weighted temperature by 0.35 ◦C and 0.40 ◦C, respectively. In winter, green roofs did not affect temperature, whereas cool roofs caused a temperature reduction of 0.40 ◦C. In the NEA, the cooler summers induced by green and cool roofs were estimated to reduce the heat-related mortality rates by 0.21% and 0.17%, respectively, compared to baseline. For more information, see He et al., 2020.

These results suggest that both green and cool roofing strategies have the potential to reduce the impact of heat on premature deaths. Differing effects by season suggests the need for a careful consideration of health trade-offs in choosing heat island mitigation strategies. This line of work has the potential to inform regional adaptation planning. By incorporating the dynamical WRF model, we've been able to advance our ability to examine a range of adaptation scenarios of interest to local stakeholders. (NA20OAR4310147A)

Social Dimensions of Adaptation

CCRUN's project, "Enabling urban residents to adapt to coastal flooding: Evidence from New York City neighborhoods" is investigating how co-production contributes to advancing adaptation to flooding in urban communities. The project addresses two of CCRUN's core questions by: (1) examining what influences residents' decisions whether or not to adapt and how to adapt; and (2) evaluating the impacts of different approaches to engaging with residents on their awareness and adaptation decisions. (NA20OAR4310147A)

Early findings show that 80% of participants in project workshops have said that they were not aware of the main website through which the City of New York communicates information about preparing for flooding before the workshops. They have said that the increase in flooding over time in their neighborhoods is new information. Additional responses indicate the residents were

not aware how flood risk will be changing in the future, nor what their options for action are other than raising homes, even though these were the main topics of past neighborhood meetings. They did not consider action to prepare for flooding to be urgent.

Another set of research results from the project are the expected recovery cost from future flooding for homes at different elevations. Costs change dramatically with small changes in elevation and therefore so do benefits of taking different actions to reduce future damages, which are one of the residents' incentives to act. Results from prior research have been published in Madajewicz, 2020.

CCRUN Social Science Team's (PI-Solecki) completed several research advancements over the reporting period, including the legacy of Hurricane Sandy and the role of enabling conditions and success metrics for adaptation advancement. The team also moved forward with writing up some of the results of their decision making-assist toolkits, specifically the Macro Adaptation Resilience Toolkit (MART) and the Post Extreme Event Learning Toolkit. (NA15OAR4310147) (NA20OAR4310147A)

The Social Science Team completed a survey and content analysis of urban resilience efforts along the Eastern seaboard of the US illustrated a significant legacy of Hurricane Sandy's impact beyond areas not directly impacted by the storm. The legacy proves how and under what context extreme events can serve as catalyzing conditions for rapid adaptation advancement. (NA20OAR4310147A)

Adaptation enabling conditions and success metrics are a key area for adaptation practice and is of direct interest for local practitioners and policy makers. It is critical to understand how adaptation success is measured and understood and what is the role of monitoring, evaluation, review, and learning in success. CCRUN's team was able to compile and help draft a significant assessment on the role of these phenomena of adaptation practice and effectiveness. This critical assessment will become the foundation for future work on adaptation effort in the CCRUN and capacity to expand these efforts. (NA20OAR4310147A)

Sustained Climate Assessment

CCRUN's Sustained Assessment Specialist (SAS) has facilitated the integration of CCRUN's research and engagement across the urban corridor. Over the past year, the SAS served as a liaison between CCRUN's stakeholder engagement and climate assessment efforts at the city, state, and national level. To accomplish this goal, the SAS focused on the following activities: serving as lead author of New York State's climate needs assessment, co-developing a knowledge exchange for climate action and resilience planning in New York City, and collaboration with USGCRP on a report assessing the use of the National Climate Assessment in sub-national climate adaptation efforts. (NA15OAR4310147)

Water Resources

The ability of water supply utilities to provide safe, reliable, and inexpensive water to the major cities in the urban corridor between Boston and Philadelphia (and beyond) during periods of changing climate is extremely important. CCRUN's water research recognizes the potential for water conservation as a mitigation strategy to adapt to many of these impacts. The research

focuses on how per capita water demands are changing over time and how they are likely to change in the future due to the dual effects of conservation and climate change.

Recent research assessed the impacts of climate change on summer per capita water demands relative to water conservation. Statistical models were developed for six utilities (Boston, Philadelphia, Fairfax, VA, Washington D.C., New York, and WSSC Water in Maryland) in four major cities in the northeast region to forecast daily summer water demands as a function of daily weather and conservation variables. To develop a more national perspective and to compare the utilities in the east to those in the central and western US, we also performed this analysis for six other utilities.

Performing this research required significant stakeholder engagement, as none of the daily water demand data was publicly available from these utilities and it required developing relationships with all the utilities to encourage them to share their data for this project. Models were successfully developed and calibrated over a 15-year historical period using daily demand data from partners along with daily weather data from NOAA gauges.

Once the demand models were calibrated, daily demand forecasts were produced for each summer from 2045-2055 then averaged to represent 2050, 30 years in the future. Daily weather projections were used from eight GCMs that were previously shown to accurately model historical climate in the northeast. A scenario planning approach was taken to model conservation into the future, and three possible conservation pathways were selected: Continuing Conservation Trend, which extrapolates the observed reduction in demand due to conservation into the future, Conservation Floor, which sets a maximum level of water conservation, and Status Quo, which assumes no further conservation into the future. Forecasts for each scenario are summarized then compared to current (observed) demand values.

In the scenario that assumes no conservation in the future, Status Quo, demands will slightly increase in all utilities but WSSC Water. This increase in summer per capita demand is driven by climate change. In the other two scenarios that account for future water conservation, demands for each utility decrease in the future. Thus, for the two scenarios that assume conservation will occur into the future, water conservation will have a greater impact in decreasing future demands than climate change will have in increasing demands. (NA15OAR4310147) (NA20OAR4310147A)

Outreach and Engagement Activities

Climate Coast Workshops

CCRUN Social Science Team's (PI-Solecki) work on the climate coast program includes an analysis frame that links together climate resilience practitioner and policy maker information needs with surveys and questions for local businesspeople and households. The team developed survey instruments to be executed in coastal New Jersey and Long Island. Work was paused due to the COVID-19 pandemic, however, resumed again in April 2021. This research attempts to understand the link between risk perception and engagement with local coastal resiliency programs. The work partnership with colleagues in coastal Long Island and New Jersey and Miami-Dade County. Multiple workshops with practitioners and policymakers focusing on climate resilience engagement with small businesses were held. (NA15OAR4310147)

Climate Knowledge Exchange

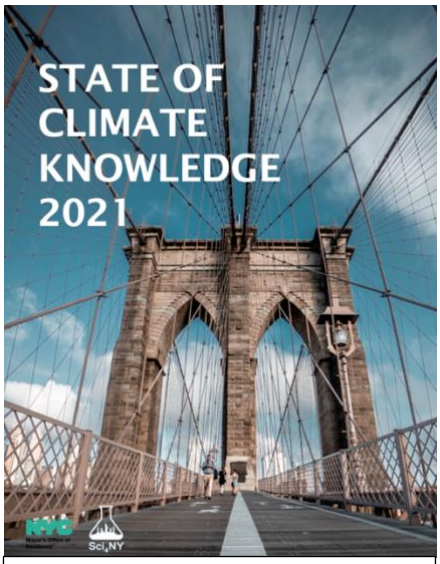

Figure 4. Cover of the State of Climate Knowledge Report.

While conducting the Climate Needs Assessment for New York State (see "Case Studies" for further detail), the Sustained Assessment Specialist co-authored the State of Climate Knowledge 2021 with the New York City Mayor's Office of Resiliency (MOR) (Figure). In 2020, the MOR initiated an engagement process, called the Climate Knowledge Exchange, to align research with climate resilience and adaptation needs. The State of Climate Knowledge 2021 is the first in an annual series that will maintain a public agenda for climate research in NYC. The report was published on Earth Day, April 22, 2021, and the SAS is currently working with the report author team on a peer-reviewed publication based on the findings of the CKE. Contributing to both the state and city engagement processes, the SAS streamlined methodological approaches to ensure the two assessments were coordinated and cohesive across spatial scales. The Climate Needs Assessment contributes to ClimAID, while the Climate Knowledge Exchange connects to the New York City Panel on Climate Change process, ensuring both reports can influence policy as well as the scientific research agenda. (NA15OAR4310147)

Community Workshops in Rockaway, New York

The CCRUN Social Science Team (PI-Madajewicz) engaged community groups of homeowners in Rockaway, New York at risk of flooding through a series of seven workshops (two sets of three workshops for sets of community groups and a separate, single event for a different group). The workshop series was developed through a co-production process that engaged NYSCI, the City of New York, and community members. The workshops were innovative in several ways. (1) They communicated information that was highly specific to participants, including flood hazard, future costs of recovery in absence of preparation, and benefits and costs of specific adaptation actions. (2) They engaged members of community groups through several layers of community organization that included RISE, a Rockaway-wide coalition, and individual community groups who operate in different parts of the region in order to catalyze networks and coordination across an area that is socially divided but faces common threats.

Rockaway is a diverse area that includes predominantly white, middle class communities on one end, mixed communities in the middle, and mainly non-white, low income, disadvantaged communities in the eastern half. The above project engages community groups from the entire peninsula, striving to build connections between the community groups that serve disadvantaged communities and the better-resourced groups that serve the middle-income communities. CCRUN's partner, RISE, has been working with low-income communities in Rockaway since 2005. (NA20OAR4310147A)

Green Infrastructure, Climate and Cities Seminar Series

CCRUN continued their highly successful Green Infrastructure, Climate and Cities monthly seminar series, led by PI-Montalto. All seminars were conducted as webinars due to the COVID-19 pandemic, however, the virtual environment boosted attendance. The average number of participants per event was approximately 130. The seminar series continues to reach a wide audience of academics, practitioners, and governmental representatives throughout the CCRUN region. This year, the presentations were organized around three mini-themes: climate action and planning, environmental justice, and resources and tools. Professional development hours (PDH) credits for professional engineers are offered at each session and we're looking into providing AICP credits for planning professionals. A total of 340 PDH credits were awarded this reporting period.

For the March 2021 seminar, decision support mapping tools that CCRUN developed were showcased. The presentations included brief demonstrations of AdaptMap, an online tool for assessing risk and flood mitigation efforts for the highly populated areas around Jamaica Bay in New York City, and The Hudson River Flood Impact Decision Support System, an interactive map application for evaluating potential flooding of shorelines of the Hudson River Valley and Westchester County under a variety of sea level rise and storm scenarios. These dynamic model-based flood mappers have great capacity for merging flood data sources, simulating changes in flooding by including possible interactions between sea level rise, tides, storm surge, and river flows. (NA15OAR4310147) (NA20OAR4310147A)

Innovations in Nature-Based Systems for Coastal Protection

CCRUN (PI-Orton) also helped organize a web panel series titled "Innovations in Nature-Based Systems for Coastal Protection". A live 2-hour webinar was hosted by the Estuarine Coastlines and People (CoPe) Research Coordination Network (RCN) every two weeks. The series resulted in the creation of a community of over 700 academics and practitioners from over 30 countries who participated in the series and provided participants with an overview of state-of-the-art practices and specific case studies of successful nature-based interventions for coastal protection. About half of the U.S. attendees were from the academic community while the other half came from local, state, and federal agencies, not-for-profit organizations, and industry. For each web panel, three to four experts were invited to provide an overview of their projects, prepared a list of questions for panel discussions, and moderated the questions from attendees. (NA20OAR4310147A)

PowerCorps in Camden, New Jersey

In Camden, New Jersey, through an ongoing relationship with the Camden County Municipal Utility Authority (CCMUA), CCRUN (PI-Montalto) is engaging PowerCorps Camden to ground truth incidences of flooding in the city. PowerCorps Camden is an environmental, educational, and civic engagement program for young Camden residents to revitalize public land in the city. PowerCorps is known to serve young people of color to provide training and education to enter the green workforce. PowerCorps Camden members are monitoring street flooding in Camden by documenting street flooding after rain events. This data is being used to calibrate the model being developed through the Cross-RISA partnership between CCRUN and MARISA and PacificRISA. (NA20OAR4310147A)

Impacts of the COVID-19 Pandemic

For some of the CCRUN research sector teams, the COVID-19 pandemic interrupted research and limited the ability for stakeholder engagement. CCRUN's flood modeling work in the Eastwick neighborhood (PI-Montalto, PI-Orton) of Philadelphia was hindered by the pandemic and then compounded by Tropical Storm Isais, which forced the team to do individual outreach with community leaders instead of holding a larger workshop. CCRUN research (PI-Montalto) on the Javits Convention Center green roof in New York City is halted due to the pandemic, as the Center remains a focal point of response operations (hospital, testing, vaccination). Planned workshops with community groups in the Rockaways (PI-Madajewicz) were held virtually instead of in-person due to COVID-19. This required the redesigning of materials such as flood maps and interactive posters, which were supposed to engage the participants in exploring adaptation actions. The pandemic also influenced the thinking about adaptation options as participants considered how recovery efforts after a storm might be organized in order to contain transmission risks in case of a pandemic.

Despite the disruptions to some CCRUN research activity, the pandemic did spur new research activities related to heat risk, especially during stay-at-home mandates. The heat mitigation project in Hunting Park in Philadelphia (PI-Montalto) was inspired by seeking adaptation strategies for the heat vulnerable neighborhood while cooling centers, pools, and public air-conditioned spaces would be closed during the summer of 2020. CCRUN (PI-Kinney) also presented at a RISA-focused session at the American Geophysical Union Annual Meeting on the challenges faced by New York City in the summer of 2020 to protect citizens from extreme heat effects while also responding to the COVID crisis. This included survey findings in disadvantaged communities in the city.

Planned Activities

Climate Resilience and Research Agenda for Philadelphia
CCRUN (PI-Montalto) has been working closely with the City of Philadelphia and the Delaware Valley Regional Planning Commission to lay the groundwork for a Philadelphia Panel on Climate Research, harnessing the knowledge of academic researchers and community leaders in the Philadelphia region. This collaborative process has led to the formation of working groups with representatives of academia, community-based organization, and practitioner groups who will be developing a Climate Resilience Research Agenda for the Philadelphia region over the summer of 2021.

This effort will focus attention on knowledge gaps that currently inhibit climate action across the region, and how to fill them. The goal is to develop a research agenda that will inform ongoing and future climate action, building on a number of parallel and previous initiatives. This research agenda will be informed by community voices, practitioner knowledge, and cutting-edge science, and their intersection.

The working groups cover four distinct focus areas: 1) Regional Climate Change and Cascading Hazards 2) Health and Environmental Vulnerability 3) Planning Low-Carbon Adaptation of the Built Environment and 4) Regional Climate Governance & Adaptive Management. Each working

group is led by a pair of academic and community-based climate leaders. The working groups themselves are composed of academic, non-profit, private for-profit and governmental representatives.

The final product of these working groups will be a research agenda that will identify knowledge gaps which currently limit regional climate adaptation actions and develop a list of research activities that can help to fill these gaps and that will help to make the region more climate resilient. Ultimately, this effort will help inform the City of Philadelphia's formation of a Philadelphia Panel on Climate Research.

The sustained assessment processes in New York City and State will also be integrated into the Philly Climate Resilience Research Agenda. The agenda mirrors similar processes in NYC, particularly the New York City Panel on Climate Change, and the SAS has connected methodological approaches, engagement strategies, and expertise across both cities through coordination with CCRUN's colleagues at Drexel and the Philadelphia Office of Sustainability. (NA20OAR4310147A)

Managed Retreat Conference 2021

CCRUN (PI-Horton, SAS-LoPresti, PI-Solecki) has been involved in the planning of Columbia University's Managed Retreat Conference, as members of the Organizing Committee. The conference, which will be held in June of 2021, will feature multiple panels and sessions related to sustained assessment and organized by the SAS. One panel, titled Regional Perspectives on US Relocation and Migration: A NOAA RISA Panel will feature presentations from CCRUN, GLISA, Pacific RISA, and ACCAP. A second panel will feature CCRUN's SAS with several individuals from NYC Mayor's Office of Resilience and local community-based organizations to discuss the Climate Knowledge Exchange and the value of sustained assessment processes in planning for coastal adaptation and relocation. Over nine-hundred and fifty people registered for the conference and close to 300 people will present across over 50 sessions. (NA20OAR4310147A)

New York State/New York City Collaboration Workshop

As mentioned earlier in the report, with efforts ongoing at both the state and city level in New York, there exists a need for coordination between the two entities. With CCRUN researchers working on both efforts, the team is playing a key role in facilitating shared dialogue, providing a consistent set of climate projections, and helping engage with key stakeholders. For the forthcoming year, there are plans to have a workshop with state and city stakeholders to discuss the new climate projections. The workshop would bring together the NPCC4 Climate Science & Projections Working Group (which features CCRUN team members Bader, Horton, Montalto, and Orton) and the New York State Technical Advisory Group for the Statewide Climate Impacts Assessment (for which CCRUN is developing the climate projections). A potential outcome from the workshop would be a report/white paper on unified projections for New York State and New York City. (NA15OAR4310147) (NA20OAR4310147A)

Program Impacts Evaluation

The CCRUN program evaluation is assessing progress toward the program goal of improving adaptation to climate risks in the urban Northeast. The three components of the evaluation are the program theory, monitoring, and evaluation.

The program theory describes what actions and inputs can bring about the improvement in adaptation that CCRUN intends to achieve, through what causal mechanisms, and what are outputs, outcomes, and impacts that the team should be measuring. The program theory has three broad components that articulate how CCRUN may achieve interim objectives on the path to achieving the goal of improved adaptation: (1) producing science that is useful for decision-making, (2) supporting the process of putting that science to use, and (3) designing and implementing uses that advance adaptation. CCRUN work is focusing on the first two components though at least one current project includes the third component.

CCRUN intends to achieve improvements in producing usable science and supporting decisions based on that science by directly engaging policymakers in the co-production of climate science. Co-production spans a very broad range of types and intensities of engagement with different types of stakeholders. The specific inputs, actions, participants, and causal mechanisms that compose effective engagement are likely to differ across decision problems and contexts. The team is working to develop specific program theories for different decision problems and contexts that can support the design of evaluations of specific engagements. In the meantime, this report features numerous examples of stakeholder engagements and the results.

The monitoring system has been tracking a consistent set of process indicators since the early years of CCRUN. The indicators inform the team whether the CCRUN process is advancing toward the objectives of useful science and support for decisions based on that science. The process indicators fall into the following categories. The decision makers with whom CCRUN researchers are working, including the length of the relationship and decision problems addressed:

- Climate information/decision support tools co-developed with the decision makers
- Publications in outlets read by decision makers
- Outreach to communicate research results and experience with using the research results to decision makers.
- Engagement with scientists
- Presentations of results in various research venues
- Peer-reviewed publications/citations of peer-reviewed publications
- Broad communications
- Contacts with the media
- Number of views of various parts of the CCRUN website
- Number of social media posts

Collecting data on outcomes of engagement, such as how information was used or what new planning and/or policy processes resulted, and impacts, such as reduced damages from flooding or morbidity from heat waves is more challenging. CCRUN has collected outcome and impact data in the context of engagements. Importantly, the team has baseline data on vulnerability and resilience to coastal flooding among urban residents in two areas of NYC, Rockaway and East Shore of Staten Island, collected after Hurricane Sandy. A current project is updating this data in Rockaway with additional information about residents' awareness of flood risks and adaptation options, sources of information, actions taken to adapt, and obstacles to adaptation. Collecting similar data after future storms will allow the team to document how adaptation, vulnerability, and

resilience are evolving over time given the use of flood projections to improve adaptation since Hurricane Sandy.

Another type of baseline data that the team has collected documents current decision processes and needs among decision makers in municipalities in New Jersey and on Long Island. The data will enable the team to assess how the adaptation process evolves over time in response to future engagements in those municipalities.

CCRUN current and future evaluation efforts rely on a number of approaches, depending on the particular evaluation problem, including ex-ante evaluation and the following approaches to ex-post evaluation: theory-based evaluation, contribution analysis, non-experimental econometric methods, and field experiments when appropriate. Ex ante evaluation assesses the potential outcomes and impacts that may result from the use of climate information or an investment in adaptation in the future, based mainly on models. Ex post evaluation assesses outcomes and impacts that occurred as a result of a particular engagement with information and/or investment in adaptation, based on data. The outcome and impact indicators are specific to decision problems and contexts. Outcome indicators may include changes in policies, codes, standards, regulations, management decisions, capital investments, allocation of administrative resources, and individual adaptation actions by urban residents. Impact indicators may include losses due to extreme events, economic outcomes such as value of infrastructure, economic outcomes, incomes, and other measures of livelihoods. Important outcome and impact indicators are ones that measure the distribution of various outcomes and impacts in the population to capture the equity of progress on adaptation, for example gentrification of neighborhoods, adaptation in historically disadvantaged communities, access to housing, performance of small businesses, changes in employment patterns, etc...,

A current project is assessing whether and how the use of new knowledge and information influences adaptation, and particularly how the impact of knowledge and information on adaptation behavior depends on the type of engagement with decision makers. The project is investigating the impacts of co-producing information about local flood risks and costs and benefits of adaptation options on adaptation behavior among coastal residents in NYC. It is comparing adaptation behavior that results from communicating the same information content through in-person workshops with and without engagement in co-production and in a third case, in which information is only available online. The "*Enabling urban residents to adapt to coastal flooding"* part of the Evidence of Impacts section discusses the lessons from the project in more detail. A full evaluation based on a follow-up survey will be forthcoming in the next year.

In another planned approach, data collected through monitoring will help to identify case studies in which the team will investigate how science that CCRUN has co-produced with policymakers is being used by practitioners in the urban northeast region and beyond, what outcomes are emerging from that use, and what are the likely impacts. Case studies will be designed based on detailed program theories. Coastal flood predictions co-developed with policymakers in New York City will be the first case study, which has been delayed by the COVID-19 pandemic.

An evaluation challenge is that outcomes and impacts can be observed only in specific contexts. The team is continuing to investigate how to select evaluation cases strategically and what methods to apply to provide evidence that can be aggregated to measure broader program impacts.

Evidence of Societal Impact

Enabling urban residents to adapt to coastal flooding

CCRUN's Social Science (PI-Madajewicz) and Coastal (PI-Orton) research teams have co-produced a series of workshops in collaboration with the New York Hall of Science (NYSCI), Rockaway Initiative for Sustainability and Equity (RISE), community groups of homeowners in Rockaway region of New York City (NYC), and the City of New York that co-develop understanding among homeowners about flood risk and actions that residents can take to reduce future flood damages. The work is part of a project titled "Enabling urban residents to adapt to coastal flooding: Evidence from New York City neighborhoods." The objective is to build understanding among residents of a highly flood-prone coastal area of benefits and costs of actions that they can take themselves, individually or in coordination with their neighbors.

Rockaway is a diverse area that includes predominantly white, middle class communities on one end, mixed communities in the middle, and mainly non-white, low income, disadvantaged communities in the eastern half. This project engages community groups from across the peninsula, striving to build connections between the community groups that serve disadvantaged communities and the better-resourced groups that serve the middle-income communities.

This research is showing preliminary evidence of contribution to increased ability to self-organize, increased learning, mindset shifts, and increased sense of urgency. Workshop participants have identified understanding the likely costs of flood damages if they do not prepare and benefits and costs of actions they can take to prepare, which we discussed in the workshops, as information that has changed their perception of the urgency and magnitude of the problem. Some participants began raising the possibility of moving away from Rockaway by the end of the workshops, while no one discussed the possibility of leaving in the first workshop.

The CCRUN team is investigating why the messages in the project workshops seem to be altering these assessments. The emerging hypotheses are that (1) we have provided information that is specific to residents' homes and directly informs decisions that homeowners make such as whether to retrofit or relocate and what resilience plans to support for their community; (2) we have organized the workshops through partners whom the residents trust; (3) the participants had the opportunity to change each other's' minds in a truly co-productive process in which they discussed each other's' risks.

Preliminary results suggest that the co-produced workshops substantially change the homeowners' understanding of risk and adaptation options. Despite past engagement events conducted by the City of New York and an excellent set of resources available online, members of community groups who were sufficiently concerned about flooding to participate in co-producing the workshops and members who attended the workshops were not aware of projected changes in flood risk nor of adaptation options that they could implement other than raising their homes, which almost all could not afford to do. In particular, they had no understanding of their specific,

individual risks, which depend on a home's elevation nor of their individual benefits and costs of adaptation actions. They have consistently reported to us that the information that is specific to their homes has changed their assessment of risks and the urgency of action. They felt empowered to consider and take action by knowing that there was a menu of individual and collective action strategies from which they could choose according to what works best for them. Also, consideration of individual risks and capacity to address those risks has produced a conviction that residents need to organize and participate in planning resilience for Rockaway. The preliminary observations are striking because the project is engaging some of the most informed, involved, and organized residents of the target neighborhoods. (NA20OAR4310147A)

Stevens Flood Advisory System

CCRUN's Coasts Team (PI-Orton) runs the Stevens Flood Advisory System (SFAS) that is widely used to warn people and enables adaptation to nuisance flooding and storm-driven flooding. Data is posted on the team's forecast webpage and the system notifies people of impending flooding via email warnings (Figure 5). In addition, probabilistic water level forecast data from the SFAS is now being provided to the National Weather Service Weather Forecast Offices in New York City/Upton and Mt. Holly. Both WFOs have been using the Stevens Flood Advisory System and cite it as being an important component of their storm forecast guidance development which serves the New York and New Jersey region. At present, they are using the numeric data from our system in their Total Water Level forecast system to help inform their forecast guidance.

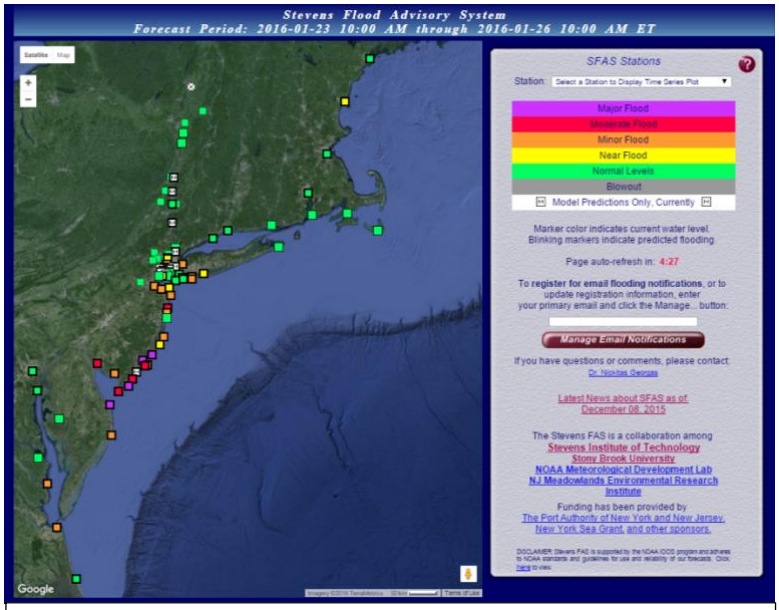

Figure 5. The Stevens Flood Advisory System (SFAS). SFAS is an ensemble-based probabilistic flood forecasting system providing total water level forecasts for coastal and estuarine waterways spanning the U.S. Mid-Atlantic and Northeast.

With CCRUN funding, the Coasts Team (PI-Orton) provides assistance for users and works to improve the models behind SFAS. SFAS is an ensemble-based probabilistic hydrologic-coastal flood forecasting system providing total water level forecasts the U.S. Mid-Atlantic and Northeast coasts, estuaries, and tidal rivers. The operational system has mainly been funded under a contract from the Port Authority of New York and New Jersey. (NA15OAR4310147)

Case Studies

C-Heat Project, Boston, Massachusetts

CCRUN's Public Health Team (PI-Kinney) is partnering with colleagues at the Department of Environmental Health in Boston on the C-HEAT project, a study to build heat resilience capacity in the Mystic Creek communities of Chelsea and East Boston. This community engaged project is

a partnership with GreenRoots, a local climate justice organization, and funded by Barr Foundation. Ongoing efforts include outdoor and indoor temperature monitoring, fine scale mapping of local heat islands, population vulnerability and community heat adaptation resources and engagement with city and community stakeholders to design and implement interventions to climate extreme heat exposure. The goals of the C-HEAT project are to 1) consider factors of locations and populations at higher risk for heat-related illness and identify potential resources and 2) analyze personal and home exposure to heat: what are the physical, social, economic, and environmental factors contributing to heat exposure?

Chelsea and East Boston sit at the edge of the Mystic River and are vulnerable to sea rise, flooding, and extreme events such as hurricanes. A high percentage of the residents living in these communities have low household income, live in older housing, rent their homes, and speak English as a second language, adversely affecting their access to resources and opportunities. Many neighborhoods were subjected to discriminatory practices such as redlining. The communities are environmentally burdened - Chelsea houses most of the road salt applied during the winter across the 351 cities and towns in Massachusetts, stores 80% of the jet fuel utilized by Boston's Logan airport and has one of the largest food trucking facilities in the Northeast, resulting in high levels of traffic and noise.

To date, the project has already led to the development of a data dashboard which maps both climate and socio-economic data and features real time monitoring of data collection. Sampling took place in the summer of 2020 and new sensors were installed in time to collect data over the summer of 2021. In the summer 2021, the goal of the project is to implement interventions to reduce the impact of extreme heat in these communities based on the work from the prior year.

As the partnership with CCRUN continues expanding there are many opportunities to integrate the work and expertise from CCRUN scientists to examine impacts of combined extreme events and contribute to climate resilience planning in these and surrounding vulnerable communities. (NA20OAR4310147A)

Climate Needs Assessment for New York State

The SAS served as lead author of the Climate Needs Assessment for New York State, conducted in partnership with the New York State Energy Research and Development Authority (NYSERDA) and published in October of 2020. Interviews were conducted between May 8th and June 4th, 2020, to gain detailed understanding of climate impacts and information needs across a range of sectors. Additionally, an online survey was distributed to current and potential users of climate information across New York State using Qualtrics software, and 102 responses were collected between April 28th and June 5th, 2020. In order to reach those who did not participate in past ClimAID efforts, a document analysis of climate action and resilience plans in New York State was conducted to identify localities for outreach, utilizing a database of planning documents compiled by the SAS. This needs assessment serves as one of many opportunities to incorporate diverse feedback into the ClimAID process. The assessment has already been integrated into multiple aspects of the ClimAID update, including the climate projections led by CCRUN's lead PI Horton. (NA15OAR4310147)

Managing Heat Waves in Hunting Park, Philadelphia, Pennsylvania

Hunting Park in North Philadelphia is a heat-vulnerable community with a largely non-English speaking, low income, elderly population, and sparse tree canopy. The Philadelphia Office of Sustainability, a CCRUN stakeholder, started community outreach in 2019 to better understand how Hunting Park residents were managing heat waves and found that many residents remain at home during heat health emergencies rather than seeking cooling shelters or other public amenities.

In 2020, when the COVID-19 pandemic closed such facilities and with stay-at-home orders in place in Philadelphia, CCRUN's Engineering and Urban Design Team (PI-Montalto) partnered with the Office of Sustainability and local community organization, Esperanza, to initiate a community-driven process to design cooling structures to be deployed on residential blocks in Hunting Park, and to hire local residents to participate in their construction (Figure 6). In addition to core CCRUN funds that were used to initially conceptualize and design the project, the team obtained a grant from the William Penn Foundation to support implementation. Over the summer, the research team worked with residents to build and deploy about 25 cooling structures (bench planters with umbrellas) and deploy an extensive network of sprinklers on one block.

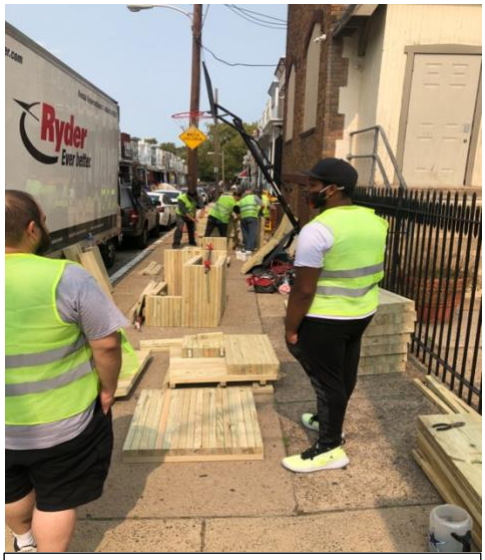

Figure 6. Working with members of the Hunting Park community and the Esperanza nonprofit community group, Drexel researchers, installed sustainable cooling systems the group had designed.

This block is also the site of a new research study simulating the urban microclimates. The goal of this study was to compare the extent to which four different heat mitigation strategies (urban forestry, shade structures, pavement wetting, and reflective roofs) could alter the street level microclimate. The ENVI-met modeling activities have concluded, and manuscripts are in preparation.

The success of this project led to an ongoing partnership with the Office of Sustainability, Esperanza, and the William Penn Foundation, and the CCRUN team is now working on scaling up the project to five additional residential blocks, with a workforce of over 10 Philadelphia residents, and hiring Civic Scientists from the local college (Esperanza College) to monitor temperature differences throughout the neighborhood. The new research is to be conducted in the summer of 2021. (NA20OAR4310147A)

Appendix A. CCRUN Publication List

Peer-Reviewed Publications

Alizadehtazi, B., Gurian, P. L., & Montalto, F. A. (2020). Observed variability in soil moisture in engineered urban green infrastructure systems and linkages to ecosystem services. *Journal of Hydrology*, *590*, 125381. https://doi.org/10.1016/j.jhydrol.2020.125381

Anderegg, W. R. L., Abatzoglou, J. T., Anderegg, L. D. L., Bielory, L., Kinney, P. L., & Ziska, L. (2021). Anthropogenic climate change is worsening North American pollen seasons. *Proceedings of the National Academy of Sciences of the United States of America*, *118*(7). https://doi.org/10.1073/pnas.2013284118

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