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

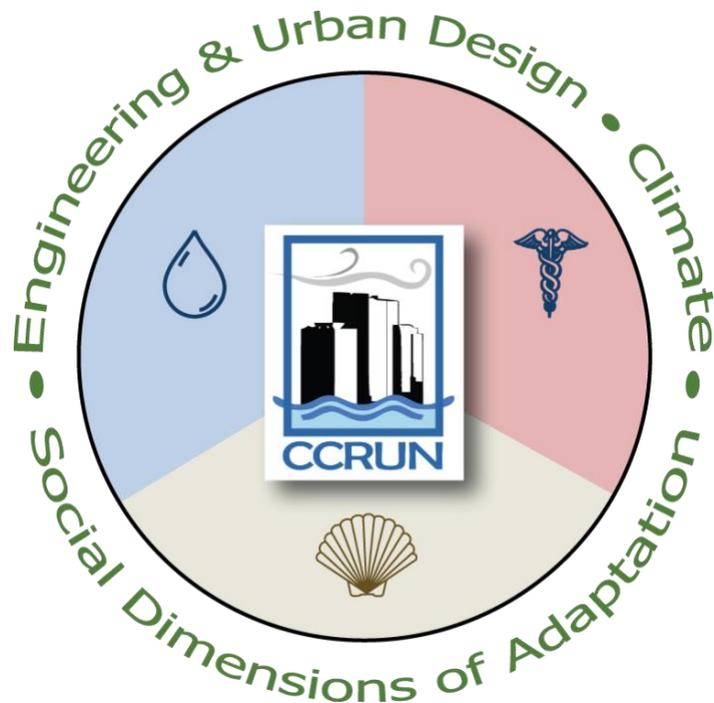## Research Highlights, June 1, 2019 – May 31, 2020

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

The CCRUN Team

Lead Investigators, Sectors, and Cross-Cutting Themes: Radley Horton (CU, Lead-PI), Patrick Kinney (Boston University)**,** Franco Montalto (Drexel)**,** Richard Palmer (UMass), Philip Orton (Stevens)**,** William Solecki (CUNY)

Program Manager: Daniel Bader (CU)

Investigators: Robert Chen (CU), Alex de Sherbinin (CU), Patrick Gurian (Drexel), Yochanan Kushnir (CU), Kytt MacManus (CU), Malgosia Madajewicz (CU), Gregory Yetman (CU)

Research & Support Staff: Maria Castillo (Boston University), Cuihua Li (CU), Ambarish Karmalkar (UMass), Dara Mendeloff (CU)*, Jane Mills (CU), Jessica Spaccio (Cornell), Korin Tangtrakul (Drexel)*, Ziwen Yu (Drexel)

Sustained Assessment Specialist: Anna LoPresti (CU)

Graduate Students and Post-docs:
Rebekah Breitzer (CUNY), Paige Brochu (Boston University), Kristoper Cadieux (Hunter College), Ziyu Chen (Stevens), Erin Friedman (CUNY), Lelia Heidari (Boston University), Carolynne Hultquist (CU), Catherine Ivanovich (CU), Marcia Pescador Jimenez (Harvard), Annesia Lamb (Brooklyn College), Khai Hoan Nguyen (Rutgers), Colin Raymond (CU), Alex Roper (UMass), Parisa Setayesh (Hunter College), Leena Shevade (Drexel), Rdiwan Siddique (UMass), Karly Soldner (Drexel), Kazi Mita (Stevens)*, Fanglin Zhang (Stevens)

Research Affiliates:
Bita Alizadehtazi (Drexel), Susana Adamo (CU), James Booth (CCNY), Arthur Degaetano (Cornell), Kevin Lane (Boston University), Peter James (Harvard), Alison Kenner (Drexel), Upmanu Lall (CU), Dong-Eun (Donna) Lee (CU), Stephanie Miller (Drexel), Jennifer Nakamura (CU), Babak Roodsari (Drexel), Raymond Sambrotto (CU), Julian Stolper (Drexel)*, Mingfang Ting (CU)

Other Collaborators:
Alfredo Aretxabaleta* (USGS), Reginald Blake (New York City College of Technology), Craig Bond (RAND), Brett Branco (Brooklyn College), Michael Burger (CU), Matt Campo (Rutgers University)*, Douglas (UMass Boston), Sarah Fernald (Hudson River NERR), Donovan Finn (Stony Brook University), Shelia Foster (Georgetown University)*, Vivien Gornitz (CU). Cynthia Herrera (CU)*, Thomas Herrington (Monmouth University), Marjorie Kaplan (Rutgers University), Paul Kirshen (UMass Boston), Debra Knopman (RAND), Howard Kunreuther (University of Pennsylvania*, Robert Kopp (Rutgers University), Robin Leichenko (Rutgers University), Arthur Lerner-Lam (CU), Ning Lin (Princeton), Reza Marsooli (Stevens), Anthony MacDonald (Monmouth University), Jon Miller (Stevens Institute), Mira Olson (Drexel), Daron Ravenborg (Fordham)* , Tiffany Troxler (Florida International University),Thomas Wahl (Univ. Central Florida), Jessica Wentz (CU), Jon Woodruff (UMass) , Rae Zimmerman (NYU)*,

*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

Integrating Co-Production

CCRUN has a long-established relationship with many stakeholders through the urban Northeast and over time, has modified the ways we interact. Acknowledging that stakeholders are both users of climate information and have knowledge and expertise to share, CCRUN is moving beyond traditional approaches to more interactive, and in some cases, real-time, forums to co-produce knowledge.

Our greatest accomplishment over the past year was incorporating co-production more deeply into a series of workshops and webinars that responded to stakeholder needs, providing them with climate risk information, tools, and training. The development of these events incorporated stakeholders' priorities and feedback from the start, ensuring that their priorities would be better addressed. At these events, CCRUN worked to establish a balance between the core-science concepts and the most critical items for decision-making. To meet this challenge, we held pre-workshop webinars and are offering a summer course for those interested in learning more. The workshops provided peer-to-peer learning, resource sharing, and networking that has led to new partnerships and relationships.

Events held in the past year that will be highlighted throughout the report include two coastal communities workshops, two stormwater management workshops, and a special webinar on climate and public health in the midst of the COVID-19 pandemic. In addition to supporting stakeholders, these events strengthened our connections with the NOAA Climate Program Office and other RISA teams from across the country.

New Areas of Focus and Partnerships

A number of new partnerships and areas of focus started during CCRUN's fifth year of Phase II. Our research partner and stakeholder network expanded while simultaneously increasing interactions amongst our research teams and the broader NOAA RISA network.

Research priorities
During the past year, CCRUN has played a major role in several initiatives geared towards reaching new stakeholders & decision-makers, while building intellectual leadership around emerging climate risk, impact, and adaptation topics. The four initiatives and topics are: 1) Managed Retreat, 2) Connected Extreme Events, 3) Legal Dimensions of Climate Attribution, and 4) Climate Risk Workshops for Financial and Other Sectors.

1) In 2019, CCRUN Co-Organized a Managed Retreat conference at Columbia University that brought together scientists, politicians, community members, and a variety of other practitioners to discuss what it means for people, infrastructure, and ecosystems as rising seas push back coastlines around the world. This conference is already leading to sustained engagements by CCRUN members around this difficult topic, with decision makers such as the New York City (NYC) government. In January of 2020, Radley Horton and Anna LoPresti presented on Managed Retreat as part of CCRUN's monthly webinar series, in what was one of the series' most well-

attended events. This sustained engagement will continue to shape the upcoming 2021 Managed Retreat conference.

2) CCRUN, through the Climate Science Team, 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 has conducted important climate research on this topic, including (Kornhuber et al. 2020 and Raymond et al. 2020a). We have also organized a major 3-day convening of approximately 150 people on this topic at Columbia University in 2019, in which decision-makers such as the Army Corps of Engineers and Insurance companies explored and described their vulnerabilities and potential adaptation strategies for connected extreme events (as described in Raymond et al., 2020b).

3) During the past year, CCRUN, in partnership with legal scholars, explored how the rapidly growing field on climate attribution interacts with the law. Climate change attribution science plays a critical role in shaping our understanding of how humans are affecting the global climate system, and in informing discussions about responsibility for climate change impacts. Confronted with this growing body of research, courts, policymakers, and private actors are now grappling with critical legal questions, such as whether governments are doing enough to adapt to climate risks, and whether corporations can be held liable for their contributions to the problem. This work culminated in the publication of a ~200-page Law Review article (Burger et al. 2020) summarizing both the science of attribution and the legal principles being applied in cases around the U.S. and globally.

4) In conjunction with other partners across Columbia University, CCRUN is working with sectors to develop training on climate hazards, impacts, and solutions. For example, we are working with the financial sector to integrate climate risk assessment into long-term planning.

Engagements with NOAA and the NOAA RISA Network
CCRUN has increased collaboration with other RISA teams and the broader RISA network over this past project year. In July 2019 and March 2020 (see Figure 1), CCRUN co-hosted two stormwater management workshops with the Mid-Atlantic RISA (MARISA), with support from NOAA, which brought scientists and stakeholders together to exchange ideas, discuss best practices, and learn the state-of-the-art in incorporating climate change forecasts into stormwater models. Representatives at the workshop included New York City Department of Environmental Protection, Philadelphia Water Department, and local governments from cities across the Northeast and Mid-Atlantic.

Figure 1. CCRUN Co-PI Dr. Franco Montalto presents at "Adapting Stormwater Management for a Changing Climate" workshop held in Washington, D.C. in March, 2020.

In early May, as part of our monthly seminar series and in collaboration with NOAA's Climate Program Office, CCRUN hosted a special webinar on "Moving from Planning to Adaptation and Back: Understanding How Best to Implement Local Climate Resiliency Strategies in a Flexible, Interconnected and Iterative Way." This seminar featured presentations from the CCRUN team and also from Western Water Assessment, with participants from NOAA joining as well. These efforts may lead to a focused RISA workshop on social science research. CCRUN and the Carolina's RISA are also working together on a manuscript on recent advances in assessment.

Later in May, CCRUN hosted a special webinar on the relationship between climate and public health, with a focus on the COVID-19 pandemic. Speakers included members of CCRUN, NOAA, and a local government in Massachusetts. The theme of climate and it's connections to COVID-19 were also discussed across the RISA network, with members of the CliMAS and Pacific RISA teams joining the webinar to reflect on similarities and differences in risk and vulnerability across diverse regions as part of the facilitated discussion.

CCRUN will also be participating in a new Cross-RISA project with MARISA and the Pacific RISA, described in further detail later in this report.

Flood modeling in Eastwick, Pennsylvania
CCRUN has begun an exciting new project for quantifying flood and climate risk and adaptation for Philadelphia, with leveraged funding from NOAA-CPO-COCA/SARP. The study site is Eastwick, Philadelphia, and the project is a collaboration between Stevens, Drexel and the Philadelphia Water Department. There have been many models of flooding developed for this part of Philadelphia, but none have included how sea level rise will converge with riverine flooding in this delta region.

The project will include four core areas of science, as well as a community engagement process, strong coordination with decision makers and a specific focus on two ongoing city planning initiatives. The core compound flood science research areas include flood modeling, extreme value analysis, climate-impact assessment, and adaptation benefit-cost analysis.

The engagement process will consist of two community workshops, including collaborative design of flood adaptation scenarios and a socially sourced validation of the flood modeling. Community members will inform the model by verifying which parts of the neighborhood have flooded during previous extreme weather events and will provide input to adaptation strategies which will be incorporated into the model.

Coordination with decision makers will occur through an advisory panel, project webinars, and the activities of our team members at the Philadelphia Water Department. Progress thus far is with model development and evaluation against observations.

Enabling adaptation to coastal flooding
CCRUN has begun work on a new project entitled "Enabling urban residents to adapt to coastal flooding: Evidence from New York City neighborhoods." This project fits into the theme of designing approaches to adaptation and evaluating their effectiveness (their impacts on adaptation). The project is: (1) engaging community groups of coastal residents in co-producing information about risks of coastal flooding and costs and benefits of adaptation options; (2) investigating if and how the engagement in co-production results in more residents taking adaptation actions, and what are the implications for advancing adaptation more broadly.

The CCRUN research team has established three groups of community organizations who are committed to participating in the project. One group will engage in co-production. One group will participate in one informational workshop. One group will serve as a comparison group that has access to existing online material. CCRUN has developed materials for 3 workshops that will constitute part of the co-production process.

This new project contributes several types of information that are not publicly available. For examples, our team has developed flood projections specific to the neighborhoods for different frequency floods currently and in 30 years that demonstrate the effects of sea level rise. In addition, CCRUN researchers have also estimated costs of flooding that residents can expect if they do not adapt based on costs of recovery from Hurricane Sandy.

The project is also a new partnership with the New York Hall of Science, a set of community groups in the Rockaways neighborhood of New York City that we have not engaged with before, and the National Weather Office in Upton, New York. The reason for establishing this new partnership is to examine approaches to changing behavior and motivating at risk populations to take adaptation actions. The NYC Mayor's Office of Resiliency is also part of this project.

Sustained Climate Assessment
In Year 5, CCRUN expanded its team to include a Sustained Assessment Specialist. Sustained assessment activities over the past year include the initiation of a climate information needs

assessment for stakeholders across New York State, in partnership with the New York State Energy Research and Development Authority (NYSERDA). An online survey and interviews were conducted to better incorporate stakeholder feedback into the next update of ClimAID, New York's state-wide climate assessment. The needs assessment work has resulted in ongoing conversations with the New York City Mayor's Office of Resiliency, which is pursuing similar efforts in regard to the New York City Panel on Climate Change (NPCC).

A second project is the development of a nation-wide database of local climate action and resilience plans. The database contains 272 plans, with 64 plans identified in the Northeast region (see Figure 2). The database has been utilized for a variety of purposes including: Identifying climate information users for the NYSERDA needs assessment; as a means to track where CCRUN and the National Climate Assessment have been utilized in adaptation planning across the US; as a research tool to identify managed retreat efforts across the region which will feed into the 2021 Managed Retreat Conference; and as the basis for planned publications in peer reviewed journals.
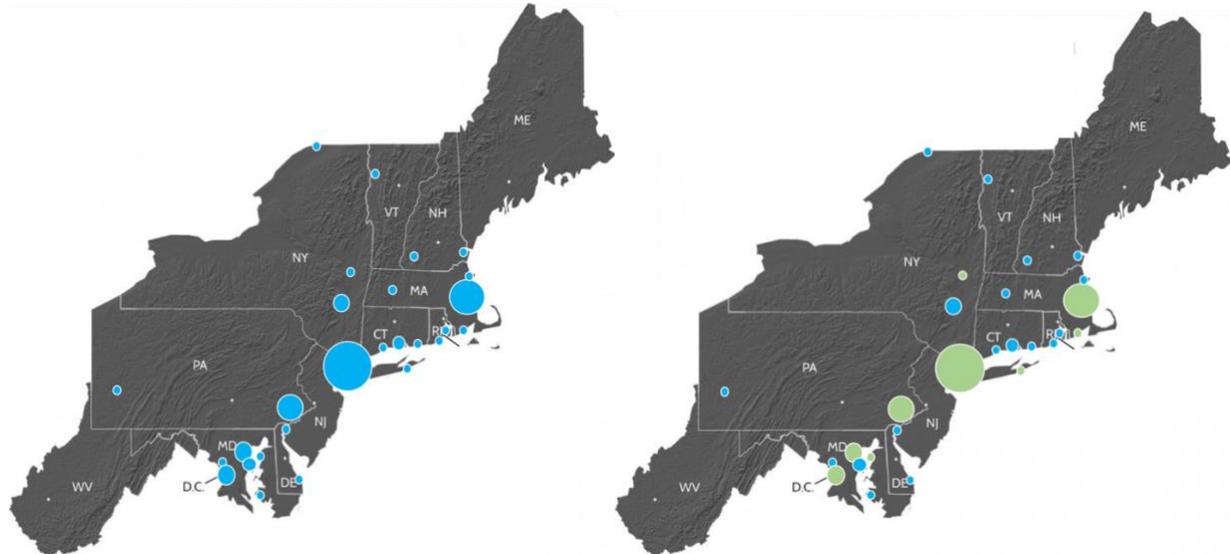

Figure 2. Map of Local Climate Action and Resilience Plans in the Northeastern Region. Circle size indicates number of plans. Left: all plan locations. Right: Plans referencing the National Climate Assessment in green.

Where are CCRUN Products in Use?

The geographic focus of CCRUN is the urban corridor in the Northeast United States stretching from Philadelphia to Boston. Across this region, and for the region as a whole, there are numerous examples of products developed through interactions between CCRUN researchers and stakeholders.

Northeast United States
- The National Weather Service Weather Forecast Offices at Upton, NY and Mt. Holly, NJ are both using the Stevens Flood Advisory System and cite it as being an important component of their storm forecast guidance development. CCRUN researchers provide

assistance for users and work to improve the models behind the Stevens Flood Advisory System (see Figure 3; http://stevens.edu/SFAS).
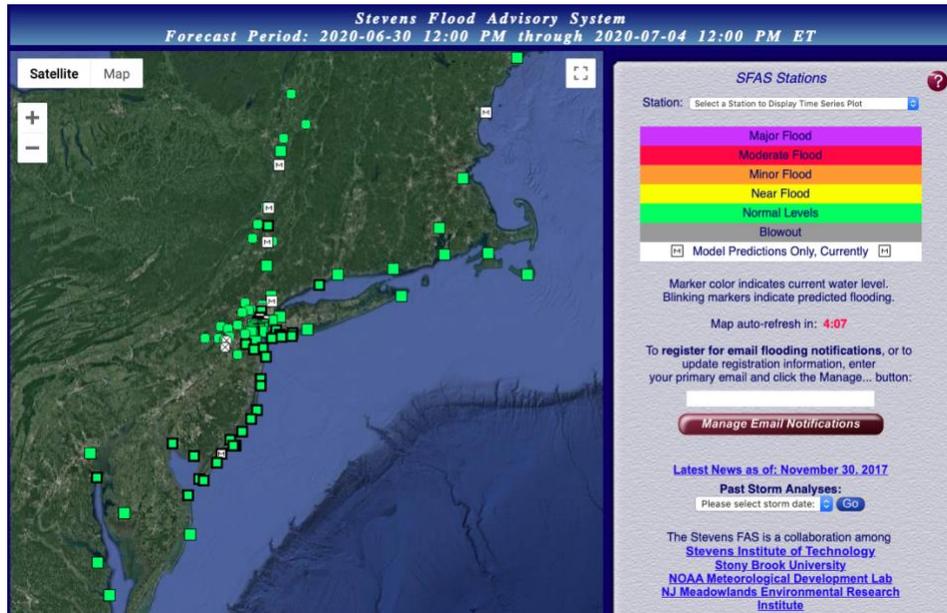

Figure 3. The Stevens Flood Advisory System (SFAS). SFAS is an ensemble-based probabilistic flood forecasting system providing total water level forecasts for coastal and estuarine waterways spanning the U.S. Mid-Atlantic and Northeast.

- CCRUN's water research has been focused on estimating (using hydrological models) the impacts of climate change on water demands in major cities in the Northeast, and as far south as Washington, D.C. metropolitan region. The team has constructed water demand models for Boston, MA and Fairfax County, VA.

Boston
- CCRUN's public health team has started a new collaboration with the community group GreenRoots in Chelsea, MA, a low income, ethnically diverse coastal community in the Boston metropolitan area. The objective of this work is to document residents' experience with and responses to heat waves. A data dashboard will be created with multiple data layers related to heat-health exposures and mitigation options.

New York State
- CCRUN's data science team has released building footprint, flood, and damage estimates data sets for a number of New York State counties as part of on-going project funded by NYSERDA (see Figure 4; http://fidss.ciesin.columbia.edu/building_data_adaptation). The project encompasses all counties adjacent to the Hudson River from the southern border of Westchester County to the Federal Dam at Troy, as well as counties outside New York City adjacent to Long Island Sound.
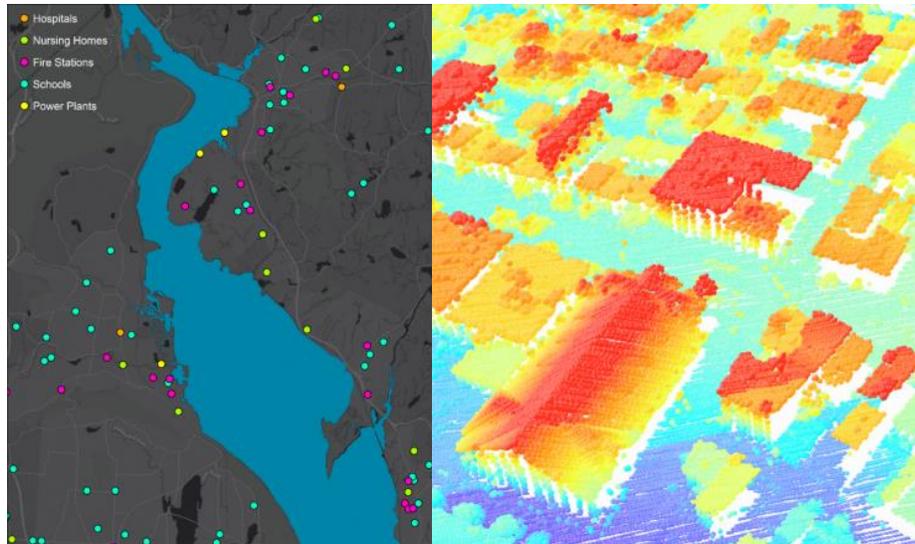
Figure 4. The New York State Building Footprints with Flood Analysis.

- CCRUN researchers contributed to Con Edison's Climate Change Vulnerability Study. As the utility assesses its risk to current and future weather and climate extremes, CCRUN has provided both quantitative and qualitative climate projections for a variety of variables including temperature, precipitation, and extreme storm events. CCRUN helped prepare the written report for the study, which was released late last year.

- Working with the NYSERDA, CCRUN has started two new projects to advance climate adaptation efforts in New York State. The first project is a climate needs assessment conducted by CCRUN's Sustained Assessment specialist. The project has gathered information from a diverse set of climate information users across the state to determine how New York's climate assessment (ClimAID) has been used, and what gaps exist that the forthcoming ClimAID update can incorporate to better meet the needs of its users. The second project is a potential update to the climate projections for New York state, which will utilize the results of the needs assessment in its recommendations to NYSERDA.

New York City
- The Rockaway Waterfront Alliance and residents of two neighborhoods of New York City, Canarsie and The Rockaways, which lie along Jamaica Bay, are using CCRUN's detailed flood and sea level rise hazard maps.

- The Science and Resilience Institute at Jamaica Bay (SRIJB) and local residents are relying on CCRUN for technical assistance in the Community Floodwatch project, for technical expertise and how to improve communication and understanding of Stevens online flood forecasts.

- In the Rockaways, CCRUN has developed workshop facilitation guides for workshops that engage communities in developing information about flood risk and in developing an approach to guiding homeowner residents through the process of making decisions about adaptation actions.

New Jersey
- The New Jersey Department of Environmental Protection is relying on a CCRUN researcher for technical assistance as a member of the Science and Technical Advisory Panel on New Jersey's Exposure to Sea-Level Rise and Coastal Storms.

Pennsylvania
- In parallel with efforts in Philadelphia, CCRUN researchers are helping to lead statewide discussions to form similar research panels in the cities of Pittsburgh and Harrisburg.

- In a program through the Pennsylvania Department of Environmental Protection, two Drexel University students affiliated with CCRUN, have been paired with local municipalities in the state (Caln Township and Bellefonte Borough) to develop a greenhouse gas inventory, a vulnerability assessment, and a climate action or adaptation plan for the municipality.

Philadelphia
- CCRUN, working with the Philadelphia Water Department, is developing a flood model for a low-lying neighborhood in Southwest Philadelphia (Eastwick) that incorporates the compound risk of sea level rise and riverine flooding.

- CCRUN is involved in conversations with the City of Philadelphia's Office of Sustainability and Philadelphia Water Department to develop a local scientific panel on climate change, inspired by New York City's Panel on Climate Change and Boston's Green Ribbon Commission.

Outreach Activities

Coastal Communities Workshops
In June 2019, CCRUN hosted a series of workshops entitled Promoting Successful Local Coastal Resiliency Policies and Programs: Addressing Key Knowledge Gaps. They were held at Stony Brook University in Suffolk County, New York, and another at Monmouth University in New Jersey. The objective of the workshops was to bring together local practitioners and policy makers in the New York-New Jersey Metropolitan Region to evaluate emerging knowledge and data needs regarding how coastal residents and business owners are responding to, or might respond to, flood risk resiliency efforts associated with extreme storms, storm surge, sunny day/nuisance flooding, and sea level rise. As an output from the workshops, household surveys will be developed to address the gaps identified by policy- makers to improve effectiveness and communication of resiliency planning efforts. The surveys will be administered by Stony Brook and Monmouth students in conjunction with CCRUN researchers.

Managed Retreat Conference
CCRUN and partners organized a conference on managed retreat, entitled "At What Point Managed Retreat? Resilience Building in the Coastal Zone", hosted by the Climate Adaptation Initiative at Columbia University's Earth Institute, which took place on June 19- 21, 2019 (see Figure 5). As one of the first major academia-led conferences on the subject, the event convened diverse stakeholders including researchers, community-based organizations, indigenous

leadership, planners, practitioners, local government, industry representatives and more to discuss the issues surrounding retreat as an adaptation option. Major themes discussed included environmental justice, community resilience, policy and decision-making, and climate modeling of various aspects of retreat from sea level rise to migration.

Figure 5. CCRUN Lead-PI Dr. Radley Horton moderates a panel discussion at the workshop, "At What Point Managed Retreat? Resilience Building in the Coastal Zone" in June 2019.

The event brought together over 300 individuals, including researchers of multiple CCRUN universities, CISA, and other NOAA affiliates. The event provided a platform for CCRUN to assess knowledge gaps and opportunities for future research agendas relevant to coastal communities in the Northeast and across RISA regions. Out of this conference, the organizers have built new partnerships for co-generating knowledge on adaptation and are developing a policy-oriented article for a leading journal, op-eds for broader audiences, and a survey to capture participant feedback that will be used to shape the 2021 Managed Retreat Conference agenda.

Stormwater Management Workshops
In partnership with MARISA, CCRUN was involved in two workshops regarding stormwater planning under climate change conditions. The first workshop, "Climate-Resilience Planning for Stormwater and Wastewater Utilities" was held in July 2019 at the Newtown Creek Wastewater Treatment Plant, in Queens New York and was led by the New York City Department of Environmental Protection, the Water Research Foundation and MARISA. At this workshop, CCRUN team members presented on the challenges of using hydraulic and hydrologic modeling for extreme precipitation planning.

The second workshop, "Adapting Stormwater Management for a Changing Climate", took place in March 2020 at the Drexel Center, in Washington, DC. This workshop brought together planning and engineering professionals across the CCRUN and MARISA region to exchange ideas, discuss best practices, and learn the state-of-the-art in incorporating climate change forecasts into stormwater models. The technical components of the workshop were covered in a series of pre-workshop webinars (~55 attendees per event), so that the workshop content could focus on peer-to-peer learning and resource sharing, including highlighting a set of NOAA tools for accessing climate data.

As a result of that workshop, CCRUN has further developed relationships with several municipalities that are seeking this type of modeling for their service area. These cities include: New Haven, CT and Lancaster, PA in the CCRUN region, and Richmond, VA; Baltimore, MD and Charles County, MD in the MARISA region. These municipalities will be partners in a course taught this summer by CCRUN co-PI Dr. Montalto, "Stormwater Management in the Era of Climate Change", which will be available to Drexel upper level and graduate students as well as professional engineers seeking continuing education credit.

Climate and Public Health Webinar
On May 20, 2020, CCRUN, along with NOAA partners, including the Climate Program Office's National Integrated Heat Health Information System, co-hosted a webinar and discussion titled Planning for Extreme Heat Events in the Context of the COVID-19 Pandemic. Panelists presented on the latest science of extreme heat exposure, potential summer 2020 heat conditions, and possible strategies for how to address summertime extreme heat if cooling centers or other public sites remain closed during that time. Discussions included proposals that could be implemented by this summer. Social and environmental equity considerations were also introduced into the discussion.

Seminar series
CCRUN's Green Infrastructure, Climate and Cities seminar series continues, with a presentation held each month. For each event, invited speakers present on a new topic related to the general themes of climate impacts, adaptation, and mitigation, with a focus on green infrastructure. A full list of topics from this past year, as well as the entire series dating back to 2015 can be found on the CCRUN website.

The seminars are held in-person at Drexel University and are also broadcast live online via webinar to allow access to a wider range of stakeholders. Over the past year, nearly 200 have attended the seminars in person, with close to 900 participating online (averaging about 100 per seminar). Stakeholders from across the Northeast attend the seminars and also have had the opportunity to present. All archived seminar series videos are also available for viewing online, with over 1200 views and approximately 80 subscribers to our Youtube Channel.

New for this reporting period, in October 2019, Drexel University applied for and was approved to be a sponsor of issuing Professional Development Hour credits for Professional Engineers. To date, 28 certificates have been issued.

Also, in May 2020, CCRUN held a RISA network-wide seminar on "Moving from Planning to Adaptation and Back: Understanding How Best to Implement Local Climate Resiliency Strategies in a Flexible, Interconnected and Iterative Way", which had close to 250 participants online.

Additional workshop and conference presentations
CCRUN team members have presented and hosted sessions at large scientific conferences including the American Geophysical Union annual meeting (AGU) and the American Meteorological Society (AMS) annual meeting. Additional presentations took place at the NOAA Climate Prediction Applications Science Workshop.

CCRUN's data science team presented many of their data tools at a variety of workshops and events. This included a meeting of the Board of Directors of the Hudson Valley Regional Council. CCRUN data tools were also featured in a presentation at the United Nations High-level Experts and Leaders Panel on Water and Disasters (HELP).

At Columbia's Lamont Campus's Annual Open House, CCRUN flood impact tools were linked to a hands-on interactive activity for children that let them explore flooding adaptation measures for the area around Jamaica Bay.

Planned Activities

Hazard Assessment and Resilience Building Around Flood Risks in Small-Medium Sized Communities
During the next project year, CCRUN will be participating in a cross-RISA partnership project with MARISA and Pacific RISA. As part of this work, CCRUN will utilize methods discussed at the March stormwater workshop to downscale precipitation in a flood modeling project. The study will prepare a comparison of the ease with which different extreme precipitation downscaling techniques can be incorporated into urban hydraulic and hydrological models.

The CCRUN team will also contribute to this cross-RISA partnership through community engagement and resilience planning. CCRUN will work with Pacific RISA on the organization and design of a community workshop to be held in Hawaii, playing a key role in the knowledge transfer and climate information between the east coast and the Pacific Islands. This workshop will include discussion of diverse approaches to adaptation including protection, accommodation, and retreat. The planned managed retreat conference for June 2021 will provide a forum for convening the three RISA teams and relevant stakeholders that have participated in the process together to discuss key takeaways, share lessons learned, and strategize next steps within the context of the larger community of practice coalescing at the event.

Managed Retreat Workshop
Building from the 2019 Conference, CCRUN will Co-organize another Managed Retreat Conference in June 2021. An even larger audience and more targeted presentations and speakers are anticipated, with more time for networking. The planned June 2021 event, titled At What Point Managed Retreat: Resilience, Relocation, and Climate Justice, will have an explicit focus on the equity aspects and implications of retreat as an adaptation strategy. The event will also place greater emphasis on providing a platform for communities and community members to share their expertise and experience with planning and implementing managed retreat, facilitating the exchange of knowledge and best practices. A range of new topic areas will be explored, or explored in more depth, including: non-coastal retreat; psychological and sociological research on retreat; ecosystem retreat, the built environment, and international experience with retreat.

Legal Dimensions of Climate Attribution
Expanding CCRUN's work with legal scholars, the team has begun exploring how the rapidly growing field on climate attribution interacts with the law. During the next year, we will publish a

scientific journal article on this topic and deepen our engagement with stakeholders. Based on our engagements to date, key audiences will include judges, lawyers, local governments, and the private sector. Key events will include judicial conferences at the federal and state level.

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 and through what causal mechanisms. 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.

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. However, 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 multiple, 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.

- Engagement with policymakers
- The policymakers 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 policymakers
- Publications in outlets read by policymakers
- Outreach to communicate research results and experience with using the research results to policy 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, as part of the monitoring process, 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 much more challenging. CCRUN has collected outcome and impact data in the context of particular 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 for Rockaway. 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 actually 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 are more difficult to measure but may include losses due to extreme events, economic outcomes such as value of infrastructure, economic output, incomes, and other measures of livelihoods and their distribution in the population.

The team has completed an ex-ante evaluation, which investigates the potential socio-economic value of coastal flood risk predictions produced by CCRUN to coastal residents. The research uses household survey data collected by a previous CCRUN study to quantify the present value of future expenditures on flood damages that coastal residents can avoid by taking adaptation actions. The study also assesses the adequacy of existing data to support evaluation of progress on adaptation. The team has presented the results at several conferences and the paper for submission to a peer-reviewed journal is in progress. The results are an input into an ongoing evaluation project that began in 2019.

A current project, described in more detail in the project database, 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.

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 policy-makers 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.

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 in order to provide evidence that can be aggregated to measure broader program impacts.

Building a Model for Scientist-Stakeholder Interactions

Through the two phases of CCRUN, researchers on the project have pioneered a model of scientist-stakeholder interactions which have helped decision-makers prepare and adapt for climate variability and change. Specifically, the "Panel" approach like the one in New York City has been successful in helping advance adaptation efforts and ensuring that local climate risk information, vetted and developed by an independent body of experts, is made available for policymakers. Over the past year, in part through the different workshops CCRUN has organized, it's become apparent that other key stakeholders and municipalities within the urban Northeast are looking to either follow a similar approach or create panels of their own.

At the coastal communities workshop held on Long Island, there was a discussion of how a panel could be created just for Nassau and Suffolk counties in New York. Attendees felt that while they have information available from both nearby New York City and New York State, a dedicated body of experts advising on the most important and relevant local issues would be greatly beneficial. Without a coordinated body, it was evident that communities struggle with multiple climate resources available but little guidance on where to go.

Stemming out from the stormwater management workshops, there is ongoing discussion about establishing a Philadelphia Panel on Climate Change (modeled after New York). There are additional conversations taking place about setting up similar panels in Pittsburgh and Harrisburg, Pennsylvania. Given the diverse audience that attended these workshops, with representatives from communities across the Northeast and mid-Atlantic, it is possible additional locations look to CCRUN in the future for guidance on how to best approach climate adaptation.

New York City is also set to embark on the fourth New York City Panel on Climate Change, with several CCRUN team members expected to serve on the panel. Within the past year, the Mayor's Office of Resilience in New York City has hired a Deputy Director of Climate Science and Risk Communication. In many ways, the creation of a specific position within local government to coordinate with scientists, and serve as a dedicated liaison to the NPCC, is a product of the many

years of interactions CCRUN has had with the City, where the growing familiarity with climate risk information warranted the need for a dedicated staff member to focus specifically on these issues and interactions (it previously had been a shared responsibility of multiple staff members).

CCRUN is well-positioned to provide the weather, climate, impacts, and resilience knowledge that is increasingly being asked for. CCRUN has also learned how to work with stakeholders to set up the optimal structure for these engagements, which differs by location and type of group.

Examples of Implemented CCRUN Work

Consolidated Edison Climate Change Vulnerability Study
In December 2019, Consolidated Edison (Con Edison) released their Climate Change Vulnerability Study (see Figure 6), for which CCRUN researchers provided the climate science risk information that serves as the foundation of the report. The study evaluated present-day infrastructure, design specifications, and procedures against projected climate change to better understand its future impact on Con Edison's energy delivery systems, as well as the economic costs and benefits of adaptation options. The historical weather analysis and future climate projections developed by CCRUN enabled Con Edison to assess the impact of a range of possible future outcomes, including a high-end, "stress test" scenario.
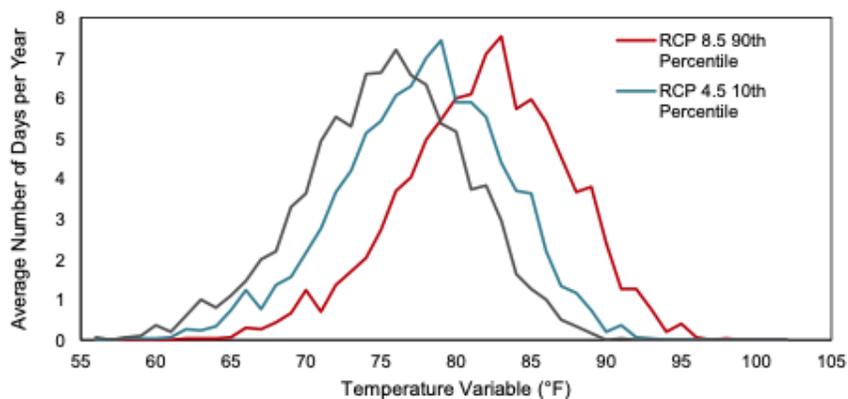

Figure 6. Distributions showing historical (black line) and 2050 projected (blue and red lines) summer (June–August) daily electric TV at LaGuardia Airport. The 2050 projections show both the RCP 8.5 90th percentile and the RCP 4.5 10th percentile distributions.

The vulnerabilities identified in the report (using CCRUN science), will help guide the company's strategy to strengthen its reliability and resilience against future weather and climate extremes. Building from this study, Con Edison will develop a detailed Climate Change Implementation Plan by the end of 2020 to operationalize the recommendations from the Climate Change Vulnerability Study.

The Climate Change Vulnerability Study provides an overall economic cost estimate of the adaptations Con Edison may need to take to prepare for future weather and climate events. By 2050, the company might need to invest between $1.8 billion and $5.2 billion by 2050 on targeted programs to protect its electric, gas and steam delivery systems and customers from the impacts

of climate change. The range of values is influenced by the different adaptation options available as well as the different climate scenarios presented by CCRUN. Within the report chapters, which are organized by climate hazard, cost estimates are presented for specific hardening and resilience measures.

For example, CCRUN provided future projections for the combined impacts of heat and humidity, measured by an agency-specific metric known as temperature variable, which can cause higher peak loads due to increases in demand for cooling. Increases in load may also require investments in system capacity to meet the higher demand. Addressing this combined risk is estimated to cost between $1.3 billion and $4.6 billion by 2050 (based on future projections using Representative Concentration Pathway (RCP) 4.5 10th and RCP 8.5 90th percentiles, respectively). The CCRUN projections allowed Con Edison to better evaluate monetary costs of adaptation, contributing to the utility's ability to plan effectively for future climate change.

However, there is room for continued collaboration, as the report doesn't provide an overall monetary value to Con Edison for economic benefits of preparing for climate change. discussion on cost-benefit is very much qualitative, with a description of the benefits to the company, not a dollar amount. There are cases within the report where rebates are discussed, which would provide incentives to customers to make changes that would help Con Edison build resilience to future weather and climate extremes. For example, giving a rebate for the use of new technology thermostats can help reduce the overall demand on systems during peak load times.

One challenge that Con Edison faces in terms of paying for potential adaptations to climate risk is that the cost may be passed to the customers in the rates that they are paying. Therefore, the company has to balance the cost-benefit of resilience not only within their own, but with consideration of the customers as well.

Climate Assessment in New York State
For many years, CCRUN climate science researchers have worked on the State of New York's climate assessment planning process. Working with the New York State Energy Research and Development Authority (NYSERDA), CCRUN prepared climate change projections for the first statewide assessment in 2011, and then in an update in 2014. This climate risk information prepared by CCRUN serves as the basis of these reports and has since been codified into law, ensuring that stakeholders throughout the state have the best available, local science.

Within the past year, CCRUN began work on two new projects with NYSERDA. The first is a climate needs assessment, focused on gathering information on how existing climate resources are being used and what needs are not being met by current resources, to ensure that future climate impact assessments are as accessible and useful as possible to a wide range of users in New York State. Data was collected through an online survey of over 100 stakeholders, and interviews with sector experts.

The results from the climate needs assessment will help inform the second new project, the potential update of climate projections for New York State. CCRUN science researchers will complete a full literature review of the relevant climate science and evaluate existing reports (such as the 2011 and 2014 state assessments) to determine if an update is necessary. The project team

will present NYSERDA with a recommendation, and should a decision be made to go forward with an update, CCRUN researchers will develop the new projections. This will be an opportunity for CCRUN to integrate new climate model data from CMIP6 and also advance methods for projecting extreme events, such as intense precipitation, and connected extremes, such as the combined impacts of heat and humidity.

While CCRUN works on possible updated climate projections, NYSERDA is advancing state adaptation work through a separate impacts assessment and economic analysis. CCRUN's work will inform these other two studies and our expectation is to be engaged with the other project teams, given the importance of the climate risk information.

The advances in climate projections methods developed as part of the work can be transferred to other municipalities within the CCRUN region and could be shared across the RISA network, for example on the topic of connected extremes. This new project has also raised the need for coordination amongst municipalities when completing climate assessments, in order to ensure consistency in the climate data that's made available. As part of this new research, CCRUN is helping make linkages between New York State and New York City, where CCRUN team members are beginning to participate in the fourth New York City Panel on Climate Change.

Appendix A. CCRUN Publication List

Select Publications

Burger, M., Wentz, J., & Horton, R. (2020). The Law and Science of Climate Change Attribution. *Columbia Journal of Environmental Law*, **Vol. 45 No. 1 (2020): Volume 45.1.** https://doi.org/10.7916/CJEL.V45I1.4730

Climate change attribution science—which examines the causal links between human activities, global climate change, and the impacts of climate change—plays a central role in many of these lawsuits. Attribution science is rapidly evolving, both in regard to attributing impacts and extreme events to climate change and in attributing greenhouse gas emissions to particular actors—and so too is its role in the courtroom and in policymaking. The Law and Science of Climate Change Attribution examines how attribution science is used in litigation and in policymaking, and how litigation and policymaking might influence current and future directions in attribution science. In so doing, the Article indicates where current research factors into various types of climate litigation, and where further work may be most impactful.

Solecki, W., Grimm, N., Marcotullio, P., Boone, C., Bruns, A., Lobo, J., Luque, A., Romero-Lankao, P., Young, A., Zimmerman, R., Breitzer, R., Griffith, C., & Aylett, A. (2019). Extreme events and climate adaptation-mitigation linkages: Understanding low-carbon transitions in the era of global urbanization. *Wiley Interdisciplinary Reviews: Climate Change*, *10*(6). https://doi.org/10.1002/wcc.616

It has become increasingly clear that cities will have to simultaneously undertake both adaptation and mitigation in response to accelerating climate change and the growing demands for meaningful climate action. Here we examine the connections between climate mitigation and climate adaptation, specifically, between low-carbon energy systems and extreme events. The article specifically addresses the question, how do responses to extreme climate risks enhance or limit capacity to promote city-level greenhouse gas (GHG) mitigation? In particular, the existing energy system structure is an important determinant of impact and potential for energy transitions. Well-developed and articulated governance strategies and ready access of effective and economically efficient alternative energy technology were key to transitions.

Zhang, F., Orton, P. M., Madajewicz, M., Jagupilla, S. C. K., & Bakhtyar, R. (2020). Mortality during Hurricane Sandy: The effects of waterfront flood protection on Staten Island, New York. *Natural Hazards*. https://doi.org/10.1007/s11069-020-03959-0

Hard defenses, such as levees or land berms, are often considered the most effective approach to reduce flood risk. This study reveals a potential increase in mortality when hard protections cannot defend a location against low-probability, extreme flood events. This study demonstrates that the elevated berm along the eastern shore of Staten Island, New York may have contributed to the concentration of fatalities in the area by increasing the speed at which seawater rose, causing some people to be trapped in places where they could not escape rising waters. The potential increase in mortality needs to be taken into account when designing coastal protections.

Additional Publications

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