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100 Resilient Cities
AKRF Environmental Services Group
All Hazards Consortium
Baltimore City Department of Public Works
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
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 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-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
Scenic Hudson
Science and Resilience Institute at Jamaica Bay
StormCenter Communications, Inc.
The Trust for Public Land
Town of Groton CT
US Army Corps of Engineers
Urban Climate Change Research Network
US Forest Service
US National Park Service
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Climate Risk in the Urban Northeast

The climate hazards that pose greatest risks and are of greatest concern to decision makers in the northeastern United States (U.S.) are high heat and humidity, extreme precipitation, and coastal flooding. Other important climate hazards in the region include cold air outbreaks, frozen precipitation, and drought. The urban environments in which most of the the region's population resides amplify some of these hazards. Historical and on-going modifications to urban landscapes within the region have contributed to urban heat islands, inland flooding, and concentration of iconic assets and housing stock on coastal, flood-prone 'fill' areas that experience enhanced storm surges.

The Northeast faces significant climate vulnerabilities (Dupigny-Giroux et al., 2018). This populous region includes large numbers of vulnerable individuals and groups, as defined by metrics including access to air conditioning, socio-economic status, and legacies of racial injustice. Vulnerabilities to extreme events and gradually progressing climate change vary substantially across the region, depending on urbanization (which spans a gradient from the largest and most densely populated city in the U.S. by some definitions, to rural areas); socio-economic conditions; governance; and infrastructure. Approaches to resilience/adaptation need to be tailored to these diverse conditions, taking into account how climate impacts cross jurisdictions, generate governance challenges, and affect interconnected infrastructures that can propagate damages and disruptions across space and time.

Fortunately, the states (Bromley-Trujillo & Holman, 2020) and metropolitan areas in the Northeast are at the vanguard of resilience efforts (Dupigny-Giroux et al., 2018; Rosenzweig & Solecki, 2019). Regional decision makers have developed sustainability and equity plans, green infrastructure programs, greenhouse gas (GHG) emissions inventories, and ecosystem restoration priorities, often with support from the Consortium for Climate Risk in the Urban Northeast (CCRUN).

About the Consortium for Climate Risk in the Urban Northeast

The Consortium for Climate Risk in the Urban Northeast, or CCRUN, was founded in October 2010 under NOAA's Regional Integrated Sciences and Assessments (RISA) program to serve stakeholder needs in assessing and managing risks from climate variability and change. In 2015, CCRUN received a second award and Phase II started. CCRUN remains the only RISA team with a principal focus on climate change adaptation in urban settings. The CCRUN team continues to provide state-of-the-art climate risk assessment information, co-generated with the region's stakeholders.

CCRUN is structured as a multi-modal network that covers the relevant portions of Massachusetts, Rhode Island, Connecticut, New York, New Jersey and Pennsylvania, so that local needs for targeted climate-risk information can be served in a coordinated way. In Phase II, CCRUN moved outside of the major cities in the urban Northeast corridor (Boston, New York City,

and Philadelphia) and increased engagement with small- to medium- sized communities in the region (e.g., Newark, Camden, Stamford).

CCRUN is designed to address the complex challenges that are associated with densely populated, highly interconnected urban areas, including urban heat island effects; poor air quality; intense coastal development, and multifunctional settlement along inland waterways; complex overlapping institutional jurisdictions; integrated infrastructure systems; and highly diverse, and in some cases, fragile socio-economic communities. These challenges can best be addressed by the stakeholder-driven interdisciplinary approach taken by the CCRUN RISA team. CCRUN has a wide network of stakeholders through the urban Northeast and maintains strong relationships with them. The team is a trusted source for weather and climate risk information and CCRUN research is integrated into policy across multiple scales of governance.

CCRUN's projects are focused in three broad sectors: Water, Coasts, and Health. Research in each of these sectors is linked through the cross-cutting themes of Climate Science, Engineering and Urban Design, and the Social Dimensions of Adaptation, the latter of which is especially important in considerations of environmental justice and equity.

CCRUN's stakeholder-driven approach to research can therefore support investigations of the impacts of a changing climate, population growth, and urban and economic policies on the social, racial and ethnic dimensions of livelihoods and of communities in the urban Northeast.

In Phase II, CCRUN focused on three questions that lie at the interface between science and decision making:

- Which climate and climate impact information products most influence decision making and adaptation action?
- Which adaptation strategies are most effective for different urban populations and in different urban contexts?
- What are the region's key conditions (e.g., institutional, regulatory, infrastructural, and/or socioeconomic) that serve as opportunities for or barriers to, 'ramping up' meaningful climate resilience practice?

Sector and Cross-Cutting Theme Based Research

Examples of CCRUN's activities are described below according to sector or cross-cutting themes: coasts; public health; water; climate science; engineering and urban design; and social dimensions of adaptation. Described here is an overview of each sector/theme along with a summary of key research findings from Phase II.

Coasts

In the Northeast region, adapting to the impacts of sea level rise, coastal flooding, and extreme events is critical for building coastal resilience. The sector takes a broad approach to coastal adaptation, moving beyond hard infrastructure solutions to incorporate ecological, social, and policy dimensions that build layered resilience. The coasts team is able to provide flood modeling

and evaluate what coastal adaptations would stop flood scenarios with sea level rise. Current sector priorities include producing climate information that results in informed and improved decision-making on coastal urban resilience.

CCRUN's Coasts Team (PI-Orton) has produced innovative research on storm surge, ensemble flood forecasting, climate change impacts, compound riverine-coastal flooding, flood hazard and risk assessment, and adaptation assessment, often under advisement or in co-production processes with stakeholders. The research initially in Phase I focused on coastal climate risk information but has broadened in Phase II to include risk and adaptation quantification.

Attribution of Anthropogenic Climate Change Effects on Hurricane Coastal Flooding

The Coasts Team collaborated with Climate Central, a US Army Corps of Engineers modeler, 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 framework can be applied to assessing the financial and human costs of human-caused sea level rise to other regions, including the Gulf of Mexico.

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. To quantify this effect, we 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. We 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.

Storm Surge Barriers

Storm surge barriers are one of the most effective approaches for avoiding damage and loss of life during floods at harbors and cities. However, the environmental effects of surge barriers are poorly understood, and there is a strong consensus that further study is needed, with participation from a broad range of scientific disciplines.

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. Climate change can detrimentally affect estuaries through warming, increased stratification and salt intrusion, and associated declines in dissolved oxygen, and this research demonstrates how the future human response to increasing coastal flood risk could compound these effects.

In a project with leveraged funding from NOAA National Estuarine Research Reserve System's Science Collaborative, CCRUN's coasts team (1) convened workshops and an advisory committee

to collaboratively develop a research agenda to better understand potential barrier effects on nearby estuaries, and (2) performed novel research in estuary effects of surge barriers, in close collaboration with key end-users such as the U.S. Army Corps of Engineers and its partners.

In Chen et al. (2020), the research evaluated the potential future effects of sea level rise on surge barrier closure frequency and duration. 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.

Quantifying the Efficacy of Natural Systems for Reducing Flooding

A broad swath of research has used hydrodynamic modeling to quantify the efficacy of nature-based flood risk reduction, or conversely, the rise in risk that can occur due to common patterns of urbanization. The CCRUN Coasts team quantified how well wetlands and oyster reefs can mitigate coastal flood and wave hazards (Brandon et al., 2016; Marsooli et al., 2016; Marsooli et al., 2017) and developed and tested novel ideas for nature-based flood risk reduction using estuary inlet or channel geometric modifications (Fischbach et al., 2018; Orton et al., 2016). A shorefront berm led to more dangerous conditions in one neighborhood of Staten Island, when it was overtopped during Hurricane Sandy (Zhang et al., 2020). It is well-established that urbanization has contributed to worsening inland flooding, with example disasters like Hurricane Harvey, but our work has demonstrated that urbanization of estuaries, through port dredging and wetland landfill development, has worsened extreme event flooding (Orton et al., 2020) and nuisance flooding at many locations around the United States (Li et al., 2021).

Public Health

Communities in the Northeast face several health risks from the impacts of climate change. These include heat related illness from rising temperatures, respiratory health impacts from worsening air quality, disease and displacement resulting from rising seas and coastal storms, and disruption of critical services like access to medical care during extreme events impact physical and mental health–impacts which are often disproportionately felt by marginalized and low-income residents. CCRUN's Health Team (PI-Kinney) has worked with stakeholders to produce actionable research for use in public health messaging, preparedness, and warning systems.

The overall objective of the CCRUN Health Team's work has been to examine health vulnerability to climate extremes experienced in urban areas of the northeast United States across multiple dimensions, including individual demographics and health status, individual and neighborhood-level economic status, built environment, exposures to temperature extremes, and exposures to other environmental risks including air pollution. Our work has involved analyzing and quantifying exposure-response functions linking daily morbidity and mortality outcomes to temperature and air pollution at the urban and suburban scales. Our initial efforts focused on the New York City study area, but over time expanded to Philadelphia and Boston. The team also

developed a series of future projections of health risks under a range of scenarios of climate change and vulnerability factors that have been used by city officials in assessing climate-related health risks in the context of climate action planning.

Incorporating Adaptation into Future Projections of Heat-Related Mortality

CCRUN Health Team researchers developed new models for incorporating adaptation into future projections of heat-related mortality, based on empirical observations over the 20th century in NYC. Using a unique dataset on daily death counts in NYC starting before 1900, we first quantified decade to decade changes in the exposure-response function linking high temperatures to increased death risk. This work revealed that heat-health responses decreased markedly over the 20th century, but that the pace of that decline showed signs of slowing in the last few decades. Our research speculated that increasing air conditioning prevalence may have been responsible for the observed decline in risk, an observation that has been replicated in other locations in the recent literature. The 2017 paper (Petkova et al., 2017) developed a model to project changes in risk into the future, in conjunction with both climate and population projections over the 21st century. This work found that increases in heat-health risks driven by climate change in the 21st century may be reduced, but not eliminated, by further reductions in the exposure-response function for heat and mortality.

Global Greenspace Indicator

In more recent work, for the Lancet Countdown on Health and Climate Change, CCRUN researchers developed a global greenspace indicator for their 2020 and 2021 reports. This indicator provides an estimate of the magnitude of green vegetation in global cities across all seasons using the satellite-based Normalized Difference Vegetation Index (NDVI), with values between -1 and 1, and higher values indicating higher greenness levels. Four exposure metrics were calculated for each city, including peak NDVI (maximum NDVI across all seasons); annual mean NDVI based on the four-season average; and the population weighted averages of the former. Researchers used publicly available data from the Landsat satellite and computed the indicator for 1,029 urban centers of over 500,000 inhabitants across 139 countries. 'Exceptionally High' greenness was defined as peak NDVI >0.7 and 'Exceptionally Low' greenness as peak NDVI <0.2. Peak NDVI in 2020 averaged 0.35 ('low') and annual mean NDVI averaged 0.29 ('very low'). Population-weighted averages were even lower (0.34 peak NDVI; 0.27 annual NDVI), indicating inequalities within urban centers regarding access to urban green space available. The metrics also identified global inequalities in access to urban green space, with 71 (81%) of urban centers in regions of 'low' human development in 2020 receiving NDVI ratings of 'low' to 'exceptionally low', compared to 143 (57%) of cities with 'very high' human development.

Water

The CCRUN Water Team (PI-Palmer) investigates how climate change may impact water supplies and quality in the urban Northeast, especially related to the impacts of drought on urban drinking water. The team has evaluated the Boston-NYC-Philadelphia urban corridor served by some of the major water supply utilities in the region. Using tools and models including ensemble hydraulic forecasting, the team can quantify improvements in water sector management and

provide climate information that builds resilience to droughts and other water-related impacts of climate change.

Working with stakeholders in Philadelphia, a new partnership, with a focus on hydrological modeling, was formed between CCRUN researchers and stakeholders in the metropolitan area. The goal of this research was to build a model of the Philadelphia water supply system. Stakeholder meetings focused on defining the scope of work, discussing on-going modeling problems, and reviewing climate downscaling methods. In addition, a modeling workshop was held where the CCRUN researchers had the opportunity to interact. Stakeholders involved in this new partnership include the Philadelphia Water and the Delaware Valley Regional Planning Commission.

In Phase II, the CCRUN Water team expanded their research to include the water systems in both Philadelphia and Washington D.C.. The addition of these two cities allowed for a more complete assessment of the vulnerability of water resources to climate risk in the entire Northeast region. In the Washington, D.C. area, CCRUN has established a connection with the Interstate Commission on the Potomac River Basin, which studies the region's water supply.

Key Findings

Providing water to major cities is a billion-dollar industry. Infrastructure investments in water supply for cities like NY City, Boston, Philadelphia, and the Washington, DC metropolitan areas impact tens of millions of people and are measured in billions of dollars. Our study suggests that investments to cope with anticipated increases in per capita water demands would be inappropriate unless the number of individuals served in these cities is expected to increase significantly in the near-term. The questions related to specific populations and disadvantaged or underserved communities are important but go beyond the granularity of our study. However, if utilities can push back in time investments to expand water supplies this does allow the possibility to not increase water prices directly due to system expansions.

Climate

CCRUN'S Climate Team (PI-Horton) provides the cities in the urban Northeast with the latest information on climate change and its potential impacts and offers recommendations on climate change adaptation and resilience strategies. The climate science team researches a variety of climate hazards including extreme temperatures and humidity, heavy downpours, droughts, and sea level rise and coastal flooding. This cross-cutting theme addresses communities' and decision-makers' need for relevant, useful, and timely climate information, working with regional stakeholders to build resilience to climate change.

The Climate Team has a) provided climate information and assessments for applications sought by decision makers, and b) advanced peer-reviewed applied research on climate impacts and adaptation. In practice these two activities are highly connected. For example, our stakeholder driven work with the Consolidated Edison energy company has fostered applied research on the relationship between humid heat, human health, and energy demand at urban scales. Similarly,

our applied research on how extreme heat impacts airplane take-off weight restrictions has been taken up in planning by entities ranging from individual airline companies to airplane and engine manufacturers, to individual airports with short runways.

Peer-reviewed publications have focused on impacts of, and adaptation to, short duration events. We have advanced understanding of the dangers of humid heat waves (Coffel et al., 2017a; Raymond et al., 2020a). We have assessed heat impacts on aviation (Coffel, 2017b), human health (e.g., Ngo & Horton, 2016; Petkova et al., 2017), infrastructure (e.g., (X. Chen et al., 2021) and agriculture (Kornhuber et al., 2020). We have also investigated the relationship between cold air outbreaks and forest pests (Lesk et al., 2017), and between extreme precipitation and agriculture (Lesk et al., 2020). Other applied research topics have included regional sea level rise and coastal flooding projections (e.g., (Horton et al., 2015) and review articles on emerging topics such as 1) compound extreme events (Zscheischler et al., 2020) and their impacts (Raymond et al., 2020b), and 2) science and legal dimensions of climate attribution (Burger et al., 2020).

Correlated Extreme Events

CCRUN, through Horton and 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 CCRUN has conducted important climate research on this topic, including (Kornhuber et al., 2020 and Raymond et al., 2020).

Climate Change Attribution Science

CCRUN, in partnership with legal scholars, began exploring 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 reduce emissions and 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.

Engineering and Urban Design

The Northeast is the most densely populated region of the country–a region where the built environment will play a central role in the ability of communities to adapt sustainably to a changing climate. The construction, operation, and maintenance of infrastructure systems also represent key components of our region's portfolio of greenhouse gas emissions, making infrastructure decisions central in devising pathways toward carbon neutrality.

Researchers in CCRUN's Engineering and Urban Design Team (PI-Montalto) performs multidisciplinary research in support of multifunctional infrastructure design. The team addresses challenges associated with urban heat islands, compound flooding, combined sewer overflows (CSO), and ecosystem loss, developing locally tailored guidance for municipalities, often with a specific focus on nature-based solutions like green infrastructure. Research efforts are concentrated on three areas: 1) research into the impacts of climate change on urban drainage systems, 2) nature-based strategies for building urban sustainability and resilience, 3) heat risk reduction.

The team engages with stakeholders through partnerships and educational opportunities including a seminar series to produce usable and accessible information on building resilience in the built environment.

The Impacts of Climate Change on Urban Drainage Systems

Collaborating with the climate team, CCRUN researchers developed a non-stationary precipitation generator that uses GCM outputs and historical relationships between precipitation, pressure, and temperature, to produce synthetic sequences of future hourly precipitation suitable for urban drainage system modeling (Yu et al., 2018;2019). The team organized a March 2020 workshop, "Adapting Stormwater Management for a Changing Climate" to discuss NOAA tools with stormwater utility representatives. The outcomes were incorporated into a novel course on stormwater modeling under climate change, offered for 20 Professional Development Hours (PDHs) to practicing engineers and students. With NOAA COCA and NOAA-AdSci funding, researchers are collaborating with the Philadelphia Water Department and community stakeholders to investigate flood scenarios in the Eastwick Neighborhood of southwest Philadelphia. The team has also been investigating urban drainage system response to extreme precipitation focusing on inlet efficiency (Shevade et al., 2020), model scale and resolution (Jeffers and Montalto, 2018), and strategic redirection of stormwater to parklands (Feldman et al., 2019) or its harvesting, storage, and non-potable use, e.g., toilet flushing and urban irrigation, (Rostad et al., 2016).

Nature-based Strategies for Building Urban Sustainability and Resilience

In the Northeast, nature-based strategies (NBS) have been implemented for stormwater management (e.g., by small, medium-sized, and large stormwater utilities throughout the region), as a form of coastal protection (e.g. along the shores of Long Island, and New Jersey), as well as for compensatory mitigation for development impacts (Miller et al., 2014). CCRUN's stakeholder partners are interested in economic valuation of the co-benefits of natural area restoration projects, green stormwater infrastructure (GSI), urban parks and forests and other enhanced, restored, and engineered green spaces.

Because many ecosystem services provided by NBS are determined by their ability to partition water, CCRUN has dedicated attention to monitoring critical hydrologic fluxes within different types of urban green spaces, especially evapotranspiration (DiGiovanni et al., 2018), soil moisture

patterns (Yu et al 2018, Alizadehtazi et al 2020), and canopy interception (Rakestraw et al., 2017, Alizadehtazi et al., 2019, Campellone et al., 2020), examining extreme and non-extreme events separately (Catalano de sousa et al., 2016a). In partnership with the Jacob K. Javits Center, the team has investigated the ability of large-scale green roofs to provide thermal buffering (Alvizuri et al., 2017), retain stormwater (Abdualfaraj et al., 2018), and reduce the intensity of the local urban heat island. Additional research has evaluated the impacts for forecasted extreme heat and extended flooding on urban vegetation, for example in GSI (Catalano de sousa et al., 2016b).

At the neighborhood scale, the engineering team investigated the ability of coastal green spaces to protect coastal property from the effects of Hurricane Sandy (Wong et al., 2020) and explored innovative strategies for managing street runoff within enhanced urban parks (Feldman et al., 2019). A central premise to this work has been that stakeholder perceptions can both constrain and amplify the ultimate application of NBS in urban communities. Experts and residents often disagree regarding the expected benefits of different NBS strategies, and where they should be implemented (Miller et al., 2014, Miller and Montalto, 2019). However, through agent-based simulations in Camden (Zidar et al., 2017), Philadelphia (Zidar et al., 2017b), and NYC (Wong and Montalto, 2020), the team has found that NBS programs customized to the needs and goals of specific neighborhoods present more opportunities for advancing broader sustainability and resilience goals, than programs optimized for one benefit (e.g., stormwater management).

Heat Risk Reduction

CCRUN's work in this area focused on measurement and modeling of urban microclimates, and piloting and evaluation of various strategies for reducing urban heat risks. We monitored microclimatic conditions in NYC and Philadelphia, using ENVI-MET to fill in the gaps between monitoring locations. 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 goal of this second 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.

Social Dimensions of Adaptation: Socio-Spatial Research on Adaptation

CCRUN's Social Science research (PI-Solecki) focused on developing new knowledge on climate adaptation and resilience practice that will be most useful for local climate risk managers and practitioners. The work involved a series of engagements centered around needs assessment regarding climate impact information and adaptation strategies, and the conceptual and operational links between everyday resilience practice and more profound and challenging transformative adaptation. Several key intervention sites were identified and formed the basis of the analysis and work. Researchers identified specific opportunities for CCRUN tools and skill sets to be used within the wider CCRUN region. The post Sandy context provided a perfect opportunity to understand the adaptation legacy and lessons learned from Hurricane Sandy, and how this can be (or was) translated to other cities. In particular, one of the research interests was

the role of extreme events, decision-making contexts and management practices that support the development of policy transitions. Central hypotheses for the work included: 1) Climate risk decision-making is driven by proximate drivers and underlying root and context drivers; 2) but that the capacity for transformative climate action is significantly connected to quality-of-life ambitions; and that 3) in specific situations, extreme events can become catalysts for advancing pro-active climate resilience.

Specific research findings include that 1) macro-adaptation strategies that are associated with positive community goals including economic development are better received than 'risk-reduction-only' strategies, 2) perception and definition of extreme events in individual communities are multi-faceted and these differences play a significant role on the capacity and structure of the communities response, and 3) effective municipal - community based organization interaction includes three forms of equity - distributional, contextual, and procedural equity.

Key Findings

Fundamentally, stakeholders and practitioners in the urban northeast require targeted decision support tools that are relevant for specific and action-oriented information needs. This research finding was a result of the CCRUN social science team's general needs assessment survey where stakeholders and practitioners noted that had many general "big box" tool kits to choose from but also needed more targeted "boutique" resiliency tools.

CCRUN social science researchers completed a survey and content analysis of urban resilience efforts along the Eastern seaboard of the United States 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. The team also found that the role of extreme events in driving policy change is quite variable.

Work on the climate coast program included 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. This research defined 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).

Community based organizations can be apprehensive about municipal level efforts at enhanced resiliency because of concerns regarding "green gentrification" and resiliency efforts which enhance the market value of their communities and costs of living for local, long-term residents.

Social Dimensions of Adaptation: Socio-Economic Research on Adaptation

CCRUN's Social Science Team (PI-Madajewicz) has advanced adaptation to coastal flooding in urban neighborhoods through four steps of the adaptation process: understanding vulnerability and resilience, co-developing approaches that advance adaptation in collaboration with decision makers, implementing those approaches, and evaluating their effectiveness. This research focused on coastal neighborhoods of New York City, especially Rockaway and Staten Island. Part of the work also investigated current and future exposure to flooding in Boston.

Evaluation

An ongoing impact evaluation is investigating if and how the co-production approach influenced attitudes toward taking adaptation actions in the communities and adaptation behavior. The research team is comparing changes in adaptation outcomes over time among community groups who participated in the co-production process and those whose members only had access to information developed and disseminated through the City of New York and other initiatives that have been engaging communities in considering flood risks. The evaluation will examine how lessons learned apply to other urban contexts. The evaluation uses a mixed method approach with a quantitative difference-in-difference, intention to treat, method based on baseline and follow-up surveys as well as qualitative analysis of workshop transcripts. An additional component of the evaluation work is the evaluation of CCRUN and of approaches to adaptation co-developed as part of CCRUN. An ongoing effort is to elaborate more complete program theories for CCRUN initiatives and use the theories to examine how CCRUN has influenced decision making about adaptation and adaptation outcomes in case studies.

Vulnerability and Resilience to Coastal Flooding

Interdisciplinary research showed how determinants of vulnerability and resilience to flooding among urban coastal residents differ from those typically used to develop social vulnerability indices, based on primary data collected to document recovery from Hurricane Sandy in Rockaway and Staten Island (Madajewicz, 2020, Madajewicz & Coriolo 2016). The research also showed that different types of vulnerability and resilience are distributed differently across socio-economic groups and these differences are important for decision making. Middle to low-income homeowners are less financially resilient to flooding than are renters, who may be poorer. Non-white populations are particularly vulnerable to loss of access to services, and especially to food. Households who have disabled or chronically ill members are more vulnerable and less resilient than others on all dimensions. The elderly do not show greater vulnerability or less resilience than do younger groups, but the research did not document impacts on physical and mental health. The study suggests the importance of indicators of vulnerability and resilience other than those typically included in social vulnerability indices, such as assets, ratio of expected damages to income, access to information, and presence of community groups with skills relevant to the hazard. The research provides a basis for developing a social vulnerability index that is more informative about who needs what kind of support and why in building resilience to flooding relative to commonly available indices that aggregate generic factors, which are believed to be associated with vulnerability to any hazard.

Assessment of co-production of information about flood risks

The preliminary results from the ongoing assessment of co-production of information about flood risks and benefits and costs of adaptation actions on residents' adaptation behavior suggest that information must be highly specific to the decisions that an individual resident can make to influence attitude toward taking action and potentially future behavior. While the need for information that is specific to decisions has received considerable discussion, what information is specific enough has not been well characterized. Information that is specific enough for residents of coastal areas includes flood risk that is specific to their individual homes, expected costs of flood damages for their individual homes, and similarly specifically quantified benefits of adaptation actions. Furthermore, discussions of individual risks and action options are sufficient to motivate communities to consider and begin to plan collective action. The ongoing co-production effort is developing very specific guidance regarding the type of information and engagement that influences adaptation behavior among residents and is catalyzing community-level planning for flooding.

Sustained Climate Assessment

CCRUN's initial work for the Sustained Assessment focused on support of the National Climate Assessment effort of the Northeast U.S. and the team's goal to expand their network to smaller cities,

To achieve this goal, the team initiated a collaboration with members of the GIS team in Westchester County, New York. The purpose of this collaboration was to bring attention to sea level rise mapping tools that support a wide range of geospatial applications for infrastructure management, emergency dispatching, health and human services, transportation systems, and environmental and land use planning in the area. Preliminary discussions and arrangements are being made to conduct a technical training workshop for a targeted audience who require such tools for regulatory compliance and infrastructure planning purposes.

Other initial activities in support of the sustained assessment have included Lead PI Horton's contributions as a member of the USGCRP Climate Scenarios Task Force and the Sea Level Rise Task Force. Both activities have had dual goals of supporting NCA4 and building sustained assessment capabilities, for example through the stakeholder contributions to the Sea Level Rise Task Force. Horton also was an author on the USGCRP-led Climate Sciences Special Report, which also serves the aforementioned dual goals. Co-Lead PI Solecki also supported the Sustained Assessment, through his authorship of the Northeast Chapter of NCA4.

With the hire of a Sustained Assessment Specialist in 2019, CCRUN ramped up sustained assessment activities to 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 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. 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 for the Managed Retreat Conference; and as the basis for planned publications in peer reviewed journals.

CCRUN's Role in the Region

In Phase II, CCRUN built strong partnerships with small- and medium- sized communities in the urban Northeast, while continuing to work with stakeholders in Boston, New York City and Philadelphia. New locations of engagement include (but are not limited to) Camden, New Jersey, Stamford, Connecticut, Westchester County, New York, and Ocean City, New Jersey. Recent project years also saw a greater focus on research at the smaller community scale. From organized climate forums with neighborhood partners to targeted community-based research, themes of environmental justice are integrated into the team's research. As the risk of weather and climate extremes continues to place strain on the vast network of infrastructure systems across the urban Northeast, CCRUN has maintained infrastructure as a core research objective, partnering with utilities in the region. Across the urban Northeast, CCRUN research is influencing decision-making across multiple levels of government. Presented here are a few key examples of projects which illustrate the well-established role of CCRUN in the region.

Partnering with Communities

As illustrated by CCRUN's climate science and public health teams' research, urban areas face significant heat-health risks, especially during the summertime. In New York City, residents of the Hunts Point neighborhood in the Bronx are disproportionately susceptible to these hazards as a result of legacies of environmental injustice--one example of which is the high concentration of major roadways that exacerbates the effects of the urban heat island. This places young children, elderly, lower-income residents, and those with pre-existing medical conditions at greatest risk. With the impacts of extreme heat already being felt in New York, the City's Department of Health and Mental Hygiene Heat wanted to better understand how heat risk varies across New York City.

Partnering with the Health Department, CCRUN researchers worked to analyze the spatial differences in heat mortality and morbidity. A social vulnerability index (for extreme heat) was developed by the CCRUN team and the index identified the South Bronx as an area with high heat sensitivity. The results from the research were then integrated into City policy, as the Mayor's Office of Resiliency used the vulnerability index as the foundation of their Cool Neighborhood's strategy. To execute this program and make it most effective, the City recognized the need to engage at the neighborhood scale through partnerships with community groups.

The Point CDC, a Community Based Organization in Hunts Point, was an important partner and collaborator in implementing the program at the community scale. The Be A Buddy program was developed to reach vulnerable residents in their homes, and was designed to prepare the community for future climate events through climate health education and community preparedness. The Program is aimed at increasing community resilience, reducing vulnerabilities to heat emergencies and extreme weather and promoting connections between local residents.

With the appropriate tools provided through the Be A Buddy, The Point is helping prepare residents in Hunts Point for extreme heat events. It encourages citizen science and lets residents be their own first responders. CCRUN research is supporting the important work Community Based Organizations are doing to help New Yorkers stay safe now and plan for the future.

Supporting Critical Infrastructure Providers

The dense infrastructure networks (e.g., transportation, telecommunications, energy, water supply) of the urban northeast are vulnerable to weather and climate extremes. The potential for cascading impacts, for example, transit system interruptions after a power outage, illustrates the interconnected nature of these systems and how the interdependencies of urban areas exacerbates these risks. CCRUN has worked with many utility providers and infrastructure operators throughout the urban Northeast, ensuring they have access to weather and climate and risk information that will inform their adaptation and resiliency planning. One example, working with the electric, steam, and gas utility New York City, Consolidated Edison, is presented here.

In December 2019, Consolidated Edison (Con Edison) released their Climate Change Vulnerability Study, 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.

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.

Working at Multiple Levels of Governance

In addition to working directly with communities, CCRUN researchers engage with both local (municipal and city) and state level officials. Science information developed by CCRUN is codified into policy and law in both New York State and New York City. Presented here are examples from New York State and New York City.

While conducting the Climate Needs Assessment for New York State, the Sustained Assessment Specialist co-authored the State of Climate Knowledge 2021 with the New York City Mayor's Office of Resiliency (MOR). 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.

New York City's Mayor's Office of Resiliency's Climate Resiliency Design Guidelines provide step-by-step instructions for City agencies on how to supplement historic climate data with specific, regional, forward-looking climate change data in the design of City facilities. The climate science the guidelines are based upon is a result of the work of CCRUN researchers participating in the New York City Panel on Climate Change (NPCC).

The guidelines establish citywide guidance on incorporating projected impacts from climate change into the planning, engineering, and construction, and renovation of City facilities and capital projects.

The integration of the NPCCs work into the City's resilience planning was further solidified this past year, with the release of updated Climate Resiliency Design Guidelines by the Mayor's Office of Recovery and Resilience, coinciding with the release of the NPCC 2019 report. Climate projections developed by CCRUN are the backbone of the guidelines, which provide step-by-step instructions for City agencies (e.g., Department of City Planning, Department of Environmental Protection) on how to supplement historic climate data with specific, regional, forward-looking climate change data in the design of City facilities. CCRUN also works with and helps inform the City's Climate Adaptation Task Force, which brings in entities from the broader metropolitan region, including the private sector.

The New York State Department of Environmental Conservation's Community Risk and Resiliency Act (CRRA) establishes a standardized set of sea level rise projections for the state of New York. These projections were developed by CCRUN Climate and Coasts team members. The CRRRA requires applicants for permits or funding in certain programs to demonstrate the sea level rise and coastal flood risk have been considered. The Act also requires DEC, working with the New York Department of State, to develop guidance on the use of natural systems to enhance community resilience.

Phase II Accomplishments

In addition to the relationships CCRUN has developed across the urban Northeast, CCRUN's accomplishments can in part be measured by the impact that they are having on stakeholders. While this includes policy decisions, CCRUN's success is also reflected by our programming (workshops and other stakeholder engagement events), data tools and resources developed, and legacy with decision-makers. Highlighted here are key examples of each.

Workshops and Stakeholder Engagement

CCRUN co-organized and participated in a number of workshops over the course of Phase II. Throughout Phase II, CCRUN also continued our Green Infrastructure, Climate, and Cities Seminar Series, which included special events with other NOAA partners. These forums are an opportunity for CCRUN researchers to present their research while also allowing stakeholders to provide critical feedback, which in turn can influence the research agenda.

At What Point Managed Retreat?

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. 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.

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.

Towards the end of Phase II, in June of 2021, CCRUN again helped co-organize the 2nd Managed Retreat Conference. The conference featured multiple panels and sessions related to sustained assessment. One panel, titled Regional Perspectives on US Relocation and Migration: A NOAA RISA Panel included presentations from CCRUN, GLISA, Pacific RISA, and ACCAP. A second panel featured CCRUN's Sustained Assessment Specialist 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. Close to nine-hundred and fifty people attended the conference and approximately 300 people presented across over 50 sessions.

Coastal Community 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.

Workshop on Correlated Extremes

CCRUN co-hosted the Workshop on Correlated Extremes, which took place at Columbia University on May 29-31, 2019, preceded by an evening panel on May 28. It featured a blend of invited talks and abstract submissions (both talks and posters), with a significant amount of time devoted to discussions. Total in-person attendance was around 175 people, which included CCRUN team members and stakeholders.

The goal of the workshop was to aid in coalescing the community of interested researchers and practitioners around shared definitions, themes, best practices, and future research priorities. The organizers are optimistic that the cross-disciplinary interactions the workshop will foster will contribute to inspiring future research and supporting actionable science and risk calculations.

There is emerging recognition of the societal impacts associated with climate extremes that occur close together in space or time. There is also growing evidence that we may be approaching critical "tipping points" in the climate system. The close interconnectivity of systems and networks makes certain combinations of events especially hazardous from an impacts standpoint. This is particularly true in urban environments like the CCRUN project region, where complex social, economic, infrastructure and transportation systems are exposed to climate hazards.

As awareness of these events increases, the body of research on correlated climate extremes and their impacts is rapidly growing and encompasses a wide variety of event types. Advances in atmospheric and climate science, statistics, policy, and social sciences all contribute to the knowledge base on correlated extremes. This topic is a growing interest to the RISA network and CCRUN has worked with other teams on a manuscript for peer-reviewed journal submission.

Community Engagement Workshops

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.

Stormwater 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

CCRUN Seminar Series

CCRUN continued their longstanding Green Infrastructure, Climate, and Cities and seminar series over the course of Phase II. A broad array of topics have been covered through the series, where for each event, invited speakers present on general themes related to climate science, climate impacts, adaptation and resilience, and mitigation. The series has hosted subject matter experts, allowed for cross-RISA collaboration, and engaged a number of local partners and community groups. Over 50 seminars were held in Phase II, with hundreds of attendees (both online and in person). All of the seminars are available for viewing online via CCRUN's website. In 2019, Drexel University, where PI Montalto leads the seminar series, applied for and was approved to be a sponsor of issuing Professional Development Hour credits for Professional Engineers.

The seminar series has also been used to host special events. In May of 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.

Another special webinar, also held in May 2020 and put together in collaboration with NOAA's Climate Program Office, was titled "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, along with other NOAA participants. One key outcome from this effort was more organized RISA (network wide) efforts on social science research.

Data Tools and Resources

During Phase II, CCRUN researchers worked on a number of data tools and products, making data accessible to stakeholders to directly support decisions while also informationally providing an opportunity curious individuals to visually explore climate impacts. Some of the tools developed

by CCRUN also provide real-time data which can be critical during extreme weather and climate events.

AdaptMap

AdaptMap uses a dynamic flood model to demonstrate how sea level rise may worsen storm-driven flooding in Jamaica Bay and enables users to select flood adaptation scenarios to see how they reduce flooding. In addition to visualizing flood impacts, map layers and animations are also available for stakeholders to download. A user could, for example, view an animation of the Bay for a 100-year storm tide, under a medium sea level rise scenario, and compare three different adaptation options to better understand current and future risk to Jamaica Bay

One feature of the tool is the ability to view a cost benefit analysis of different adaptation options for Jamaica Bay. The three adaptation scenarios included emerged from a flood mitigation workshop that was held with government agency representatives, urban planners, designers, scientists, and the general public, to take input on an initial set of concepts and allow for new ideas to be contributed.

Through the analysis stakeholders have access to detailed breakdowns of the implementation costs and estimated economic damages avoided for the following adaptation scenarios: inlet narrowing; narrowing and sand replenishment; and narrowing and shallows restoration. This data allows stakeholders to assess the monetary losses, number of damaged buildings, hospitals impacted, land area flooded, and many other impacts associated with different storm return periods from 5 to 1,000 years. A cost-benefit ratio is provided for each option. Results of the analysis show that all three nature-based adaptation options are cost effective over the time period of 2016 to 2055 and can reduce large amounts of flooding and damage. This is true even under high discount rates of 7%, where the most expensive option--inlet narrowing with shallows restoration--estimates a net saving of more than $675 million by 2055. For a relatively cheaper adaptation option like inlet narrowing alone, the analysis shows net benefits of $793 million (discount rate: 3%). The range of adaptation options, discount rates, and damage data available through AdaptMap's benefit cost analysis supports stakeholders in decision-making processes in Jamaica Bay and builds capacity for long term adaptation planning.

Hudson River Flood Impact Decision Support System

The Hudson River Flood Impact Decision Support System tool illustrates the scale of potential flooding in the Hudson River Valley under different sea level rise and storm scenarios. Stakeholders within the region, including municipal and regional planners, can access the tool to help prepare for future flood events. When using the tool, the user is able to view critical infrastructure, such as transportation and emergency services, along with the flood map, allowing them to identify those areas that may become vulnerable in the future. A unique feature of the tool is that it includes freshwater flowing into the Hudson River, in addition to tides, storm surge, and sea level rise, therefore illustrating the combined impacts of heavy rainfall and coastal flooding. The tool was also upgraded to include tidal flooding and a broader geography (Westchester New York, on Long Island Sound).

Stevens Flood Advisory System

Stevens Institute runs the Stevens Flood Advisory System (SFAS) that is widely used for flood warnings and improves emergency response and adaptation to nuisance flooding and storm-driven flooding. In addition to posting data on our forecast webpage (http://stevens.edu/SFAS) and notifying people of impending flooding via email warnings, we are now providing probabilistic water level forecast data to the National Weather Service Weather Forecast Offices at Upton and Mt. Holly. They have both 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. Now, they are using the numeric data from our system in their Total Water Level forecast system to help inform their forecast guidance. Under CCRUN funding, 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.

Climate Summary Gauges

The Northeast Regional Climate Center's Climate Summary Gauges are based on daily data from the ThreadEx dataset developed by the NRCC. The long-term time series of each variable is sorted and divided into four segments, each containing one quarter of the total available data. These quarters correspond to categories from below normal to above normal climate conditions at stations throughout the Northeast. Stakeholders can access the tool for local climate statistics for a number of stations throughout the urban Northeast.

Social Science Toolkits

CCRUN's social science team worked to develop decision-maker toolkits focused on knowledge co-production and proactive planning. Post Extreme Event Learning Toolkit (PELT) and Macro-Adaptation and Resilience Toolkit (MART). These tools are intended to be applied to a range of local and regional sectors in support of a) disaster risk reduction and resiliency plans and b) project level investment strategies.

PELT is a boutique toolkit that allows a diverse range of users to take full advantage of the post-extreme event "policy window" by providing a moment for reflexive or individual based assessment; collaborative or co-production of knowledge; and collaborative action to address future events. PELT uses four modules that attempt to address the following questions: 1) What is the event and why is it important to learn about it? 2) What do we know and need to know about this event? What can we learn from each other? 3) How do we communicate our knowledge of these events to others? 4) What are the next steps for continued learning?

MART provides a template for multi-stakeholder groups to examine the discourse surrounding climate change and risk in order to transform short-term adaptation measures into long term, macro-adaptation processes. In order to make these toolkits successful and equitable in diverse stakeholder environments (e.g. community organizations, practitioners, researchers, and private

interests), the team is looking into potential partnership with outside non-profits who already specialize in community-based environmental justice work.

Scientist-Stakeholder Collaboration Process

The New York City Panel on Climate Change, an advisory body to the New York City's Mayor Office, in many ways represents the strength of scientist-stakeholder collaborations, such as those spurred through the RISA program, and demonstrates how co-generated science can influence decision-making. It's a model for other communities and municipalities to follow and has been a focal point of CCRUN's research since it began in 2010.

Established in 2008, the NPCC, in-part through the support of CCRUN, has pushed new boundaries of urban climate science, enabling New York City to set an example for other cities of how science-stakeholder partnerships can achieve science-based responses to climate change challenges. The recommendations of the NPCC have been incorporated into tangible resilience policies, including those that are helping the City to rebuild after Hurricane Sandy, and to withstand the impact of a changing climate in the decades to come.

During CCRUN Phase II, the NPCC celebrated its 10th anniversary (2018/2019), corresponding with the release of the third NPCC Report. CCRUN team members and researchers have contributed to the Panel, whether it be preparing the climate projections of record for New York City, working as lead chapter authors, or serving as panel Co-Chair.

One of the key recommendations for policy in the report is:
"The City should task the NPCC to coordinate with other regional organizations, such as the Consortium for Climate Risk in the Urban Northeast (CCRUN), to conduct integrated climate assessments for the New York metropolitan region on a regular basis. These assessments should encourage the participation of a wide range of city and regional agencies and communities, and a full range of systems and sectors."

As researchers on the team work with stakeholders outside of the City, CCRUN can be the vehicle that brings together information that would be best shared across groups. With well established relationships in place and a strong scientific team, CCRUN stands ready to fill this need of being the science in place, in time, as it has been in years past.

Following the "model" of the NPCC, towards the end of CCRUN Phase II, team researchers in Philadelphia, working closely with the City of Philadelphia and the Delaware Valley Regional Planning Commission, began 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 developed a Climate

Resilience Research Agenda (CRRA) for the Philadelphia region.This effort was organized and convened by co-PI Dr. Montalto and his colleagues at Drexel.

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
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. Co-PI Dr. Orton is participating in the Regional Climate Change and Cascading Hazards working group, co-led by CCRUN program manager, Daniel Bader.

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

NOAA Partnerships

Organization/Agency/Division	Short Projection Description
NOAA Northeast RCSD	The stormwater workshops organized by CCRUN and MARISA were supported by the Northeast Regional Climate Services Director.
NOAA Northeast Regional Climate Center	Working with the Northeast Regional Climate Center, CCRUN developed a climate summary gauge which provides climate data for stations throughout the Northeast.
NOAA Sea Grant	The Community Flood Watch Project helps empower residents to report flooding events in their neighborhoods. By training citizens to document flooding, linking local observations and community knowledge to scientists and city leaders working on flooding issues, will allow their voices and concerns to be heard.
NOAA Sea Grant	CCRUN partnered with NY Sea Grant and the Science and Resilience Institute at Jamaica Bay (SRIJB) on a community climate forum series.

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