WHEN CITIES PLAN FOR HEAT:

A COLLABORATIVE FRAMEWORK TO INTEGRATE PLANNING AND CLIMATE

by

MARIANA BARRETO ALFONSO FRAGOMENI

(Under the Direction of J. Marshall Shepherd and Rosanna G. Rivero)

ABSTRACT

Heat and extreme heat events are the deadliest weather-related hazards in the United States, and kill more than hurricanes, tornadoes and floods. Heat vulnerability is a field of study in urban climatology focused on the impacts of heat on human health and well-being. Studies in this field have shown that social and environmental factors play a role in determining vulnerability and are related to urbanization. Land-use planning is responsible for decisions that regulate and ultimately alter the urban form and land use; therefore, it is in a position to assimilate findings from heat vulnerability studies to reduce risks human life and well-being. Yet, while there are clear intersections between urban climatology and land-use planning, studies have indicated limited interactions between both disciplines and suggest that struggles are related to knowledge gaps.

Using Chatham County, Georgia, in the United States, as a case study, this dissertation uses an integrative research approach to explore the challenges of applying urban climatology in land-use planning. It uses co-production lenses and geodesign as additional theoretical frameworks that examine the use of heat vulnerability studies in the development of a heat response plan. This study works in collaboration with planners to understand the data needed to support decision-making. It explores the production and application of knowledge to better understand if struggles to the application of urban climatology in land-use planning are linked to methodological and practice. Findings from this dissertation indicate that Chatham County has seen land surface heating over a 20-year period, and that this is further linked to specific land cover changes, specifically from tree cover to high density urbanization. It also finds that a systemic approach allowed planners to confidently use heat vulnerability data, as it supported the use of experiential knowledge to contextualize information. Finally, this research shows that planners rely on thought processes that seek to contextualize and visualize information as a source of inspiration and in support of a vision for the future. Furthermore, information is used to ensure the legitimacy of actions and to reduce the risk of failure. It is also used to create guidelines and performance standards that support and justify action. This dissertation concludes that the production and application of urban climate data in land-use planning can be established through collaboration, and as a co-produced process. It also proposes the need for planning strategies that embrace revision and explore a cyclical approach to knowledge transference, which would foster the incorporation of new knowledge as it is produced.

INDEX WORDS: Heat vulnerability, Urban climate, Land-use planning, Co-production, Heat response planning, Knowledge transference

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DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2019

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August 2019

DEDICATION

I dedicate this work to my family, for without them I would not have gotten this far. To my husband Breno, who helped me push through and believed in me throughout my journey as a graduate student. We dared to dream and accomplished our goals together. To my daughter, Ana Clara, may this be a symbol of perseverance and an inspiration to follow your dreams, wherever they might take you. And to my parents, who taught me that love overcomes distances, and have always been by my side, even when we are miles apart.

ACKNOWLEDGEMENTS

First, I would like to thank my advisors J. Marshall Shepherd and Rosanna G. Rivero and my committee members, Jennifer Rice, Andrew Grundstein and Nik Heynen for the time and patience dedicated to help me through the process of attaining this degree. To Sergio Bernardes, associate director of UGA's Center for Geospatial Research, for all the support and time dedicated to developing the data that was critical to this research. To the University of Georgia's Graduate School for awarding me with the 2017 Innovative and Interdisciplinary Research Grant and the 2018 Summer Research Travel Grant for Doctoral Students. To the Coastal Regional Commission of Georgia, for the financial and technical support, that enabled me to develop a workshop in Chatham County. Especially, to Lupita McClenning, former director, and Russell Oliver, senior planner, for their time, effort and support in making the Heat Response Planning workshop happen. To the University of Connecticut's Department of Plant Sciences and Landscape Architecture for giving me the space, support, and resources to finish my dissertation from a distance. Especially, Peter Miniutti, coordinator of the Landscape Architecture program, who made me an integral member of the LA group. A special thanks to my friend and colleague Manasi Parkhi, who took time off her own research to help me in the workshop, taking notes and observing the activities. And finally, to my friends in the Department of Geography, in the Integrative Conservation Program and in my Brazilian community, you made my time in Athens a unique and memorable experience. You were my family away from home and I will cherish your love and support forever.

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INTRODUCTION AND LITERATURE REVIEW

Heat is the deadliest weather hazard in the United States (Borden and Cutter 2008). According to the National Weather Service (NWS 2019) over a fifth of all weather-related deaths, between 1986 and 2018, were attributed to heat. Studies in heat vulnerability have shown that particular groups of people are more likely to suffer from heat-related morbidity and mortality (Cutter, Boruff and Shirley 2003, Sheridan and Dolney 2003, Sheridan, Kalkstein and Kalkstein 2008, Johnson, Wilson and Luber 2009), furthermore, impacts are directly related to urbanization and urban land cover (Clarke 1972, Sheridan and Dolney 2003, Johnson and Wilson 2009, Reid et al. 2009). More importantly, heat vulnerability is expected to increase as the result of climate change and rapid urbanization (KC, Shepherd and Gaither 2015).

Literature on urban climatology has detailed the impacts of the built environment on climate. It has pointed to direct causes for change and suggested the need to apply urban climate knowledge in fields such as urban planning and decision-making (Kratzer 1937, Lowry 1977, Voogt and Oke 1998, Oke 2006, Souch and Grimmond 2006, Seto and Shepherd 2009, Stewart and Oke 2012, Webb 2016). On the other hand, urban planning literature indicates limited approaches to address how practice may reduce climatic impacts at a city or regional scale, such as Alcoforado et al. (2009), Demuzere et al. (2014), and Eliasson (2000). Moreover, very few planners and climatologists have attempted to address the limitations and barriers that exist to develop plans and projects that address urban climate at the city or county scale (Snyder et al. 2012).

Heat, like many climate issues, is a complex problem that is being exacerbated by climate change, and impacts not only our environment, but also our personal health and well-being. The urgency and 'wicked' nature of complex issues, such as heat, have pushed for the production of 'usable' knowledge that is co-produced by climate scientists and practitioners (Cash, Borck and Patt 2006, Dilling and Lemos 2011, Lemos et al. 2014, Meadow et al. 2015). However, struggles to the application of climate science still exist, and indicate that there are additional factors that limit the use of knowledge in land-use planning. The development of climate-oriented land-use planning is linked to a better understanding of the barriers that exist in the transference and application of knowledge among the urban climate and land-use planning fields. This requires studies that apply mixed methods and explore plural epistemologies to comprehend the multiple facets of knowledge production, circulation and application (Goldman and Turner 2011). In this dissertation, I apply an integrative approach to understand how urban climate data can be incorporated in land-use planning, by exploring the production and application of data to support heat response planning in Chatham County, Georgia.

1.1 Purpose of the study

This project is based on the premise that struggles in the incorporation of urban climatology, as a component of plans at a city scale, are related to methodology and practice. It begins by observing how on the one hand urban climatology, through simulations and models, sees the urban climate as a dynamic process that changes over time, while land-use planning, using overlay methods, looks at climate as a layer of the urban fabric, either as a moment or as a synthesis of time. Therefore, unlike urban climatologists, planners either disregard or synthesize spatial-temporal characteristics of the urban climate (Figure 1.1). To intersect both disciplines and overcome the differences in methodological approaches, this project uses the development of a heat response plan to understand the struggles of knowledge transference and application among the two disciplines. It uses heat vulnerability as a focus indicated by local decision-makers, that combines multiple and dynamic climatic processes that affect human life and well-being.

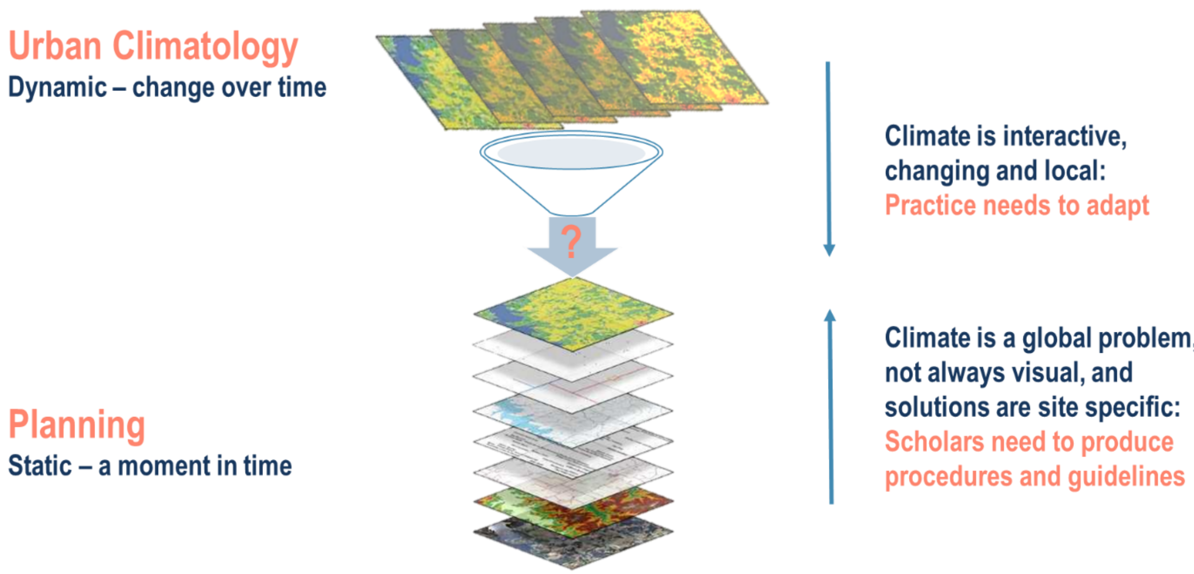

Figure 1.1 *- Methodological divergences between urban climatology and physical planning.*

1.2 Case Study

Chatham County, Georgia, is situated in the southeastern coast of the United States (US) and has narrowly addressed urban climatology in land-use planning by focusing on flooding and sea level rise. According to the US Census Bureau (2010), it had a population of 265,128 in 2010 and based on recent population estimates it grew to 290,501 people by 2017. It is the most populated county in the region (Figure 1.2) and its county seat and largest city is Savannah, also the fourth biggest city in the state of Georgia.

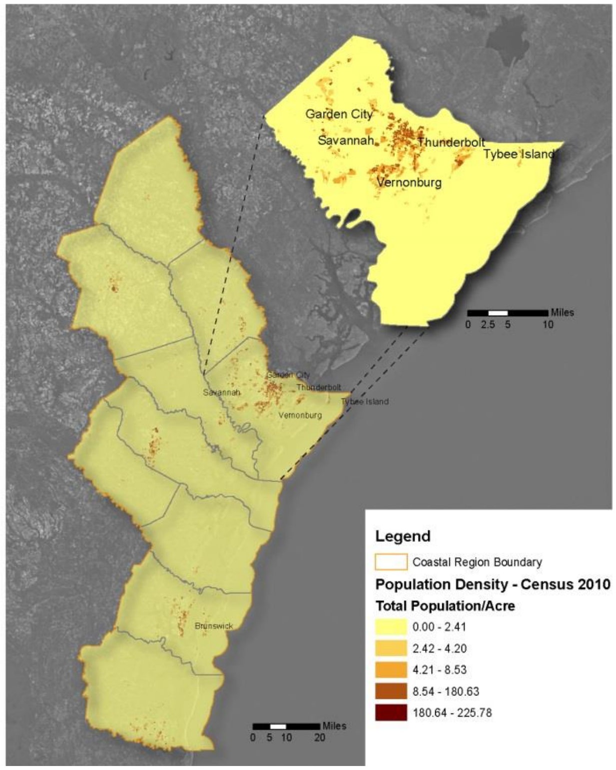

Figure 1.2 *– Population density of the Georgia Coast, based on the 2010 US Census. This image highlights Chatham County, and illustrates a higher population density in comparison with the coastal region.*

Savannah is a historic port city and one of the state's main tourist attractions. Situated in a hot and humid climate, the city houses and attracts several people who are potentially vulnerable to heat (Table 1.1). Social vulnerability to environmental hazard is strongly associated with age and social economic status (Cutter, Boruff and Shirley 2003). In the case of Chatham County population projections from the Savannah Metropolitan Planning Commission indicate an expected 70.8% growth for the over 65 years of age population group by 2030. Studies in heat vulnerability have indicated a high association between populations over 65 years of age and heat mortality and morbidity (Sheridan, Kalkstein and Kalkstein 2008, Reid et al. 2009, Johnson et al. 2012, Maier et al. 2014). This population group is linked to pre-existing conditions such as diabetes, pulmonary and heart diseases, along with other physiological factors that reduce the body's ability to maintain a normal thermoregulatory process.

Table 1.1 *– Demographic profile of Savannah, GA with estimated percentage of heat vulnerable populations.*

Total population estimate 2016	**146,763**
Infants and children age 0 to 5 years[1]	7.1%
People 65 years of age and older[1]	11.7%
Low-income population[1]	25.4%
Fluctuating population estimates	
Annual tourist population 2016[2]	13.9 million
Homeless population[3]	4,513

[1] U.S. Census, 2018 – estimates from 2010
[2] Savannah Area Chamber of Commerce, 2018 Economic Trends
[3] Chatham Savannah Authority for the Homeless, 2018 (https://homelessauthority.org/about-homelessness/)

Furthermore, recent reports cite Savannah as a city potentially at risk for extreme heat exposure and point to the need for plans that identify and mitigate heat related risk factors (ASTHOCCC 2014, USGCRP 2016). Additionally, Savannah's historic downtown serves as a contrast to contemporary land-use planning practices used in the city. This example of colonial land-use planning, designed by James Oglethorpe (de Vorsey 2012), is composed of multiple urban parks inserted within the built environment. The contiguous presence of green space promotes wind flow and mitigates the effects of urban heat islands in the neighborhood (Debbage and Shepherd 2015), which is unseen in other regions of the city. The use of Chatham County as a case study allows this research to investigate two issues at the intersection of climate and land-use planning: (a) how professional practice can apply urban climatology in a county scale, and (b) how heat vulnerability can be the missing link to the application of urban climatology in planning.

1.3 Theoretical Framework

The research presented in this dissertation was theoretically influenced by work on integrative research approaches (Hirsch et al. 2013). It seeks to break away from disciplinary silos and demonstrate more nuanced, plural and incommensurable aspects of social-environmental problems (Miller et al. 2008). Integrative research is a process that explores issues through "lenses" that focus on perspectives of value and valuation, process and governance, and power and inequality, rather than strict disciplinary views (Hirsch et al. 2013). It supports the production of "agile science", that though grounded on a specific discipline seeks to be "(a) be conversant across a range of disciplines and knowledge domains, (b) move easily between the worlds of academia and practice, and (c) translate research into action" (Welch-Devine et al. 2014).

As Hardy (2018) describes, the use of integrative research approaches can support research that aims to recognize and address the tensions that surface when different visions come together in issues such as hazard research and planning. In this dissertation this overarching theoretical framework is used to explore heat vulnerability from a co-production perspective. It seeks to understand the needs of planning practitioners and focuses on the application of climate knowledge, while trying to grasp the processes and tensions that derive from different points of view. Though at its core the research focuses on the study and application of urban climatology, focused on heat and vulnerability, it uses the co-production framework as a way to understand how knowledge in heat vulnerability can be used in land-use planning (Dilling and Lemos 2011, Meadow et al. 2015), and as a way to explore the processes used by planners to produce, circulate and apply urban climate knowledge (Goldman and Turner 2011). Furthermore, it tries to understand the processes that lead to the usage, or not, of knowledge in practice, and how new forms of knowing support, or conflict, with institutional processes and social order (Jasanoff 2004, Hilgartner, Miller and Hagendijk 2015b).

1.4 Chapter Summary

In broad terms this dissertation attempts to answer the following question: *How can climatological data be incorporated in the planning of the built environment in Chatham County,* *Georgia?* Each chapter in this research attempts to address a facet of the production and application of urban climate knowledge, in the context of heat vulnerability planning, to investigate if and how barriers to the transference of knowledge between urban climatology and planning are linked to methodological and procedural divergences, rather than disciplinary knowledge gaps.

Chapter 2 focuses on the knowledge produced to support the co-production of a heat response plan. It introduces the topic of heat, and through the analysis of land surface temperature (LST) it contextualizes the dynamics between land cover changes and increases in land surface temperature over time. This chapter presents an analysis of spatial-temporal changes in land cover data and surface temperatures to address the question: **In what way can analysis of spatial-temporal changes to land cover and temperature aid land-use plans to define and address socio-environmental thresholds related to urban climate interactions?** It uses remote sensing techniques to analyze thermal and land cover changes during a 20-year period (1992-2011). It hypothesizes that the combined analysis of changes in land cover and temperature over time could indicate what types of development are linked to higher climatic impacts. Furthermore, it discusses the implications of this study to decision-making and the use of the findings in adaptation measures that support the incorporation of tree canopy cover. It also suggests that the methodology applied to synthesize the findings produce spatial-temporal maps that can be applied in both climate planning and heat vulnerability studies.

Using some of the data developed for the previous chapter, Chapter 3 focuses on addressing the sub-question: **How can heat vulnerability mapping be applied in county scale land-use plans to inform decision-making on urban climate interactions?** It discusses the combined use of an 'iterative interactive' co-production and geodesign frameworks to develop a collaborative approach to heat response planning. It aims to address the hypothesis that difficulties in the application of urban climatology in planning are related to methodological mismatches, that go beyond the need for creating new models or simulations. Furthermore, it hypothesizes that the use of heat vulnerability can aid the process of collaboration between both disciplines and visually depict social and environmental aspects of urban climatology that are adaptable to decision-making methods used in land-use planning. This chapter uses the concepts of heat vulnerability and applies it in a 1-and half day workshop. Yet rather than incorporate a mapped heat vulnerability index, the study presents the data that indicates heat vulnerability and allows practitioners to discuss and determine if and how data will be used. The findings from this chapter demonstrate the usage of climate data and the proposal of a heat response plan that is informed by concepts of heat vulnerability. This process enabled practitioners to use their local and experiential knowledge along with the urban climate data. Therefore, this chapter points to an approach that moves beyond complex models and numbers, and furthermore, is adaptable to local practices and knowledge.

Finally, Chapter 4 explores a critical human geography lens of co-production to observe and discuss the process of knowledge usage, based on observations, dialogues and recorded notes of the workshop described in Chapter 3. In addition to discussing the qualitative findings of the applied methodology, explored in Chapter 3, this chapter draws on interactional co-production to offer a perspective on methodological mismatches between both disciplines. It attempts to address the question: **How can planning practitioners and urban climatologists utilize a coproduction framework to cultivate better understandings of the dynamic, localized, and socio-environmental aspects of urban climate interactions?** This chapter hypothesizes that specific methodological approaches determine the usability of knowledge and are further tied to the barriers of knowledge transference between the studied disciplines. The findings in this chapter lead to discussions of how knowledge is used to create multiple levels of policies that are designed to legitimize and justify action. Furthermore, the findings indicate the use of knowledge as a ‘fail-safe’ and support action, while safeguarding planners from potential critiques. This chapter concludes that barriers to knowledge transference are linked to uncertainty and nuance. It also discusses the need for planners to acknowledge and embrace trade-offs, recognizing the possibility of failure. Moreover, this chapter discusses the importance of a collective vision for the future as the source of inspiration for planners. Discussions of climate change are dire and do not fit in to the visions created by local communities. Therefore, urban climatologists need to communicate certainties expressing the trade-off and explore the use of scenarios. This approach would give planners the autonomy to decide on how to act and allow the use of practioners’ experiential knowledge.

1.5 Literature Review

1.5.1 Urban climatology and planning

Literature at the intersection of climate and planning, from perspectives in land-use planning and design practices, point to the use of climatic recommendations with regards to site selection, urban fabric, public spaces, landscaping, and vegetation, in general terms (Eliasson 2000, Romero 2001, Alcoforado et al. 2009, Mehmood, Crawford and Davoudi 2009). Many authors in urban climatology have pointed to the incorporation of climatic elements as part of design guidelines and project considerations (e.g. (Kratzer 1937, Lowry and Lowry 1988, Olgyay and Olgyay 1992, Givoni 1998, Hebbert and Webb 2012, Webb 2016). These publications focused mainly on temperature, relative humidity, nebulosity, precipitation, wind and solar energy and how these impact human health and well-being. In other words, these studies address issues of human bodily responses, in comfort or stressed, to climatic interactions. Yet, in most, the approach to dealing with climatic variables is depicted as site specific. Furthermore, these studies discuss interactions on a city scale, but for the most part prescribe solutions at block, site, and/or building levels. On the other hand, concerns about the impacts of cities on the natural environment, have led urban planners to marginally address climate. For instance, two influential authors in planning, Ian McHarg (1971) and Kevin Lynch (1960), discuss the use of variables relative to terrain and natural resources in planning methodologies.

In urban climatology, literature looks at the interactions of the existing urban form and how climate responds to changes in land-use and land cover (Lowry 1977, Voogt and Oke 1998, Oke 2006, Seto and Shepherd 2009, Demuzere et al. 2014). Applied approaches date back to 1937 when Pater Albert Kratzer, a German meteorologist published a book called Das Stadtklima – The Urban Climate. Kratzer's book led the city of Stuttgart, Germany to hire a meteorologist in its Environmental Planning Agency. Romero (2001) points out that not many literary examples reference guidelines that would enable land-use planners to address climate in a city or regional scale. One of the few existing examples is a book entitled Atmospheric Ecology for Designers and Planners by Lowry and Lowry (1988). While this publication goes into detail on how urban climatology could be incorporated into planning, it is not a vastly cited book in the field. The need for identifying design and land-use planning strategies has led to the ongoing Urban Heat Island Network project (Snyder et al. 2012), that attempts to call upon academics and practitioners to collectively discuss how studies in UHI can aid decision-making and design. This project intends to further address the application of urban climatology in planning, specifically focusing on land-use planning practice, and how it relates to scale, as well as, dynamic and localized effects of climate.

This project identifies the methodology proposed by Ian McHarg, described in his book Design with Nature (1971), as the basis for current land-use planning practices. In this work

McHarg outlines spatial analysis overlay techniques that are currently implemented in technologies such as geographic information systems (GIS) and technology frameworks such as GeoDesign (Goodchild 1992, Tomlinson 2007, Steinitz 2012, Rivero et al. 2015). The methodology narrowly includes climate, targeting specifically air pollution, urban hydrology, and riparian buffering. It also recognizes these elements as climatic features linked to urban form that could be mapped and analyzed. This approach is key to the questions posed in this project, as McHarg's methodology, through the application of Geodesign (Steinitz 2012), set the basis for analysis techniques currently used in planning practice. Furthermore, it gives further insight on how (a) climate is narrowly discussed, lacking a consideration of impacts to society; (b) it is addressed in a stationary form, not accounting for changes over time; and finally, (c) the methodology points to a specific form of practice, heavily reliant on visualization and generalization of the variables it accounts for.

1.5.2 Heat vulnerability as a link between land-use planning and urban climatology

Human bioclimatology is a sub-field of urban climatology. In this study it is used as a form of rendering visible the ways in which urban climate impacts human well-being and health (Mayer 1993, Auliciems 1998, Jendritzky and Grätz 1998, Fagence et al. 2013). More specifically, this study draws on literature in bioclimatology that discusses heat vulnerability, therefore, the risks and impacts of heat and exposure to extreme temperatures on human life (Sheridan and Dolney 2003, Wilhelmi and Hayden 2010, Johnson et al. 2012, Maier et al. 2014). In general, studies in the field of heat vulnerability attempt to express the experience of climate and point to unique and individualized perceptions of temperature. Furthermore, this metric seeks to recognize how the combination of climatic components can cause discomfort, stress and health hazards to particular groups of people (Sheridan and Dolney 2003). Several studies have pointed to the capabilities of heat vulnerability as a component to decision-making (Reid et al. 2009, Wilhelmi and Hayden 2010, Johnson et al. 2012, Maier et al. 2014), yet, as Wolf, Chuang and McGregor (2015) indicate most studies in this field have not attempted to apply the methods and data produced, or engaged with decision-makers during the development of the data. Therefore, they have not resulted in a replicable application in land-use planning in the US. This dissertation seeks to analyze in what ways bioclimatology, specifically heat vulnerability, could be incorporated into planning methodologies and in what ways it can align with trends in land-use planning focused on social vulnerability and resiliency, depicting temporal and dynamic aspects of climate in relation to human well-being and health.

In planning, the term vulnerability has become vastly used as a way of defining social and environmental exposures to risk (Cutter et al. 2003, Cutter and Finch 2008, Mendes 2009, KC et al. 2015). The identification of vulnerabilities to climate have generated future land-use plans and policies that intend to promote resilient communities. Better known as resilience planning, this approach is applied as the capacity of a city, to bounce back from a disturbance or natural disaster (Holling 1973, Walker et al. 2004). Resilience plans focus on three issues: (1) the ability of a city to absorb or buffer disturbances and still maintain its core attributes, (2) the ability of the city to self-organize, and (3) the capacity for learning and adaptation in the context of change (Eraydin and Tasan-Kok 2013). This project proposes a link between bioclimatology's focus on identifying human vulnerability to heat and land-use plans aimed at resilience. It hypothesizes that since heat vulnerability simultaneously considers social and environmental interactions, it can depict the urban climate in a way that can be adapted to techniques based upon GIS and overlay methods, such as Geodesign (Steinitz 2012). Furthermore, this research assumes that such approach could aid land-use planners to evaluate changes spatially and temporally. It proposes that a dynamic understanding of variables can enable urban climatologists and planners to co-define possible thresholds that derive from changes in urban form and alter climatic interactions.

1.5.3 Integrating critical approaches to planning practice and co-production

Through a mixed method approach, this dissertation uses the co-production framework in two ways. First the concept is used to pragmatically aid this project in identifying how urban climatology and land-use planning can co-produce a heat response plan. To do so this research applies an iterative interactive approach of co-production (Bremer and Meisch 2017), which derives from studies in environmental sciences and public policy (e.g. (Lemos and Morehouse 2005, Dilling and Lemos 2011, Lemos et al. 2014, Meadow et al. 2015). The use of this first approach of co-production seeks to avoid what Cash et al. (2006) describe as the "loading dock approach", in other words, producing knowledge with the expectation that it is usable, pertinent and applicable to practice. The second approach to co-production is rooted in Science and Technology Studies (STS), inspired particularly by the work of Sheila Jasanoff (2004), to explore the cognitive processes that permeate the production, circulation and application of climate knowledge in the context of a heat response plan. This framework is used to recognize that the production, and ultimately the usability of climate science in planning is shaped by goals, directives and widely circulated ideas about society and environment (Goldman and Turner 2011).

Furthermore, this study takes an interactional co-production approach in STS, meaning that it focuses on the challenges and conflicts that arise as new knowledge and opportunities for change interact with existing practices and institutions (Hilgartner, Miller and Hagendijk 2015a). Interactional co-production, as Tim Forsyth (2019) describes, can depict how contemporary political factors reshape, or assimilate, knowledge claims. This approach seeks to understand "how developments in science and in society emerge together from deliberations and confrontations about old and new views on what “is” (knowledge, science) and what “ought” to be (politics, ethics, aesthetics)” (Hagendijk 2015). Furthermore, Jasanoff (2004) suggests that processes of co-production are composed of “ordering instruments”, in other words, instruments and practices that are needed to support the creation of institutions, discourses, identities and representation. This study focuses on two concepts that derive from Jasanoff’s proposed “ordering instruments”. First, the study adheres to the concept that institutions serve as “inscription devices of society,”. In other words, they function as repositories of knowledge and power, and thus establish ways of knowing and acting. This, in turn, creates routines that are repeated either because practitioners are socialized into their use or because doing things differently would be too cumbersome (Hilgartner et al. 2015a). Second, this research considers the concept of “sociotechnical imaginaries”, proposed by Jasanoff and Kim (2009), which refers to a collective vision for what social life and social order should be in the future, reflected in the design and establishment of projects and plans. Therefore, ‘imaginaries’ refer to a desired future that the state and society believe should be attained. To do so political actors use science and technology as instruments for decision-making, but also for the construct of a collective vision for the future (Hagendijk 2015).

The engagement with critical theory enables a discussion on how practice and expertise in both fields visualize climate knowledge differently. The use of the co-production framework seeks to engage with social critiques of planning practice, as a way of reflecting on the limitations of traditional planning techniques and the use of knowledge as an “ordering instrument” (Jasanoff 2004). It seeks to demonstrate that individually, planning and urban climatology do not elucidate more varied and complex aspects of urban climate interactions that are inherently dynamic, localized and social (Meadow et al. 2015). This project looks to critical theory as a way of further understanding possible procedural divergences between urban climatology and planning, that have often been discussed as knowledge gaps. It simultaneously explores the collaborative potentials for co-producing knowledge and investigates the potential barriers that exist by using deliberate and specific concepts of co-production. ion of a ‘iterative interactive’ lens (normative) and a ‘interactional’ lens (descriptive). It first focuses on an ‘iterative interactive’ lens (normative), which stems from environmental and policy studies, to explore the production and usability of knowledge through collaboration. Then it applies an ‘interactional’ co-production lens (descriptive), inspired by the work of Jasanoff (2004) and Hilgartner et al. (2015b), to understand how the decision-making processes in planning play a role in the current struggles with climate knowledge transference and application. The use of these two lenses seeks to move this research beyond testing a collaborative process and towards a more critical understanding of the methods and cognitive processes that determine the usability of knowledge.

1.6 Doing Integrative Research

As a student in the Integrative Conservation (ICON) PhD program I learned to look beyond disciplinary boundaries and I sought to explore the multiple perspectives of the incorporation of climate knowledge in land-use planning. First and foremost, I had to recognize that urban climatology and its application in land-use planning was complex. Decision-making at the intersection of these two disciplines simultaneously affect society and the environment in varied ways and there are multiple perspectives on how to address these problems. From the interpretation of what climate issues to be addressed to the application of heat vulnerability science in a heat response plan, I had to be open to multiple views and interpretations of if and how heat was relevant to land-use planning. More importantly, I had to recognize that some aspects of my research would be incommensurable. This meant that I had to acknowledge that not all values can and will be captured and measured by this project, and it is part of the process of engaging in integrative research, as discussed by similar studies such as Vercoe et al. (2014). Throughout this research this meant that I needed to be cognizant that not all views would be accounted and incorporated in my attempt to produce a study that developed and applied ‘usable’ climate knowledge.

With usability in mind, the integrative framework led me to focus on the development of a project that is relevant to practice. This meant that I needed to engage directly with planning practitioners and decision-makers, so that I could develop a research program that was applicable and pertinent to local needs. Direct engagement with decision-makers meant being open to address a climatic issue that they identified as important. Though I saw heat as a potential issue to address this approach supported the interaction with local decision-makers, so that I could understand what climatic issues they viewed as a threat, and what was relevant from their perspective. Thus, meeting practitioners one-on-one meant that I questioned my own assumptions of what was relevant and in what ways the research I was producing could inform and facilitate land-use planning. Furthermore, it allowed me to understand the political and social contexts that reinforced certain perspectives of when and why heat was considered an issue to be addressed and how my research could aid facilitate the application of knowledge on the subject.

These one-on-one meetings also allowed me to establish trust and build relationships so that I could collaborate with local planners and decision-makers. As part of my training as an integrative researcher I learned to value and recognize that the exchange of knowledge is not a one-way process, where researchers give information to end users. Therefore, collaboration ensured that I was not only producing locally relevant research, but also working with practitioners to understand how climate data could be pertinent and applicable. Collaboration stimulated me to think about the development of my research program as a cycle rather than a linear process. This meant that the research process was developed with my collaborators, to suit not only my research interests, but also their needs and their context, so that my findings could inform and facilitate the development of a heat response plan. Additionally, collaboration allowed me to bring plural views of the problem to work together to understand how heat could be incorporated in land-use planning. This in turn exposed me to different disciplinary and epistemic perspectives of the problem and gave me the opportunity to address my research through multiple angles.

Part of the process of establishing collaboration and directly engaging with local planners and decision-makers meant that I had to strategically communicate what my research entailed and the issues they were faced with. In some cases, the discussion on climate was met with resistance, given certain political contexts. Therefore, direct engagement often began by discussing issues that were clearly addressed in policies, plans and were documented at the local level. I also embedded strategic communication as part of the collaborative process, so that we could collectively think through different ways of communicating the threats of heat to lay audiences. During my research I recognized that messaging and communication of risk were a major problem for institutions such as the National Weather Service, and that local health districts did not have communication strategies for heat events. Therefore, I understood that my research could also inform and facilitate the development of a communication plan for heat, as a health threat, to both decision-makers and vulnerable populations.

I applied an integrative methodology in this study, therefore, I used mixed methods from diverse disciplines to answer the questions presented in this document. This allowed me to explore the potential roots and misunderstandings that limited the use of climate knowledge in land-use planning. The methods I applied in this study stem from research in urban climatology, planning, and social sciences to simultaneously clarify the relationships between urban climatology and land-use planning and indicate the potential misunderstandings that limit the integration of knowledge from both disciplines.

Finally, I applied multiple theoretical framings in this study to understand and illustrate the different perspectives that frame the issue of applying climate knowledge in land-use planning. I started this process by using a normative lens of the co-production framework, inspired by studies in political and environmental sciences, focused on the production of usable and relevant scientific knowledge (Bremer and Meisch 2017). Once the topic of heat was established, I incorporated the use of heat vulnerability studies (urban climatology) and geodesign (planning) to explore the methodological divergences and distinct perspectives between both disciplines. Furthermore, I used an interactional co-production framework, from Science and Technology Studies, to unpack the processes and interactions that occurred during the project and how this illustrates potential convergences and divergences to the application of climate science in land-use planning. More importantly, the use of these framings also allowed me to further explore the values and perspectives that permeate decision-making on climatic issues and allowed me to recognize that certain values could not be counted and measured by this research.

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CHAPTER 2

A 20-YEAR ANALYSIS OF LAND COVER AND LAND SURFACE TEMPERATURE CHANGES IN CHATHAM COUNTY – GA, IN THE UNITED STATES.

2.1 Introduction

According to the United Nations, over 80% of the United States' population lived in urban areas in 2018, and it is estimated that close to 90% of the country's population will live in cities by 2050 (UN 2018). Meanwhile, urban climate studies, beginning with Luke Howard (1833) in London, have shown that cities affect climate and can produce uncomfortable and unhealthy living environments. As populations grow, cities are challenged to make decisions on how to accommodate growth while guaranteeing the health and well-being of its inhabitants in the face of a changing climate. Simultaneously, urban climatologists strive to further understand the interactions that occur in cities to better transfer knowledge to fields such as urban planning, and support climate-oriented decision-making (Oke 1988, Seto and Shepherd 2009, Ng 2012, Ren 2015). One of the methods used to aid in the interpretation of how cities impact climate has been the analysis of the impacts of land use/cover (LULC) on surface temperature, aiding in the comprehension of surface urban heat island (SUHI) (Rinner and Hussain 2011). However, previous studies have pointed to the struggles of understanding the relationships between these factors due to the limited access to a composite of spatial-temporal data that could represent thermal changes as they relate to urban growth and land cover change (Rinner and Hussain 2011, Stewart and Oke 2012, Wang and Huang 2015).

SUHI is one of three types of urban heat islands (UHI). The other two types are known as urban canopy heat island or canopy layer heat island (CLHI) and boundary layer heat island (BLHI) (Figure 2.1). In all three cases UHI occurs as a response to urban land use and land cover changes that alter the energy balance, and it is one of the main causes of local atmospheric anomalies (Arnfield 2003). The SUHI represents the relative warmth of urban surfaces. It is observed and can be indirectly calculated through remote sensing methods and depicts the increased skin temperature of urban surfaces in relation to rural and vegetated land cover types. CLHI corresponds to air temperature increases that occur between the city surface and the maximum building/roof top height. While BLHI is the increase in air temperature above roof top level, extending a kilometer or more vertically and several kilometers downstream (Oke 1995).

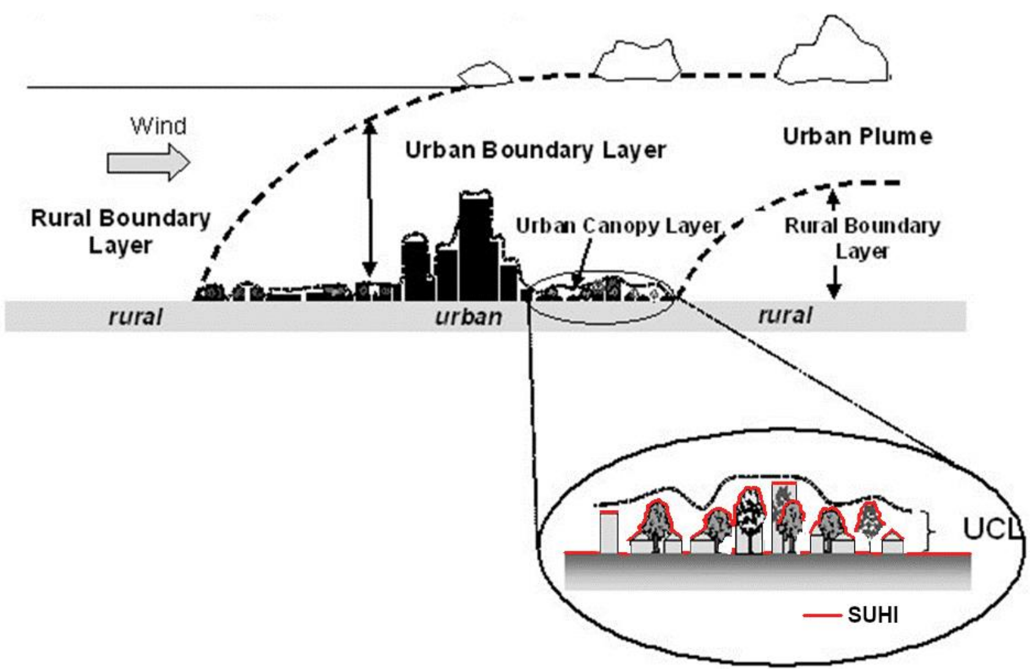

Figure 2.1 *– Schematic diagram of the main components of urban heat island, adapted from Voogt (2004).*

Some studies have indicated similar spatial patterns and relationships between the CLHI, BLHI, SUHI (Voogt and Oke 2003, Weng and Quattrochi 2006, Nichol et al. 2009). Yet, both CLHI and BLHI tend to be stronger at nighttime, while SUHI displays peaks during the daytime

(Arnfield 2003). This is important to note as some studies on heat related mortality and morbidity have linked the nighttime effects of air temperature UHI to a higher number of heat related fatalities (Clarke 1972, Weisskopf et al. 2002, Dousset et al. 2011, Laaidi et al. 2011). However, as Johnson et al. (2012) point out, studies in heat vulnerability have indicated that land surface temperature (LST) can be a strong predictor of heat related mortality during extreme heat events (Johnson and Wilson 2009, Johnson, Wilson and Luber 2009, Dousset et al. 2011). Furthermore, studies have also shown that intra-urban temperature variations are more evident through satellite remote sensing of SUHI and are strongly related to land cover (Aniello et al. 1995, Dousset and Gourmelon 2003).

Thermal remote sensing has been an important tool for the field of urban climatology for many years and a suggested tool for the visualization of SUHI (Voogt and Oke 2003, Weng and Quattrochi 2006). The use of thermal satellite images has produced better understandings of the relationships between urban surfaces, specifically LULC, to the thermal behavior of urban environments (Weng, Lu and Schubring 2004, Yuan and Bauer 2007, Buyantuyev and Wu 2010, Zhou, Huang and Cadenasso 2011, Zhou et al. 2014, Fu and Weng 2016). Yet, as described by Zhou et al. (2014), vegetation abundance and impervious cover are consistently identified as the most important determinants of LST increases. While these findings are significant the simple divide of '*rural*' (vegetated) and '*urban*' (impervious surface area) do not account for the complexities of the surfaces observed in cities, as discussed by Stewart and Oke (2012).

Though a large quantity of remotely sensed images exist processing time and system capabilities have been a true impediment to the development of a robust spatial-temporal analysis of urban temperatures and environments (Wang and Huang 2015, Fu and Weng 2016). Additionally, selecting and attaining images with little to no cloud cover can be time-consuming and limit the scope of the study. Combined, these two issues have been a critical impediment to the analysis of extensive time frames. Therefore, previous studies considered a limited number of satellite images to understand the relationships between LULC and LST and very few studies have been able to develop datasets with a large and regular temporal frequency (Fu and Weng 2016).

Through the application of Google Earth Engine as tool to retrieve, process and synthesize satellite imagery this study attempts to understand the long-term spatial-temporal relationships of land cover changes and land surface temperature (LST) variations. It uses Chatham County, Georgia, in the United States as a case study and suggests a pathway to the analysis of changes in LST and land cover data in a 20-year period (1992 to 2011). Moreover, it uses thermal satellite imagery as a proxy to understand the occurrence of urban canopy heat island and its relationship to land cover changes. This is a novel approach that enables a robust spatial temporal analysis that goes beyond the assessment of LST, and further, explores their relationships to land cover changes. This paper examines the hypothesis that a combined spatial-temporal analysis of land cover and LST changes could indicate what types of development are linked to higher thermal impacts. Additionally, findings could lead to adaptation measures and point to land cover types that reduce surface temperatures. Mainly by comparing changes in land cover to changes in land surface temperature, the study further links the relationships between urbanization and surface heating, depicting the occurrence of SUHI and its potential intensification over time.

2.1.1 Case Study

Chatham County is known for its extensive tree canopy cover. Likewise, its capital, the city of Savannah, is well-known for its tree covered historic downtown, permeated by plazas and street boulevards. Yet it is also the most urbanized area in coastal Georgia, while Savannah is the fourth biggest city in the state. A heat vulnerability study by Maier et al. (2014) identified Chatham as one of the most vulnerable counties in the state. Reports cite Savannah as a potentially at-risk city for extreme heat exposure and indicate the need to identify and mitigate heat related risk factors (ASTHOCCC 2014, USGCRP 2016). Furthermore, KC, Shepherd and Gaither (2015) found that overall the county is highly vulnerable to climate and has a moderate to high vulnerability to climate change, compared to other counties in the Georgia. With that in mind, this study seeks to understand the evolution of urbanization in the county and the effects of land cover change to LST during a 20-year study period. To do so, the study area focuses on a boundary that represents the most urbanized areas of the county (Figure 2.2).

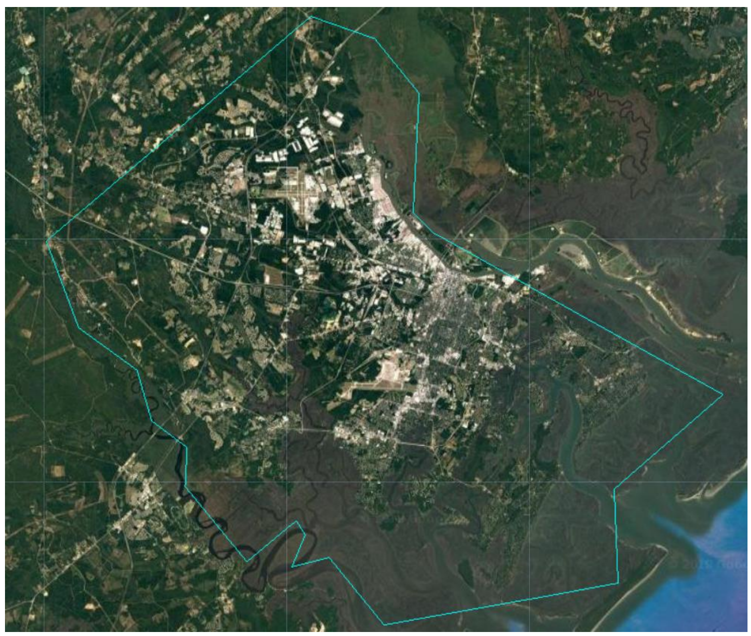

Figure 2.2 – *Study boundary focuses on the most urbanized area of Chatham County, Georgia, with emphasis on the city of Savannah, the biggest city in the county.*

2.2 Data and Methods

To understand the spatial and temporal changes that have occurred in Chatham County, Georgia, we developed an analysis of the National Land Cover Database (NLCD) and Landsat 5 Surface Reflectance (Tier 1) images, performed using the Google Earth Engine platform (Gorelick et al. 2017). The use of this tool enabled the analysis of approximately 299 images for the period between 1992 to 2011. The choice of analysis period was determined by the NLCD database, with available land cover datasets for 1992, 2001 and 2011.

2.2.1 Land cover

As previously mentioned, analyses using NLCD included land cover products for 1992, 2001 and 2011. Three layers were used from the database: land cover (1992, 2001, 2011), impervious surfaces (2001 and 2011) and percentage tree cover (2001 and 2011). Land cover change analysis used two approaches: (a) the generation of a land cover change map containing coded values for observed land cover (Table 2.1); and (b) the generation of a land cover change matrix, indicating the areal coverage of changes for Chatham County. These representations were then used with the analysis of changes in land cover that contribute to increases in temperature.

Impervious surfaces and percentage tree cover that are part of NLCD were used during analyses to help explain the observed changes in temperature. The Error layer resulting from the modeling effort to estimate percent tree cover was also used.

Table 2.1 *– NLCD class code correspondence table from 1992 to 2001(Class code 2001 also applies to 2011 dataset).*

Description	NLCD 1992 class code	NLCD 2001 class code
Open water	11	11
Perennial ice, snow	12	12
Urban, recreational grasses	85	21
Low intensity residential	21	22
High intensity residential	22	23
Commercial, industrial, roads	23	24
Bare rock, sand	31	31
Quarry, strip mine, gravel pit	32	31
Transitional barren	33	31
Deciduous forest	41	41
Evergreen forest	42	42
Mixed forest	43	43
Shrubland	51	52
Orchards, vineyards, other	61	82
Grasslands, herbaceous	71	71

Description	NLCD 1992 class code	NLCD 2001 class code
Pasture, hay	81	81
Row crops	82	82
Small grains	83	82
Fallow	84	82
Woody wetlands	91	90
Emergent, herbaceous wetland	92	95

2.2.2 Remotely sensed products

This study uses Landsat 5 Thematic Mapper (TM) data, collection 1, Tier 1, with images available from 1984 to 2012. The images produced by this satellite contain seven bands, four of them in the visible and near-infrared (VNIR), two in the short-wave infrared (SWIR) and one in the thermal infrared (TIR) of the electromagnetic spectrum region. While the VNIR (Bands 1 through 4) and SWIR (Bands 5 and 7) bands have a resolution of 30 meters per pixel, the TIR band (Band 6) is collected at 120 meters per pixel and then resampled using cubic convolution to 30 meters per pixel. Surface reflectance data products are created using the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS), a specialized software used to apply atmospheric correction routines to Level-1 Landsat Thematic Mapper (TM) or Enhanced Thematic Mapper Plus (ETM+) data (Masek et al. 2006).

The analysis of changes in land surface temperature (LST) involved the use of the thermal band (Band 6) of Landsat 5 Surface Reflectance (Tier 1) to compute atmospherically corrected maximum brightness temperature during the period of January to December, for three years preceding and including the year of analysis, as follows: period ending in 1992 (PE1992) considered images from 1990 to 1992; year ending in 2001 (PE2001) considered images from 1999 to 2001; period ending in 2011 (PE2011) considered images from 2009 to 2011. The three-year period was used to account for interannual variability in surface temperatures due to weather while minimizing differences in land cover and emissivity that could result from analyses based on large time periods. A total of 299 images were used to create composites for maximum brightness temperature for each period: 88 images for PE1992, 106 images for PE2001, and 105 images for PE2011. Those were then used to generate a spatial representation of change over time by calculating slope and amplitude.

It is important to point out that brightness temperature differs from LST for a variety of reasons. Studies point to partial absorption of blackbody radiation by water vapor in the atmosphere and surface emissivities, which vary spatially and spectrally (Ottlé and Stoll, 1993). Additionally, the urban geometry traps radiated and incident energy in urban canyons, that in turn increases the pixel-average emissivity, while satellite viewing angles create biases towards vertical surfaces and miss horizontal areas (Voogt and Oke 1998). To transform brightness temperature to LST an empirical multispectral correction for water vapor is needed to account for the moisture content that exists in the atmosphere (Dousset and Gourmelon 2003). Brightness temperature values are lower than LST (Dousset and Gourmelon 2003), therefore, it provides a conservative estimate of temperature changes in the county.

2.2.3 Data analysis

Point data were extracted from the NLCD and Landsat maximum brightness temperature images using GIS software. Latitude and longitude data were obtained for all the points in each image, and tabular data were extracted for further statistical analysis. Samples from the different files generated were merged by latitude and longitude, rounding the values to the 4th decimal place. Only samples with valid observations for maximum temperature and land cover for a combination of two years were kept (Table 2.2). The difference between years was calculated for every point with valid data, always subtracting the temperature from the most recent year. The change in land cover was obtained by a concatenation of the codes from the two years in each pair comparison, with earlier information included first. All data manipulation and operations were made with an in-house script using R package (R Core Team 2018) and Tidyverse package (Wickham 2017).

***Table 2.2** – Number of valid observations made for maximum temperature and land cover for each analysis period and equivalent coefficient of determination.*

Years	Overlapping samples	Coefficient of Determination
PE1992 - PE2001	10,411	0.19
PE2001 - PE2011	9,839	0.29
PE1992 - PE2011	9,746	0.41

A linear model was fitted to evaluate the response of temperature slope to changes in land cover, following the model:

$$Slope = Land\ Use\ Change + e$$

Only classes of land cover change containing at least 21 observations were used for the linear model. Tukey's honest significant difference test (Tukey 1949, Abdi and Williams 2010) was used to locate the pairwise difference between sample means. If the test finds significant differences in temperature increases between land cover changes, different letters are used to indicate it, on the other hand if no difference is found the same letter is used. The letters are displayed in a bar chart for each type of land cover change found. Therefore, change types identified with the same letters do not present statistically significant differences between each other.

2.3 Results

2.1.1 Land cover changes between 1992 to 2011

The analysis of the NLCD dataset from 1992 to 2011 (Figure 2.3) and its resulting change matrix (Table 2.3), indicate that Chatham County has lost approximately 10.1% of tree cover during the studied period (1992 to 2011), which resulted in an estimated areal loss of 100.3 km2 (24,784.67 acres). An estimated 8.1% of the total area analyzed has changed from a pervious land cover type to developed/impervious land cover type (2011 code classes: 22, 23, and 24), indicating areal loss of pervious cover of approximately 81.1 km2 (20,040.25 acres). While 3.2% or 31.5 km2 (7,783.82 acres) of the studied area appears to have gained tree cover during this period (Table 2.4).

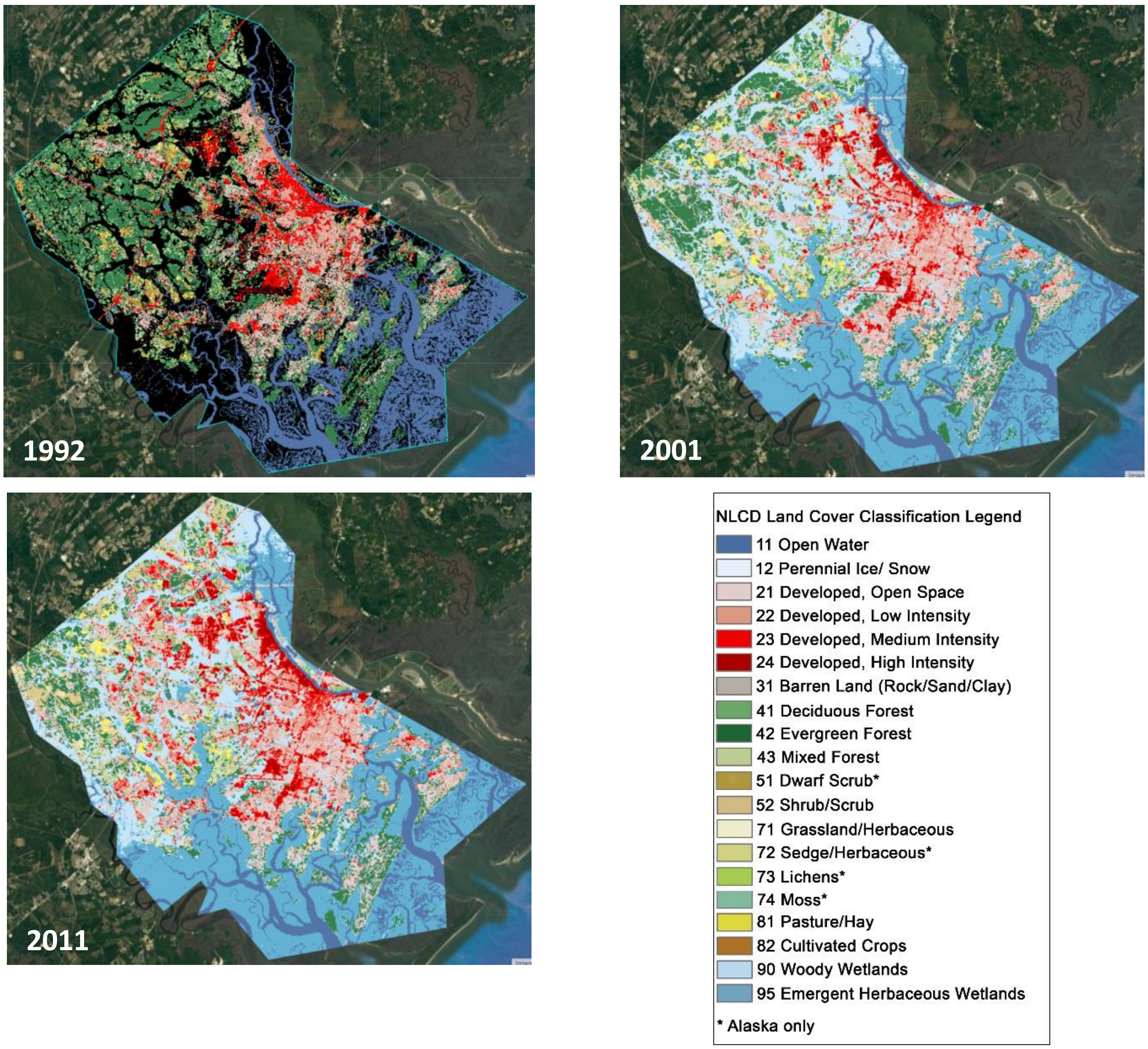

Figure 2.3 *– NLCD images for Chatham County, Georgia, United States.*

***Table 2.3** – Land cover change matrix, indicating the areal coverage of changes for Chatham County in squared kilometers, between 1992 and 2011(Areas in red highlight land cover changes above 1 km^2).*

1992 (Was)	Areal Land Cover Changes (km²)	2011 (Became) 11 Open water	21 Urban, rec grasses	22 Low resid	23 High resid	24 Com, ind, roads	31 Bare rock	41 Decidous forest	42 Evergreen forest	43 Mixed forest	52 Shrubland	71 Grassland, herbaceous	81 Pasture	82 Row crop	90 Woody wetland	95 Emergent, herbaceous wetland
11	Open water	86.1	0.6	0.4	0.6	0.6	0.9	0.0	0.8	0.0	0.1	0.2	0.0	0.0	0.8	89.5
21	Low- resid	0.1	23.2	12.7	3.0	0.8	0.2	0.6	5.5	0.7	1.7	0.6	0.2	0.0	5.7	2.1
22	High-resid	0.1	8.3	11.3	4.9	3.5	0.2	0.0	0.2	0.0	0.1	0.1	0.0	0.0	0.2	0.3
23	Com, ind, roads	0.3	10.1	14.5	12.1	9.8	0.2	0.1	0.4	0.1	0.2	0.3	0.0	0.1	0.6	0.5
31	Bare rock, sand	0.1	0.4	0.5	0.6	0.7	0.2	0.0	0.1	0.0	0.1	0.2	0.0	0.1	0.2	0.2
32	Quarry	0.1	0.0	0.1	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
33	Transition barren	1.0	8.7	6.7	2.6	1.0	1.0	0.9	4.1	0.7	3.0	1.9	1.2	0.2	2.1	2.3
41	Decidious forest	0.2	4.7	3.0	1.4	0.5	0.4	1.5	4.1	1.3	3.7	1.2	0.5	0.1	8.2	1.0
42	Evergreen forest	1.2	25.8	16.4	8.4	3.0	2.0	2.8	66.2	6.9	19.9	5.7	0.6	0.4	26.6	5.3
43	Mixed forest	0.3	6.8	3.6	1.7	0.5	0.5	1.6	8.6	2.5	4.1	1.3	0.3	0.1	10.9	1.1
81	Pasture, hay	0.0	1.5	0.8	0.6	0.4	0.1	0.2	0.9	0.2	1.1	0.5	0.8	0.1	0.7	0.2
82	Row crops	0.4	5.3	5.0	2.8	2.0	0.8	0.5	2.1	0.3	2.6	2.3	3.0	1.0	2.0	1.1
85	Urban, rec grasses	0.0	7.4	2.0	1.8	1.2	0.1	0.0	0.5	0.0	0.3	0.4	0.2	0.0	0.5	0.3
91	Woody wetlands	1.2	8.2	7.1	3.6	1.5	1.1	0.9	8.9	1.3	4.1	1.6	0.3	0.1	102.5	15.7
92	Emergent, herbaceous wetland	4.7	1.7	0.7	0.3	0.2	0.6	0.1	2.3	0.1	0.3	0.2	0.0	0.0	5.0	142.2

Land cover types that have remained the same during the studied period
Changes from pervious land cover types in 1992 to impervious land cover types by 2011.
Changes within urbanized land cover types during the studied period.

***Table 2.4** – Summary table of land cover changes from 1992 to 2011 in Chatham County, GA.*

Loss of tree cover[1]	100.3 km^2	24,784.67 acres	10.1%
Loss of permeability[2]	81.1 km^2	20,040.25 acres	8.1%
Gain of tree cover[3]	31.5 km^2	7,783.82 acres	3.2%
Total area analyzed in NLCD	995.7 km^2	246,042.83 acres	100%

[1] Calculated using the sum of areas that changed from forested or woody wetlands (1992 code classes: 41,42,43, and 91) to urban, recreational grasses, low intensity residential, high intensity residential, and commercial, industrial, roads (2011 code classes: 21, 22, 23, and 24).

[2] Calculated using the sum of areas that changed from open space/ vegetated use to developed land cover types (2011 code classes: 22, 23, and 24).

[3] Calculated using the sum of areas that changed from non-forested to forested cover types (2011 code classes: 41, 42, 43)

2.3.2 Maximum brightness temperature changes between 1992 and 2011

Maximum brightness temperature analysis indicates that there was a surface temperature increase in surfaces between the studied periods, as can be seen in Figure 2.4. A comparative histogram of the maximum temperature for each studied year (Figure 2.5) shows that in PE1992 the maximum temperature reached was 41°C (105.8°F), while in PE2001 and PE2011 surface temperatures reached 49°C (120.2°F). Average maximum brightness temperatures in PE1992 were approximately 25°C (77°F), which accounted for roughly 22.29% of its area. In 2001, average maximum temperatures reached 29°C (84.2°F) for approximately 19.60% of the county's area. While in 2011, estimates show that 20.13% of the area reached an average of 27°C (80.6°F).

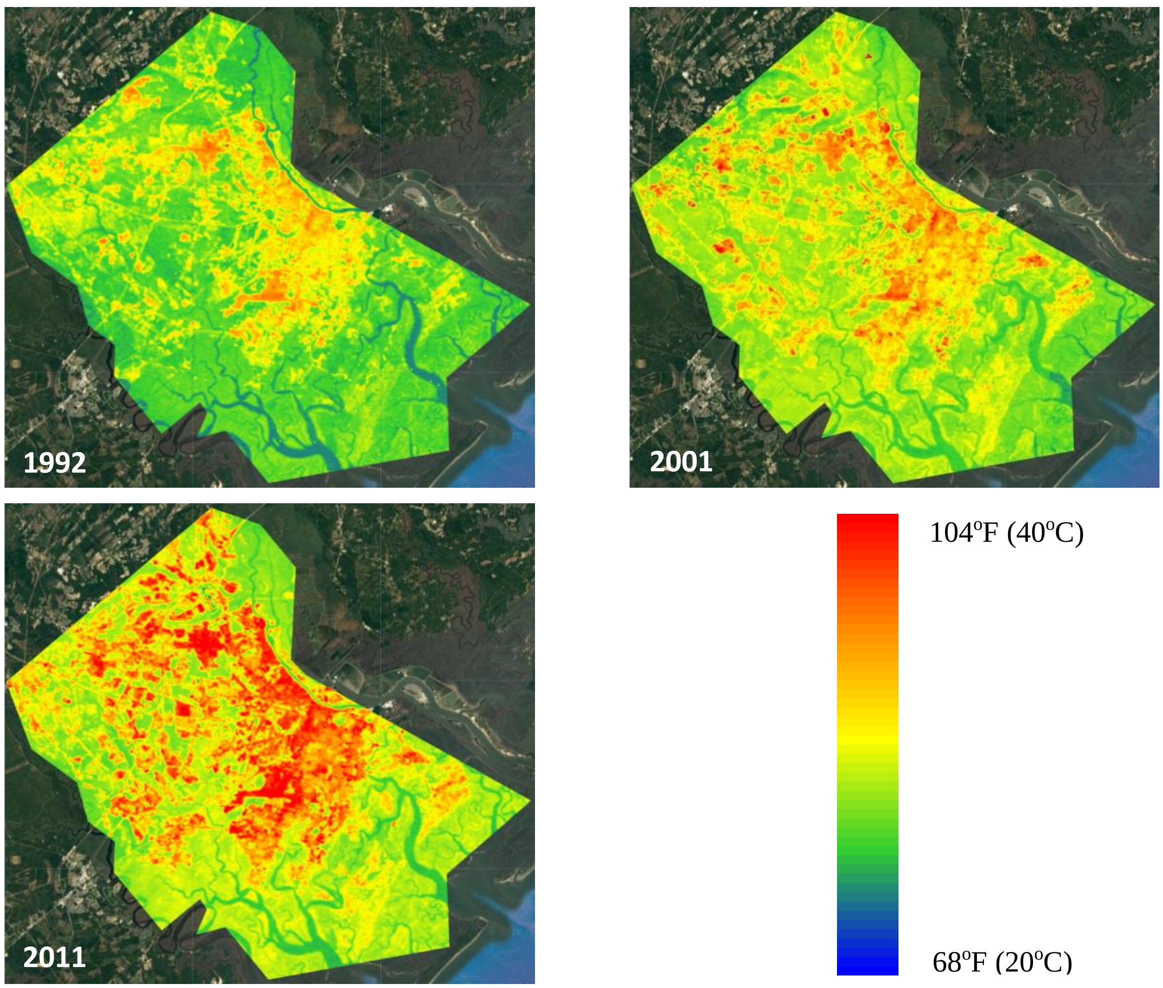

***Figure 2.4** – Maximum brightness temperatures per year analyzed for Chatham County, Georgia, United States.*

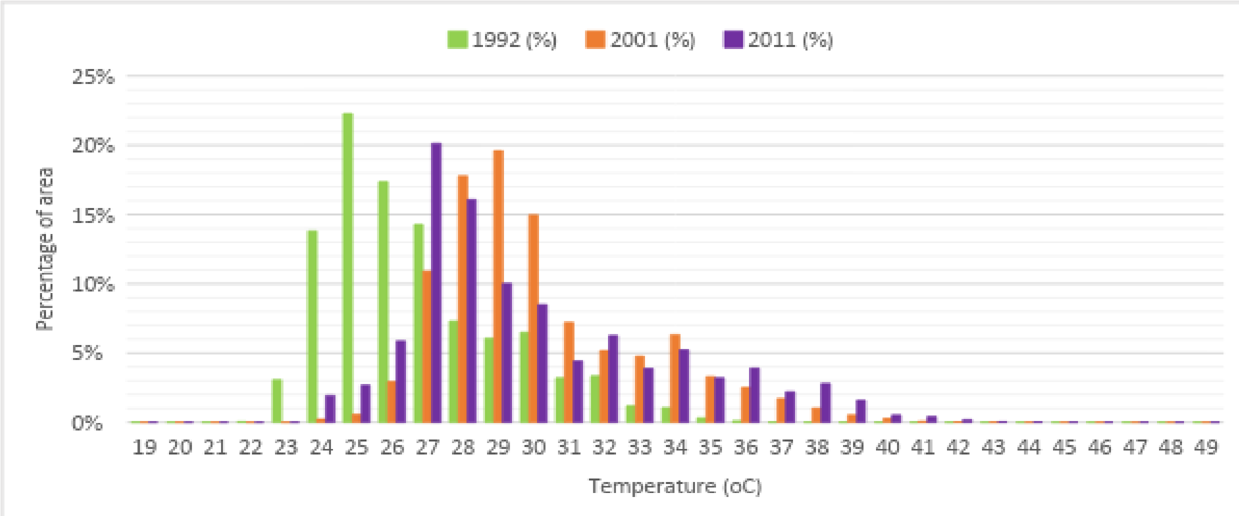

Figure 2.5 *– Comparative histogram of maximum brightness temperature by percentage of area between PE1992, PE2001, and PE2011.*

The higher peak maximum brightness temperatures for PE2001 (29°C) versus PE2011 (27°C) could be related to extreme weather events that occurred during the PE2001 period. Based on climate data gathered from NOAA's Threadex (Long-term Extremes for America) dataset, both studied periods hold temperature records during summer months (June through July). The year 1999 broke temperature records in late July and early August, with temperatures ranging between 37.7°C (100°F) and 38.3°C (102°F) and a heat index of approximately 46.1°C (115°F). Also, during PE2001, the year 2000 faced the hottest day for the studied period, and the second hottest day on record for the county, reaching 40°C (104°F), as seen in Figure 2.6. While 2010 and 2011 also broke daily records and faced extreme heat alerts, the amplitude of air temperature spikes was not as high as seen in the PE2001 studied period (Figure 2.7). For instance, though August 2011 is the hottest on record since 1870 (NOAA 2019), reaching an average of 87°F, it did not necessarily cause surface temperatures to reach as high as seen in the PE2001 period. However, if we look past the extreme temperatures, as shown in Figure 2.8, maximum air temperature medians indicate that PE2011 saw a warmer trend than PE2001 from May through September, though PE2001 presented seemed to be hotter in late May, early June and mid-August was visibly hotter during

PE2001 than PE2011. It is also important to note that given the limitation of remote sensing, specifically due to cloud cover and acquisition dates of images, the satellite images used to depict the studied periods could have captured the effects of the hottest days and extreme weather events for one period and not for another.

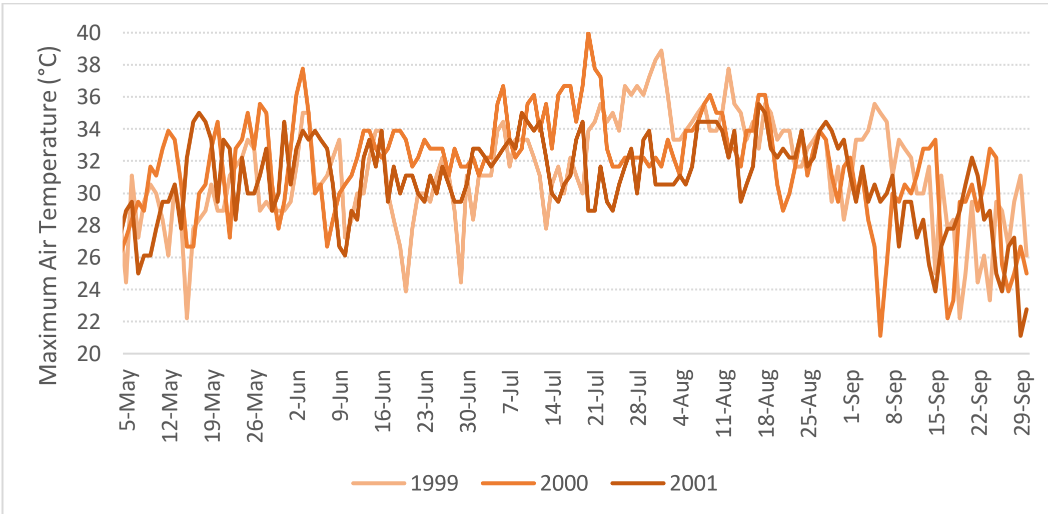

***Figure 2.6** – Maximum daily ambient air temperature acquired from the Savannah International Airport weather station for PE2001, per year, from May through September (NOAA 2019).*

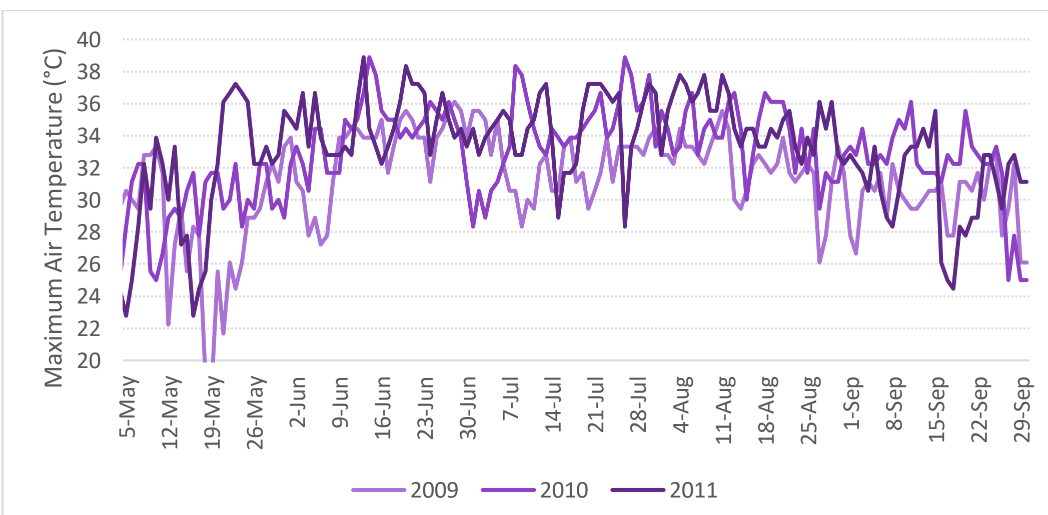

***Figure 2.7** – Maximum daily ambient air temperature acquired from the Savannah International Airport weather station for PE2011, per year, from May through September (NOAA 2019).*

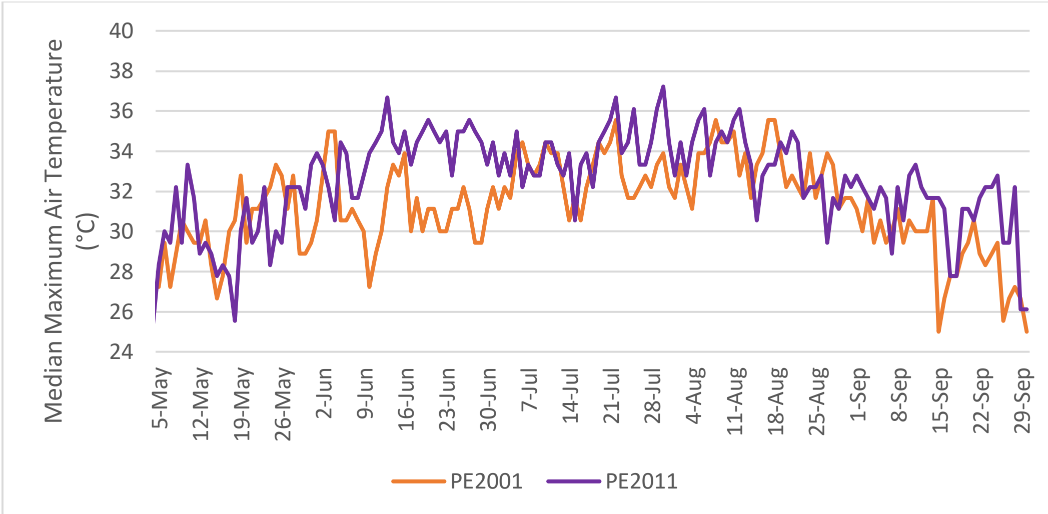

***Figure 2.8** – Comparison between median maximum daily ambient air temperature acquired from the Savannah International Airport weather station for PE2001 and PE2011, from May through September (NOAA 2019).*

Additional analysis of the remotely sensed images, calculating slope and amplitude of maximum brightness temperature change between PE1992 and PE2011, indicates that multiple areas of the county have experienced an increase of over 15ºC, approximately 27ºF (Figure 2.9). Moreover, air temperature readings acquired from the Savannah International Airport weather station (NOAA 2019), indicate that the PE1992 study period at times saw higher temperatures than PE2001 and PE2011 (Figure 2.10). Therefore, the analysis indicates that the brightness temperature increases found during the studied period are related to land surface changes.

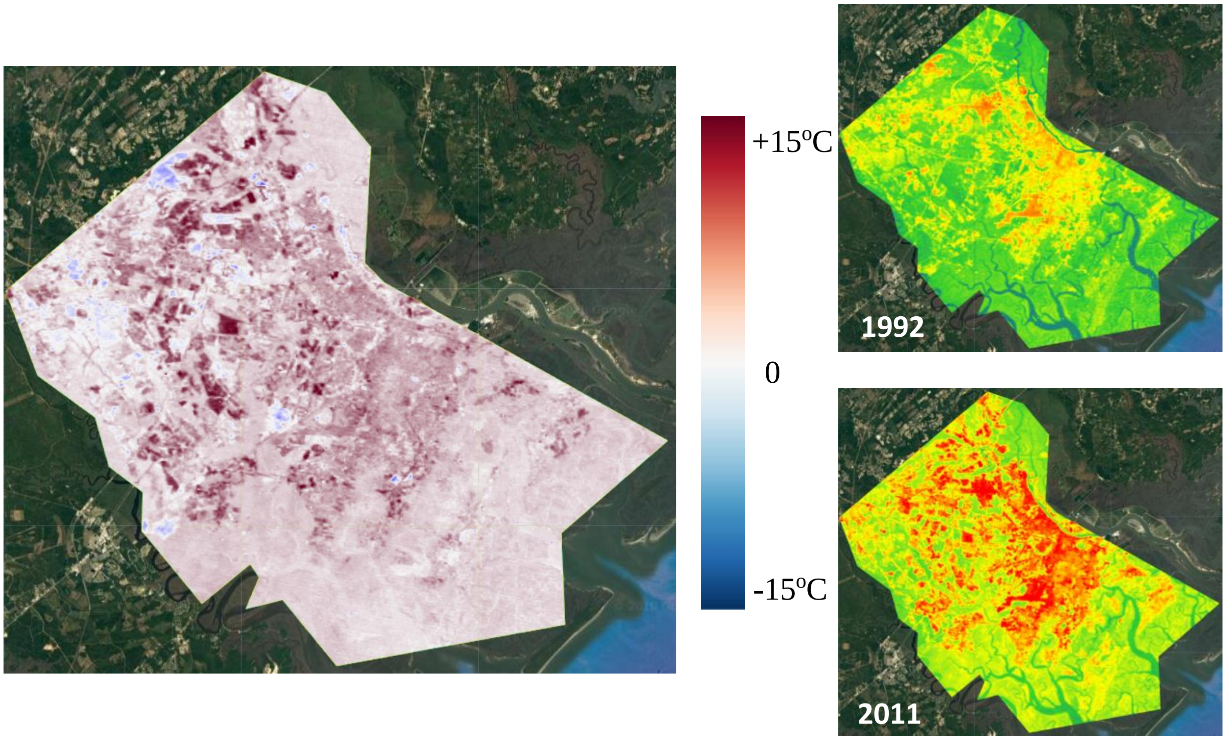

Figure 2.9 *– Delta maximum temperature between PE1992 and PE2011 (PE2011 minus PE1992) for Chatham County, Georgia. Maximum value reached higher than 15ºC (27ºF) but was capped for visualization purposes.*

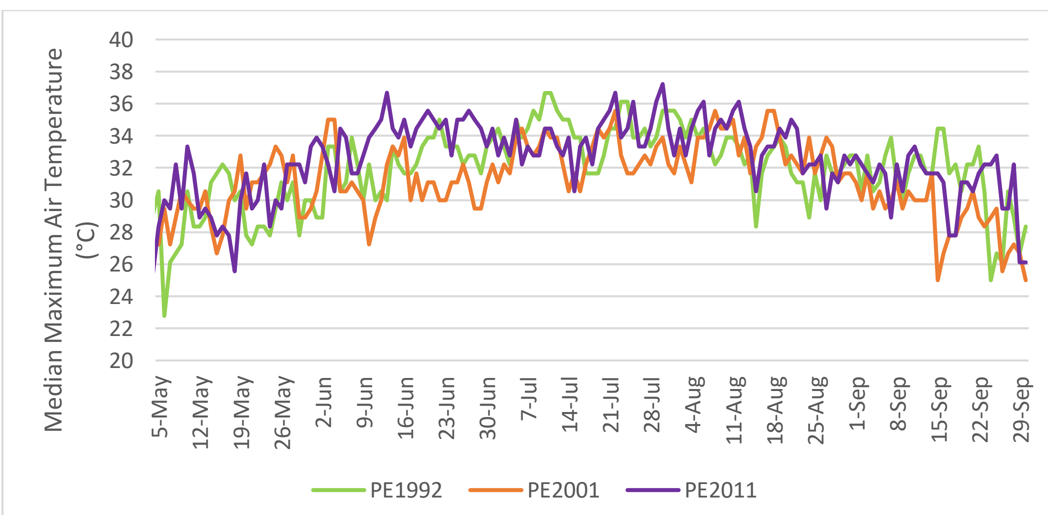

Figure 2.10 *– Comparison between median maximum daily ambient air temperature acquired from the Savannah International Airport weather station for PE1992, PE2001 and PE2011, from May through September (NOAA 2019).*

2.3.3 Relationship between land cover change and brightness temperature increases

Statistical analysis enabled further understanding of the relationship between land cover changes and maximum brightness temperature increases from PE1992 to PE2011. In all three studied periods temperatures were higher for developed land cover types (NLCD 1992 class codes: 21, 22, 23 and 85; and NLCD 2001/2011 class codes: 21, 22, 23, and 24). On the other hand, open water and vegetated land cover types, such as forested and wetland areas displayed lower temperatures (NLCD 1992 class codes: 11, 41, 42, 43, 91, and 92; NLCD 2001/2011 class codes: 11, 41, 42, 43, 90, and 95), as seen in Figures 2.11, 2.12, and 2.13.

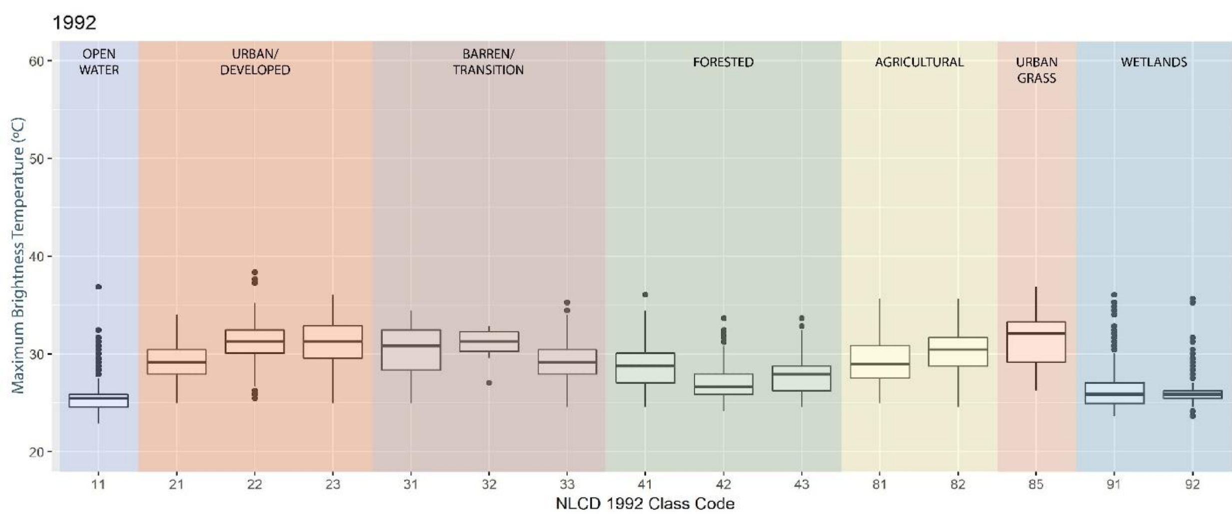

Figure 2.11 *– Maximum brightness temperature per land cover type during PE1992 in Chatham County, Georgia. Temperature measured in degrees Celsius (ºC).*

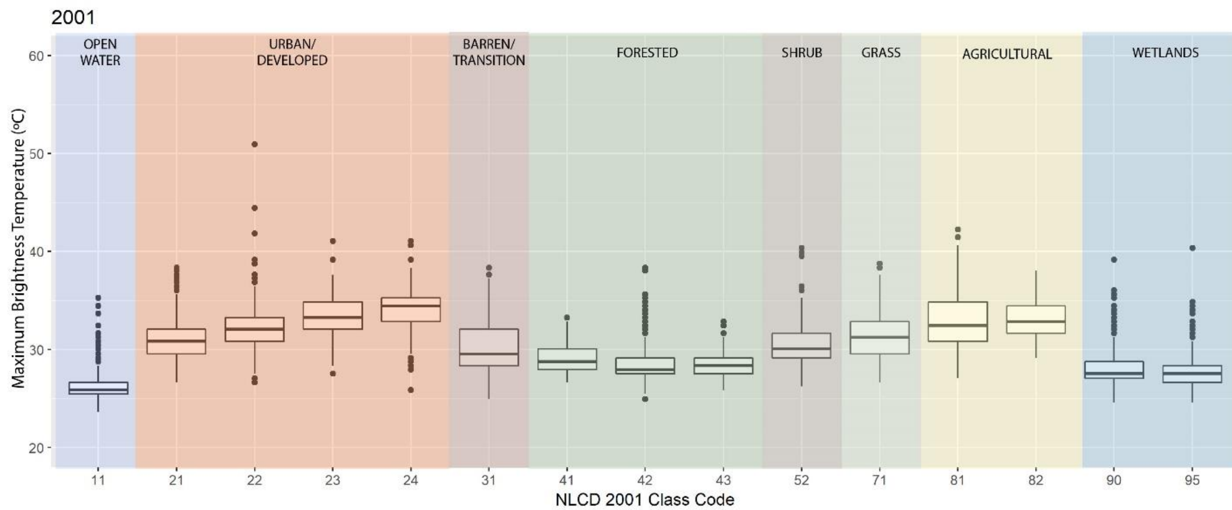

Figure 2.12 *– Maximum brightness temperature per land cover type during PE2001 in Chatham County, Georgia. Temperature measured in degrees Celsius (ºC).*

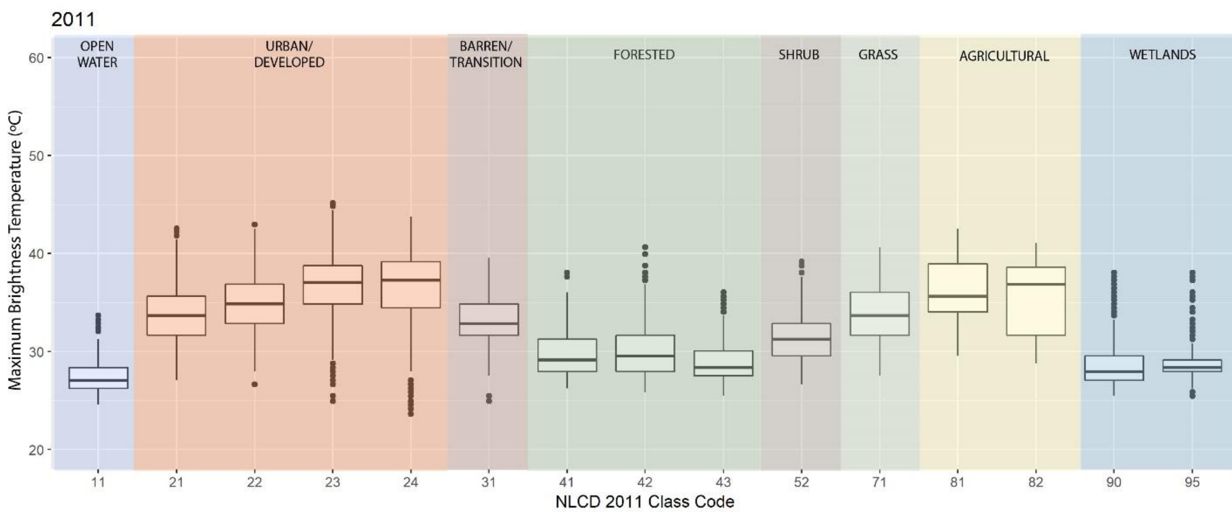

Figure 2.13 *– Maximum brightness temperature per land cover type during PE2011 in Chatham County, Georgia. Temperature measured in degrees Celsius (ºC).*

A linear regression analysis was done to understand what types of land cover changes were associated with the higher maximum brightness temperature changes. The post-hoc Tukey HSD test allowed a better understanding of the statistical significance among the different land cover changes. Results were grouped using a letter coding system. Changes with the same letter assigned to them represent no significance among each other. Therefore, land cover changes with different letters had statistically significant temperature changes when compared to each other. For example, land cover changes from evergreen forest to high intensity residential (1) indicated the highest LST increases and were assigned the letter ‘a’. It was followed by changes from woody wetland to high intensity residential (2), which was assigned the letters ‘a, b’. Next, changes from evergreen forest to commercial, industrial, roads (3), received letters ‘b, c’. This means that the LST increases found are not statistically significant between 1 and 2, since they are both assigned the letter ‘a’. However, the results obtained for 1 are statistically significant when compared to 3, and other land cover changes that follow. With that said, most of the land cover changes resulted in temperature increases, and the highest thermal changes were seen from forested land cover types, particularly class code 42: Evergreen forest and 91: Woody Wetlands, to urban land cover types, as seen in Figure 2.14.

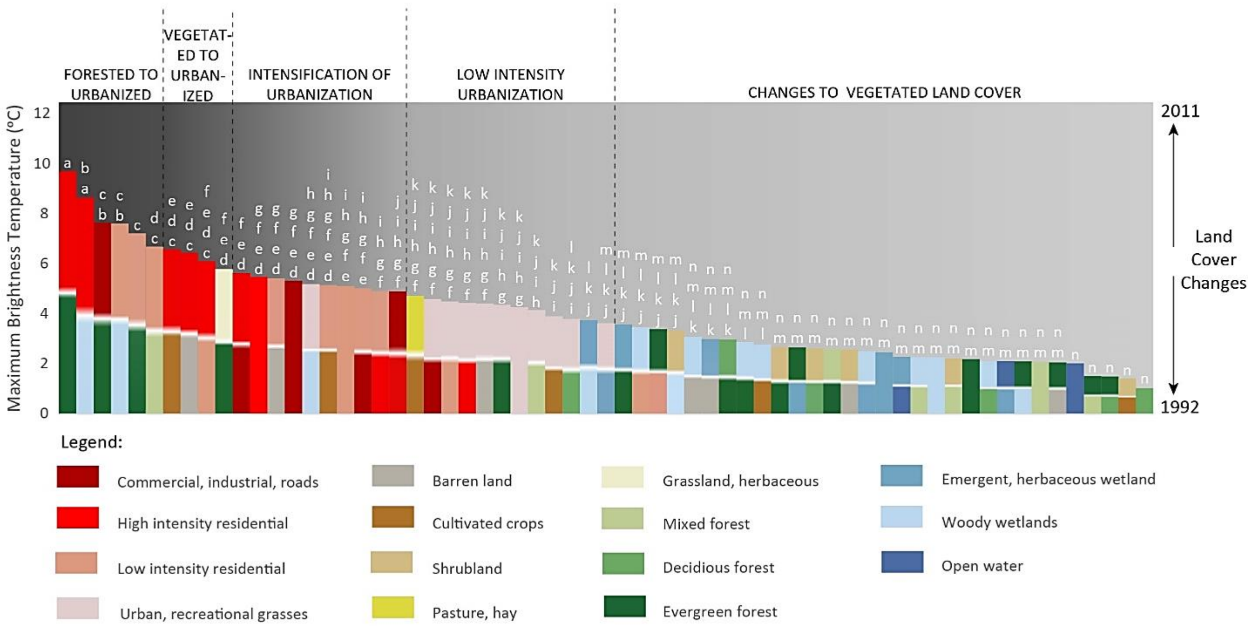

***Figure 2.14** – Results from linear regression analysis for PE1992 to PE 2011 with a post-hoc Tukey’s HSD test. Brightness temperature changes (ºC) based on land cover change.*

2.4 Discussion and Conclusion

A dynamic understanding of variables can enable urban climatologists and planners to co-define possible thresholds that derive from changes in urban form and alter climatic interactions. The results of this study depict the relationship between land cover and brightness temperature changes, reinforcing previous findings that clearly link urbanization to SUHI. However, through a spatial-temporal analysis of the case study, this paper clearly demonstrates an increase in surface temperatures during the 20-year studied period and links it to the loss of forested and wetland land cover types, specifically evergreen forests and woody wetlands areas. More importantly, these results confirm this paper's hypothesis that certain types of land uses lead to higher LSTs over time. As seen in figure 2.14, urban development is responsible for the highest values, and urbanized areas that did not change land cover type showed significantly higher LSTs than vegetated land cover types.

It is important to point out that since this study considers maximum brightness temperature from January through December for all the studied years, it is also capturing the loss of leaves that occurs in deciduous forests during fall and winter months. Thus, the apparent reduced influence of deciduous forest in surface temperature changes, when compared to evergreen forest land covers, represent the effects of seasonality during the studied period. Additionally, this aligns with the findings of brightness temperature reductions in areas that shifted from deciduous forest to evergreen forest land cover identified during the PE2001 to PE2011 (Table 2.5). As a follow-up further analysis of seasonal changes are needed to better understand the behavior of deciduous forest land cover changes in relations to thermal variation. Seasonal analysis, particularly during the summer months (June through August) could indicate a higher temperature change in areas that transitioned from deciduous forest to other land cover types.

The results from this study are similar to findings from a time-series analysis developed by Fu and Weng (2016) in the metropolitan area of Atlanta, Georgia, where the highest LST changes were seen from evergreen forest to urban-medium intensity land cover types. It also found similar changes from woody wetlands and mixed forest. Additionally, deciduous forest cover also displayed smaller temperature variations compared to changes from other forest cover types. Moreover, the findings from this paper corroborate previous conclusions that indicate that vegetation abundance and impervious cover are important determinants to the intensification of SUHI and LST increases over time.

The combined use of remotely sensed images and GIS software applications allow us to better characterize the structure of the urban surface and understand its relationship to temperature variations. However, as discussed by Voogt and Oke (2003), further improvement needs to be made to the representation of urban surfaces. Datasets such as tree cover changes and impervious cover changes were not incorporated in this study and could explore further the relationship between land cover changes and brightness temperature variations. Remote sensing at the city and county scale is still unable to capture the impacts of small-scale structural features. In the case of Chatham County, and in particular the city of Savannah, the NLCD dataset is unable to identify the tree covered plazas that permeate the city's historic downtown, and therefore does not represent its potential contribution to the overall urban surface structure.

The findings of this paper show linkages with decision-making and identify areas where loss of tree canopy cover and wooded areas have produced high temperature shifts when developed on. The data and knowledge produced in this study could serve as insight for the creation of heat-oriented plans that seek adaptation measures that promote intra-urban greening. Moreover, more exploration needs to be done on the usability of the data created and its potential applications not only as a planning tool but also in the development of a heat vulnerability index that addresses the temporal aspects of urban heating.

2.5 Supplementary Tables

Table 2.5 *– Linear regression analysis results for PE1992 to PE2001 with a post-hoc Tukey's honest significant difference test.*

Class	**From class**	**To class**	**Temp Change (°C)**	**Groups***
42_52	Evergreen forest	Shrubland	4.294937	a
42_71	Evergreen forest	Grassland, herbaceous	4.226761	a
42_22	Evergreen forest	Low intensity residential	4.128947	a
42_23	Evergreen forest	High intensity residential	4.103333	ab
91_71	Woody wetlands	Grassland, herbaceous	4.041667	ab
82_81	Row crops	Pasture, hay	3.423077	abc
43_22	Mixed forest	Low intensity residential	3.326087	abcd
91_22	Woody wetlands	Low intensity residential	2.736538	bcde
91_95	Woody wetlands	Emergent, herbaceous wetland	2.406977	cde
91_21	Woody wetlands	Urban, recreational grasses	2.337333	cdef
42_21	Evergreen forest	Urban, recreational grasses	2.335909	def
23_23	Commercial, industrial, roads	High intensity residential	2.187395	def
21_23	Low intensity residential	High intensity residential	2.182143	defg
82_71	Row crops	Grassland, herbaceous	2.083333	defg
41_22	Deciduous forest	Low intensity residential	2.025	defg
22_24	High intensity residential	Commercial, industrial, roads	1.965625	defg
42_95	Evergreen forest	Emergent, herbaceous wetland	1.965	defg
42_90	Evergreen forest	Woody wetlands	1.958583	defg
33_21	Transitional barren	Urban, recreational grasses	1.957303	defg
92_42	Emergent, herbaceous wetland	Evergreen forest	1.93	defg
33_22	Transitional barren	Low intensity residential	1.925	defg
22_22	High intensity residential	Low intensity residential	1.903448	defg
42_41	Evergreen forest	Deciduous forest	1.811765	defg
21_21	Low intensity residential	Urban, recreational grasses	1.785135	efg
22_21	High intensity residential	Urban, recreational grasses	1.774359	efg
21_22	Low intensity residential	Low intensity residential	1.763699	efg
21_52	Low intensity residential	Shrubland	1.763636	efgh
92_95	Emergent, herbaceous wetland	Emergent, herbaceous wetland	1.754247	fgh
23_22	Commercial, industrial, roads	Low intensity residential	1.732414	fgh
92_90	Emergent, herbaceous wetland	Woody wetlands	1.686667	fgh
92_11	Emergent, herbaceous wetland	Open water	1.652703	fgh
42_43	Evergreen forest	Mixed forest	1.596667	fgh
82_90	Row crops	Woody wetlands	1.58	fgh
43_52	Mixed forest	Shrubland	1.573913	fgh
91_90	Woody wetland	Woody wetlands	1.543974	gh
22_23	High intensity residential	High intensity residential	1.538462	gh
41_21	Deciduous forest	Urban, recreational grasses	1.537778	gh
43_21	Mixed forest	Urban, recreational grasses	1.536585	gh

Class	From class	To class	Temp Change (ºC)	Groups*
21_90	Low intensity residential	Woody wetlands	1.525714	gh
33_90	Transitional barren	Woody wetlands	1.505714	gh
23_21	Commercial, industrial, roads	Urban, recreational grasses	1.467717	gh
11_11	Open water	Open water	1.353194	gh
23_24	Commercial, industrial, roads	Commercial, industrial, roads	1.332258	gh
33_95	Transitional barren	Emergent, herbaceous wetland	1.312	ghi
21_42	Low intensity residential	Evergreen forest	1.29322	ghi
43_90	Mixed forest	Woody wetlands	1.286726	ghi
41_90	Deciduous forest	Woody wetlands	1.271429	ghi
85_22	Urban, recreational grasses	Low intensity residential	1.219048	ghi
82_22	Row crops	Low intensity residential	1.187234	ghi
82_21	Row crops	Urban, recreational grasses	1.185714	ghi
11_95	Open water	Emergent, herbaceous wetland	1.183618	ghi
82_52	Row crops	Shrubland	1.171429	ghi
42_42	Evergreen forest	Evergreen forest	1.118308	ghi
33_52	Transitional barren	Shrubland	1.020833	ghi
91_43	Woody wetlands	Mixed forest	0.977273	ghi
33_42	Transitional barren	Evergreen forest	0.886364	ghi
85_21	Urban, recreational grasses	Urban, recreational grasses	0.835593	ghi
43_43	Mixed forest	Mixed forest	0.716129	ghi
41_52	Deciduous forest	Shrubland	0.490909	ghi
43_42	Mixed forest	Evergreen forest	0.453846	hi
82_42	Row crops	Evergreen forest	0.148	hi
91_42	Woody wetlands	Evergreen forest	-0.00682	i
41_42	Deciduous forest	Evergreen forest	-2.16727	j
*Different letters in the same column indicate significant statistical differences (p<0.05).				

Table 2.6 - *Linear regression analysis results for PE1992 to PE2011 with a post-hoc Tukey's honest significant difference test.*

Class	From class	To class	Temp Change (ºC)	Groups*
42_23	Evergreen forest	High intensity residential	9.717742	a
91_23	Woody wetlands	High intensity residential	8.663889	ab
42_24	Evergreen forest	Commercial, industrial, roads	7.66087	bc
91_22	Woody wetlands	Low intensity residential	7.625714	bc
42_22	Evergreen forest	Low intensity residential	7.23913	c
43_22	Mixed forest	Low intensity residential	6.706061	cd
82_23	Row crops	High intensity residential	6.595833	cde
33_23	Transitional barren	High intensity residential	6.463333	cde
21_23	Low intensity residential	High intensity residential	6.127273	cdef
42_71	Evergreen forest	Grassland, herbaceous	5.804545	def

Class	From class	To class	Temp Change (ºC)	Groups*
23_23	Commercial, industrial, roads	High intensity residential	5.648649	def
22_23	High intensity residential	High intensity residential	5.489796	defg
33_22	Transitional barren	Low intensity residential	5.44	defg
23_24	Commercial, industrial, roads	Commercial, industrial, roads	5.336957	defg
91_21	Woody wetlands	Urban, recreational grasses	5.2	defgh
82_22	Row crops	Low intensity residential	5.165385	defghi
21_22	Low intensity residential	Low intensity residential	5.116522	efghi
23_22	Commercial, industrial, roads	Low intensity residential	5.04	efghi
22_22	High intensity residential	Low intensity residential	4.9288	fghi
22_24	High intensity residential	Commercial, industrial, roads	4.905405	fghij
82_81	Row crops	Pasture, hay	4.741667	fghijk
23_21	Commercial, industrial, roads	Low intensity residential	4.607813	fghijk
21_21	Low intensity residential	Urban, recreational grasses	4.509009	fghijk
22_21	High intensity residential	Urban, recreational grasses	4.458333	fghijk
33_21	Transitional barren	Urban, recreational grasses	4.420455	fghijk
42_21	Evergreen forest	Urban, recreational grasses	4.379725	ghijk
85_21	Urban, recreational grasses	Urban, recreational grasses	4.277922	ghijk
43_21	Mixed forest	Urban, recreational grasses	4.168132	hijk
82_21	Row crops	Urban, recreational grasses	3.916923	ijk
41_21	Decidious forest	Urban, recreational grasses	3.803704	ijkl
91_95	Woody wetlands	Emergent, herbaceous wetland	3.760504	jkl
92_21	Emergent, herbaceous wetland	Urban, recreational grasses	3.636	jklm
42_95	Evergreen forest	Emergent, herbaceous wetland	3.581429	jklm
21_90	Low intensity residential	Woody wetlands	3.480952	jklm
21_42	Low intensity residential	Evergreen forest	3.403571	jklm
91_52	Woody wetlands	Shrubland	3.35	jklm
33_90	Transitional barren	Woody wetlands	3.089286	klmn
33_95	Transitional barren	Emergent, herbaceous wetland	3.004348	klmn
42_41	Evergreen forest	Decidious forest	2.985185	klmn
42_90	Evergreen forest	Woody wetlands	2.882653	lmn
82_90	Row crops	Woody wetlands	2.786364	lmn
42_52	Evergreen forest	Shrubland	2.682692	mn
92_42	Emergent, herbaceous wetland	Evergreen forest	2.662857	mn
41_52	Decidious forest	Shrubland	2.628	mn
42_43	Evergreen forest	Mixed forest	2.615	mn
33_52	Transitional barren	Shrubland	2.586667	mn
92_90	Emergent, herbaceous wetland	Woody wetlands	2.51791	mn
92_95	Emergent, herbaceous wetland	Emergent, herbaceous wetland	2.465728	mn
11_95	Open water	Emergent, herbaceous wetland	2.304073	mn
43_90	Mixed forest	Woody wetlands	2.280374	mn
91_90	Woody wetlands	Woody wetlands	2.269561	mn
43_52	Mixed forest	Shrubland	2.228	mn

Class	From class	To class	Temp Change (ºC)	Groups*
42_42	Evergreen forest	Evergreen forest	2.192372	mn
41_90	Decidious forest	Woody wetlands	2.115	mn
92_11	Emergent, herbaceous wetland	Open water	2.111538	mn
91_42	Woody wetlands	Evergreen forest	2.110377	mn
43_43	Mixed forest	Mixed forest	2.085185	mn
33_42	Transitional barren	Evergreen forest	2.066667	mn
11_11	Open water	Open water	2.03179	n
43_42	Mixed forest	Evergreen forest	1.526136	n
41_42	Decidious forest	Evergreen forest	1.503448	n
82_52	Row crops	Shrubland	1.424	n
41_41	Decidious forest	Decidious forest	1.036364	n

2.6 References

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CHAPTER 3

A COLLABORATIVE APPROACH TO HEAT RESPONSE PLANNING: A CASE STUDY TO UNDERSTAND THE INTEGRATION OF URBAN CLIMATOLOGY AND LAND-USE PLANNING

3.1 Introduction

In the United States (US) prolonged exposure to heat and extreme heat events are associated with the highest morbidity and mortality rates resulting from natural hazards (Borden and Cutter 2008). Furthermore, studies have shown that heat-related mortality could occur as the aftermath of natural disasters, such as hurricanes, when massive power outages can lead to prolonged heat exposure and death (Kalkstein and Davis 1989, McKinney, Houser and Meyer-Arendt 2011, Issa et al. 2018, Shultz et al. 2019). Coastal communities in the Southeastern US are used to high temperatures, however, are vulnerable to prolonged exposure to heat as the aftermath of hurricanes and tropical storms, due to power outages. To address this issue, cities must develop heat response plans (HRP) that reduce health risks related to prolonged heat exposure. Luber and McGeehin (2008) suggest that public health departments, emergency management agencies, planning agencies and climatologists must work collaboratively to develop HRPs. These plans are intended to identify at risk populations through heat vulnerability maps, create public communication strategies, and incorporate environmental design strategies that mitigate the effects of heat in urban areas (Luber and McGeehin 2008, Habeeb, Vargo and Stone 2015).

Prolonged exposure to heat can impact a person's ability to thermoregulate, causing heat stress, and in some cases can lead to death (Luber et al. 2006). Research on heat vulnerability show that heat-related illnesses and mortality are not only linked to bodily responses, but rather stem from a combination of social and environmental factors (e.g. (Reid et al. 2009, Johnson and Wilson 2009, Maier et al. 2014). Studies indicate that climate change and increased urbanization can increase heat-related health risks and increase vulnerability (e.g. (Sheridan and Dolney 2003, Luber and McGeehin 2008, Stone, Hess and Frumkin 2010, Habeeb et al. 2015, KC, Shepherd and Gaither 2015). Studies on heat vulnerability mapping spatially examine variables, identified in epidemiologic literature, that are associated with increased vulnerability to heat-related illnesses and mortality (Reid et al. 2009). Moreover, these studies focus on the depiction of social and environmental aspects, and particularly on how urban form and urban land covers play a role in the identification and exacerbation of heat-health risks (Sheridan and Dolney 2003, Kim and Ryu 2015).

Yet, according to Wolf, Chuang and McGregor (2015) past studies in heat vulnerability have not fully addressed the application and usability of knowledge produced in the field. The authors indicate that studies in heat vulnerability acknowledge the potential use of the data produced, however, do not actively work with decision-makers to understand the usability and application of what is produced. This in turn creates what Cash, Borck and Patt (2006) describe as *the "loading-dock approach,"* in other words, researchers assume the demand and usability of information, and expect that it will be assimilated by practice as needed. With that in mind, this study attempts to address heat vulnerability by establishing a collaborative framework that stimulates climate scientists and planners to transfer and produce usable knowledge (Dilling and Lemos 2011). It indicates a pathway to develop and apply data in collaboration with decision makers using a co-production framework inspired by research in environmental studies and public policy (Lemos and Morehouse 2005, Cash et al. 2006, Lemos, Kirchhoff and Ramprasad 2012, Meadow et al. 2015). Furthermore, this case study indicates that the use of a systemic approach to collaboration using geodesign (Dangermond 2010, Flaxman 2010, Ervin 2011, Steinitz 2012, Batty 2013) can result in the successful application of climate data. The combined use of both theoretical frameworks supports the production of knowledge that is adapted and pertinent to local context and practice.

This study discusses the results of a workshop developed with local decision-makers in Chatham County, Georgia, United States. It brings together local and regional decision-makers from the National Weather Service (NWS), Chatham Emergency Management (CEMA), the Department of Planning of the Coastal Regional Commission of Georgia (CRC), the private sector, and researchers from the field of environmental planning and urban climatology. Through a collaborative approach, it attempts to identify the types of data needed to support the development of an HRP and uses a workshop setting to promote the application of heat vulnerability science. This research aims to examine how heat vulnerability mapping can be applied in county scale land-use plans to inform decision-making on urban climate interactions. It explores a collaborative approach to apply knowledge in heat vulnerability and urban climatology in the development of a heat response plan (HRP). It is based on the premise that difficulties in the application of urban climatology in land-use planning are related to methodological mismatches, that go beyond the need for creating new models or simulations. Furthermore, it hypothesizes that the application of heat vulnerability mapping can aid the process of collaboration between both disciplines and visually depict social and environmental aspects of urban climatology that are adaptable to decision-making methods used in land-use planning.

3.1.1 Theoretical Framework

The co-production framework applied in this research is concerned with the usability, or usefulness, of knowledge (Lemos and Morehouse 2005, Dilling and Lemos 2011, Lövbrand 2011, Lemos, Kirchhoff and Ramprasad 2012). It is rooted in studies in environmental sciences and public policy and focuses on how science can be interactive and knowledge-driven, seeking to simultaneously understand complex issues and respond to current decision-making needs (Lemos and Morehouse 2005). This approach explores knowledge production as a process where both practitioners and scientists set the agenda for what is needed to address climate (Dilling and Lemos 2011). Moreover, it sees the interaction between science and practice as a way of ensuring the legitimization and credibility of the knowledge created (Cash, Borck and Patt 2006).

The idiom of co-production applied here proposes an iterative process between science and decision-making fields to develop research questions and methods (Lemos and Morehouse 2005). It is aimed at addressing complex issues, such as heat vulnerability, that relate to policy- and decision-making and consider the simultaneous environmental and social dimensions of climate (Dilling and Lemos 2011). This is a growing field of study and as Meadows et al (2015) discuss it shows promising potentials if explored through different avenues and integrated to multiple disciplines. In this study the combination of the geodesign and co-production frameworks attempts to simultaneously incorporate methods familiar to land-use planning fields (Geodesign) and understand how and what kind of information can be used to support the development of an HRP (co-production).

Geodesign is a conceptual framework that seeks to promote a collaborative pathway for plan conception and evaluation. As Flaxman (2010b) describes 'its axioms are that design and plan quality is increased by informed professional and public deliberation, that all projects have multiple impacts (good and bad), and that proposed changes should be judged within an explicit spatial context." It attempts to overcome a tendency from design fields, such as landscape architecture and planning to work in isolation, recognizing that urban spaces are complex and require a multi-stakeholder effort to understand the trade-offs of decisions made (Steinitz 2012). Furthermore, the geodesign framework attempts to break from the traditional model of design, which tends to be static, to embrace dynamic forms of design and decision-making that look at diverse temporal and spatial aspects of the urban landscape (Batty 2013).

3.2 Study Area – Chatham County, GA

Chatham County is in the coastal region of the US state of Georgia. According to the US Census Bureau (2010), it had a population of 265,128 in 2010 and it is estimated that by 2017 it grew to 290,501 people. It is the most populated county in the region (Figure 3.1) and its county seat and largest city is Savannah, also the fourth biggest city in the state of Georgia. Savannah is a historic port city and one of the state's main tourist attractions. Situated in a hot and humid climate, the county houses and attracts several people who are potentially vulnerable to heat (Table 3.1).

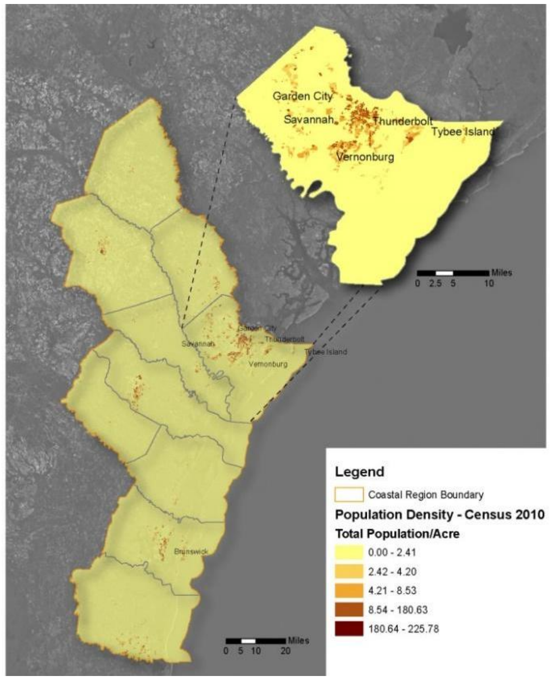


Figure 3.1 *– Population density of the Georgia Coast, based on US Census 2010. This image highlights Chatham County, and illustrates a higher population density in comparison with the coastal region.*

Table 3.1 *– Demographic profile of Savannah, GA with estimated percentage of heat vulnerable populations.*

Total population estimate 2016	**146,763**
Infants and children age 0 to 5 years[1]	7.1%
People 65 years of age and older[1]	11.7%
Low-income population[1]	25.4%
Fluctuating population estimates	
Annual tourist population 2016[2]	13.9 million
Homeless population[3]	4,513

[1] U.S. Census, 2018 – estimates from 2010
[2] Savannah Area Chamber of Commerce, 2018 Economic Trends
[3] Chatham Savannah Authority for the Homeless, 2018 (https://homelessauthority.org/about-homelessness/)

The county has experienced approximately 25 heat or excessive heat events since 1996, with temperatures reaching up to 104°F. Moreover, Chatham County is among the counties, in the state of Georgia, with the highest vulnerability to heat (Maier et al. 2014, KC et al. 2015). To be more specific, a study by Maier et al. (2014) shows that heat vulnerability in the county is linked to poverty, higher concentration of racial minorities, lower education levels, in addition to a prevalence of elderly citizens and people with pre-existing health conditions. As seen in Table 3.1, approximately a fourth of the population of the county is considered low-income, not accounting for the existing homeless population, and a little under a fifth are at a vulnerable age, under 5 or over 65 years of age. Furthermore, the urbanized character of Savannah, and the land cover types associated with it, are shown to exacerbate heat vulnerability (Maier et al. 2014).

In addition to the demographic and climatic variables that indicate Chatham County's potential heat vulnerability, the choice of site and focus occurs for three reasons. First, like many coastal counties, planning departments both at the county and city level in Chatham County have begun to discuss climate through stormwater management and sea level rise, while addressing the vulnerability of such cities to flooding. Such actions and interests stem from the creation of the Biggert-Waters Act (2012) that presents changes to the US Federal Flood Insurance, and has generated an opportunity to discuss the impacts of climate on communities. Second, Chatham County is situated in a hot-humid climatic region of the state of Georgia, thus exposed to heat, particularly in the summer. Recent reports (ASTHOCCC 2014; USGCRP 2016) have pointed to an increase in health risks due to extreme heat exposure in the city of Savannah. These reports also call upon institutions, such as the Georgia Coastal Health District, to engage with planners to address growing risks of extreme heat events. Additionally, the county was impacted by power outages caused by hurricane Irma. And third, Savannah's downtown neighborhood, a representation of colonial planning (de Vorsey 2012), has proven to be resilient to natural hazards over time. While from a thermal standpoint its design, composed of plazas, allows contiguous tree cover to permeate the urban fabric, which promote wind flow and reduce impacts of urban heat islands as discussed by Debbage and Shepherd (2015).

3.3 Methodology

This project combines the use of the geodesign framework (Dangermond 2010, Flaxman 2010, Ervin 2011, Steinitz 2012) and the co-production idiom (Lemos and Morehouse 2005, Dilling and Lemos 2011, Lemos, Kirchhoff and Ramprasad 2012, Lemos et al. 2014), under the general framework of a case study. In broad terms, the combination of these two theoretical frameworks seeks to produce actionable knowledge and are used to support interdisciplinary decision-making. The combination of both aims to simultaneously bridge methodological and data driven knowledge gaps. While, co-production attempts to understand what is needed and works collaboratively to define the research questions and the knowledge that needs to be produce (Dilling and Lemos 2011), geodesign attempts to bring together multiple stakeholders of the place (Steinitz 2012) and support decision-making using a combination of mapping and design to produce a participatory process (Campagna et al. 2016). Thus, the integration of these two frameworks seeks to address existing methodological divergences and support knowledge transference by proposing a collaborative approach that pushes participants (researchers and practitioners) to collectively produce the structure and knowledge needed to develop an HRP. The combination of the geodesign and co-production frameworks attempts to simultaneously incorporate methods familiar to land-use planning fields, while recognizing the transdisciplinary nature of an HRP and its socio-environmental ramifications.

3.3.1 Co-production methods

The use of co-production in this project began by applying a Rapid Assessment Process (RAP), or Rapid Qualitative Inquiry (RQI), a methodology that seeks to gather the insiders' perspective of an issue through intensive teamwork and data triangulation (Beebe 2014). It is suited for complex situations where issues are not yet well defined and where resources are limited for the development of active research (AR) and long-term ethnographic research (Beebe 2014, Meadow et al. 2015). In this context the use of RAP/RQI methods ensures that there is a demand for climate data and that the information produced is applicable in decision-making (Dilling and Lemos 2011). Thus the focus of the workshop and findings of this research relied on information gathered from two participant groups: a convenience group, which gave a broad understanding of the need for an HRP and the types of data needed; and a key informant group that would interact with researchers to apply data, and was composed of members who volunteered to participate in the HRP workshop. Therefore, the RAP/RQI methodology (Beebe 2014), sought to gather the decision-makers' perspective to understand the demand and usefulness of climate data in Chatham County (Beebe 2014, Meadow et al. 2015).

The RAP/RQI methodology was applied in the project to aid in the definition of application needs and in the identification of stakeholders. The focus of the project was determined through information gathered from the convenience group, composed of collaborators from the fields of planning, public engagement, natural resources and public health to decide upon what climatic issues needed to be addressed from a planning perspective. To do so, a total of 9 meetings took place between July and November of 2017. The feedback received during this phase led the project to the focus on heat, and the proposal for developing a heat response plan (HRP) for Chatham County. The insights gathered also signaled that decision-makers feared the occurrence of massive power outages as the aftermath of hurricanes and tropical storms and the resulting heat health-risks related to prolonged exposure. The convenience group also led the research to two key questions:

(1) what methodology would be best suited to spatially and temporally depict heat vulnerability, while using readily available data?, and (2) who should be involved in the collaborative process?

Of the members of the convenience group three participants were identified as key informants, two planners from the CRC and one meteorologist from the NWS. The two planners were familiar with the Geodesign framework and suggested a workshop that would focus on the creation of an HRP. Therefore, the CRC sponsored the creation and implementation of the workshop described in this study. It was responsible for recruiting planners to attend the workshop, and through an ongoing partnership with the American Planning Association (APA), offered professional credits as an incentive for local planners in attendance. The participant from the NWS was asked to attend the workshop and give an overview on local climate conditions, trends, and information on heat vulnerability. During this phase, the group also identified the need to include participants from the local emergency management agency (CEMA) and the health department. Only a member of CEMA volunteered to participate in the workshop and give an overview of existing plans for addressing heat vulnerability in the county. The remaining participants volunteered to participate in the workshop and sought APA professional credits.

A focus group interview was included at the end of the workshop to inquire participants about the process and strategies to ensure the applicability and implementation of an HRP. This part of the workshop followed a semi-structured interview protocol that sought to better understand the usability and the needs for heat vulnerability data. Questions explored the applicability of a collaborative process and the replicability of this framework. They also sought to understand the need for further engagement with other institutions, and the limitations or barriers to developing a heat response plan at a county scale.

3.3.2 Geodesign

In this context, the use of the geodesign framework was made possible by using Geodesign Hub© (www.geodesignhub.com), a planning support system (PSS) developed to connect geography and design in a participatory process (Campagna et al. 2016) and applied to multidisciplinary and multiscale planning processes (Rivero et al. 2015). In simple terms, it is a geovisualization tool that incorporates aspects of Geographical Information System (GIS) as a common language between multiple fields of study. Furthermore, geodesign uses a systems approach to interpret data, which is commonly used by planners, partially adapted from the overlay method proposed by Ian McHarg (1971) and incorporated in GIS. In this study, this systemic form of representation allows variables of heat vulnerability to be expressed as systems and allow the workshop participants to interpret each dataset individually or in relation to others. It is important to point out that geodesign has been applied in Chatham County in the past, as described in the work of Rivero et al. (2015), yet it did not focus exclusively in climate, nor did it address heat explicitly during the decision-making process.

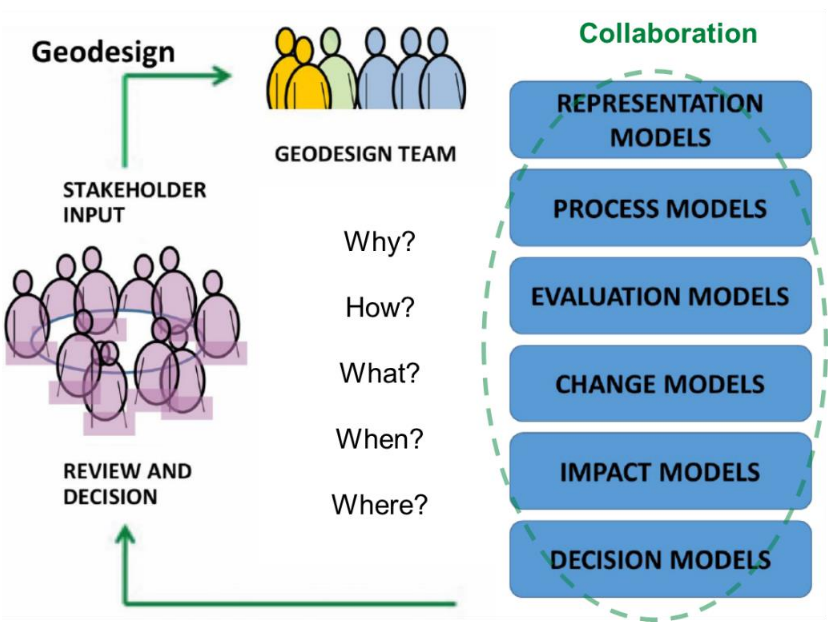


***Figure 3.2** – Adapted diagram of the geodesign workshop process, based on the framework proposed by Steinitz (2012).*

The use of Geodesign in the workshop offered an opportunity for an intensive collaborative process that could open a channel of discussion between local decision-makers working in the fields of planning and climate. Furthermore, as Steinitz (2012) discusses, the use of geodesign allows the planning process to consider the people of the place. In this workshop the local planners also gave insight to local knowledge. Therefore, the framework supports and recognizes that planners use personal experiences and knowledge of place to interpret the socio-environmental relationships and connect them to the topic at hand. This enables an exchange of knowledge between the workshop participants, rather than stimulating one-sided knowledge transference (from climate to planning).

The format chosen for the workshop was a 1-and-a-half-day workshop, using Geodesign Hub©, followed by a 45-minutes focus group to discuss the process, knowledge exchange, sustainability and implementation of an HRP. The workshop took place between July 17 and 18, 2018, in Richmond Hill, Georgia. There were nine participants in attendance, six members from the CRC, a private planning consultant, a member from the NWS and another from CEMA. Also, two members from the University of Georgia worked on mediation and note taking, with remote support from one member from the University of Georgia and another from Geodesign Hub. Proposed policies and projects were recorded in the Geodesign Hub platform, along with descriptions and notes entered by the participants. The program also kept track of proposed timelines, the priorities established by groups and allowed comparative analysis of the points of agreement and disagreement during the planning process. This data was used to analyze the process and identify the ways in which climate data and knowledge was used.

3.3.3 Evaluation Maps

After discussions with the informant group a total of eight (8) systems were identified for the workshop and geodesign process following the framework established by Steinitz (2012) and informed by studies in heat vulnerability (Reid et al. 2009, Johnson et al. 2012, Maier et al. 2014). The systems identified represent social and environmental factors of the county that are linked to heat vulnerability, such as age, economic status, housing quality (linked to overcrowding and presence of air conditioning), presence of green infrastructure, storm surge flooding, among other issues. The systems were used throughout the HRP process and functioned as a stimulus for planners to use the heat data produced by climate scientists, but also, to relate to the information, and incorporate their knowledge of place to the planning process. In other words, the use of systems that represented specific heat vulnerability variables allowed planners to situate the data while applying it.

Each system was expressed as an evaluation map as shown in Figure 3.3. The color scheme used in the evaluation maps follows the methodology suggested by Steinitz (2012), where green expresses the need to act, yellow indicate areas that do not apply to the system evaluated and red represent existing areas or areas that should not be addressed. Additionally, three shades of green were used to represent levels of priority for action, the darker the green the higher the priority. These three categories of green were designated as: feasible (dark green), suitable, and capable (light green).

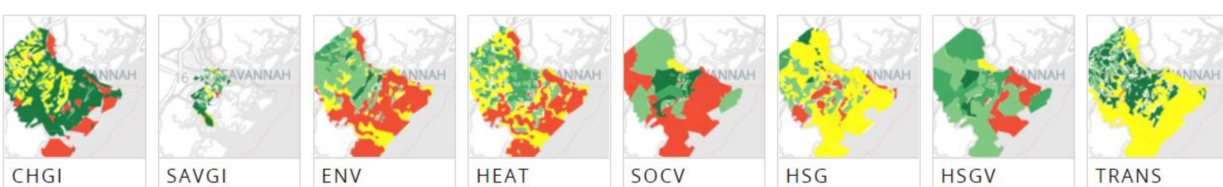


Figure 3.3 *- Evaluation maps developed for participants as seen in the Geodesign Hub platform, representing 8 systems to inform the development of a heat response plan.*

3.3.3.1 Green Infrastructure – County level (CHGI) and Savannah (SAVGI)

Green infrastructure was expressed in two evaluation maps (Figure 3.4): one representing Chatham County green spaces (CHGI) and another representing smaller green areas within the city of Savannah (SAVGI). CHGI was generated using the National Land Cover Dataset (NLCD) and was supplemented with Chatham County future land use plans, to define existing and proposed conservation areas. Similarly, SAVGI used NLCD data in combination with Savannah future land use plan retrieved from the Savannah GIS (SAGIS) portal. The division of two scales of green infrastructure allowed participants to visually identify intraurban green spaces, such as greenways and neighborhood parks and squares, which are not visible in the NLCD dataset. Studies in urban climatology indicate that the presence of green space, particularly tree canopy cover, reduce land surface temperatures (Dousset and Gourmelon 2003, Weng, Lu and Schubring 2004, Buyantuyev and Wu 2010, Zhou et al. 2014), which was also shown in Chapter 2.

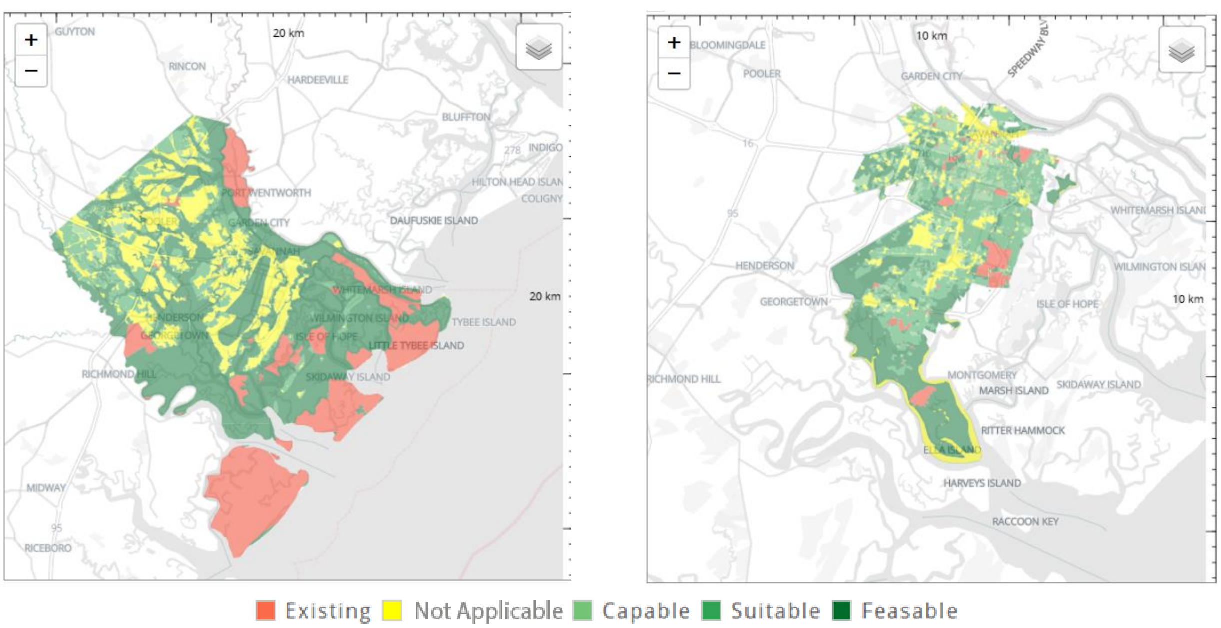


Figure 3.4 *– Green infrastructure evaluation maps for Chatham County and Savannah, Georgia. The map on the left shows the evaluation for the entire county (CHGI) and on the right for Savannah (SAVGI).*

3.3.3.2 Environmental Vulnerability (ENV)

This evaluation map was developed based on Chatham County's existing flood vulnerability, using the Federal Emergency Management Agency (FEMA) flood maps, and identifying storm surge by category. The use of this dataset sought to depict areas most impacted by storms, and thus prone to power-outages. This map attempts to show the intersection between other natural hazards and heat. It aims to depict the linkage of heat death risks as an aftermath of large storms and hurricanes, due to power-outages as shown in climate studies that discuss direct and indirect causes of hurricane mortality (McKinney et al. 2011, Issa et al. 2018, Shultz et al. 2019).

3.3.3.3 Heat Vulnerability (HEAT)

The heat vulnerability evaluation map was created based on data developed in collaboration with the University of Georgia's Center for Geospatial Research. The data explored in this chapter and used to produce the heat evaluation map is a preliminary dataset produced during the development of the study presented in Chapter 2. This evaluation map considers spatial and temporal aspects of heat and is based on the frequency of temperature above 30^{o}C (86^{o}F) as described below.

Heat Data Used

Based on discussions with the informant group and the focus on heat vulnerability mapping, data was developed in collaboration with the University of Georgia's Center for Geospatial Research to ensure that spatial and temporal aspects of heat would be considered in the workshop. Following the methodology proposed by Johnson et al. (2012) the data developed used satellite imagery to represent land surface temperature. However, unlike the extreme heat vulnerability index (EHVI) proposed by Johnson et al. (2012), this study incorporated heat over time. Therefore, the maps developed were the result of the compilation of 44 Landsat satellites 5 and 7 images, surface reflected corrected (Tier 1). The images used were analyzed for brightness temperature using Landsat's thermal band (Band 6), during summer months (June through August) between the years of 1994 and 2012. Two synthesis maps were generated with this dataset, one that depicted the maximum brightness temperatures reached throughout the studied period (Figure 3.5) and another that showed the frequency of temperatures above 30°C (86°F) (Figure 3.6). Both synthesis maps were presented to the workshop participants during the discussion phase of the workshop, yet only the frequency map was used to develop the evaluation map for the creation of the HRP.

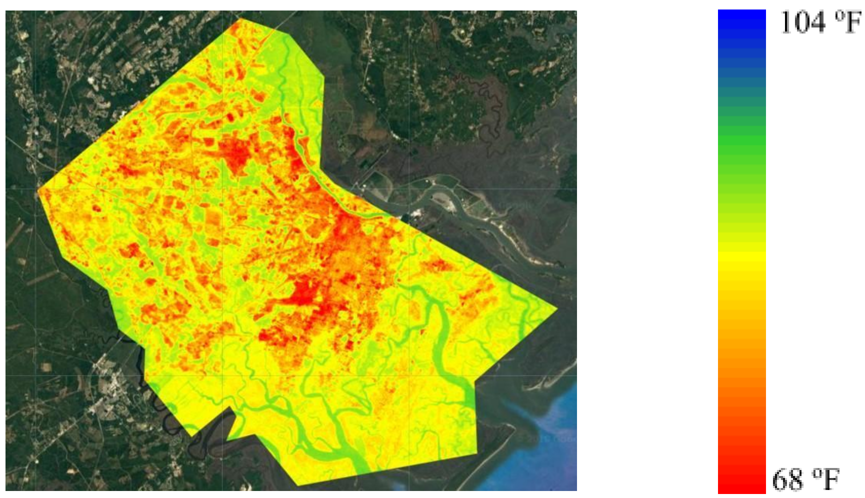


Figure 3.5 *- Maximum brightness temperature during the months of June through August between the years of 1994 and 2012 for Chatham County, Georgia, United States.*

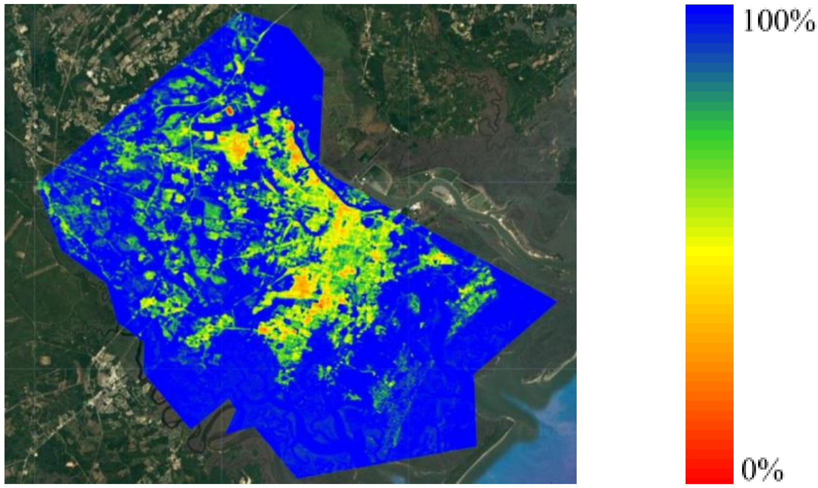


Figure 3.6 *– Frequency of brightness temperature above 30ºC (86ºF).*

3.3.3.4 Social Vulnerability (SOCV)

This evaluation map was developed using the social vulnerability index (SVI) developed by the Center for Disease Controle (CDC) (Flanagan et al. 2011, Flanagan et al. 2018). In broad terms, a simpler version of the SoVI dataset (Cutter, Boruff and Shirley 2003) used by Johnson et al. (2012), divided in only 15 categories as opposed to the 45 categories expressed by SoVI. In line with research in heat vulnerability, the use of a social vulnerability index sought to represent groups more associated with vulnerability, such as population over 65 years of age, and low economic situation (Cutter et al. 2003).

3.3.3.5 Housing Demand (HSG)

The housing (HSG) evaluation map indicates areas that could support a demand for additional housing in the county. Chatham county demographic projections indicate that the county will have an increased housing demand, especially as it becomes a destination for retirement communities. Therefore, this map was developed using Chatham County future land use maps, to identify existing and proposed areas designated for single-family residential, multi-family residential and mixed-use development.

3.3.3.6 Housing Vulnerability (HSGV)

Research in heat vulnerability have indicated that housing conditions are simultaneously related to economic status (Cutter et al. 2003) and the presence of cooling systems, such as air conditioning (Davis 1997). Therefore, this evaluation map used the CDC's SVI dataset (Flanagan et al. 2011, Flanagan et al. 2018) to depict areas in the county that: have poor housing conditions, suffered from overcrowding, and/or have no vehicles in the household.

3.3.3.7 Transportation (TRANS)

This final evaluation map was the result of a walkability analysis that looked at existing roadways and the location of the cooling stations designated by CEMA in its exiting Cooling and Heating Station Plan. This map also included existing roadways designated as evacuation routes. This analysis was developed by the research group to inform issues of accessibility to critical facilities. Reduced accessibility indicates potential isolation, which is shown to exacerbate heat vulnerability (Borden and Cutter 2008, Cutter et al. 2008).

3.3.4 Workshop Flow

The workshop was composed of five parts. It began with a round of technical presentations and discussions to introduce the topic of heat vulnerability and its context in Chatham County. This was followed by a tutorial on how to use the Geodesign Hub platform, where participants practiced how to use tools, visualize evaluation maps, and add proposals. The third phase was described as the policy and project proposal, at this point participants were familiar with the platform and were able to include their inputs, while seeing what other participants were doing in real time. The fourth part of the workshop was described as the interest group phase, where participants were grouped together to focus on aspects of heat vulnerability. Finally, the last part consisted of the focus group discussion and was aimed at evaluating the workshop and the applicability of the collaborative approach to heat vulnerability in Chatham County and neighboring counties.

I. Round of technical presentations

The workshop began with 2 hours of presentations and discussions. Representatives from the NWS, CEMA, and the University of Georgia talked about the forecasting and messaging process, statistics on current and predicted vulnerabilities, the existing CEMA Comfort Station plan, and the linkages between land-use, heat and health. Participants were encouraged to ask questions, make comments and express their experiences with the use of climate data. The intent of this part of the workshop was to start a conversation and stimulate knowledge exchange between professionals from climate and planning fields.

II. Geodesign Tutorial

After the technical presentations, participants were introduced to the Geodesign Hub platform and were asked to use it as a tool to develop an HRP. A trial session was created so that participants could explore the platform. This part of the process was intended to encourage participants to create forms and insert information in a test-environment. As the workshop progressed, participants were asked to go back to this part of the platform to train new skills and gain confidence in them before applying them to the plan proposal. This part of the process also helped non-planners, or those with no GIS background to better understand the Geodesign Hub platform as a decision-making tool that relies on representation and visualization.

III. Using evaluation maps to propose policies and projects

Participants began the process with a set of eight (8) evaluation maps, developed by the research team with the use of readily available datasets, as previously discussed. Participants initially worked individually, each focused on a single evaluation category. They proposed policies and projects that would seek to mitigate or address heat vulnerability. For instance, a participant working on green infrastructure focused on policies that promoted urban greening and proposed projects for the creation of greenways and parks that served more vulnerable areas of the county.

IV. Interest groups

On the second day of the workshop participants were split up into 2 groups, one tasked to focus on the physical planning (e.g. sustainable development), while the other was tasked with heat health and communication (e.g. siting of cooling stations and health promotion policies). Each group set priorities and goals, and produced a plan using the policies and projects proposed during the evaluation phase. Once the teams produced their plans, they were then asked to present it and discuss the points of divergence. This then led them to a negotiation phase so that the teams could combine their visions into a single HRP.

3.4 Results

3.4.1 Proposed policies and projects

During the first part of the workshop each participant was designated one of the eight systems to propose policies and projects that would address heat vulnerability in the county. In total 49 proposals were made during the workshop, 34 policies and 15 projects (Table 3.2). Participants included additional projects and policies during the planning phase of the workshop as needed. Overall, TRANS and CHGI were the systems with the most proposals. The first took a city-based approach to proposals. It identified the different municipalities in the county and proposed targeted policies and projects. While CHGI delineated proposals focused on the entire county and with an emphasis on identification of areas to implement adaptation efforts. Both systems were developed by local planners and there is evidence of the use of knowledge of place in the proposals.

Table 3.2 – *Policies and projects proposed during the workshop per system, where cells represented with hatch pattern indicate policies and solid colors indicate projects.*

CHGI	SAVGI	ENV	HEAT	SOCV	HSG	HSGV	TRANS
1 - Conserve "feasible" GI on Future Land Use Map	1 - Gray/ Lighter-colored pavement	1 - Airport Area Hazards	1 - Heat Planning phase 1	1 - Long Term Care Facility	1 - Hydration station for Pets	1 - Housing in Region	1 - Sidewalk to Pooler Library via Louisville Road
2 - Reduce impervious surface requirements	2 - Green Roof Initiative	2 - Port Area Hazards	2 - Possible new cooling station locations	2 - Largest Homeless Camp	2 - Housing Market 4	2 - Hospital in Region	2 - Sidewalk Pooler Library via Rogers Street
3 - Education and Outreach Heat Plan	3 - Additional Trees	3 - Logistical Park Hazards	3 - Disregard	3 - Stillwell Towers - Functional/ Med Needs Pop	3 - Housing market 2018-2021	3 - Current and Proposed Recreational Facilities	3 - Sidewalk to Community Center Bloomingdale, GA
4 - Include Heat Plan in Resilience Component RegPlan	4 - Grass-Block Parking Development and Awareness	4 - International Paper Location	4 - Include shade in existing splash pad locations	4 - Salvation Army Homeless Shelter	4 - More housing in Coastal Georgia2018-2024	4 - Map the vulnerable population for transit priority	4 - Sidewalk connecting Greenway Bloomingdale, GA
5 - Dispatch transit to vulnerable pop on heat days	5 - Include green roofs as permitted use	5 - Gulfstream Location	5 – Heat Planning Phase 2	5 - Chatham Apartments Vulnerable Housing	5 - Housing in Savannah 2020-2022	5 - Recreational/parks/comfort stations for vulnerable populations	5 – Sidewalk Tybee Island, GA Library
6 - Create a Heat Plan Outreach Coalition	6 - Allow green roofs as permitted use		6 – Heat Planning Phase 3	6 - New Long Term Care Facilities	6 - Workforce housing	6 - Parks/Open Space/Comfort Stations Low Income Areas	6 - Sidewalk to Health Centers
7 - Incentivize building materials that mitigate heat	7 - Heat-Reducing Building Projects						7 - Complete Streets Policy
8 - Reduce parking requirements for commercial uses							8 - Connect Sidewalks to Critical Facilities
							9 - Complete Streets Policy Bloomingdale
							10 - Complete Streets Policy Thunderbolt, GA

Furthermore, these two systems and their proposed policies and projects indicate two types of knowledge of place used to inform decision. The participant proposing transportation measures identifies specific locations and refers to specific cities. He uses his experiential knowledge to propose projects and policies. During the workshop this participant constantly told anecdotal stories of his experiences in these places to justify and explain why he is making decisions. For example, as he is adding the project titled "*Sidewalk to Health Centers*", he remarks: *"I know that the population that's there, just because I park at the parking lot that's there, most of the people that are hanging out there, I know that just from eyesight that they are vulnerable."*

The second type of knowledge of place identified in this process is seen in the proposals in CHGI, where the participant makes references to existing policies and plans. This participant uses a combination of spatial and political knowledge to establish the grounds to propose. For instance, she referred to the existing regional comprehensive plan: "*Amend Regional Plan to include assessment of heat related deaths, create guiding principles and performance standards for compliance with Regional Plan.*" In another moment, she discusses changes to existing requirements: "*Reduce parking requirements for commercial uses.*" In fact, most of the proposals made by this participant were guided by similar understandings.

Another finding observed during this phase was that local planners identified smaller areas and described specific projects and policies. While others made broader proposals that restricted itself to large areas depicted by analyzing combined systems. For instance, actions on heat were proposed by a member from the NWS. Items proposed in this system prioritized action and were described as follows: "*Phase 1 area is small and was selected at intersection of highest heat and social vulnerabilities."* A similar approach can be seen from another participant who did not live or work in the county, who looked at environmental vulnerability. She states: *"Airport Area*

Hazards: With the amount of tourists entering the area, it is important that tourists have an awareness of the heat and potential advisories." The inputs and considerations reflect aspects that were presented and discussed earlier in the day and are general.

The findings observed during this phase of the workshop relate to what Steinitz (2012) describes as the change model. It is when participants identify what needs to happen for the county to effectively respond to heat. Furthermore, we can identify two types of approaches in the proposals presented. Participants with knowledge of place tended to offer what Steinitz describes as *offensive strategies,* which means that they sought opportunities for change and used their knowledge to support how to address these issues. On the other hand, participants who were not from the county tended to seek defensive strategies, meaning that they avoided areas identified as less appropriate and focused on the constraints offered by the evaluation maps.

3.4.3 Preliminary Plans

Workshop participants were divided in two groups. Group 1, designated as the Physical group (PHY), was assigned to focus on a heat response plan that addressed adaptation measures and county development. Group 2, called the Communication group (HCOM), was tasked to focus on health communication and promotion, and county development. Before beginning the planning process each group created a decision model that determined the guiding priorities for plan development based on the eight existing systems (Figure 3.7).

Figure 3.7 – *Decision model comparison showing the priorities established by both groups for the development of the preliminary plans.*

Based on the decision models created, both groups found the heat system (HEAT) to be equally important and ranked it as their number one priority. The PHY group identified county-wide green infrastructure (CHGI) also as a top priority, tied with heat, followed by the city of Savannah's green infrastructure (SAVGI). The HCOM group, on the other hand, ranked social vulnerability and housing vulnerability equally in second place, followed by county- wide and city green infrastructure equally ranked in third place. For both groups environmental vulnerability and housing demands were the least important systems for the development of a heat response plan.

Overall there was little disagreement between the groups. Both had different goals but agreed on heat as the top priority, which made sense given the focus of the workshop. The groups shifted for secondary priorities, but even then, the systems showed small variations in the rankings. This finding indicates that participants took an anticipatory approach to designing the preliminary plans. An anticipatory design approach signals that participants were confident to make decisions (Steinitz 2012). This is often seen in smaller design projects or in rapid and initial assessment processes. Furthermore, this approach to decision-making is often seen in groups composed of experienced decision-makers, with knowledge of place. Therefore, the observations and decision models obtained show that the participants were confident on how to address heat vulnerability. It also demonstrates that participants recognized the socio-environmental overlaps that influenced decisions on the physical environment and on communication of risk.

3.4.2 Proposed Preliminary Plans

In the preliminary planning phase, the HCOM group proposed the use of 26 actions, 6 projects and 20 policies, while the PHY group used 22 actions, 6 projects and 16 policies, as seen in Figure 3.8. Overall the groups focused more on policies geared towards county-wide green infrastructure (CHGI) and social vulnerability (SOCV), as well as projects focused on heat. Both groups gave little emphasis to transportation (TRAN) and included no projects for this system. The same was observed for housing (HSG), which was a low priority for both groups during the establishment of the decision model.

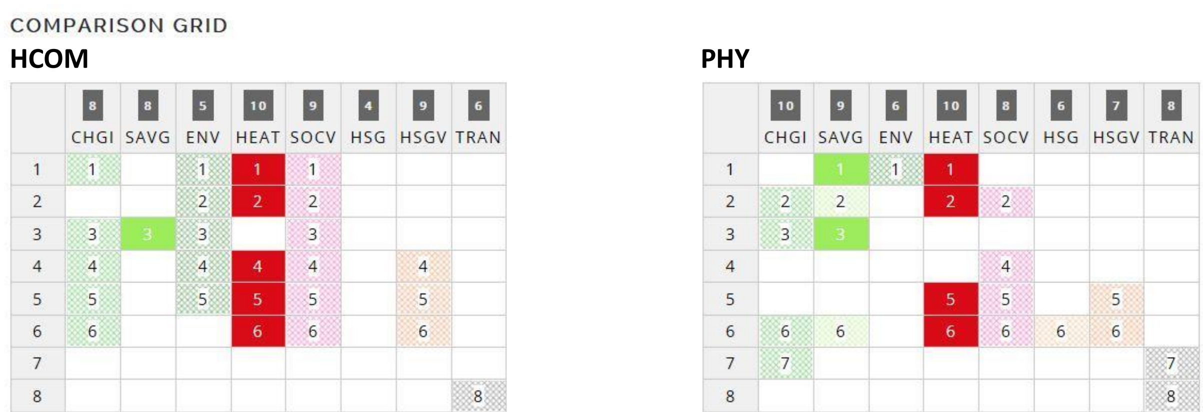
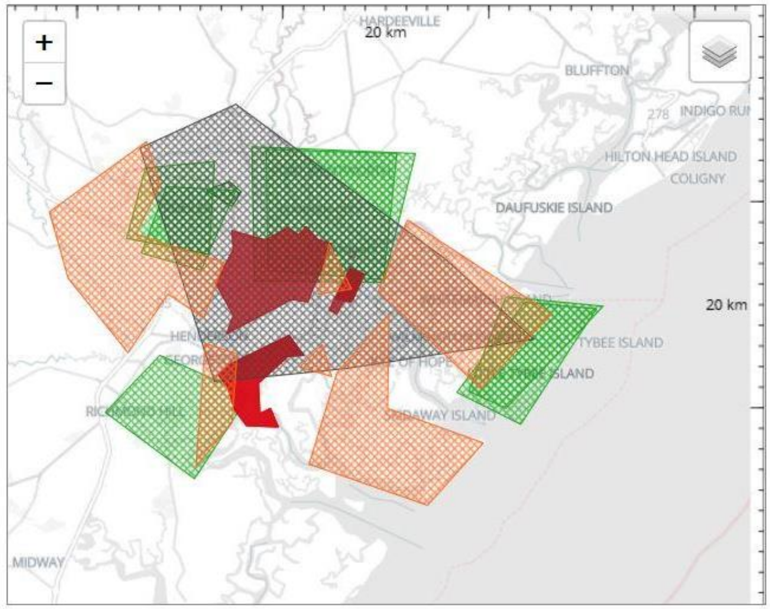


__Figure 3.8__ – Comparison between the Communication group (HCOM), on the left, and the Physical group (PHY) preliminary plans proposed, identifying the projects (solid color) and policies (hatched pattern) used.

The PHY group seemed to follow their proposed decision model more closely than the HCOM group, choosing more policies and projects within the established priority systems. On the other hand, the HCOM group identified the environmental vulnerability system (ENV) as one of the least important systems but opted to use all the policies proposed for it. Additionally, the group designated the city of Savannah's green infrastructure (SAVGI) as one of the top priorities, but only used one of the seven actions proposed.

As seen in Figure 3.9, the groups agreed on the use of 15 actions, 5 projects and 10 policies. In particular, the groups agreed on the use of most of the heat projects and social vulnerability policies proposed. Consensus was found on the use of most of the heat projects (HEAT) and social vulnerability policies (SOCV) proposed. Little to no points of agreement were found in the use of other systems. Based on the decision model, the consensus on the use of social vulnerability is intriguing. While this was a high-ranking secondary priority for the HCOM group it was not for the PHY group. As previously mentioned, the differences in rankings were not striking, furthermore, from a decision-making standpoint, social vulnerability indicates where the at-risk people are. Therefore, for the PHY group these are areas that need infrastructure, and for the HCOM group this is where the education and communication to the general public needs to occur. While this is not established as a high-ranking priority for the PHY group it informs action.



	CHGI	SAVG	ENV	HEAT	SOCV	HSG	HSGV	TRAN
1			1	1				
2				2	2			
3	3	3						
4					4			
5				5	5		5	
6	6			6	6		6	
7								
8								8
9								
10								

***Figure 3.9** – Diagram depicting agreement between the preliminary plans proposed by the groups.*

In total the groups disagreed in 18 actions, 2 projects and 16 policies, as seen in Figure 3.10. Most of the disagreement between the groups was related to the use of adaptation policies and projects proposed in the green infrastructure systems, especially at the county level (CHGI). Additionally, the use of environmental vulnerability (ENV) policies was also a point of conflict. As previously mentioned, this is partly due to a shift in priorities from the HCOM group, which opted to use all policies proposed for the ENV system. However, the non-inclusion of these policies from the PHY group is also intriguing. Though the group did not rank this system as a high priority, environmental vulnerability referred to areas that are prone to storm surge and likely to be impacted by storms. Therefore, thematically these areas align with the physical interventions as well as communication and education. However, the policies proposed for this system discuss and reflect a higher focus on public awareness and risk communication, than intervention. This indicates that participants of the HCOM group shifted priorities when they began to read in more detail the policies proposed and identified the call for communication in environmentally vulnerable locations.

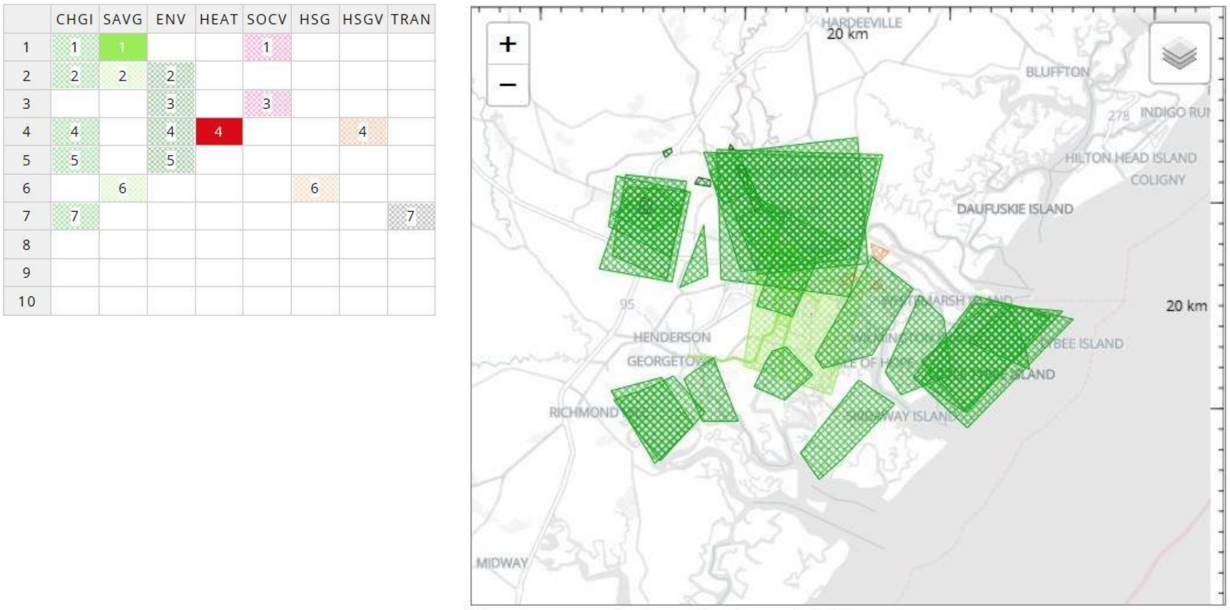


Figure 3.10 – *Diagram showing the points of disagreement between the preliminary plans proposed by both groups.*

3.4.4 Negotiation Phase

During the negotiation phase the groups discussed the points of disagreement and decided on ways to merge their preliminary plans that would maintain the priorities established by both. They began by focusing on the green infrastructure policies. The groups spent considerable time discussing adaptation measures proposed. There was ample discussion of the use of policy "*2-Reduce impervious surface requirements,*" proposed for the CHGI system. The PHY group proposed using this policy, however, the HCOM group questioned the impacts of pervious paving surfaces on heat adaption measures. One member of the HCOM group stated: "*the focus of the plan is not to promote permeability*." Another member of the same group added that "*greening is not the same thing as using permeable paving*." The PHY group members tried to rebuttal by citing the Environmental Protection Agency's strategies for climate change adaptation, stating: "*the EPA says it right here, under adaptation strategies, apply green infrastructure strategies, use permeable pavement to allow runoff to flow through and be temporarily stored prior to discharge*."

The HCOM group questioned the PHY group's view of combining stormwater management and heat adaptation. In this moment the meteorology and climate specialists brought up albedo as an important factor. As one participant pointed out, "dark surfaces will absorb solar radiation and will cause heating. It is not about the permeability of the surface. It is all about the material and color of it." He went on to explain that in the case of heat islands trees and vegetation promoted cooling through shading and evapotranspiration. In the end, the groups agreed to use this policy under the condition that the description of the policy would indicate the use of '*cool pavement materials*.' Thought compromise was reached, the PHY group recurrently came back to the issue of stormwater and interpreted the incorporation of green infrastructure as a 'win-win' approach. One member of the PHY group mentioned that "*we can't think of heat without thinking of other climatic problems. Plus, it's the coast we can't forget about flooding*."

Discussions about flooding returned during the negotiations of the use of environmental vulnerability policies in the plan. The PHY group members pointed to the contradictions of the HCOM group's views of green infrastructure, indicating that they equally recognized the importance of storm surge and flooding when incorporating all the policies under the ENV system. Group members from the HCOM group justified the use of these policies as areas prone to power losses as well as storm surge and flood hazards. The groups compromised on the use of all policies under the ENV descriptor, while interpreting their incorporation from different angles. On the one hand the PHY group seemed to agree on the use of such policies as a way of addressing stormwater and flooding issues, seen as important climatic factors that could not be disassociated from a heat response plan. Yet for the HCOM group this meant responding to areas where heat illnesses could occur as the aftermath of other hazards, such as hurricanes and subsequent power outages.

3.4.5 Negotiated Plan

The final negotiated design incorporated 33 actions, 7 projects and 26 policies (Figure 3.11). This meant that the groups decided to merge their plans to ensure that green infrastructure and social vulnerability were addressed at higher priorities as proposed by the decision models. One discrepancy of the negotiation phase was the decision to maintain the use of all environmental vulnerability policies proposed, even though both groups initial identified that system as less important. However, as described previously the group members agreed during the negotiation phase, that these policies responded to other climatic concerns that were tied to heat vulnerability in the county.

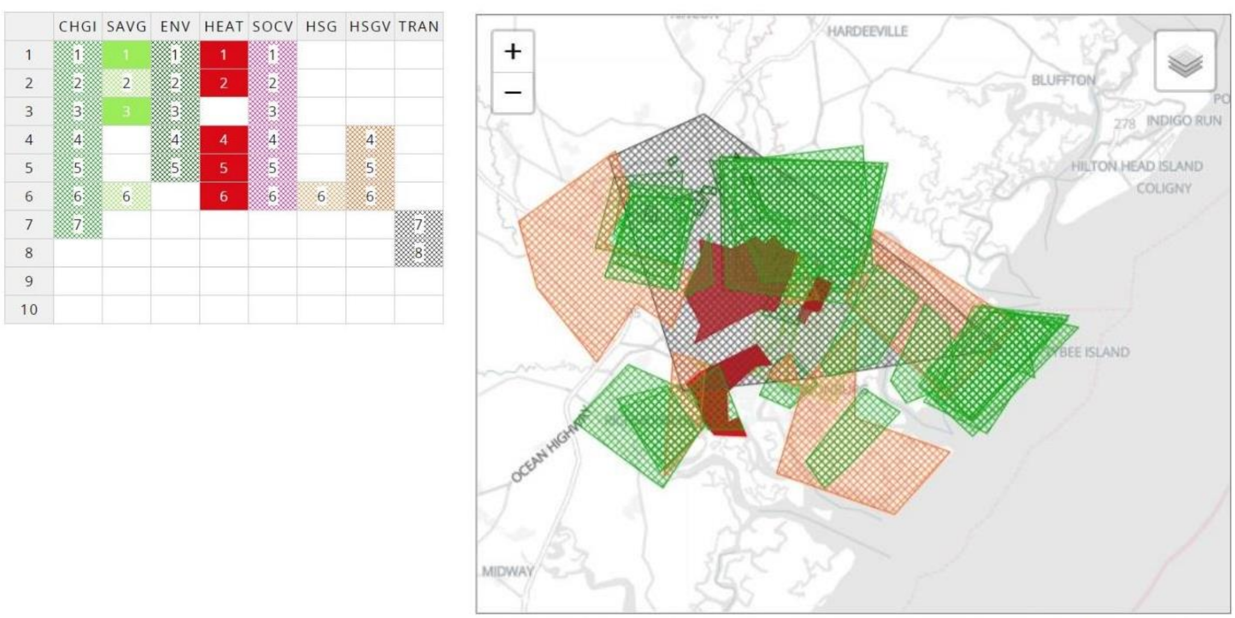


Figure 3.11 *– Final negotiated design developed by the groups, merging the goals of the interest groups (physical – PHY and communication – HCOM).*

3.5 Discussion

The use of coproduction in combination with geodesign allowed this project to address aspects of knowledge transference and the application of climate data. On the one hand, the use of coproduction attempted to address the usability of heat vulnerability mapping in decision making and tried to avoid the '*loading dock'* approach to the creation and application of climate knowledge as described by Cash et al. (2006). Furthermore, this approach is informed by findings from Wolf et al. (2015), that argued that previous research in heat vulnerability mapping has made minor attempts to work with decision makers to develop or apply data used and produced in heat vulnerability studies. Therefore, the use of the coproduction framework allowed this project to focus on the need and applicability of the maps and data produced.

This study began by working with local planners and decision-makers to understand if there was a demand for heat vulnerability studies and in what way knowledge in this field could support decision-making. As discussed by Dilling and Lemos (2011) coproduction processes need a fora where climate scientists and planners can come together. Though a rapid and intense exercise, the 1- and a half day workshop offered the opportunity to explore the application of climate data. This process also informed the type of data needed and the existing points of intersection between research and practice interests. Moreover, the institutional support gained from agencies such as CEMA, NWS, and particularly the CRC, indicate contextual factors that are supportive of this line of knowledge transference and application proposed by the coproduction framework (Dilling and Lemos 2011, Lemos et al. 2012, Lemos et al. 2014).

Complimentary to the coproduction framework, geodesign enabled a systemic approach to the development of an HRP. It supported the use of heat vulnerability variables as systems and stimulated participants to incorporate their knowledge of place in the decision-making process. This aligns with the intended outcomes of geodesign, as proposed by Steinitz (2012). This was evident throughout the workshop, yet clearly identified in the first phase of the workshop, when participants proposed policies and projects. In this phase it was evident that the use of experiential knowledge allowed participants to contextualize heat vulnerability, this in turn informed the decisions made and promoted confidence for the proposal process.

Furthermore, the decision model and the negotiation process showed that the participants of the workshop used an anticipatory design approach. As Steinitz (2012) describes this is a common approach observed in rapid assessment planning process, such as the one applied in the workshop. More importantly, it also reflects that decision-makers have confidence in the direction and intent of the plan. This also points to the use of a combination of scientific and experiential knowledge to create projects and policies. This is tied to what Kristen Hammond (1990) describes as *case memory*, in other words, our experiences and knowledge are used as a repository for decision-making. This cognitive process forms the backbone of decision-making in design fields and is often observed when the designer has grasped the concepts fully to represent and propose action.

3.6 Conclusion

The results of the study indicate that barriers to the application of urban climate knowledge in land-use planning are linked to methodological divergences, but also to the contextualization of information. The combined use of the coproduction and geodesign frameworks gave insights to the applicability of scientific knowledge. The first informed the direction of the research and the types of data needed to support decision-making. The second offered a systemic way of incorporating planning that allowed planners to use their knowledge of place to contextualize and inform the creation of a plan.

The initial conversations with the convenience group indicated no need for a new tool, model or simulation for visualizing climatic issues. This group pointed to the need for visualization and analysis of information that was synchronous with existing decision-making practices.

Therefore, the workshop approach and the use of geodesign proposed a systemic option that aligned with the needs of the local planners and promoted an exchange of knowledge that enabled a collaborative approach to develop a heat response plan for Chatham County. This applied approach recognizes that planners analyze problems through overlays and in a systemic form, while allowing urban climatologists to express dynamic aspects of climate, such as the frequency of high temperatures over time. Furthermore, rather than expressing heat vulnerability as a numerical synthesis, in other words an index, the approach presented here enabled urban climatologists to express the dynamic and complex variables that can affect human health and well-being. This in turn allowed planners to contextualize the information and make decisions that combined climate and place-based knowledge.

The use of heat vulnerability mapping, as proposed by this paper, allowed participants from urban climatology and planning backgrounds, to visually interpret the socio-environmental impacts of heat in the county and evaluate policies and projects that would address the problems identified. As a result, policies and projects used in the final, negotiated plan, focused on heat adaptation, social and housing vulnerability and green infrastructure as the main components for heat response planning.

Furthermore, the study showed that decision-makers do not identify climate issues in isolation of each other and interpret the need to incorporate actions that promote multiple benefits. In particular, the concern with flooding and storm surge were extremely present in this case study, given the nature of coastal environments and the experiential knowledge that local decision-makers have in working with flood resiliency planning.

Future areas of research, however, should consider ways of incorporating urban form as part of the evaluation. This needs to be addressed as a system so that the collaboration process can also interpret the three-dimensional implications of the urban environment in climate interaction and their importance in the development of climate-oriented plans. This would further enable the exchange of knowledge on the implications of density and urban geometry in urban climate processes and inform policy and design adaptation measures.

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CHAPTER 4

FIRST POLICY, THEN ACTION: A CO-PRODUCTION APPROACH TO UNDERSTAND THE APPLICATION OF URBAN CLIMATE KNOWLEDGE IN LAND USE PLANNING.

4.1 Introduction

Barriers to the incorporation of scientific knowledge produced by urban climatology in land use planning are often interpreted as a problem that results from disciplinary knowledge gaps. Literature in urban climatology is extensive and has discussed the application of climate science and attempted to transfer knowledge to the planning field (Landsberg 1973, Chandler 1976, Givoni 1992, Givoni 1998, Ng 2012, Stone, Vargo and Habeeb 2012, Snyder et al. 2012), however, the struggles in application of urban climate science in this field point to challenges that go beyond knowledge transference. This paper argues that, instead, limitations to the application of knowledge are not linked to transference, but rather, to the thought processes that planners use to understand and address issues. This, in turn, determines the usage, or non-usage, of climate science knowledge.

This study focuses on how knowledge is transferred and applied, and how that in turn produces new ways of knowing. Furthermore, it explores the conflicts that arise when new information is introduced and how these new understandings for change interact with existing institutions and routines. It explores the ways in which planners are professionally trained to act and how that trigger a thought process when new knowledge is introduced. To do so, it uses an interactional co-production framework from Science and Technology Studies (STS) to explore these processes in the context of heat response planning in Chatham County, Georgia, in the United States: a coastal county exposed to hot and humid conditions that render its population, particularly its growing elderly and low-income, vulnerable to heat health risks. It focuses specifically on the processes used by planners during a heat response planning workshop, exploring the discussions and actions taken to develop a heat response plan.

This allows this study to demonstrate the process that results in the production of policies and plans and how that in turn determines and reinforces the simplified ways in which climate knowledge is used and acted upon. I attempt to answer the following questions: What are the processes used by planners to respond to climatic issues such as heat vulnerability? How do these processes determine the application of the scientific knowledge produced? How does this process enable or limit the use of climate knowledge in decision making at the city scale? To answer these questions this study relies on recorded narratives and observations made during a heat response workshop in Chatham County, Georgia

This study discusses three findings that are linked to the application of urban climate knowledge in land-use planning. The first shows how climate knowledge regarding heat needs to be contextualized and visualized by urban planners first, in order to establish it as an issue to be addressed. Next, the paper will show how planners use with climate information in a way that ensures action based on that data is fail-safe, where knowledge is used to validated and justify information with the intent of promoting political transparency. Finally, the paper will discuss how planners seek out the creation of guidelines and performance standards to ensure that knowledge is applied in a specific way, under the guidance of it proposing institutions.

This paper concludes that planners rely on a process that simultaneously contextualizes heat and legitimize actions to reduce and address vulnerabilities. This process is rooted in a need to stabilize and institutionalize knowledge so that planners can formally recognize heat as a problem. Once the problem is established and legitimized, it can become part of specific institutional routines and render action unquestionable. Lastly the plans, guidelines and procedures created are less malleable to the use of new information as they rely on stabilized and institutionalized ways of knowing. The introduction of new and nuanced information needs to be supported through contingency interventions that support revisions and enable collaboration for the production and application of urban climate knowledge in planning.

4.2 Conceptual framework

Urban climatologist Albert Kratzer (1956) once wrote: "*Only when we possess sufficient knowledge of the bright and dark sides of city climate are we in a position to use this information and to formulate a technique for city construction based on considerations of climate. Yet something is already accomplished, when we realize that we do not have to accept city climate simply as a fact but can influence it.*" Kratzer was one of the first, of many, urban climatologists to call attention to the need for applying urban climate knowledge in city planning and design (e.g. (Lowry and Lowry 1988, Oke 1988, Olgyay and Olgyay 1992, Givoni 1998). This discussion is recurrent in the field of urban climatology, and often concludes that there are knowledge gaps between urban climatology and city planning. Recent studies have revisited the issue of urban climate application and its importance in fields such as city planning and design (e.g. (Mills 2006, Oke 2006, Souch and Grimmond 2006, Mills et al. 2010, Hebbert and Jankovic 2013, Sailor et al. 2016). For instance, Mills (2014), attributes barriers to knowledge–policy transference to a lack of accessible knowledge and appropriate tools, as well as the lack of a '*supportive political context*'.

Hebbert (2014) goes further and argues that it is partially attributed to a resistance from urban decision-makers and the changing character of urban climatology itself. However, research on the coproduction of science and policy has indicated that this is further linked to policy-making and procedural forms of absorbing information (Corburn 2009, Webb 2016). In contrast to the positions discussed by urban climatologists, this study suggests that the limited use of urban climate knowledge in land use planning (here used as a synonym to city planning) stems from professional practice. Furthermore, these limitations, or targeted forms of knowledge application, are guided by a thought process that is imprinted in planning practitioners during their professional training.

This study uses Science and Technology Studies (STS) as a more socially and politically engaged approach to thinking about the production, circulation and application of urban climate knowledge. This means that the production, and ultimately the usability of climate science in planning is shaped by goals, directives and widely circulated ideas about society and environment (Goldman and Turner 2011). Moreover, studies in political ecology, as suggested by Goldman and Turner (2011), have examined the role of knowledge, expertise and technical practice in the creation of environmental policies, while other studies have explored the ways in which technical knowledge is packaged, stabilized and circulated over time (e.g. (Scott 1998, Agrawal 2005, Cote and Nightingale 2012). Studies on the coproduction of urban climate planning, such as Corburn (2009), have come to similar conclusions, suggesting that '*authoritative technical knowledge*' is stabilized and institutionalized so that it can become a '*given*'. Similarly, Webb (2016) suggests that this process of applying, stabilizing and institutionalizing urban climate knowledge in planning is further tied to historic, long-term socio-cultural contexts of the city, and political and policy decisions made in the past. In other words, this approach aims to recognize that context, culture, values and subjectivity impact decision-making, just as much as facts, objectivity and reason, and furthermore, are determinants to the '*usability*' of urban climate knowledge.

With that in mind, this paper draws on the STS framework of co-production, inspired by the works of Jasanoff (2004) and Hilgartner, Miller and Hagendijk (2015b), to explore the rationale used by planners to determine whether knowledge is used, or not, and how. This framework has been vastly used in studies at the intersection of environmental science, policy and practice, and refers to the recognition that knowledge and action are interdependent (Wyborn 2015, Miller and Wyborn 2018). To be more specific, this study takes an interactional co-production approach, meaning that it focuses on the challenges and conflicts that arise as new knowledge and opportunities for change interact with existing practices and institutions (Hilgartner, Miller and Hagendijk 2015a).

Interactional co-production, as Tim Forsyth (2019) describes, can depict how contemporary political factors reshape, or assimilate, knowledge claims. This approach seeks to understand "how developments in science and in society emerge together from deliberations and confrontations about old and new views on what "*is*" (knowledge, science) and what "*ought*" to be (politics, ethics, aesthetics)" (Hagendijk 2015). Furthermore, Jasanoff (2004) suggests that processes of co-production are composed of "*ordering instruments*", simply put, instruments and practices that are needed to support the creation of institutions, discourses, identities and representation. This study focuses on two concepts that derive from Jasanoff's proposed "ordering instruments". First, the study adheres to the concept that institutions serve as "inscription devices of society". Put differently, they function as repositories of knowledge and power, and thus establish ways of knowing and acting. This, in turn, creates *routines* that are repeated either because practitioners are socialized into their use, or because doing things differently would be too disruptive (Hilgartner et al. 2015a).

Second, this paper embraces the concept of "*sociotechnical imaginaries*", proposed by Jasanoff and Kim (2009), which refers to a collective vision for what social life and social order should be in the future, reflected in the design and establishment of projects and plans. Therefore, imaginaries refer to a desired future that the state and society believe should be attained. To do so political actors use science and technology as instruments for decision-making, but also for the construct of a collective vision for the future (Hagendijk 2015).

The use of interactional co-production in this research focuses on how planning practitioners address urban climate science. It uses the topic of heat and the production of a heat response plan to examine the processes used by planners to incorporate new information in the context of their existing routines, institutional frameworks and day-to-day concerns. It uses the heat response planning workshop as an instrument to examine the processes that define how planners respond to climatic issues, such as heat vulnerability, in the context of the professional routines and imaginaries that shape what is expected of the future. Furthermore, it seeks to understand how these processes determine what knowledge on heat is used, and how this enables, or limits, the use of climate knowledge in decision-making at the local scale.

4.3 Background

Heat is the deadliest natural hazard in the U.S. (Borden and Cutter 2008), and more importantly, it is particularly dangerous to children, elderly citizens over 65 years of age, and low-income populations (Cutter, Boruff and Shirley 2003, Johnson, Wilson and Luber 2009). These are also the populations that often do not have the resources and/or mobility to protect themselves from heat exposure. According to the National Weather Service (2019) over a fifth of all weather-related deaths were heat fatalities. However, determining heat-related deaths can be difficult, since pre-existing conditions such as diabetes, cardiac and respiratory diseases are usually seen as the ultimate causes of deaths, rather than the stressor, heat.

Chatham County is situated in a hot-humid climatic region of the state of Georgia, in the United States. It is exposed to heat, particularly in the summer, and has seen approximately 25 heat or excessive heat events since 1996, with temperatures reaching up to 104^{o}F. A study by Maier et al. (2014) indicates that Chatham County is among the counties, in the state of Georgia, with the highest vulnerability to heat. The study also indicates that this is due to poverty, higher concentration of racial minorities, lower education levels, and underlined by a prevalence of elderly and those with pre-existing health conditions (Maier et al. 2014). Approximately a fourth of the population of Chatham County is considered to by low-income, and a little under a fifth are at a vulnerable age, under 5 or over 65 years of age. More importantly, these numbers and studies demonstrate that the experience and vulnerability to heat is uneven. Individuals in the county will not be affected by heat in the same way. Furthermore, Maier et al. (2014) point out that the types of land use that surround people, also influences how vulnerable they are to heat.

4.4 Methods

This study uses a workshop created in partnership with the Regional Planning Department of the Coastal Regional Commission of Georgia (CRC) to develop a Heat Response Plan (HRP) for Chatham County. Additionally, the workshop had support from the National Weather Service (NWS) Peachtree Office and Chatham County Emergency Management (CEMA). A member from each of these agencies participated in the workshop and opened the workshop by presenting on heat statistics, vulnerability and local action plans. Planning practitioners were offered professional credit through the American Institute of Certified Planners (AICP) and signed up to participate voluntarily. The workshop occurred between July 17 and 18, 2018, in Richmond Hill, Georgia. The format chosen was a 1-and-a-half-day workshop, followed by a 45-minutes focus group to discuss the process, knowledge exchange and ways to apply an HRP in the county. In total nine participants attended the workshop, 6 members were planners from the CRC, one was a private consultant, one worked in the Chatham County Emergency Management Agency (CEMA) and one worked for the National Weather Service (NWS). In total, seven of the participants self-identified as planners, and two as non-planners.

The process also included two researchers, an urban climatologist with a planning background and a planner. The first was an active participant in the workshop, simultaneously serving as a moderator and participant, while the second focused on observing and taking notes. Two additional members gave support and observed the workshop process remotely. After the workshop, the researchers met to discuss the outcomes, and took notes on what they observed during the process. The observations focused on both the engagement of the participants and the outcomes of the workshop, trying to better grasp the interactions of the group and the plan proposed.

The findings of this research are based on the analysis of audio recording transcriptions, observation notes, and the proposals made by the participants, recorded in a web-based platform (Geodesign Hub). Participants were asked to design and insert descriptive text to explain their proposals. They were also asked to identify if proposals should be applied as policies or projects. The analysis process relied on transcription and coding to identify recurrent themes, with the aid of a computer software MAXQDA (VERBI 2017). Audio recordings were transcribed directly into the software, while participant descriptions were imported from Geodesign Hub into MAXQDA. Observations were incorporated as memos in the transcribed text. The coding was developed as common themes emerged and indicated recurrent processes that informed if and how knowledge was being used during the development of the HRP.

4.5 Finding 1: A process of contextualization and visualization of information

Throughout the workshop, participants sought to identify the issues that were linked to heat vulnerability. This was evident in conversations when participants discussed their experiential knowledge to justify where proposals were occurring. For instance, when proposing a policy titled: '*Connect Sidewalks to Critical Facilities*,**'** a planner made the following comment to his group: "most of them don't have a car, and it is a 10, 12-story building that you would need to evacuate." His comment shows the use of experiential knowledge to identify where to act. He goes on to state that: "*I park at the parking lot that's there. Most of the people that are hanging out there, I know that just from eyesight that they are vulnerable*." This narrative supports further observations that indicated that participants attempted to contextualize the information and used the web-platform to visualize where things were occurring. It was through this process that they proposed forms of action. However, 'action' was not synonymous with the proposal of projects. For instance, it was not about simply planting more trees or incorporating green roofs. As one participant described: "*We can't propose projects without policies. First, we need to create the policies that can help us enforce, finance and stimulate projects*." Therefore, the thought process is one of validation and legitimization.

For the planners in the room, it seemed as though creating policies meant first recognizing the problem itself. Policies where thus used as instruments to contextualize and territorialize heat. Some of the proposed policies included descriptions such as: "*Create Future Land Use Map for Resilience Component of Regional Map specifically for Heat*," or even suggested the need to establish phases based on the mapped "*intersection of highest heat and social vulnerabilities*."

Moreover, during group discussions comments such as: "*if they're looking at the homeless camp folk, there is a lot of homeless that are around the Salvation Army in Savannah, it is huge!*" indicated that planners used experiential knowledge to further contextualize action. They would anecdotally discuss specific locations that would set the tone for who might be vulnerable. These observations and descriptions indicate a need to visually represent heat in a contextual way. In other words, who is vulnerable, why, and how does that play a role in the '*imaginaries*' that the county aspires towards 50 years from now. This is quite evident in the first policy description, after all a 'Future Land Use Map' functions as a representation of the spatial-social order that the county envisions.

The process of contextualizing and visualizing heat allows institutions, in this case the Coastal Regional Commission of Georgia, to assimilate heat in its decision-making routines. This in turn, allows further knowledge on heat to be introduced, but more importantly, it allows planners to produce additional representations, that in turn serve to circulate knowledge among other planners and institutions. This process seeks to make action specific to local contexts and more justified. Once heat is understood as a legitimate stressor to the county, planners will begin the process of securing funds and resources so that projects and incentives can be proposed. Thus, the knowledge used serves a very valid and important role in raising awareness and promoting potentially life-saving actions. However, this same knowledge also serves the purpose of maintaining political transparency (Ezrahi 1990, Jasanoff 2004). It is used to justify action by stating that scientific knowledge has indicated that this should be important to 'you', as an individual, and this is why the county and this institution is acting.

This finding demonstrates the process of stabilization and institutionalization of knowledge discussed by Corburn (2009). Through contextualization and visualization heat is recognized as a ‘*thing*’. This in turn allows heat to be examined as either a collaborator or a deterrent to the attainment of the ‘*imaginaries*’ (Jasanoff and Kim 2009). In other words, this process allows planners to identify the aspects of heat vulnerability that will impede the realization of the imagined future. For instance, how will heat impact a community that is projected to increase its current elderly population by 75% and that aims to attract retirees? Therefore, this process is one of legibility and legitimization. Once heat is established as a ‘*thing*’ it can be incorporated into institutional routines. Its linkages to the imagined future can be justified and will serve to maintain the idea of political transparency (Ezrahi 1990, Jasanoff 2004). It insures that heat is simultaneously institutionalized and applicable (Corburn 2009, Webb 2016). However, it also serves as an element of inspiration for planners. The process of using experiential knowledge indicates that planners attempt to relate to the data, by recalling locations and experiences in their daily lives that further support the existence of heat. Planners, like most designers, seek inspirations to create plans, thus in this process heat becomes a problem to be solved, which triggers what Kristian Hammond (1990) describes as case memory, where planners either resort to their mental collection or seek out information to develop solutions.

4.6 Finding 2: Fail safe vs. Safe to fail

The process of using scientific knowledge to maintain political transparency is also tied to an observed need to justify action, which in many ways is tied to the professional training that planners receive. Thomas Campanella (2011) describes that the contemporary planner is trained to be a “jack-of-all-trades, master of none.” Another common analogy observed suggests that planners are trained to be “the conductors of an orchestra,” further indicating that they do not need to know how to play every instrument, but rather know what they should sound like. These anecdotal forms of describing the profession indicate that contemporary planners are trained to be generalists. Therefore, they are trained to seek information that will support action and the attainment of the imagined future of the county.

However, when uncertainty is present justifying action becomes muddled. For instance, when explaining the heat index (an estimation of the temperature experienced by a person that considers air temperature and humidity), a participant from the National Weather Service (NWS) describes that the data acquired and used to issue heat alerts is obtained from a meteorological station that is in the shade. He goes on to explain that different NWS offices use different thresholds to issue heat-related weather alerts, to avoid over-messaging, "*because [in Chatham] we could issue a heat advisory basically every day, in the summer*." Finally, he reports that data from the NWS and CDC indicate that heat-related mortality occurs at lower thresholds than those used to issue alerts and reiterates the fact that the heat index is derived from data acquired in the shade. He ends by saying: "*In my opinion, and it is unfortunate that that happens, we are actually issuing too few [warnings]*." In fact, in its website the NWS informs that "Since heat index values were devised for shady, light wind conditions, **exposure to full sunshine can increase heat index values by up to 15°F."** Therefore, this moment of the workshop illustrates the use of knowledge to describe underestimations of the data that is currently used to support decision-making.

Later in the day, a participant from the Chatham Emergency Management Agency (CEMA) introduced the existing Comfort Station Management Plan, an annex to the existing Emergency Operation Plan, which refers to how the agency would respond to heat or cold events. The group skimmed through a printed version of the document and discussed the general criteria for setting up a comfort station during heat events. As they overviewed the general concepts, they came across the following description: "*Excessive Heat Warnings are issued within 12 hours of the onset of extremely dangerous heat conditions. The general rule of thumb for this Warning is when the* *maximum heat index temperature is expected to be 105° or higher for at least 2 days and nighttime air temperatures will not drop below 75°."* At this moment, the participant from CEMA paused and remarked: "*I was able to make note, cause I need to update what the heat advisory criteria is. We'll change that to 110."* She was subsequently cautioned by the member from the NWS that CEMA should first contact the local NWS agency to discuss how to proceed. And though she recognized that there is nuance to the thresholds used she went on to state: "*Yeah, it may be different around here. But I made a note to follow up at least, to check that. So, we got that for both winter weather and for heat events."*

This follow-up moment points to the challenges of incorporating nuance and uncertainty in decision-making. Even though the emergency management planner understood that the data is faulty, she needs to use a source and a database that will render her agency's actions transparent and justified. Heat advisories and warnings ensure a credible way of supporting action. It is associated with policies established by the NWS and it is recognizable to the general public. Moreover, even if the NWS does communicate the variability of its data through its website and employees, the issuance of a heat alert will still be dependent on the heat indexes obtained from weather stations. The intent of the use of quantifiable data in this process of legitimizing action seeks a 'fail-safe' approach. Once knowledge is supported by policy it is not only 'unquestionable', it should ensure that action is needed and will solve, or diminish, the problem at hand. Therefore, when knowledge supports nuance and uncertainty it indicates the possibility of failure.

The process of using data to justify action is thus tied to the idealization of establishing fail-safe plans. This aligns with findings from Jack Ahern (2011) in a study of the implementation of green infrastructure projects. Ahern (2011) observed that practitioners tend to have a fear of failure and develop action plans that do not foresee shortcomings nor evaluate the performance of the implemented projects. This once again reiterates a process where the knowledge used to support action needs to be ‘unquestionable’. While, at first, thought processes are needed to contextualize and render heat visible, recognizing it as a ‘thing’ rather than an invisible stressor, further knowledge is needed to support what will be done and how funds will be reallocated. This is evident in policy descriptions such as: “*Amend Regional Plan to include assessment of heat related deaths*.” Thus, to know how many people have died of heat-related illnesses in the past further supports and justifies action. It gives evidence and paints a picture of how heat has affected people in the county, so it can support projects that will reduce future vulnerabilities.

Therefore, these findings stem from the need to validate action and extinguish any apparent risk of failure. For example, by using thresholds for the heat index established by the local NWS, CEMA safeguards itself and produces an apparently ‘fail-safe’ plan to reduce heat vulnerability. It uses a socially acceptable and previously validated criteria that justifies the implementation of a comfort station plan when needed. The same is seen in the proposed policy that seeks to identify heat related deaths. Afterall, this data would come from another local or state agency and would support the creation of other fail-safe action plans.

These findings indicate that to promote action, planners either use knowledge that has already been stabilized and institutionalized, or propose further production of contextual and visual information, that can support transparent and unquestionable action. This aligns with findings from Webb (2016), in a case study in New York City, which indicated that overall policies lacked an explicit use of urban climate science, even though urban climatologists were heavily engaged in the decision-making process. This is further linked to the function of institutions as inscription devices of society (Jasanoff 2004), specifically as they establish ways of acting. The use of knowledge is once again tied to the need to justify action. Furthermore, as discussed by Corburn

2009, in local scales, issues of the legitimacy of technical analysis arise given the extent of political accountability that is expected, therefore, institutions and practitioners tend to support existing data, rather than relying on new information, to avoid failure. This is also tied to the planning training of 'generalists', which relies on the use of information that ensures the success of action. More importantly, it indicates that while fearing failure, planners repeat certain forms of knowledge use that are not malleable to new and none institutionalized data. This aligns with observations made by Hilgartner et al. (2015b) which suggest that decision-makers repeat certain patterns of knowledge usage either because it is an established process or because altering these would be cumbersome.

4.7 Finding 3: Specific policies for specific actions

Finally, the workshop revealed a third process involved in the use of climate knowledge by planners, which relates their desire for support policies that will promote specific types of action, which provides incentives or develops targeted projects. This part of the process is linked with not only the need to justify, but further *prioritize* the allocation of resources and financial support for the development of projects. This was observed in participants' descriptions of policies they wanted, which indicated the need for promoting incentives, such as: "*Provide incentives to use building materials that mitigate heat absorption and reflection*," or "*Through incentives and/or public outreach, encourage the use of grass-block parking in order to reduce the amount of heat absorbed by parking areas.*" This was also seen in policies that indicated changes in requirements or existing permitted uses, such as: "*Allow green roofs as permitted use*" or in cases where priorities are necessary, like: "*prioritize sidewalk network to comfort stations/critical facilities. Have new developments that do not need sidewalks to pay 'in lieu' of fee to connect the sidewalk network*."

This part of the process indicates a third form of knowledge usage that is linked to a need to legitimize the use of resources. In other words, the process begins by using knowledge to contextualize and visualize the problem, heat, and further, establishes that it has an impact and/or aligns with the '*imaginaries'* envisioned for the future. After that, the next strata of action proposed seeks to use knowledge to support and justify action, moreover, it uses information to safeguard action from failure. Finally, this last part of the process points to the use of knowledge to secure and justify the investment in targeted projects. Moreover, it sets up the framework for where, when and how to act. It is during this phase that participants suggest that the institution, in this case the CRC, should establish and enforce "*guiding principles and performance standards for compliance with [the] Regional Plan."* This means that to be eligible to the resources and incentives a project must abide by certain guidelines and principles. This goes back to Jasanoff's (2004) concept of '*ordering instruments*', and the institution as the instrument for establishing routines.

This process of knowledge use is also linked to the stabilization and institutionalization of knowledge. One participant proposed the creation of a "*Heat Plan Outreach Coalition.*" The description of this policy was: "*Partner with NOAA, health officials, community leaders, and elected officials to promulgate the Heat Plan.*" Therefore, this is also a moment to share with other institutions that this is an issue and here are the intentions and actions to be taken. The idea of a '*Heat Coalition*' was brought up again during the focus group discussions. The group was asked about what purpose it would serve and if they saw it as a way of revising the heat plan, to incorporate new information. The discussion suggested that the coalition would serve as a boundary institution that would promote exchange among participating stakeholders. It would be a form of exchanging "*statistics, do outreach, and create political will within Chatham.*" Participants indicated that regional planners should be involved and that a focus group should be developed “*to raise awareness and [create] a targeted agenda.*” Thus, the proposal of a ‘heat coalition’ was seen as a way of further exchanging stable and institutionalized information. It did not envision the possibility of new information, neither did it seek further engagement with academia. The group suggested the inclusion of other local government institutions that would have an interest and the knowledge to support action.

This third and last part of the observed process ensures that planners and other practitioners follow the *routine* established by the institution. Furthermore, the establishment of guidelines and performance standards reiterates the ‘fail-safe’ approach previously discussed. It establishes what specific actions will lead to the attainment of incentives and resources, but it also justifies the specific types of actions to be taken. More importantly, these guidelines and performance standards rely on replicability and generalization, they are not produced to test new forms of action, but rather to apply projects that are fail-proof. Thus, the policies that indicate specific projects, or actions, serve as a safety-net for planners. It is once again a form of demonstrating transparency, but further, it is intended to protect planners and decision-makers from any contestation. If action is contested in the future, practitioners can point to the guidelines and standards stipulated in the policies to indicate that actions follow a scripted code of conduct. With that in mind, the establishment of a ‘heat coalition’, as foreseen by the participants, promotes an even wider safety-net, which attempts to connect various institutions to ensure that regulatory knowledge is exchanged and validate the actions proposed.

The findings from this section show that to be actionable knowledge needs to support incentives and establish codes of action. This is linked partially to what Corburn (2009) suggests is a need for legitimacy of technical analyses, where decision-makers do not associate climate scientists as the appropriate ‘experts’ for making regulatory science in the context of the political accountability that is expected in local decision-making. This is not to say that planners do not value scientific knowledge or recognize the uncertainties and nuances presented, but rather it reiterates the process of using information that is first stabilized and institutionalized (Corburn 2009, Goldman and Turner 2011, Webb 2016). More importantly, the observations here further indicate the use of information for the establishment of routines (Jasanoff 2004), and point to the difficulties in breaking these process when new information is introduced (Hilgartner et al. 2015a).

4.8 Discussion and Conclusion

Climatic issues are complex and urban climate science is constantly advancing. Furthermore, the scientific knowledge produced indicates new understandings on climatic responses to environmental change, as described by Hebbert (2014). Studies in urban climatology, as seen in Chapter 2, indicate that changes in land surface result in increases in land surface temperatures. This supports and aligns with past studies in the field that have attempted to transfer knowledge in urban climatology to decision-making fields such as planning (e.g. (Oke 1988, Olgyay and Olgyay 1992, Givoni 1998, Mills 2006, Oke 2006, Mills 2014, Sailor et al. 2016). Studies have also indicated that land surface temperatures are linked to heat vulnerability (Johnson et al. 2012), furthermore Chatham County is vulnerable to heat and this is expected to worsen in the future (Maier et al. 2014, KC, Shepherd and Gaither 2015). Yet, as this paper points out decision-makers do not readily recognize the scientific knowledge produced in these types of studies as stabilized and institutionalized sources that support application. Given that they have not been incorporated in the regulatory framework, which in turn limits their usability as a justifying mechanism. Moreover, there is still uncertainty in many aspects of climate science, which does not support the establishment of 'unquestionability.' As discussed throughout the paper, these findings align with past studies in co-production and STS which suggest that stabilization and institutionalization are an integral part in determining the 'usability' of climate knowledge (Corburn 2009, Goldman and Turner 2011, Webb 2016). Therefore, this study indicates that to ensure that climate information is applied, urban climatologists must work with planners to produce information that can be contextualized and visualized, and therefore incorporated into the regulatory framework.

The findings in this paper demonstrated that the usage of knowledge is intrinsically related to '*sociotechnical imaginaries*' as suggested by (Jasanoff and Kim 2009). Planners use information simultaneously to contextualize and visualize information in light of these '*imaginaries*', and in turn these are used to support the role that information has on the attainment of the envisioned future. Therefore, it is also a source of inspiration, used to solve problems that threaten the proposed vision. Furthermore, the process of simultaneous inspiration and contextualization rely on experiential knowledge, given that planners relate to the information given and search through their professional and personal experiences to inform the decision-making process, as discussed by Hammond (1990) and Steinitz (2012).

The observations also indicated and supported the use of knowledge to establish routines and guidelines that prescribe forms of acting and reiterate the function of institutions as 'ordering instruments' or, more importantly, as 'inscription devices of society' (Jasanoff 2004). The process of institutionalizing knowledge promote a desired image of transparency (Ezrahi 1990), and ensure the function of the institution as both a source of knowledge and power, indicate what the issues are and how they should be addressed. Moreover, the establishment of these routines ensures a fail-safe approach to decision-making, which leaves little to no room for uncertainty. This mentality is prevalent in the planning profession that trains practitioners to be generalists (Campanella 2011) and promote the identification of information that justifies and validates action.

However, in the face of complex issues, such as climate change, planners need to move away from the fear of failure and accept uncertainty. Ahern (2011) suggests the need for a shift towards a safe-to-fail mentality in practice. Meaning that if planners are willing to recognize the possibility of failure, they will be better equipped to understand the trade-offs that could be present in the application of proposed actions. Complimentary to this, the use of contingent interventions, common in adaptive management approaches, could enable planners to produce plans that are open to revisions and work in collaboration with a range of other fields (Corburn 2009). This would also ensure that new and nuanced information is incorporated in the decision-making process.

It is important to point out that planners are not ill-intended in their practices, yet they are trained and inscribed in a process that constantly creates instruments and routines that seek to legitimize action. For the most part, these people live in the communities that they plan for; therefore, they are also impacted by the decisions made. Furthermore, as previously discussed, the same instruments that serve to establish order are also the source of inspiration for the development of plans. In other words, '*socio-technical imaginaries*' are used by planners to conceptualize plans and projects, and they serve as inspirational instruments. Most local planners believe in the visions that they create, because they have a stake in the matter and decisions impact them directly. The applicability of urban climatology in land-use planning relies on a cyclical exchange of information, it requires constant revision. Urban climatologists are thus called to recognize the experiential knowledge that planners use to apply the information produce. Better yet, they need to work with planners to effectively contextualize and visualize the nuances and uncertainties that inhibit the application of urban climate science.

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CHAPTER 5

SUMMARY AND CONCLUSION

5.1 Summary

This dissertation used an integrative approach to examine barriers to the transference of knowledge between urban climatologists and land-use planners. To do so, it applied a coproduction framework, used in environmental and public policy science, to determine the focus and demand for urban climate data and knowledge. This approach set the theme of the research, focused on heat, and enabled the identification of the types of data needed in decision-making that were analyzed and discussed in Chapter 2. In combination with this lens of coproduction, the study also used a geodesign framework to foster the application of heat vulnerability knowledge, in a workshop setting. The results of the workshop were first examined to understand the integration of heat vulnerability in decision-making, as discussed in Chapter 3. Finally, this research further explored the interactions that occurred during the workshop to understand the processes that determine the 'usability' of knowledge through an interactional coproduction lens used in Science and Technology Studies (STS), seen in Chapter 4.

As a whole this dissertation is focused on the production and application of heat-related climate knowledge to evaluate if barriers to knowledge transference were linked to methodological divergences. But rather than examine the philosophical, structural and conceptual differences that exist between urban climatology and land-use planning, this study explored the production and application of heat-related knowledge to better understand why these differences exist and what purposes are served, as suggested by studies such as MacMynowski (2007). It was also guided by the understanding that very few studies in heat vulnerability have attempted to apply findings in decision-making, as discussed by Wolf, Chuang and McGregor (2015), and often assume that there is demand for climate knowledge that should be easily absorbed by practitioners (Cash, Borck and Patt 2006).

At its core this research used an integrative research approach through which it attempted to embrace plural disciplinary views to understand how urban climate science can be applied in land-use planning. To do so it worked with practitioners and sought to produce actionable knowledge, as discussed by Welch-Devine et al. (2014). It attempted to unpack the complexities that exist in addressing climatic issues, such as heat vulnerability, and embraced the different disciplinary views of urban climatology and land-use planning (Hirsch et al. 2011). Furthermore, through coproduction, this study sought to critically explore the intellectual and institutional, difficulties that exist in integrating climate science in planning. And by combining the coproduction and geodesign frameworks it attempted to recognize and observe practical difficulties of integration, while actively seeking to produce solutions, as proposed by Welch-Devine et al. (2014).

Moreover, this research tried to respond to a recent call for a deliberate approach to the use of the coproduction framework (Meadow et al. 2015, Bremer and Meisch 2017), explored in two chapters in this document. Therefore, it attempted to define clear boundaries between the lenses of coproduction research used in this project. First it focused on a lens that stems from environmental science and public policy, which is focused on the usefulness and application of knowledge (Dilling and Lemos 2011, Lemos and Morehouse 2005, Lemos et al. 2014, Cash et al. 2006), explored in Chapter 3. Then is explored a lens that stems from human geography research in STS, specifically interactional coproduction, which focuses on the processes used to apply knowledge (Jasanoff 2004, Jasanoff and Kim 2009, Hilgartner, Miller and Hagendijk 2015, Wyborn 2015), examined in Chapter 4.

This study began by developing a spatial-temporal analysis of land surface temperatures to understand the relationships between land cover changes and surface temperature increases (Chapter 2). This part of the research focused on the production of data that highlighted the dynamic relationship between urban land cover types and surface temperatures over time. It relied on readily available data and sought to synthesize the findings through mapping, to promote their application in decision-making. The preliminary data produced in Chapter 2, which identified the maximum brightness temperatures and the frequency of brightness temperatures above 30oC (86oF) reached in Chatham County, were used in the geodesign process described and examined in Chapters 3 and 4. The workshop enabled this study to explore two aspects of knowledge application. On the one hand, it examined the combined use of coproduction, inspired by studies on environmental science and public policy frameworks, and geodesign as theoretical frameworks that supported the application of heat vulnerability mapping in a systemic form (Chapter 3). While, on the other hand, it explored the processes used by planners to assimilate climate information and make it applicable for plans and projects, using an interactional coproduction lens (Chapter 4).

The findings in Chapter 2 indicated that certain land cover changes were related to higher land surface temperature increases. More importantly, changes from forested and woody wetland land cover to urban land cover types produced the highest impacts to surface temperature. These results confirmed the hypothesis that certain types of land cover changes result in higher thermal changes. Furthermore, Chapter 2 concurs and supports findings from previous studies in the field, particularly with Fu and Weng (2016), and previous studies that indicate that vegetation abundance and impervious cover are consistently identified as the most important determinants of LST increases (Zhou et al. 2014). This chapter contextualizes the occurrence of heat in Chatham County and how it has changed over time. The findings from this chapter link urban climatology to land-use planning by indicating how past decisions on urban expansion have impacted the local climate.

In Chapter 3 results showed the combined use of coproduction and geodesign as theoretical frameworks to the application of heat vulnerability mapping. It demonstrated that the use of heat data, along with social and environmental variables identified by heat vulnerability studies, in a systemic approach allowed planners to develop a heat response plan. The results from the studied workshop indicated that participants were able to use climate data with confidence. The decision-making process relied on knowledge of place and demonstrated a process of contextualization used to both visually interpret information and justify action. Findings from this chapter align with previous studies that indicate the use of anticipatory design strategies when planners are confident and incorporate experiential knowledge in the decision-making process (Steinitz 2012).

Finally, in Chapter 4 the first findings further supported the results obtained in Chapter 3 and pointed to the need to contextualize and visualize information. But the discourse analysis used in this chapter allowed further interpretation of the thought processes that determine the 'usability' or not, of climate data. It also identified that information is used as a 'fail-safe', in other words, data is an instrument to justify and validate action. Additionally, it also found that practitioners used information to promote specific actions and to support a common vision for the future, also described by Jasanoff and Kim (2009) as ´sociotechnical imaginaries'. The research further linked the use of information to the establishment of institutional routines, recognizing institutions as an archive of knowledge and power (Jasanoff 2004). Therefore, knowledge and data are used by practitioners to create policies that recognize heat as a problem (establish what is known) and prescribe guidelines and standards that determine how to act.

5.2 Conclusion

Instruments such as zoning ordinances and future land-use plans support and foresee urban development, therefore, they are responsible for past and future changes to land use and land cover. By understanding the impacts caused from the removal of vegetation, most importantly, tree canopy cover, this study concluded that plans need to be cautious and explore ways of maintaining urban greening within the city. In other words, green spaces need to permeate the urban network, breaking the contiguity of urban surfaces, to reduce the effects of urban heat islands, as also discussed by Debbage and Shepherd (2015). This conclusion goes in direct contradiction with current trends in planning, such as New Urbanism that support urban density as a climate adaptation strategy. Yet, it offers new grounds for discussing the need to strike a balance between urbanization and urban greening, as an integral component of the city, rather than elements that punctuate the urban surface or a divide between urban and rural environments. Furthermore, this research indicates the importance of maintaining tree canopy cover, as the most effective way of reducing SUHI.

The application of urban greening, however, needs to be considered in conjunction with other areas of study. Given the complexity of addressing this issue, and the need for new plans that incorporate urban tree canopy cover, other fields of research must be considered to better understand the trade-offs that exist. For instance, decision-making should also consider public health implications, such as increase in pollen concentration and the effects of pollution trapping under tree canopy close to vehicular traffic. Social perceptions of nature should also be considered, for example, safety concerns and linkages between urban greening and gentrification.

With that said, this study also concludes that the pathway to applying urban climate knowledge relies on the interaction between scientists and practitioners. It points to the need to coproduce processes of application that recognize experiential knowledge, or as Steinitz (2012) describes, *knowledge of place.* In other words, coproduction needs to go beyond understanding needs for producing '*usable*' information, it should seek to understand how the data will be applied. As seen in Chapter 3, the data produced is applied with confidence when practitioners not only understand the problem, but also are able to contextualize it. Therefore, the issue is not merely about transferring knowledge, but understanding that application is tied to visualization and experiential knowledge. Methodologically urban climatologists focus on the dynamics between urban form and climate and the changes that occur over time, while land-use planners think through information systemically, looking at the interplay of several environmental and social aspects and their implications for the future. This systemic approach used by planners allows information to be contextualized in its present state, so it can support actions for the future. This goes beyond visualizing information and is further linked to knowledge of place.

This study also indicates that usability and application of climate knowledge are directly connected to process and institutional routines. Furthermore, contextualization is linked to what Jasanoff and Kim (2009) identify as '*sociotechnical imaginaries*'. Simply put, a collective vision of what the county, or city, wants for the future. As observed in this study, this vision is the source of inspiration for planners and it is a determinant to the usability of knowledge. However, the application of information is further linked to a need to create policies that justify action and reduce the risk of failure. When faced with nuance and uncertainty, planners tend to reject information, or leave out uncertainty, as these weaken justifications for action and indicate the possibility of failure. This process of using information to justify and legitimize action towards the attainment of a common vision simplify issues, such as heat vulnerability, promoting a ‘win-win’ approach to the problem. Yet as discussed throughout this research, like many climatic issues, heat vulnerability is complex. It impacts society and the environment in multiple ways, and there are far too many implications to approach this issue as a ‘win-win’.

In line with integrative research, this study concludes that there is a need to embrace trade-offs, in other words, losses will inevitably occur. Rather than ignore the uncertainties, policies and actions should embrace them and recognize that failures might occur. As a starting point planners and urban climate scientists alike need to embrace knowledge transference as an iterative process. Better yet, the exchange of information should be a cycle, where research and application work together and accept the changes and failures that might result from uncertainty. Information needs to be revisited and plans should embrace revision. Decision-makers need to recognize that information is not ‘unquestionable’, and thus be open to multiple scenarios. Furthermore, urban climate scientists need to understand that visions for the future play a role on the use of information in planning, and communities rely on these visions. Findings from urban climatology sometimes do not offer a positive and hopeful vision for what is to come, but they can express scenarios and allow communities the autonomy to interpret and decide on if and how to prepare for what might come.

5.3 Concluding Thoughts on Doing Integrative Research

As I stated in the introduction of this document, the process of developing an integrative research meant realizing that urban climatology and its application in land-use planning was a complex issue, due to its socio-environmental impacts and the multiple perspectives that exist on how to address it. More importantly, this process led me to realize that certain values and perspectives were incommensurable, in other words they were not captured and accounted for in my research. For instance, there was no way to measure the likelihood of a similar collaborative process occurring without the aid of a facilitator, such as myself. Would heat inevitably become the object of interest among decision-makers in Chatham County? These are some questions that lead to the aspect of incommensurability in this research that I cannot answer. The will to address this issue does not strictly rely on the importance and relevance of the questions that I aimed to answer in this dissertation or in the data produced by it. It is contingent on political will, practices and values that are beyond the grasp of this study and further reiterate the complexity of the issues I sought to address.

As I highlight in Table 5.1, I tried to produce a study relevant to local planning practice in the coast of Georgia, therefore, direct engagement with decision-makers was crucial in the development of the research program. The choice of subject focused on heat and heat vulnerability stemmed from meetings and discussions with local decision-makers that informed the direction and scope of this study. For instance, these conversations allowed me to understand that to local decision-makers heat was perceived as a threat when related to hurricanes. More specifically, heat was seen as a threat due to major power outages that can occur during hurricane and tropical storm events. While I perceived heat as an issue within itself that could be aggravated by urbanization or extreme heat events; for the most part local decision-makers saw heat as something that residents are accustomed to. The concern with power outages resulted from limited to no access to air conditioning and thus the need to ensure that people would have access to cooling stations and facilities that would reduce heat vulnerability.

Table 5.1 *– Summary of integrative research framework applied in this study.*

<table>
<tr>
<td>Criteria for integrative research:
(4) Relevance to practice
1. Direct engagement with planners to develop a research program that addresses real world problems
2. Collaboration to facilitate decision-making</td>
<td colspan="3">CO-PRODUCTION OF RESEARCH

What climate issue to address?
→ Heat

What knowledge, data, is needed?
→ Accessible data, adaptable to existing methods</td>
</tr>
<tr>
<td>(3) Strategic Communication
Engage with other fields of practice in ways that are effective in reaching them and aid in the understanding of the problem.</td>
<td>Heat Vulnerability Mapping
• Social Vulnerability (SVI)
• Environmental Hazards Housing Vulnerability (SVI)</td>
<td>HEAT RESPONSE PLANNING (HRP) Workshop</td>
<td>Collaborators
• Planners
• Meteorologist
• Climatologist
• Hazard Planner</td>
</tr>
<tr>
<td rowspan="2">(2) Mixed Methodology
Illustrate the roots of misunderstanding to facilitate the bridging of diverse camps Illustrate how to bridge multiple perspectives to clarify the nature of the problem

(1) Multiple theoretical frameworks
Define the problem from multiple theoretical lenses/ perspectives and illustrate the differences between them and what these differences give rise to.</td>
<td>Climate (Heat) Data production and analysis</td>
<td>HRP

Policies & Projects</td>
<td>Workshop and Focus Group

Observations and Transcriptions</td>
</tr>
<tr>
<td>Theoretical Framework

Urban Climatology</td>
<td>Theoretical Framework
Coproduction
Geodesign
Heat Vulnerability</td>
<td>Theoretical Framework

Urban Climatology, Planning, Critical Human Geography</td>
</tr>
<tr>
<td>Resulting Chapters</td>
<td>Spatial-temporal Analysis of Land Surface Temperature (Chapter 2)</td>
<td>A Collaborative Approach (Chapter 3)</td>
<td>A Co-Production Approach To Understand The Application (Chapter 4)</td>
</tr>
</table>

These conversations also allowed me to build trust and relationships that formed the basis for collaboration. I worked with local planners to understand how we could experiment with the use of climate data. The relationships established with the Coastal Regional Commission of Georgia (CRC) were essential to the development of the workshop presented and discussed in Chapters 3 and 4. I worked with members of this institution to set an agenda and understand the format and duration of the workshop. Other collaborations with members of the National Weather Service (NWS) Peachtree office and Chatham Emergency Management Agency (CEMA), brought different perspectives to the workshop and stimulated an exchange of information, rather than setting me up as the expert that introduced new information to practitioners. Instead the collaborative approach made me a participant and a voice among the group, someone who brought an additional perspective. During the workshop the discussions, decision-making and focus group were all moments were multiple voices were heard, and I served as a facilitator rather than the expert that set the tone and direction of how knowledge should be used and to what purposes.

Strategic communication was an integral part of the workshop. I intentionally discussed heat within the context of Chatham County. As part of the workshop I used existing plans that outline the visions for the future of the county, such as the Comprehensive Plan, to describe how heat vulnerability could impact residents in the future. For example, projections from the Savannah Metropolitan Commission indicate that the population over 65 years of age will grow significantly by 2030. I described the impacts that higher temperatures could have on this vulnerable population. More importantly, I tried to compliment technical information presented by collaborators from the NWS and CEMA, contextualizing this on the visions for the future expressed in existing plans. Furthermore, I proposed that part of the heat response plan developed in the workshop should address communication to residents and tourists. Though my research was focused on communicating my research to decision-makers, I attempted to address communication of heat vulnerability to lay audiences as a collaborative process that should be incorporated in the plan.

I applied a mixed methods approach in this study to explore a more nuanced understanding of the application of climate science in land-use planning, as represented in Table 5.1. I began by using quantitative analysis to understand and contextualize the occurrence and evolution of surface heat island and its relationship to land use changes. This enabled me to establish the relationship between the two disciplines, while producing a dataset that was adaptable to the workshop setting that was established with my collaborators from CRC. During the workshop quantitative and qualitative data was collected that allowed me to understand the methodological divergences and convergences during the development of the heat response plan. While the quantitative data expressed the types of policies and projects produced, and the levels of agreement and disagreement; the qualitative data collected was analyzed for comprehension of information, thought processes and confidence of data usage.

Finally, I used multiple theoretical framings to understand and depict the barriers to applying climate science in land-use planning (Table 5.1). For instance, the use of the normative lens of co-production allowed me to explore the need for a boundary person or object that supports the process of creating climate informed plans. Meanwhile I used heat vulnerability study to inform the variables that needed to be considered in a plan, rather than offering a single index that expressed the level of vulnerability of different areas in the county. Furthermore, I used geodesign to support a systemic approach to addressing heat vulnerability that is commonly used in planning practices yet stimulates contextualization and highlights knowledge of place. Lastly, I applied interactional co-production to unpack the thought processes used by planners to apply new knowledge produced by climate science.

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APPENDIX A

IRB APPROVAL LETTER

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Office of Research
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EXEMPT DETERMINATION

Dear James Shepherd:

On 6/7/2018, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title of Study:	When Cities Plan for Heat Health Impacts: A Collaborative Framework to Integrate Planning and Climate
Investigator:	James Shepherd
Co-Investigator	Mariana Fragomeni
IRB ID:	STUDY00005513
Funding:	Graduate School;
Review Category:	Exempt, DHHS (2)

The IRB approved the protocol from 6/7/2018 to 6/6/2023.

This is an exempt study, so it's not necessary to submit a modification for minor changes to study procedure. You can keep us informed of changes that don't affect the study scope by using the Add Comment feature.

Please close this study when it is complete.

In conducting this study, you are required to follow the requirements listed in the Investigator Manual (HRP-103).

Note that I removed the old IRB address from the consent forms and added a statement explaining there is a limited expectation of privacy in focus groups.

Sincerely,
William Westbrook, IRB Analyst
University of Georgia