Knowledge Discovery for Exploring the Relations between Climate Change and Population Dynamics

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Introduction

Climate and human mobility are essentially interconnected and interdependent. Our mobility through ground transportation system powered by fossil fuel is one of the primary forces behind the two major global crises of today's society, namely energy scarcity and climate change. On the other hand, long term change in climate and frequency of climate extreme events, such as hurricanes, floods, snow and ice storms can have both short term mobility challenges and cause long term human migrations as an adaptation phenomenon. Human settlements develop around stable environments where shelter and sustenance are found, and on a higher level, economies can be built. Climate change is expected to shift these stable regions and consequently induce large scale migrations, which in turn can result in famine, cultural conflict, disease propagation, and stress on natural resources and critical infrastructures. In the near term, to reduce oil dependence, environmental impacts, and congestion, a number of alternative energy supply, distribution, and end-use transportation systems, technologies and policies are presently being explored. However, it is still unclear when and in what precise combination these sources and technologies will emerge as successful and sustainable solutions. Ideally, future plausible development and implementation strategies for alternative energy resources and technologies will secure and support a societal system in which energy, environment, and mobility interests are simultaneously optimized. In the longer term, under climate change scenarios it is plausible to expect displacement, migration, and resettlement as an interactive consequence of climate change and its impacts on water resources, land cover and land use. Given the intertwined nature of such a system across wide geographic scales, assessing the effectiveness of possible planning strategies and discovering their unanticipated consequences require data collection, modeling, and simulation at the finest data, process, and societal response levels *coupled* with the system's behavior over large spatial and temporal scales.

Knowledge Discovery from High Resolution Data Driven Simulations

The process of knowledge discovery often extends beyond common data mining techniques on volumes of disparate data to detect patterns, to a new level whereby high resolution data are coupled with modeling and simulations of physical systems to test hypotheses and discover "evolving or emerging" behaviors and trends. In the latter case, such emerging behaviors often reflect unforeseen and undesired consequences of system design. For example, using a high-resolution climate model, researchers have showed that unique spatial pattern of land surface heterogeneity (due to clear cutting along roads) can trigger mesoscale circulations leading to more clouds and rain over the cleared patches [1]. Subsequent studies with satellite data have validated this hypothesis. Another interesting example that illustrates an energy policy-relevancy of similar modeling and simulation based research is the impact of large wind farms on local meteorology [2]. It was shown that turbulence generated in the wake of the turbine rotors can significantly affect surface temperature and humidity. These effects can be minimized by reducing rotor-generated turbulence. Interestingly, low-turbulence rotors are also economically efficient because they can harness the energy that would have otherwise been lost to turbulence. These results have important implications for land use planning through siting, design and impact assessment of wind farms.

Research Challenges and Opportunity

For knowledge discovery, characterization of the interactions between the human dynamics and transportation infrastructure or climate change are essential and requires integration of three distinct components, namely, data, models and computation. In transportation, previous research has attempted to develop simulations to address scenarios regarding the relationships among energy, emissions, air quality, and transportation. These include detailed physical models of transportation engineering, including CORSIM, TRANSIMS [7, 3], VISSIM [4], PARAMICS and OREMS [8]. Very recently, few models have started addressing the human dynamics of physical and social systems, such as SEAS [5] and Repast/Mason [9] and others [6]. However, none has been able to successfully integrate both the physical as well as behavioral aspects to characterize the interdependencies within the US transportation system and can address the interplay between energy, environment, and quality of life.

For climate change impacts, many researchers have studied regional vulnerabilities. Multiple vulnerability indexes have been developed that can be applied in climate change impact models include the Environmental Sustainability Index (ESI) created by the Yale Center for Environmental Law and Policy and CIESIN at Columbia, the Environmental Vulnerability Index (EVI) from the South Pacific Applied Geosciences Commission, and the Social Vulnerability Index (SoVI) from the Hazards & Vulnerability Research Institute at the University of South Carolina. Each of these indices has its own take on vulnerability, which is a large factor in how regional populations will be affected by changing climates. The impacts of climate change will vary by region, because not all populations are as vulnerable to changes [10]. A recent collaborative effort from the UN University Institute for Environment and Human Security, CARE International and the Center for International Earth Science Information Network (CIESIN) identified many potential threats of climate change and regional vulnerabilities to climate change; however, the report is very clear in concluding that the research does not attempt to characterize how many migrants will likely be displaced by climate change, or their probable destinations. Climate induced migration is the result of many forces that exist in a complex space of social, psychological, cultural, physical, and economic systems. While there are many theories of what will drive future migrants and what this means to global stability, there are presently no highly detailed conceptual or computational models that focus on the problem.

Both transportation and climate induced migration is the result of many forces that exist in a complex space of social, psychological, cultural, physical, and economic systems. Progress has largely been limited by data and computational challenges necessary for accommodating the required high resolution along spatial, temporal and behavioral dimensions [11]. Integration of high resolution socio-demographic data [12] and models bring much promise for capturing the social/behavioral dimension [13]. This dimension is essential in enabling us to characterize the interplay and interdependencies between (transportation) technology and societal features or between climate change and human migration that are likely to: (i) have an impact on the success of future transportation or adaptation technologies and (ii) be overlooked by current approaches of modeling at aggregated scales.

A High Performance Modeling and Simulation Framework to Implement Scenarios

To represent the complex social phenomena, we have developed a modeling a simulation framework to utilize an Agent Based Modeling (ABM) platform as well as a discrete event modeling platform. We employed both a micro and a meso scale simulation approaches with implementation of social units (e.g., individuals, households, firms, or nations) and their interactions, and observe the global structures that these interactions produce. In this paper we describe our efforts in developing benchmark databases that enables a scalable modeling and simulating framework that can be utilized across the entire US. We illustrate the capability by simulating a transportation scenario that allows an assessment of plausible market penetration Plug-in Hybrid Vehicle (PHEV) at a sub-County scale and its potential impact on the local electric grid and reducing the carbon footprint through displacement of gasoline. Specific insights derived from the results are highlighted to illustrate the complexity of the demographic dependency for the future success of novel transportation technologies. We will also present results from our ongoing research to highlight the development of a conceptual model of climate induced migration. Specifically, we will review the current state of the art in high resolution modeling and simulation for addressing this class of spatial analysis and the associated computational challenges. Ongoing effort to develop benchmark databases for such spatially explicit modeling and strategies to extend that to a computational modeling and simulation framework will also be discussed.

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