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Workshop on Human Activity at Scale in Earth System Models

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January 26, 2017

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CLIMATE CHANGE SCIENCE INSTITUTE
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ORNL/TM-XXXX/XXX

Climate Change Institute and Urban Dynamics Institute

Workshop on Human Activity at Scale in Earth System Models

With contributions by: Melissa Allen, H M Abdul Aziz, Mark Coletti, Joseph Kennedy, Sujithkumar Nair, OluFemi Omitaomu, Robert Axtell, Christopher Barret, Budhendra Bhaduri, Marcia Branstetter, Thomaz Carvalhaes, Katherine Evans, Nina Fefferman, Jack Fellows, Marc Fialkoff, Aaron Frank, Kevin Gurney, Cyd Hamilton, Mark Horner, Lucy Hutyra, Binita KC, Anthony King, Keith Kline, David McLenna, Benjamin Polly, Benjamin Preston, Amy Rose, Kristin Safi, Shade Shutters, Linda Sylvester, Benjamin Thomas, Peter Thornton

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

Notation	Description	Page List
ABM	agent-based model	13, 14, 15
ACME	Accelerated Climate Modeling for Energy	9
ASU	Arizona State University	ix
BU	Boston University	ix
CAS	complex adaptive system	23
CCSI	Climate Change Science Institute	2
CESM	Community Earth System Model	8
DICE	Dynamic Integrated Climate-Economy Model	15
DSGE	dynamic stochastic general equilibrium	13
ESM	Earth System Model	8, 9, 26
FSU	Florida State University	ix
GCM	Global Climate Model	15
GIST	Geographic Information Science and Technology	11
GMU	George Mason University	ix
IAM	Integrated Assessment Model	8, 15
NREL	National Renewable Energy Laboratory	ix
ORNL	Oak Ridge National Laboratory	ix
RAND	RAND Corporation	ix
SITIS	Situation Synthetic Information Systems	17
UDI	Urban Dynamics Institute	2

Notation	**Description**	**Page List**
UT	University of Tennessee	ix
UWM	University of Wisconsin-Madison	ix
VGI	Volunteered Geographic Information	27
VT	Virginia Tech	ix

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Peter Thornton	ORNL

We specifically thank Jack Fellows, director of the ORNL Climate Change Science Institute and Budhu Bhaduri, director of the ORNL Urban Dynamics Institute for their for their intellectual contributions to and financial support of this project.

Figure 1. Workshop Participants, Workshop on Human Activity at Scale in Earth System Models. Front Row (L to R) Adam Sisco, Olufemi Omitaomu, Melissa Allen, Kelly Measom, Binita KC, Linda Sylvester, Kevin Gurney, Lucy Hutyra, Jack Fellows, Marc Fialkoff, Robert Axtell, Christopher Barrett, Aaron Frank, Katherine Evans, Cyd Hamilton, Budhendra Bhaduri. Back Row (L to R) Someone, Husain Aziz, Thomaz Carvalhaes, Kelly Sims, Anthony King, Benjamin Thomas, Sujithkumar Surendran Nair, Shade Shutters, Mark Horner, Amy Rose, Marcia Branstetter, Nina Fefferman, Benjamin Polly, David McLennan, Jessica Moehl, Mark Coletti, Kristin Safi (Photo by Jason Richards).

EXECUTIVE SUMMARY

Changing human activity within a geographical location may have significant influence on the global climate, but that activity must be parameterized in such a way as to allow these high-resolution sub-grid processes to affect global climate within that modeling framework. Additionally, we must have tools that provide decision support and inform local and regional policies regarding mitigation of and adaptation to climate change. The development of next-generation earth system models, that can produce actionable results with minimum uncertainties, depends on understanding global climate change and human activity interactions at policy implementation scales. Unfortunately, at best we currently have only limited schemes for relating high-resolution sectoral emissions to "real-time" weather, ultimately to become part of larger regions and well-mixed atmosphere. Moreover, even our understanding of meteorological processes at these scales is imperfect. This workshop addresses these shortcomings by providing a forum for discussion of what we know about these processes, what we can model, where we have gaps in these areas and how we can rise to the challenge to fill these gaps.

The workshop begins by recognizing that current scientific tools do not readily allow for studying the interaction between the policies, economics and technology affecting human behavior and ultimately, climate change. Some progress towards this goal, however, has been made in the coupling of Earth System models with Integrated Assessment Models [1]. However, extant science and policy investigations of the causes and consequences of global climate change on human and natural systems and from these sources use Earth System Models (ESMs) and Integrated Assessment Models (IAMs), which do not have overt human representation. Instead, the representation of human influence in these models has been limited to coarse estimates of fossil fuel emissions or the economics of energy markets, among others. Some gains in high-resolution representation of these processes have been made by a variety of researchers [e.g., 2, 3, 4, 5, 6], but the integration of these techniques remains a difficult problem.

In this workshop, reasons for the difficulty of integration were explored in eleven presentations and three breakout sessions. Through these sessions, gaps in the capabilities were identified. Included among these were:

1) Biases and limitations on accuracy in urban emissions and uptake contributions.

2) Differences in definitions of "urban" and consequent allocation of contribution of "urban" emissions to the overall environment.

3) Limited modeling capability for high-resolution evaluation of the impact of alternate fuel sources on the environment (e.g., What is the global impact of zero-energy districts?).

4) Limited modeling capability for modeling the impacts of land use change over time.

5) High uncertainty in high-resolution modeling, although higher resolution is able better to capture atmospheric (and potential human) anomalies that impact regional climate.

6) Tradeoffs among data, scale and computational feasibility.

7) No holistic modeling framework that integrates climate and non-climate drivers and explicit representation of human behavior and choice in the earth system exists.

This and other similar workshops convened around these topics are evidence that the scientific community is ready to take on the integration of human modeling and earth system modeling. However, this integration is a large undertaking. Thus, it is concluded that the larger goal be broken down into smaller initiatives (e.g.

population, traffic, building and industrial energy use, land cover change), rather than throwing numerous human models at the earth system modeling community all at once. The incorporation of an integrated assessment model with an earth system model proved to be the right first step on which to build further integration. A possible pathway for the next step in integrating human activity into the earth system is that of aggregating emissions calculated from high-resolution human processes into the spatial and temporal data types needed by earth system models; then to consider at a later date which of these processes can be more tightly coupled within the system (giving thought to solving scheme compatibility, workflow, coupler criteria and file exchange).

ABSTRACT

Can changing human activity within a geographical location have significant influence on the global climate? In what ways should current global climate models parameterize human activity so that such high-resolution influences can be determined? How can we build decision support systems that inform local and regional policies regarding mitigation of and adaptation to climate change?

The development of next-generation earth system models, that can produce actionable results with minimum uncertainties, depends on understanding global climate change and human activity interactions at policy implementation scales. Unfortunately, at best we currently have limited schemes for relating high-resolution sectoral emissions to "real-time" weather, or to the larger regions into which they ultimately become part of the well-mixed atmosphere. Moreover, even our understanding of meteorological processes at these scales is imperfect.

This workshop addressed these shortcomings by providing a forum for discussion of what we know about these processes, what we can model, and where we have gaps in these areas. Additional topics covered what scales additional knowledge and modeling are required to help assess the efficacy of city targets, policies and incentives for reducing global atmospheric CO_2.

1. INTRODUCTION

The Workshop on Human Activity at Scale in Earth System Models began with opening remarks from Jack Fellows, director of the Climate Change Science Institute (CCSI), and Budhu Bhaduri, director of the Urban Dynamics Institute (UDI).

Dr. Fellows began the session by talking about how the CCSI was formed in 2009 with the objectives of building regional and global climate models, to improve their performance, and to study the inter-relationship between society and climate change. The CCSI also performs experiments to improve representation of sensitive ecosystems in climate models. Additionally, key climate datasets are archived and advertised for general use on CCSI systems. They also engage in scalable research with projects exploring utility tipping points, regional vulnerability and resilience, policy evaluation, and optimal energy and water usage.

Next, Dr. Bhaduri welcomed the attendees and described the UDI, which has the objective of garnering understanding of complex urban systems using behavioral and physical sciences. The UDI strives to gain insight into population distribution and urban land use changes over time to better inform policy. Related to that, the UDI provides research to support optimal creation and use of urban infrastructures by efficient and robust interconnected energy and water systems. The UDI also has as part of its mission to consider climate change with regards to the reliability and resiliency of infrastructure services.

2. PRESENTED TALKS

Each of the talks presented an aspect of the research that would integrate highly-resolved human activity, at its most quantitative, into the earth system as a whole. Since most of human activity occurs in cities, it is in cities that we begin the investigation.

(Note that the presentation slides are provided starting from page A-1).

2.1 *The Urban Carbon Cycle: Uncertainties and Surprises*, Lucy Hutyra, BU

Urban areas are the clear, dominant source of global fossil fuel CO_2 emissions. However, urban areas are also a heterogeneous mix of biological CO_2 sources and sinks. The magnitude and timing of CO_2 sources and sinks varies diurnally and seasonally with phenology, climate, and management. Lucy Hutyra's talk presented results quantifying spatial and temporal variability in urban-scale fossil fuel emissions and explores how biological fluxes vary across urban gradients.

Very often we begin papers and studies with the statistic that 70 percent of greenhouse gas emissions occur in cities. The source of this statistic [7] is less declamatory. The text cites anthropogenic greenhouse gas emissions resulting from cities as "between 40 and 70%" and regrets the impossiblity of making accurate statements about the scale of urban emissions, since there is no globally accepted method for determining their magnitude, and no consistent measurement efforts at city scale.

In fact, different inventories show different areas of high greenhouse gas emissions (road networks, night lights, power plants) which highlight the scale of uncertainty in measurements. Hutyra's work seeks to harmonize existing data to common scales and then to further extend greenhouse gas source and sink measurement and modeling to higher spatial and temporal resolution.

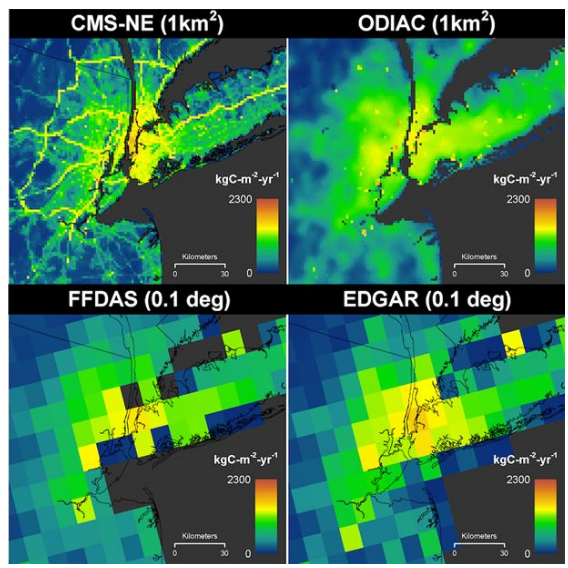


Figure 2. Inventory construction (top-down vs bottom-up) is clear in the resultant patterns of emissions. Emissions differences among the four methodologies for NYC are profound.

Various agencies indicate that sources of greenhouse gas emissions from human activity in cities is unequally distributed across emissions sectors [8, 9]. Hutyra's studies confirm these differences and show a wide range of total and sectoral percentage (35% to 100% variation) of greenhouse gas emissions by state.

Hutyra's work also highlights the contribution of urban and exurban biogeochemical sinks for greenhouse gases and the contribution these make to overall atmospheric content of these chemical species. Edges of vegetated areas, whether occurring in urban or exurban settings are characterized by higher light availability, temperature, vapor pressure deficiency and wind, and provide up to 89 ± 17% of increased carbon uptake [10, 11, 12]. Further, edge vegetation responds well to urban areas due to increased CO_2 and N. However, the growth difference between edge trees and interior ones is largest in cool years and smallest in hot years, meaning that with increased global and local warming in the future, cities will see less benefit from edge vegetation. In fact, the benefit of the edge effect could be up to 1/3 less.

For yards in urban areas, warming could cause 2 to 3 times the respiration among plants, and even a seasonal hysteresis as evidenced by a recent experiment in which July respiration exceeded the fossil fuel CO_2 emissions [13].

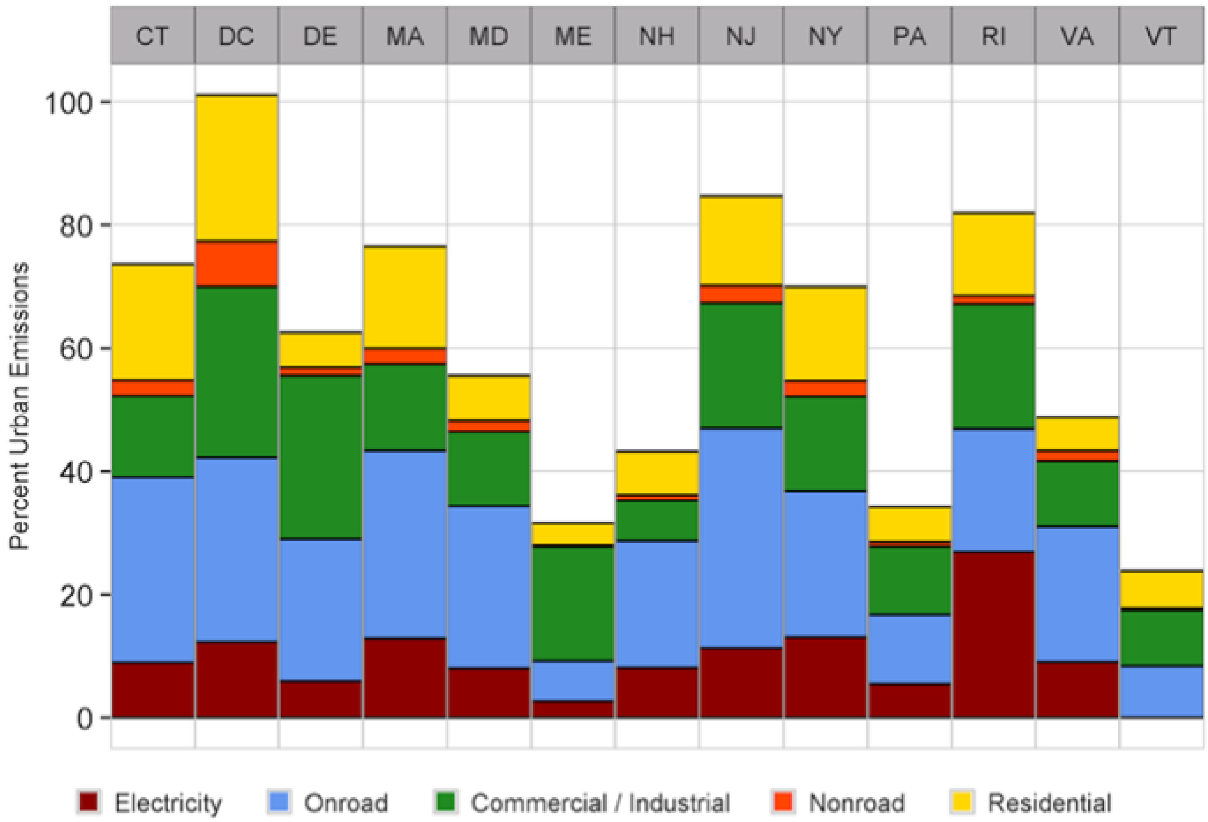


Figure 3. Shows a wide range of total and sectoral percentages of CO_2 emissions by state

This type of information, at this detail, must become part of the modeling of cities at both local and earth system scales. Small differences such as these can add together make large differences in the aggregate and provide guidance emissions reduction plans for each city neighborhood. For full slides on this presentation, see page A-3.

2.2 *High-resolution Emissions Modeling and Earth System Modeling*, Kevin Gurney, ASU

Knowing that certain roads, types of vehicle or parts of a city dominate road emissions and why people drive at specific times could tell city planners where and how to lower emissions efficiently. Improvements in traffic congestion, air quality, pedestrian conditions, and noise pollution could be aligned. Scientists are gathering the required data in studies that match sources of CO_2 and methane with atmospheric concentrations. Now the research community needs to translate this information into a form that both city managers and earth system modelers can use. For instance, emissions data need to be merged with socio-economic information such as income, property ownership or travel habits, and placed in software tools that can query policy options and weigh up costs and benefits. Kevin Gurney's talk highlighted the work he and colleagues are doing regarding acquiring and modeling these complex systems.

The focus of Gurney's talk was greenhouse gas emissions and climate change mitigation. As he measures and models these two things, he has concentrated on balancing determinism with parameterization analyzing how much they change and how important those changes are. One source of uncertainty in modeling urban emissions that Gurney identifies is that of the definition of "urban." He notes that it is a loose term and variable, and can cover a small area to to a large landscape. Nevertheless, as one expands what one considers worth capturing in the human active portion of the landscape, the areal coverage can become significant, even in the context of the usual Earth System Model scales. Urban areas, how ever defined, have been shown to be emissions "multipliers." That is, 80% emissions are from less than 3% of the overall landcover and 99% are from 30% of overall cover.

MICHEL ABDUL-MASSIH & BEDRICH BENES/PURDUE UNIV.

Figure 4. This visualization of carbon dioxide emissions data from Marion County, Indiana shows that large buildings and main roads (red areas) emit the most.

❖ *Size Matters – Kevin Gurney* ❖

Gurney proposes a resolved (high-resolution) characterization of emissions using earth system model approaches. He notes there has been a large growth in work over last 10 years (e.g. State of the Carbon Cycle Reports [14]) partly enabled by remote-sensing imagery, compute power, and sub-grid data that is now grid-resolved. An example of this high-resolution grid-resolved sub-grid data approach is Gurney's Vulcan project depicted below. The project produces CO_2 emissions at the specific locations at which they occur, then aggregates these values to a common 10 km grid for use in further modeling and analysis. The next step is to incorporate Life Cycle studies for even better accuracy.

Ultimately, Gurney says, three resolutions (from 1km - 10km) described by three approaches for quantifiying CO_2 fossil fuel emissions need to be considered: bottom-up, top-down and inverse modeling. At fine space/time scales, where actual energy consumption decisions are made, the feedbacks may be large and may put tremendous pressure on the energy supply infrastructure. Cities need to understand and manage their carbon footprint at the level of streets, buildings and communities. [15]

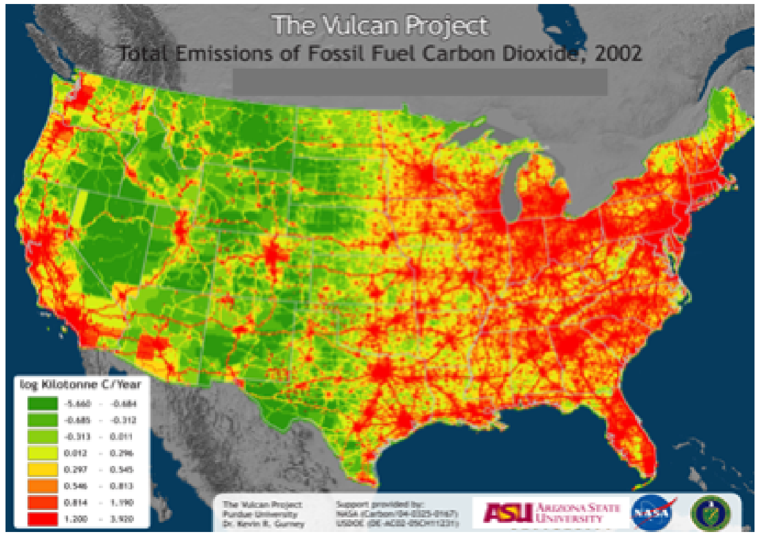


Figure 5. Gurney's Vulcan project produces CO_2 emissions at "native" resolution: points, roadways, powerplant locations. They are then transformed onto a common 10 km grid. Results shown here were produced hourly for 2002.

In other words, "size matters" [16] and place is critical. Spatial variation in emissions [and uptake] within a given region is large. Data and modeling constraints (physical, social, technological) are significant at local scale, causing uncertainty in both measurement and prediction. However, tremendous progress has been made in the past decade; research has been advanced in service of the climate change inverse and forward problem, especially in the form of improvements in highly-resolved and regularized emissions data. With this information, we need to move forward into the evaluation of feedbacks between climate change and energy/emissions at the "human" scale (hourly and sub-kilometer).

For full slides on this presentation, see page A-9.

2.3 *Zero Energy Districts and URBANopt*, Ben Polly, NREL

Several major U.S. cities are interested in constructing Zero Energy Districts. Ben Polly's presentation described how the National Renewable Energy Laboratory (NREL) is working to extend technical resources and tools for Zero Energy Buildings to support the cost-effective design, procurement, construction and operation of Zero Energy Districts. Specific district projects in the Denver area were discussed along with a description of the URBANopt Zero Energy District design tool, which is being developed by NREL.

A Zero Energy Building is an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy [17]. NREL's URBANopt tool is being developed to be used for the design of Zero Energy Districts. The spatial resolution for the tool is at the district level (e.g., city blocks). The EcoDistrict non-profit argues that the district scale is "the optimal scale to accelerate sustainability – small enough to innovate quickly and big enough to have meaningful impact." [18] A 2016 report [19] by the President's Council of Advisors on Science and Technology (PCAST), describes "Urban Development Districts" as "living laboratories from which fundamental knowledge about urban processes and practical implementation practices can be learned, adapted, and generalized to other districts..." There are several district-scale projects in Denver, Colorado investigating the feasibility of high-performance energy districts in their early master planning phases. For example, the National Western Stock Show will be redeveloped into the National Western Center and goals to investigate zero energy have been included in the initial master plan. For this district a variety of technologies are being considered including waste heat recovery from wastewater lines that run above ground through the district.

Another example is the 80-acre Sun Valley neighborhood, which is located west of downtown Denver and just south of a new stop on the W light-rail line. Sun Valley is Denver's lowest-income community. The Denver Housing Authority is examining rebuilding facilities on approximately 40 acres in Sun Valley at much higher efficiency levels and three times the density, with a mixture of public, low-income, and market-rate housing. High-efficiency buildings, district thermal energy, and solar PV are being considered as options to target zero energy goals.

Figure 6. NREL is working to extend technical resources and tools for Zero Energy Buildings to support the cost-effective design, procurement, construction and operation of Zero Energy Districts

Some Zero Energy District design principles that the URBANopt tool will help energy master planners implement are: maximization of building efficiency, maximization of solar potential, maximization of renewable thermal and heat recovery, and maximized load control. This tool will assist in district-scale energy planning, implementation and evaluation in U.S. cities.

2.4 *Integrated Assessment Models in Earth System Models*, Peter Thornton, ORNL

Peter Thornton's talk started by acknowledging the idea that human activities are significantly altering biogeochemical cycles at the global scale, and the scope of these activities will change with both future climate and socioeconomic decisions. This situation poses a significant challenge for Earth system models (Earth System Models (ESMs)), which can incorporate land use change as prescribed inputs but do not actively simulate the policy or economic forces that drive land use change. One option to address this problem is to couple an ESM with an economically oriented integrated assessment model, but this is challenging because of the radically different goals and underpinnings of each type of model. However, by allowing climate effects from a full ESM to modulate dynamically the economic and policy decisions of an integrated assessment model, a robust and flexible framework capable of examining two-way interactions between human and Earth system processes can be developed.

To illustrate this idea, Thornton described the integrated Earth System Model (iESM), in which a complex earth system model is integrated with an Integrated Assessment Model (Integrated Assessment Model (IAM)) in order to capture human activity within the earth system. This integration was accomplished by coupling relevant mechanisms between two selected models: Community Earth System (Community Earth System Model (CESM)) and the Global Change Assessment Model (GCAM). These two models follow completely different modeling paradigms, where CESM doesn't have capability to represent human activity, while IAMs represent natural processes in a superficial way and both the model are developed largely independently of each other. The basic philosophy of coupling of CESM with GCAM was to exploit the strength of each of the model by treating each of the models to specialize in its specific domain, standalone models and pass the useful simulated information about natural and human systems between these models to achieve a two-way coupling within a single integrated system. This two-way coupling of CESM and GCAM was established by replacing GCAM's assumptions of long-term ecosystem steady state carbon updating global carbon cycle (simulated by CESM) at every time step and incorporating land use decisions realized by GCAM simulations onto the land component of CESM's global grid.

2.5 *Developments in high-resolution modeling that will improve efforts to understand human activity as related to climate change*, Katherine Evans, ORNL

Earth system models, such as the Accelerated Climate Modeling for Energy (ACME), are now capable of high-resolution (1/4 degrees or less grid spacing), fully-coupled simulations that track key climatic variables of interest (e.g., temperature, water vapor). In order to provide useful high-resolution simulations in a timely manner, there exists a delicate balancing act between increased spatial resolution and model complexity, and maintaining performance targets on leadership class computing facilities. To meet this challenge, the Department of Energy is investing in computer science, mathematics, and computational science advancements (as part of the BER/ASCR SciDAC and ACME projects, among others). In the atmosphere model, for example, the adoption of implicit time-stepping methods at unprecedented resolutions and complexity allows the model to eliminate the need for subcycling some of the physics calculations. It is also able to maintain similar performance as explicit time stepping for configurations with strongly regionally refined grids. These high resolution models are important targets for new methods because they are better able to simulate many of the natural phenomena on a human-scale.

For example, in the study of drought and precipitation, it is critical to accurately capture the 'atmospheric rivers,' which transport water vapor from the tropics to northern latitudes. Most precipitation on the Northwest coast of the U.S. is delivered via events such as these atmospheric rivers. When simulated by an ESM with low spatial resolution, these rivers form too far South, while high resolution models are able to more closely match observations, as depicted in Figure 7. By separating the fluid-flow scales into low, intermediate and high frequency components, we can determine that these atmospheric rivers are modulated by flow upstream over the Eastern Pacific Ocean, primarily through advection transport of intermediate scale eddies. Unlike typical gobble scale resolution models, high-resolution simulations are able to capture this scale of phenomena better. Similarly, when studying the statistics of extreme precipitation events over the United States, low resolution models underestimate the frequency 99.9 percentile events in the Northwest and Southeast, while high resolution models better represent them.

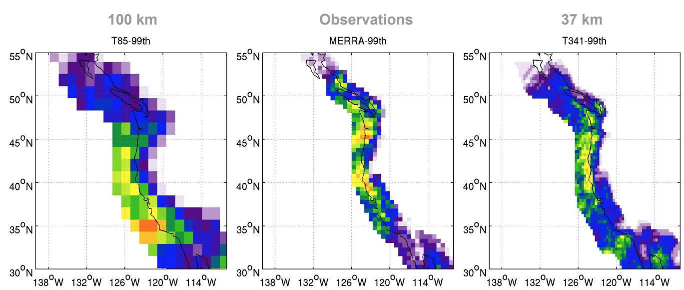


Figure 7. This shows the "atmospheric rivers" over the west coast of the United States. The first and third images depict the results of 100 km and 37 km resolution scale simulations, respectfully. The middle image corresponds to actual observations. The 37 km resolution simulation was able to capture the observed atmospheric river at higher fidelity.

High resolution ESMs can now be used to quantify the likelihood of an extreme event, such as the hydrological event in India, 2013, which caused upwards of 5800 deaths. Using ESM simulations of the event dynamics that were forced with historical and pre-industrial climates, it was possible to identify 4 interconnected proximal causes, and determine that this event was at least a century-scale event. Similarly, a warm upper troposphere anomaly centered over the Western Canada drives cold Arctic air to the surface of the Southern United States. The early 2014 North American cold wave was triggered by such an anomaly. ACME, through current research efforts to increase the vertical spatial resolution, may be able to simulate these anomalies and determine the frequency of such events for different climate scenarios.

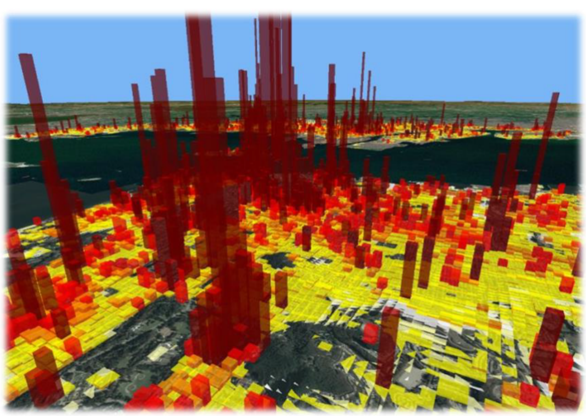
Summarily, ESMs are ever increasingly capable of modeling natural phenomena at the human-scale. This will allow us to connect the simulation of natural phenomena with earth system models to the investigation of impacts, adaptations, and vulnerabilities we experience in our changing world. This includes combining climate simulations and vector born diseases, assessing future water supplies, creating an integrated energy water risk assessment tool, and other being planned within DOE. For full slides on this presentation, see page A-18.

2.6 *From LandScan to Adaptive Population Agents: Modeling the Human Component*, Amy Rose, ORNL

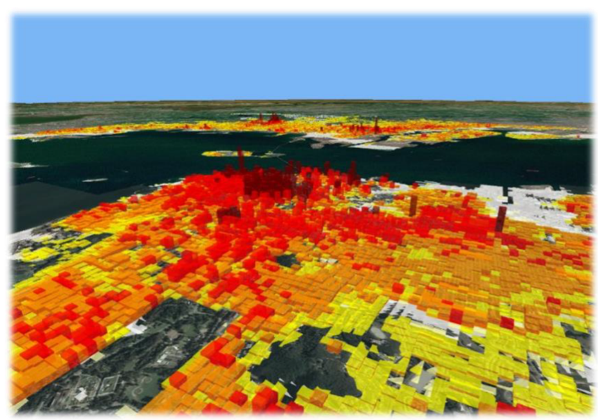
The LandScan Global population distribution model has been used for decades as a critical component of applications such as humanitarian response, disease mapping, risk analysis, and evacuation modeling. Exploring ways to extend this model is an important consideration with research across domains continuing to push toward the use of higher resolution input data, both in terms of spatial and attribute fidelity, as well as scenario driven output. Dr. Rose provided a brief summary of the current activities at ORNL regarding population distribution modeling and simulation of synthetic population that will play critical role in the context of large scale agent-based modeling. The key focus was on the ORNL product, LandScan, that provides high resolution population distribution at global scale. LandScan provides the finest resolution population distribution data ever produced for the world that captures diurnal variations of population. LandScan has been used in several applications including locating population during natural disasters. One example was the integration with the Global Earthquake Model.

The HPC-based scalable computational framework used by the Geographic Information Science and Technology (GIST) group at ORNL can quickly process settlement mapping, even for population that was not previously mapped. The talk initiated discussion on available data sources that can produce this fine resolution population distribution. Understanding future population distributions is critical for urban resiliency, development of sustainable infrastructure and assessing the impacts of climate change. A discussion on generation of population agents identified three major dimensions: scale of representation (units), spatial resolution, and temporal scale. Further, Dr. Rose mentioned the recent research at ORNL–American Population Simulator–which can provide synthetic population at census block group level. This simulator is already being used for several works including a solar panel project for EPSA, an urban mobility simulation, and an estimation of neighborhood energy consumption.

For full slides on this presentation, see page A-23.



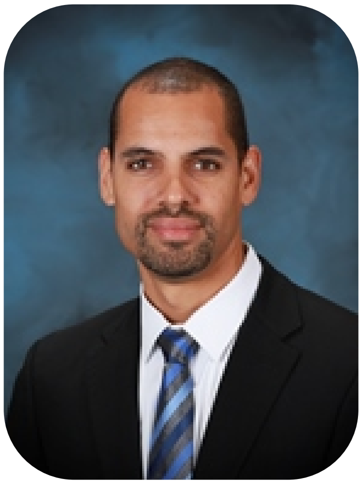
(a) San Francisco population distribution during the day.



(b) San Francisco population distribution at night.

Figure 8. These show the diurnal LandScanUSA population distributions for San Francisco.

2.7 *Science for Solutions: Climate Risk Management in a Post-Paris World*, Ben Preston, ORNL



The climate policy agreement that was reached in Paris in 2016, which a number of countries have already ratified, established national commitments to greenhouse gas mitigation targets while emphasizing the important role of adaptation in addressing climate risk. The implementation of the Paris Agreement through national, sub-national, and local initiatives will place new demands on the climate change research community and Earth system models. Meanwhile, as the climate change community orients itself toward solutions, it must recognize the importance of the Sustainable Development Goals (SDGs) for establishing a broader framework in which those solutions will be pursued. The pursuit of climate risk management in the context of sustainable development creates the need for a more holistic policy framing that integrates climate and non-climate drivers and, ultimately, more explicit representation of human behavior and choice. This in turn raises questions regarding how science can be best aligned to this changing policy context. Ben Preston's talk explored these questions from the perspective of both consumers and producers of climate change science products.

Over the last four decades climate change research has evolved through different paradigms. The initial focus was to get a fairly clear understanding about the likelihood of future, which later lead to evaluating different societal strategies to reduce the impact of changing climate. Now humanity has entered in a new normal, where humans are not only the principal causal agent of global climate change but can also become pursuers of adaptation and mitigation. Thus a new research paradigm in the community has evolved in which evaluation of the impact of current societal responses to future changes in climate is emerging as a central focus. Hence, the Intergovernmental Panel on Climate Change has started thinking of framing climate change impact, adaptation and vulnerability (IAV) analysis within a climate risk management framework with great emphasis on science lead solution oriented IAV program. However, adoption/adaptation of science based solutions by any society is largely a problem of choice by different actors. Additionally, choice space of a society is limited by natural and cultural endowment in the region as well as human, social and institutional capital attributes of the region. Thus, it is fairly clear that in days to come, the climate change IAV community will need to develop tools to account for human/societal behavior for a given sets of choice constraints (imposed/opened-up by different policies) and how different societal attributes facilitate/hinder climate friendly behavior of society or find innovative ways to exploit existing IAM tools to address these societal behavioral choice questions.

For full slides on this presentation, see page A-29.

2.8 *Full-Scale Agent Models for Earth System Science*, Rob Axtell, GMU

Models mediate between theory and the real world. More specifically, *positive models* show how social systems work, and *normative models* on how to make them work better. Finding ideal policies is confined to normative models since naturally policy changes are supposed to improve quality of life in some way and are not used in exploratory roles. Typically, different policy approaches are exercised in normative models to converge on the most ideal.

Unfortunately, many of our current normative models do not consider social dynamics at all, or give them very little weight. For example, a water management system in northern New Mexico has the normative goal of providing fair water access to the area's population, which is used by farmers, ranchers, and Indian reservations as well as for recreation. However, of the approximately 1 million lines of FORTRAN code to implement this water management system, only one line has any behavioral aspect, that of considering elasticity of demand.

Another example is that of fishery management system that has the objectives of ensuring the sustainability of fish species while maintaining viability of fishing fleets. Initially a top-down approach was taken to control the harvest of setting a seasonal catch limit based on an exogenous model of fish and an aggregate fishing fleet that had an optimal harvest. Unfortunately the policy derived from this top-down model meant in reality fishing fleets trying to get their seasonal total allowable catches as quickly as possible, which resulted in global harvest declines. To address this problem, a different, bottom-up approach was tried, instead. With this approach individual fishing vessels based on actual vessels and schools of fish were modeled. Instead of a global total catch quota, the fishermen had tradeable catch quotas. When implemented, this approach had stabilized fish populations and sophisticated management of choke species, which are a type of fish for which there currently is a low quota that may stop a vessel from fishing even if they are below their quota for other kinds of fish [20].

❖ *Social sciences are the* ***hard*** *sciences* – Herbert Simon ❖

Agent-based models (ABMs) were also successfully used to model much of the underlying dynamics of the 2008 housing bubble as shown in Figure 9. An ABM of 2 million people in the Baltimore-Washington metropolitan area was seeded with household demographics from the Bureau of the Census and the IRS, details of structures were gathered from county tax records, current mortgage information was garnered from a company, CoreLogic [21], and real estate transactions were collected from MLS [22].

State-of-the-art dynamic stochastic general equilibrium (DSGE) models implemented by the Federal Reserve used a single class of firm, which did not capture the rich variance in actual US firms. By contrast, an ABM comprised of all actual firms and their employees based on IRS records was able to derive high fidelity macro-economic behavior from this very large micro-economic model [23]. For the modeled period, there were approximately 30 million total firms, of which about 6 million had employees, and about 100 thousand firms are created and destroyed each month; there were also about 120 million employees with approximately 10 million in flux each month.

So what are some of the problems with typical aggregated ABMs? For one thing, fluctuations are not Gaussian at full scale, so when not simulating to full scale, fluctuations either do not match actual behavior, or the parameters have to be adjusted to get correct behavior, which may lead to other aspects of the simulation

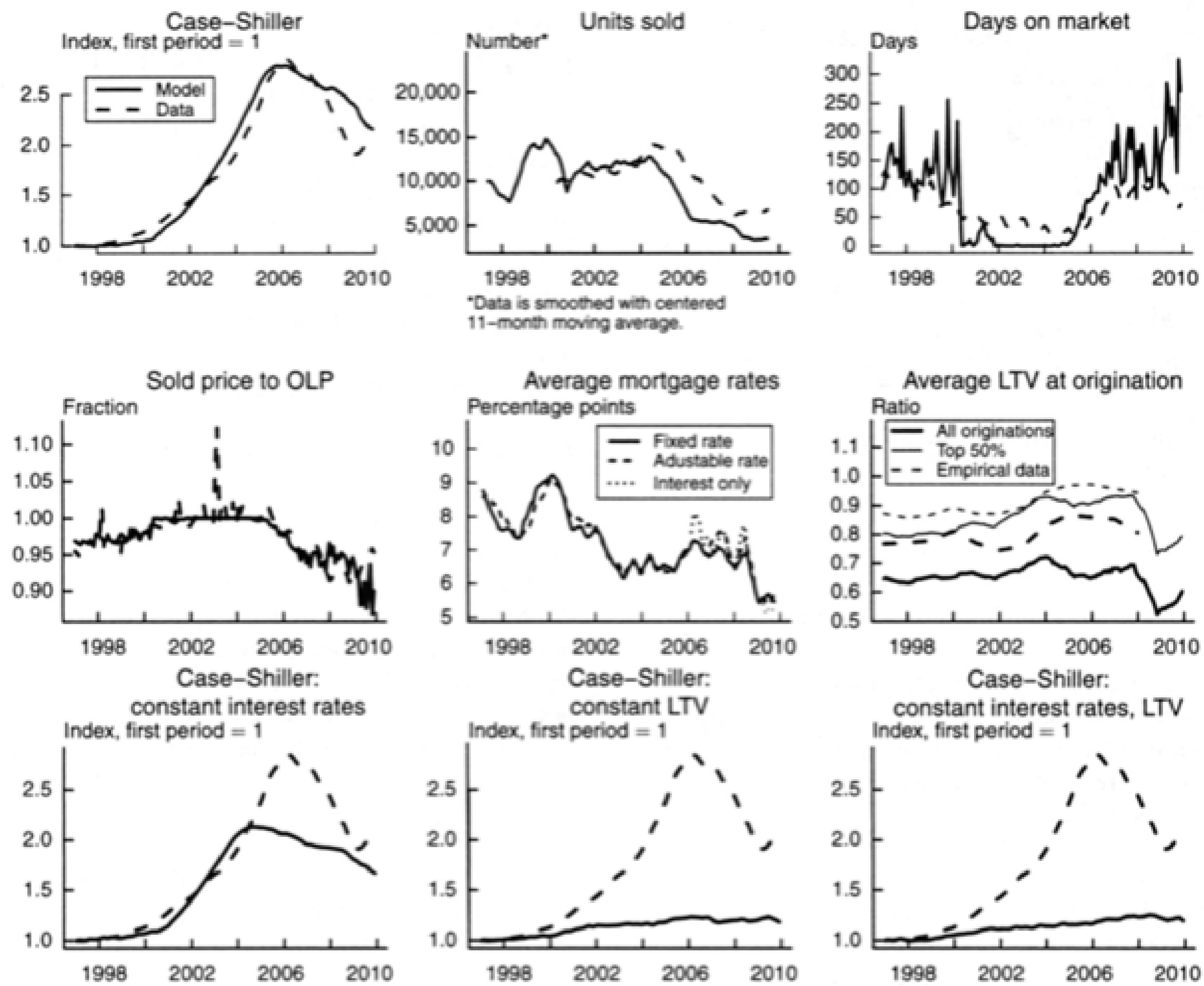


Figure 9. Shows an agent-based model was able to match most of the behavior of the 2008 housing bubble for the Baltimore-Washington metropolitan area.

becoming invalidated. Moreover, social systems are hard to aggregate; there is some fidelity loss that occurs when representing multitudes of real-world entities by an aggregate statistical proxy. Also, social systems are stiff in that the only way at time t to get to some time $T > t$ is via an intermediate step, $(t + T)/2$.

The rationale for using ABMs at full scale include heterogeneity in that agents no longer are proxies for statistical aggregates, but actually mirror existing real-world entities. At full scale bounded rationality can be expressed in human agents; that is, agents must make decisions based on information they have within a given period of time within realistic cognitive constraints, instead of being omniscient, rational agents with limitless computational resources. Moreover, at full scale ABMs social networks can be properly modeled instead of relying on “perfect mixing” of agent archetypes, and can better model social network complexities, which play a critical role in all aspects of human activity. Also, ABMs operate at sufficient scale to explore non-equilibrium states where there is agent-level flux, but aggregate observed stationarity. Walrasian and Nash equilibria are nice in theory, but are not necessarily applicable to real world scenarios. Moroever, ABMs

Table 2. There are two general approaches for implementing economic concepts — simple or complex. Most extant models implement some combination of "Simple" attributes and at most one from "Complexity" column

Economic conception	Simple	Complex
Quantity of agents	representative (one,few)	many (possibly full-scale)
Diversity of agents	homogeneous	heterogeneous (or types)
Agent goals, objective	static, scalar-valued utility	evolving, other-regarding
Agent behavior	rational, maximizing, brittle	purposive, adaptive, biased
Learning	individual, fictitious play	empirically-grounded, social
Information	centralized, maybe uncertain	distributed, tacit
Interaction topology	equal probability, well-mixed	social networks
Markets	WMAD, single price vector	decentralized, local prices
Firms and institutions	absent or unitary actors	multi-agent groups
Governance	benevolent social planner	self-governance, emergent
Temporal structure	static, impulse tests, 1-shot	dynamic, full transient paths
Source of dynamism	exogenous, outside economy	endogenous to the economy
Solution concepts	equilibrium at agent level	macro stead-state (stationarity)
Multi-level character	neglected dual fallacies	intrinsic macro-level emerges
Methodology	deductive, mathematical	abductive, computational
Ontology	representative agent, max U	ecology of interacting agents
Policy stance	designed from the top down	evolved from the bottom up

at scale can use real-world geospatial data instead of simulated toy worlds to achieve higher fidelity.

Table 2 depicts two general types of approaches for implementing various economic concepts. The middle column corresponds to simplistic approaches typical of modern ABMs. The last column are implementations that better capture natural multi-agent complexities, and which most existing ABMs implement a few, at most.

Given the effectiveness of ABMs, what is needed is a basic research program on agents. This would include development of software agents to study their behavior experimentally. Also, given their taxing computational needs, inroads need to be made into parallelism with commensurate simulation speedups. And, we need to get better at estimating the behavior of ABMs to provide better implementation guidance. There are proposals for a ten million dollar research center with 100 million dollars in Office of Financial Research grants. The FuturICT initiative may also get one billion dollars of funding for a full earth simulation [24].

Going forward, creating truly representative agents is a challenge. For one thing, certain first order effects dominate most others, which include economic factors, technological progress, and real estate values, some of which cannot be readily anticipated in simulations. Moreover, human adaption is endogenous. For example, according to the Lucas critique, that outcomes of policy changes are not static, and that individuals will inevitably adapt to those changes, thus possibly reducing or eliminating their effectiveness [25].

Now imagine starting over on climate and social science. Would we use IAMs with just a few representative agents? Would we still use Dynamic Integrated Climate-Economy Model (DICE)? Would we ask for better or more microdata? Would we make *behavior* the primary focus? Starting from human dimensions, would we use Global Climate Models (GCMs)? Would we invert the funding pyramid?

For full slides on this presentation, see page A-32.

Working papers:

- Rob Axtell. *Pathologies of 'Integrated Assessments' of Climate Change*. 2014
- Eric D Beinhocker, J Doyne Farmer, and Cameron Hepburn. "Next generation economy, energy and climate modeling". In: *Global Commission on Economy and Climate* 11 (2013)

2.9 *Modeling and Simulation of Large Biological, Information and Socio-Technical Systems: An Interaction Based Approach*, Chris Barrett, VT

We are motivated to use simulations because we want to garner an understanding of *sociotechnical* and *bio-sociotechnical* systems. They also allow us to gain insight into policy and operational decisions. Of course we also use simulations to make predictions, but making useful predictions is nuanced. There is also emerging consensus that granularity matters, that traditional coarse-grained approaches to simulations compromise our ability to gain understanding, insight, and to make predictions of these systems.

It used to be that science identified the need for collecting new data that drove the manufacture of specialized instruments. Now those roles are largely reversed. Today we have specialized instruments generating copious amounts of data from which we derive direction and motivation for research. Science is chasing implemented instrumented everything / computing everywhere technology. Science-as-research is not leading technological innovation.

Bio-sociotechnial systems entail interactions among many things that have many intrinsic properties and that are co-evolving.

Cities are made by, for, and with people — they are extended human forms. Just like the bee honeycomb is an extension of the natural biological functions of bees, so it follows that buildings, roads, and bridges are an extension of human biological function.

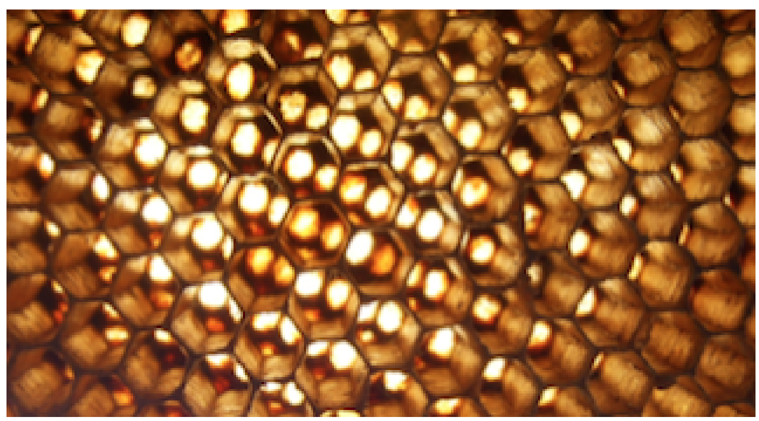


Figure 10. Built infrastructure or bee biology?

Practical meso-scale granular computation is here. Presently a 200 day ID epidemic with interventions and individual reactions for 315 million people in 145 million locations can take seconds to run and just minutes to hours to set up, whereas in 2005 a similar simulation would run over days, and took months to years to set up. It follows that we can have a global synthetic population "coordinate framework" derived from hundreds, if not thousands, of sources that can run in hours. By contrast, in 2005 a simulation of the US population took 30 days to compute after a year setup.

Situation Synthetic Information Systems (SITIS) are scalable, data-driven HPC application ecologies comprised of a cooperating and coordinating mashup of "apps", which are in contrast to the monolithic present-day models. SITIS will be able to explain and project via abduction and provisional decision making as well as incorporate the notion of "All Data" such as controlled and uncontrolled observations and procedural facts as a first order type.

Information is trending toward decentralization. That is, *meta-infrastructure* information involving transportation, communications, health, supply chains, instrumented environments, and performance monitoring are moving towards at the level of granularity of the individual.

A challenge for simulations is the notion of locality of the self or of an artifact and of their respective interactions. For example, most money is not tangible, and similarly debt is largely abstract. What are the processes by which your debt is serviced by your money?

For full slides on this presentation, see page A-40.

2.10 *Trade networks and climate change: Local effects-Global impact*, Shade Shutters, ASU

Global trade networks, particularly in agricultural goods, can transfer effects of climate change from one part of the Earth to distant, often less privileged, places. Understanding the commodities, flows, and connections in those networks can help better anticipate the spatial extent of climate-related shocks. In addition, the overall topology of those networks has profound implications for the resilience of global distribution systems and their vulnerability to cascading effects.

Shutters' work reveals that systems with adaptive agents are typically structured by complex networks, and that disruptions (such as extreme climate (weather) or political or social shocks) to these networks at critical locations can cause consequences in other, even very distant connected places. Motivated by the 2011 drought in China's wheat growing regions, which contributed to revolution in Egypt and the fall of Mubarak partly because of trade interdependencies, his work employs a two-pronged approach to analyzing trade networks. The procedures include quantifying and visualizing each country's dependency on others and quantifying and analyzing each country's local network structure (triadic structure and clustering coefficient).

When visualizing inter-country trade structure, countries can be clustered based on network similarity. Countries with similar trade patterns are likely to have similar vulnerabilities and food security risks. Additionally, networks can be decomposed into building blocks, some of which are associated with conflict. Structural balance theory predicts that nodes (countries) involved in too many "conflict" triads are less stable.

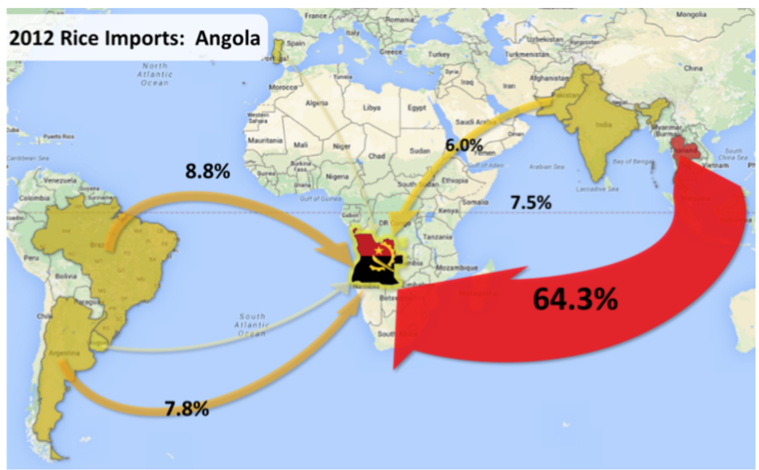


Figure 11. In an example of high dependency, Angola receives nearly two-thirds of its rice from a single country.

He concludes that local events can have global or far-off consequences. When humans are involved, these effects are often transferred through networks. Thus, integral to an anticipatory tool combining human systems and the earth system is modeling and analysis of a variety of interconnected trade networks.

For full slides on this presentation, see page A-47.

2.11 *Individuals, Societies, and Climate: Modeling Motivations to Change*, Nina Fefferman, UT

In order to model individuals and integrate these models into Earth system models, it is important to understand why and how we can expect individuals to behave. This understanding is critical even-though on the global scale individuals appear small because *they are not powerless*. Individuals make choices (e.g., green behaviors, voting) and individuals form groups such as political parties and grassroots organizations. It is then, through the groups of individuals which may act in concert independently or purposefully, that social movements are born and policies take shape. These movements and policies have the capacity to change cities, countries and the world. Foremost, it's critical to understand how much can individual behavior shift climate predictions, which generally assume certain average behaviors of populations and do not incorporate climate-behavior feedbacks. The theory of planned behavior models individual actions based on their attitude, perceived behavioral control, and perceived social norms. Attitude is made up of an individuals risk perception (how sever are the potential adverse effects?) and perceived efficacy (how much can an individual behavior influence outcomes?). An individual's perceived behavioral control is determined by how much control an individual thinks they have over whether or not to perform a behavior, and their perceived social norms is determined by how much they think the behavior is performed or approved by other in the society. A complex interaction of these three perceptions make up a persons intention, which may turn to action or behavior depending on whether or not they believe they can perform the action or not (their perceived behavioral control). That is, an individual may have a good attitude towards a green policy and believe adhering to it will be approved socially, but not feel they have the power to actually do so. Therefor, they will intend to adhere to the policy, but not actually enact the behavior because they don't believe they are able to do so. By plugging this model of human behavior into the climate rapid overview and decision support simulator (C-ROADS) to build an integrated human-climate model called PACE (perception, attitude, and carbon emissions), it is possible to see changes in the global mean temperature in 2100 that varies by ±1.5 degrees depending on the individuals' perceptions. Integrating individual behavior can significantly change climate predictions.

❖ *We **are** predictable snowflakes* – Nina Fefferman ❖

Given that individuals can affect the climate, we may then ask how can people recruit each other to green policies? That is, can we construct a 'more effective' grass roots movement and what information do we need to do so. While, many studies have looked at the success of grassroots strategies in social movements, few have considered how to structure launching one. grassroots movements are local movements where individuals (agents) attempt to persuade their friends and neighbors to a particular belief. A grassroots strategy might have access to 'global' network knowledge, such as the initial ratio of support for the cause or the initial densities of contacts an individual has with like-minded and disagreeing people. This data is they type of information that could be discovered through standard polls. The grassroots strategy might also have access to some 'local' information, such as each agents neighbors beliefs (low level), the strength of those beliefs (medium level), and who else is targeting your neighbors (high level; this allows collaboration where agents can pool their collective efforts). By modeling a grass roots strategy, with varying levels of information, it's possible to determine the effectiveness of the strategy based on the desired outcome. For example, if you want to implement a strategy that maximizes the number of individuals with a certain belief, strategies that take advantage of global network knowledge and local knowledge were more effective. Interestingly, however, strategies with high levels of local knowledge did not outperform those with low levels of local knowledge. Alternatively, a grassroots campaign may seek to minimize the number of extremist individuals of either belief. In that case, strategies utilizing local knowledge were more effective that strategies utilizing global knowledge, and strategies with high levels of local knowledge outperformed those with low levels. Therefore, developing an effective grassroots campaign requires a level of knowledge tailored specifically to the desired outcome.

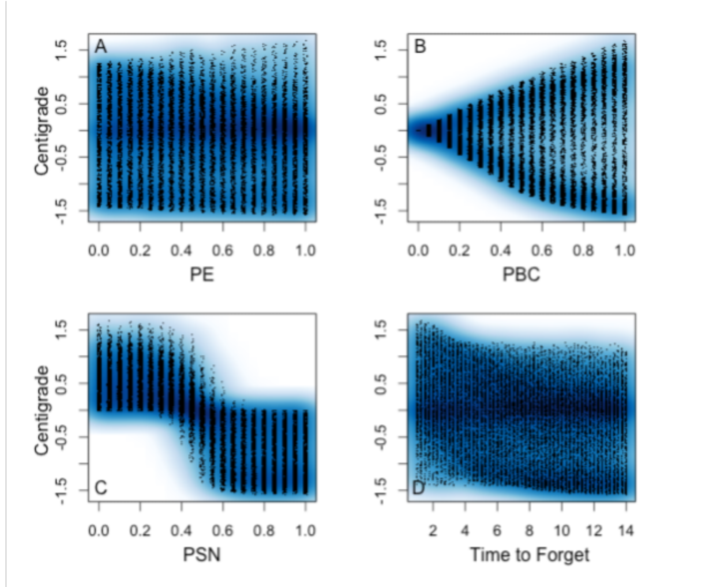


Figure 12. Effect of parameter variation on difference in global mean temperature in 2100 with inclusion of human behavior compared to the baseline.

Drawing from both models, the moral of the story is: *what* individuals believe changes how they will behave, which *can* influence climate outcomes. *Who* believes what will *change* how people react and how they try to persuade each other of social norms and movements. *How* individuals try to persuade each other *affects* how successful a movement will be. Importantly, widespread movements are how *individuals* affect global climate change.

For full slides on this presentation, see page A-52.

3. BREAKOUT SESSIONS

The workshop included three breakout sessions in which the topics of urban modeling and measurements, coupling of high-resolution modeling with modeling at coarser resolution, incorporating complex systems into earth system modeling, agent based modeling and ways to move forward in integrating these data and systems were discussed.

3.1 Urban Modeling and Measurements in Earth System Modeling

A variety of issues were raised around urban scale modeling and measurements. For instance, in order to calibrate and validate detailed models of greenhouse gas emissions, more comprehensive emissions inventories are needed. Even CO_2 at high resolution is not widely available. Furthermore, greenhouse gases are not harmonized across the agencies that are collecting the data. Not only are they not collected on the same time and spatial scales, they are also not mapped to the same coordinates. Ideally, data should be collected more frequently than every three years, but simple harmonization of existing data sets at process level would represent a large advance.

For source attribution, better access to "human data," is required, but these data bring with them cultural idiosyncrasies and privacy issues, and relevant data are sparse in world locations. However, some of these data are available from social media relationships such as google keywords, global connectivity and cell phone data. While acquiring cell phone data from companies can be fairly expensive, there is a sensor network in use [27] that can identify communication of phones to towers without compromising privacy. Additionally, products like LandScan, LSUSA [28] and LandCast [29] are available to the research community, which show population density at high resolution (1km and 90m). However, vegetation maps at higher resolution than this are needed to represent local greenhouse gas sinks, such as yards within the urban boundaries. Finally, for organizing all of these data, we also need a common definition for what we mean by "city" and what we mean by "urban."

For urban modeling, more data pertaining to infrastructure inter-dependencies within and across cities is needed. For example, while some modeling and proxies are available (e.g., electricity service area approximations [30] and initiatives to apply sensors for CO_2 measurement and a variety of other information [31]), high resolution (but still private) data on electricity generation from utilities is still lacking. Local government may be able to provide incentives for releasing some of this data under special circumstances. For instance, the Flint, MI water crisis inspired utilities to deepen their understanding of the current state of their infrastructure by issuing kits to its residents for testing and reporting lead values in the water. Data were collected and made available for further study. While unfortunate that the Flint situation was the impetus of this data collection, the result was a product that promoted citizen engagement and data availability.

Data Accessibility Challenges

- More comprehensive and higher resolution greenhouse gas inventories are needed.
- Existing inventories must be harmonized.
- Better access to "human data" is needed.
- Privacy-protected data from interdependent infrastructure stakeholders should be made available.
- Higher resolution land use and vegetation maps are needed.
- An "informatics infrastructure" should be developed, which could include ways for finding new value in old data.

Less sensationally, projects like Cities-LEAP [32] are beginning to make available sectoral electricity consumption totals by city using US census data and EIA consumption statistics to allocate regional electricity use to census tract, then to aggregate the results to the city level.

As acquisition of new data becomes more feasible, an informatics infrastructure should be co-developed. This infrastructure could include analytics for finding new patterns and new value in existing data and accommodation for theories guiding data collection with regard to scientific purpose.

Finally, data and model transferability to data-poor cities must be considered as methods are developed to evaluate those with more readily available data. One way to accomplish this transferability is to develop consistent urban typologies based on more than population density alone (e.g., by tailoring datasets to spatial, infrastructural and socio-cultural context [33]).

3.2 Complex Systems in Earth System Modeling

A *complex system* comprises a large number of interacting and connected components with emergent properties or behavior. These emergent phenomena are not directly discernible from rules that dictate how components interact, but rather arise as a byproduct of component interactions. For example, Craig Reynold's "Boids" is an agent-based simulation of a complex system where flocking behavior emerges from the interaction of a group of simulated flying (or swimming) agents using just three behavior rules [34]. These rules are: a) **separation**: avoid getting too close to neighbors b) **alignment**: steer to average direction for entire group c) **cohesion**: move towards the group's center of mass. Using these three simple rules, the intricate group flight patterns of swallows or schools of fish can be simulated.

A complex system can also be adaptive — as the environment within which the system operates changes, responses of the components within the system change accordingly. These are known as *complex adaptive system (CAS)* [35]. For example, obstacle avoidance could be added to a Boids simulation, and as obstacles are added or moved, the flocks will adapt to flow around obstructions accordingly. Ecosystems, economies, and immune systems are examples of CAS as they all have many interconnected and interacting components that can adapt in response to environmental changes.

Motivation for High Resolution Modeling

- Technical problems: Systems can be "stiff"; that is they cannot be solved taking large steps through the problem: small steps are necessary for a solution.
- Different distributions: Policies and systems are often skewed and only a portion is targeted. Policies are often written towards only a few things.
- The real data are at the individual level. There is no simple way to integrate that data unless we have a way to incorporate it and then scale.
- Understanding of interaction of disparate processes: Bottom-up approaches can help integrate social variables and natural science variables to obtain more than a qualitative "value" for the "sum" of these processes.

The Earth itself is a complex system containing myriad interconnected and interacting components. These can be organized as complex sub-systems, such as for the land, ocean, atmosphere, and biosphere, each with its own set of inter-related, interacting parts [36]. Moreover, the Earth is a type of CAS since the biosphere adapts to changes on the earth's surface or within the atmosphere. This is particularly true of humans, since social and economic systems alter due to environmental impact of climate and weather and, in turn, the by-product of aggregate human behavior has an influence on the climate.

3.2.1 Coupling High-resolution Modeling with Modeling at Coarser Resolution

Several types of vetted techniques could be applicable for combining human systems into earth system modeling, each with its own challenges with regard to coupling. Most of the challenges have to do with communication of various processes across scales. That is, non-linearities exist in both temporal and spatial scales, which makes it difficult to couple the models under consideration. Thus, we should recognize that we do not need high resolution models for every problem, and we should have a working catechism for deciding which problems require high resolution and which do not. Within this catechism should be consideration for the computational problems vs the science problems that should be addressed in each type of modeling and in their coupling.

3.2.2 Integrating Agent-based Modeling with Earth System Modeling

Agent-based modeling can be considered a special class of complex adaptive systems modeling. These systems represent groups of agents who act and react locally to actions of other agents in the system. From these actions, various types of emergent behavior arise. One reason that integrating agent-based modeling with earth system modeling is attractive is that it has the potential to model human behavior as particles in a type of gradient–perhaps analogous to flows in physical systems (such as atmosphere, water or land processes). Application of physical equations provides a mechanism for prediction of outcomes based on initial and boundary conditions for those processes.

However, caution must be used in applying agent based modeling to predictions per se. Understanding should be the main priority. Quite possibly a coupling of agent-based human systems and earth systems will require a shift in the way both the Earth System Modeling community and the agent-based modeling community think.

Perhaps a first question to consider regarding agent-based modeling is whether we need it at all. Do we really need to model billions of agents? Policy is normally generated for a group - a finite population, not everyone. Thus, we might not need high-resolution modelling for every small grid cell of the earth, but we can consider the scale needed depending on each science question. In some cases, more than one way of modeling could be used for the same problem and results compared.

Thought Questions for Model Integration

- There are constants on physical science side: Are constants truly constant or could there be changes? Thresholds?
- The current assumption is that the climate of the future will behave like climate of the past just under different forcings.
- How do thresholds vary from place to place?
- Both physical and social systems take time to react: Social systems can be slow? Which is the most rapid scale? Social or physical?
- How do we link resolution scales among social and physical variables?
- If we are running simulations over and over again are we going to get aggregate behavior?
- Ex. How do we model changes in urban area
  - Land use will change
  - Grid cell allocation for various parameters will change
  - What are the probability rules?
  - Can we assume predefined knowledge of states between which systems/agents can move?
- Spatial configuration of the grid can create bias. For example, even hexagonal vs rectangular grids can have an affect model results.

If we decide that agent-based modeling is the right tool for integrating human behavior into earth system models, there will be decisions to be made about fidelity. For instance:

- Do we we need to model processes at the settlement level?
- Should models and simulations account for urban dynamics for projections to 2050 where industry and policy change? For example, what

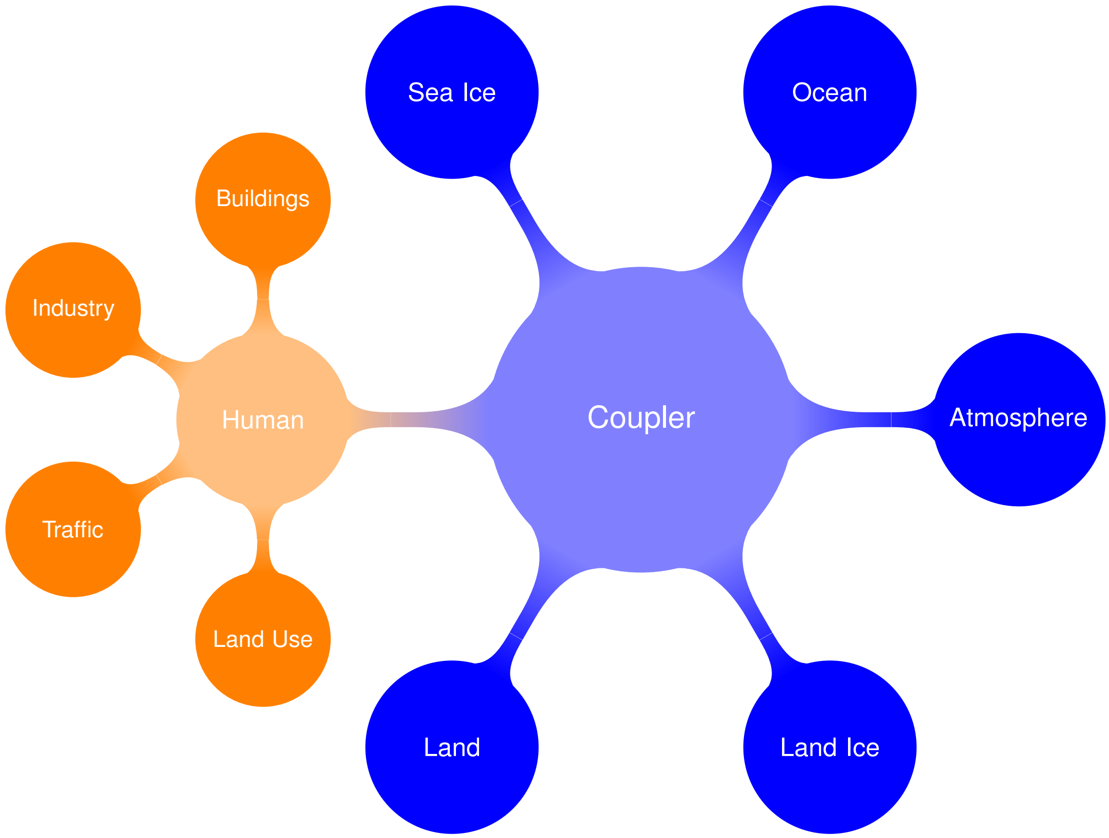


Figure 13. Schematic for connecting human energy use at neighborhood scale using agent-based models (ABMs) to greenhouse gas emissions at global scale via the ACME general circulation model. The ABMs will capture observations for building micro-climates, industry emissions, emissions due to traffic, and the current state of land allocation, which are then sent to the `Coupler` for dissemination for larger scale climate models. That is, the ABM observations will be fed as input as appropriate for sea ice, ocean, atmosphere, land ice, and land allocation macro-climate simulations.

if a new rust belt emerges?

- Do we ignore phase endogenous rapid change– the near-term and the local–small aggregate parts that suddenly spark?
- How do we represent rapid, fluid and coupled social systems in an agent-based framework?
- Should we develop a tool that allows for a variety of approaches and that incorporates stochastic elements?
- Even with the power of the fastest supercomputers, can we model all necessary agents at global scale?

3.3 The Way Forward

The overall focus of the workshop was to consider best practices for integrating human activity in appropriate ways into an "Earth System" framework. This workshop, along with many prior activities in the scientific community, suggests that the community is ready to take the next steps towards this integraton. As discussed in previous sections, there are many approaches to this task, each suitable for different time and spatial scales, and perhaps the best overarching approach is to develop a framework that allows selection of best approaches/scales for different problems–a modular structure that allows for different component options/substitutions for different resoloutions.

First steps should be to break the larger goal into smaller initiatives (e.g. population, traffic, emissions, land use/ land cover change), rather than to throw numerous human models at an ESM all at once. Additionally, the data, information and computational requirements must be determined and provided.

If agent-based modeling is to be used for any of the component models, scenarios developed will determine the data needed for calibration. For instance, if each agent will represent a person, or even, e.g., and electricity customer, high resolution population distribution and dynamics is needed along with geospatially located representative demographics data. How high a resolution is required will depend on the spatial scale being considered (neighborhoond, city, region) and the temporal scale (static, adaptive over time). Additionally, models, model inputs and outputs, model communication workflow must be determined.

Cross-disciplinary Communication

- Framing the question
- Defining the vocabulary to be used
- Determining what is tractable, what is basic and what is not realistic
- Defining, characterizing and quantifying uncertainty
- Evaluating predictive capability of the modeling

In general, we must decide where we are headed with human and earth system modeling and thus where our focus should be. We must determine which stories are best for generating decision support and what decisions are being supported. That achieved, we can harness existing tools to accomplish the goals we set, and develop new tools to fill the gaps in our capability. With these new developments must come robust checks and balances as well. Above all, we must keep evaluating, keep communicating and keep adapting our resources to solve the most pressing issues regarding humans and their changing earth.

4. CONCLUSIONS AND FUTURE WORK

The workshop featured 11 talks, each addressing a different aspect of incorporating human activity into earth system models. Three breakout sessions were held between the talks during which presenters and other participants 1) discussed the state of the art of each domain science, its data and its modeling; 2) shared anecdotes and modeling issues; and 3) considered best next steps.

A common thread in the talks and breakout sessions was that of data needs. Not only is there a need for data at higher levels of resolution gathered more frequently, but there is also a need for harmonization of the data collected. Common geospatial reference among them, in particular, is a high priority. While we move beyond data for large areas and over spans of years to that of neighborhoods and daily, hourly or smaller timescales, measurement boundaries must correspond reasonably to those of measurements in a common historical archive. New high resolution maps of urban vegetation types are needed because local carbon sinks can have a collective impact on overall metropolitan atmospheric CO_2. Better sensor programs are needed as well, such as better tracking of traffic emissions at hourly or minute rates in metropolitan areas. To make these data usable for calibration and validation of traffic models, for instance, they must be referenced to highly accurate and standardized geographical coordinates.

Social media, such as Twitter, Facebook, and Instagram, are an emerging source of relevant data at human levels of granularity. Other sources of Volunteered Geographic Information (VGI) are also available, and their types and number will increase over time. One example of this type of data is the Safecast effort [37] that allows lay citizens to contribute radiation readings to the public sphere (soon also air quality related data). Sensor infrastructure can also provide useful information. Cell phone signals (obtained in a non-invasive manner) can provide population movement statistics that can inform agent characterization for city agent-based modeling [27].

Accommodating data needs and novel data sources leads to further data related challenges. We currently find it difficult to store the large amounts of data generated by existing systems, and finer spatiotemporal resolution data streams will only amplify that challenge. Moreover, finding and accessing both new and current relevant data to a given effort is still complicated. Thus, new and efficient ways of managing, verifying and validating increasing amounts of data must be part of the path forward.

❖ *At some level ecosystems are social systems.* ❖

While the emphasis on measured data was an important component of the workshop, the principal focus was on the models themselves and on how to federate those that represent human-level activity with those representing the earth system as a whole. At some level ecosystems are social systems, and at a high enough resolution in earth system models, human behavior is no longer a "sub-grid process." The next step is to build on recent work [1], in which an existing country-level integrated assessment model is incorporated into an earth system model. Such successful coupled systems can guide new processes for integrating higher-resolution models of human activity into more regionally-refined earth system models, and can provide a foundation for benchmarking new work.

This workshop is a significant step towards incorporating more granular human activity into state of the art earth system modeling. The multidisciplinary nature of the participants and their institutions represents the vital community necessary to lead the way towards progress in this challenging and rewarding area. The time is right to formalize communication within and across this community and its models and to facilitate their integration.

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APPENDIX A. PRESENTATIONS

4.1 *The Urban Carbon Cycle: Uncertainties and Surprises*, Lucy Hutyra, BU

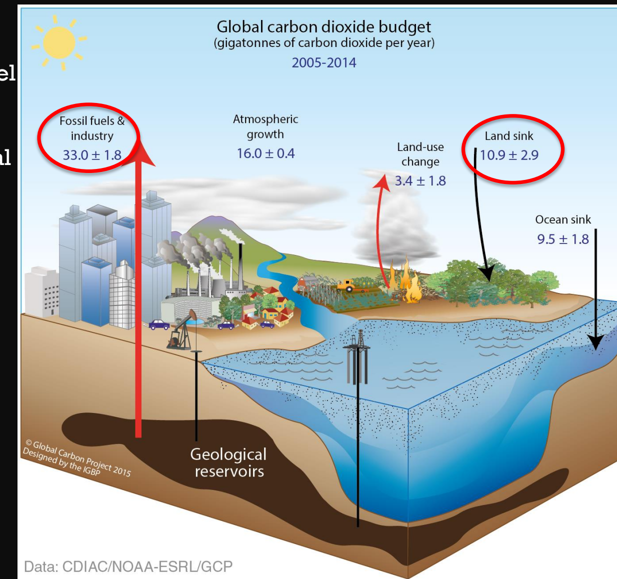
The urban carbon cycle: Uncertainties & surprises

Lucy R. Hutyra, Boston University
With Conor Gately & Andrew Reinmann

September 19, 2016 – Oak Ridge National Lab

Global Carbon Cycle

1. Urban Fossil Fuel CO_2 Emissions
2. Urban Biological Fluxes



Fossil Fuel Emissions

UN HABITAT

GLOBAL REPORT ON HUMAN SETTLEMENTS 2011

CITIES AND CLIMATE CHANGE

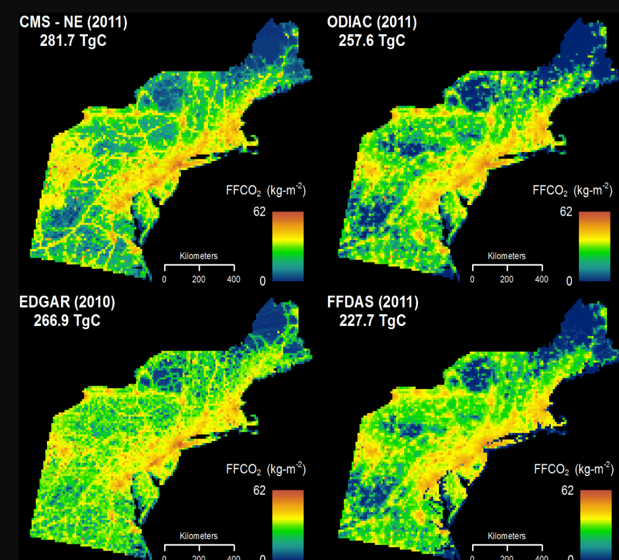
UNITED NATIONS HUMAN SETTLEMENTS PROGRAMME

An important finding of the Report is that the proportion of human-induced (or anthropogenic) greenhouse gas (GHG) emissions resulting from cities could be between 40 and 70 per cent, using production-based figures (i.e. figures calculated by adding up GHG emissions from entities located within cities). This is in comparison with as high as 60 to 70 per cent if a consumption-based method is used (i.e. figures calculated by adding up GHG emissions resulting from the production of all goods consumed by urban residents, irrespective of the geographic location of the production). The main sources of GHG emissions from urban areas are related to the consumption of fossil fuels. They include energy supply for electricity generation (mainly from coal, gas and oil); transportation; energy use in commercial and residential buildings for lighting, cooking, space heating, and cooling; industrial production; and waste.

However, the Report concludes that it is impossible to make accurate statements about the scale of urban emissions, as there is no globally accepted method for determining their magnitude. In addition, the vast majority of the world's urban centres have not attempted to conduct GHG emission inventories.

Fossil Fuel Emissions

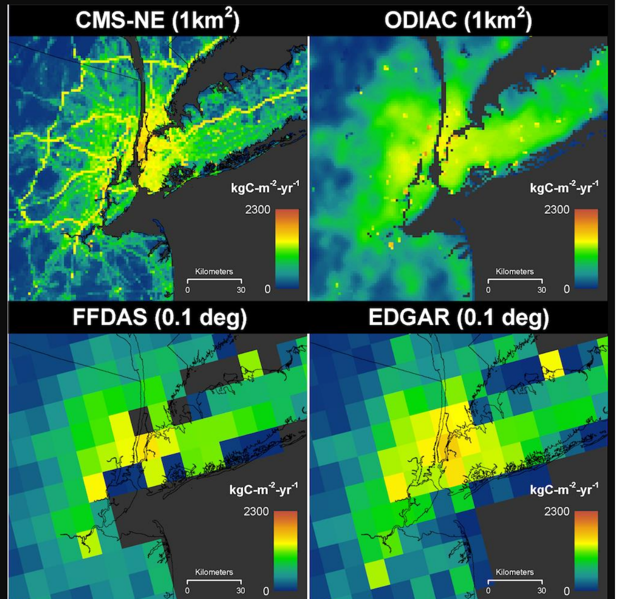
- $FFCO_2$ uncertainties on regional or urban scales are largely unknown.
- We find 'reasonable,' broad regional agreement across the NE.



Annual fossil fuel CO_2 fluxes at 0.1 degree scale (Gately & Hutyra in prep)

Fossil Fuel Emissions

- Inventory construction (top-down vs bottom-up) is clear in the resultant patterns of emissions.
- Emissions differences for NYC are profound!
- Is this good enough for policy?
- Median Δ with CMS-NE +65%, -33%, & -38%, respectively



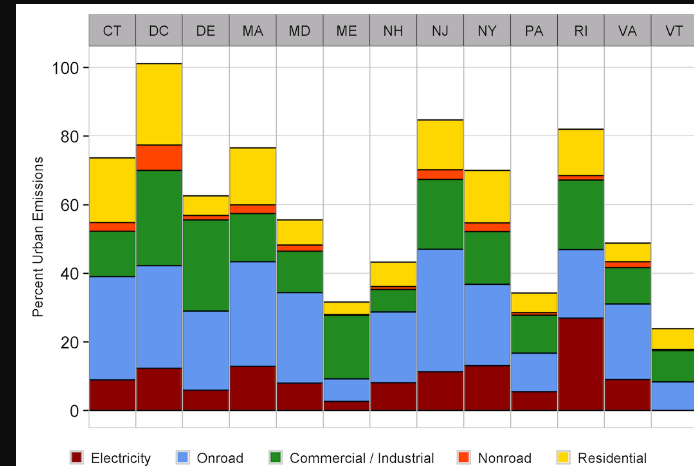
Gately & Hutyra in prep

Fossil Fuel Emissions

Urban production emissions? UN estimates 40-70%, but that's a rough global analysis.

Across the NE, direct urban emissions (CMS-NE) average 53% with large variation by state and sector source.

CMS - 53%
ODIAC – 48%
EDGAR – 43%
FFDAS – 42%

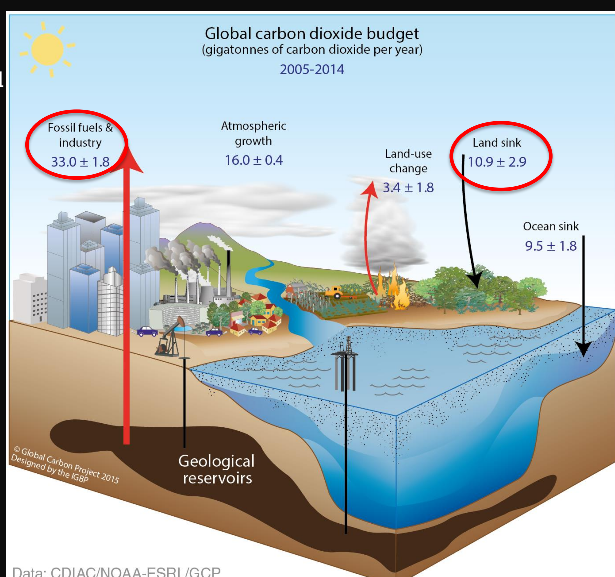


Urban defined based on the US Census Urbanized Areas

Gately & Hutyra in prep

Global Carbon Cycle

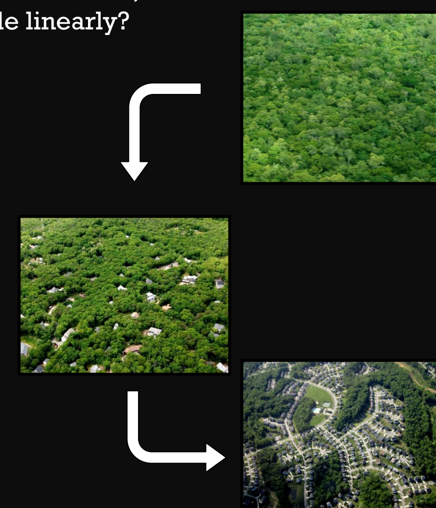
1. Urban Fossil Fuel CO_2 Emissions
2. Urban Biological Fluxes



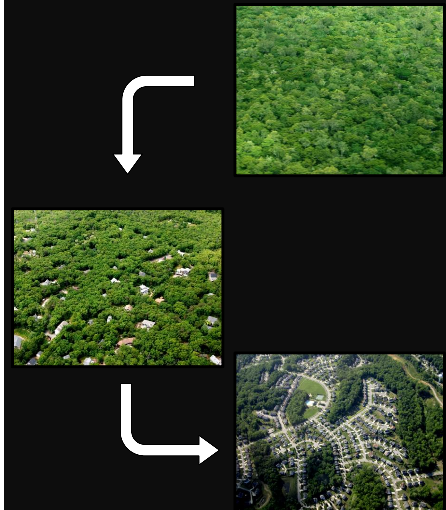
A different urban biogeochemistry?

Urban biomass is ~ 25% of adjacent rural forests, does the productivity per unit biomass scale linearly?

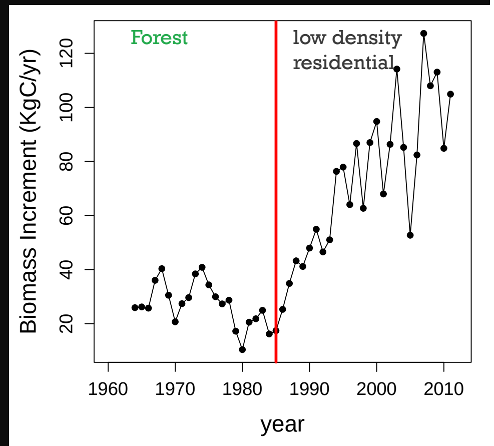
Growing Condition	Urban (relative to "Natural")
Growing season length	> → +
Air temperature	> → +
Resource availability (Light, $[CO_2]$, N dep.)	> → +
Competition	< → +
Watering	> → +
$[O_3]$, pollutants	> → -
Management	> → ?



A different urban biogeochemistry?

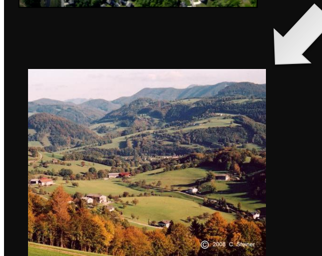


Strong, immediate + plant growth response with urbanization

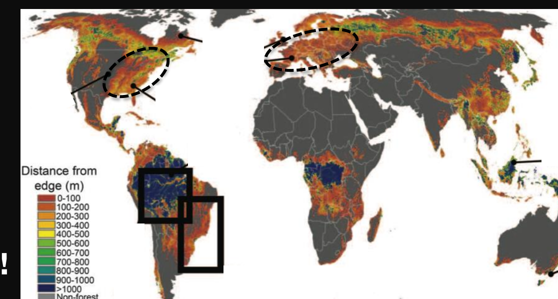


Briber et al., 2015

A different urban biogeochemistry or a rediscovery of landscape ecology ?



Edges are ubiquitous!



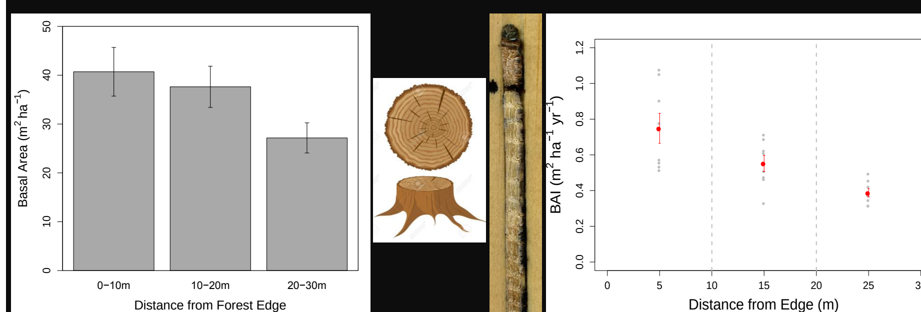
Haddad et al. 2015.

A different urban biogeochemistry or a rediscovery of landscape ecology ?

- Edge microenvironment characterized by higher:
  - Light availability
  - Temperature
  - Vapor Pressure Deficit
  - Wind
- Tropical Forests → Higher mortality and turnover rates in tropical regions
  - Reduces carbon storage
- Temperate Forests →??

Matlock, 1993; Laurance et al. 1998; McDonald and Urban 2004; Ziter et al. 2014

A different urban biogeochemistry or a rediscovery of landscape ecology ?

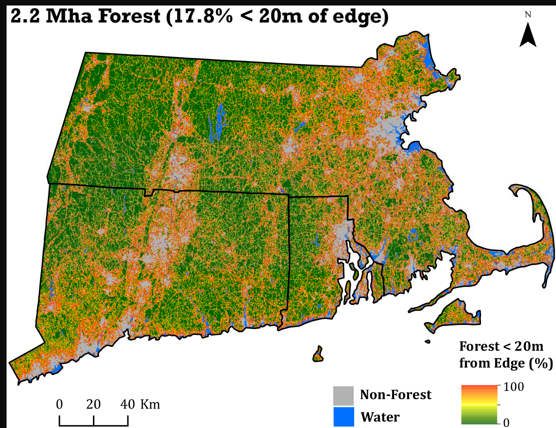


64 ± 12% increased in carbon stocks near the edge

89 ± 17% increased in carbon uptake near the edge

Reinmann and Hutyra in review

A different urban biogeochemistry
or a rediscovery of landscape ecology ?



Across southern New England, edges and landscape fragmentation increases carbon uptake and storage by 12.5 ± 2.9% and 9.6 ± 1.4%, respectively.

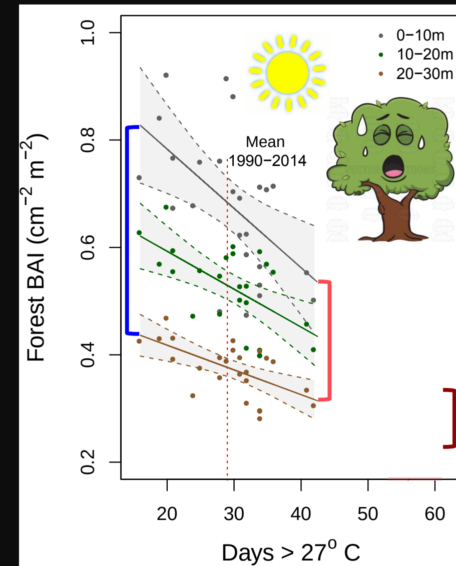
Reinmann and Hutyra in review

A different urban biogeochemistry
or a rediscovery of landscape ecology ?

Growth difference between forest edge and interior is largest in cool years and smallest in hot years

Interaction between land cover change and climate change

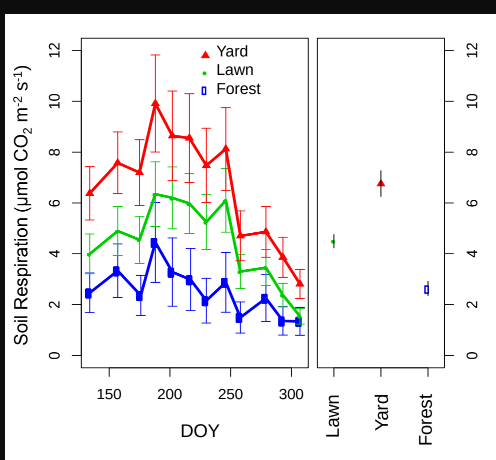
- Benefit of edge effect for forest C sink is vulnerable to a warming climate
- C benefit of forest edge effect may decline by 1/3

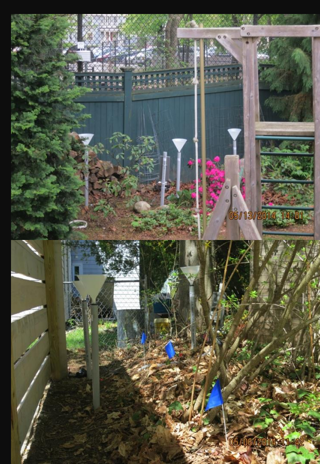


Reinmann and Hutyra in review

A different urban biogeochemistry
or a rediscovery of landscape ecology ?

Higher relative fluxes in the lawn and "yard" areas with deeper organic layers, SOM, and higher soil N. "Yard" areas variable, typically including mulch, thick litter layers, and/or flower beds.

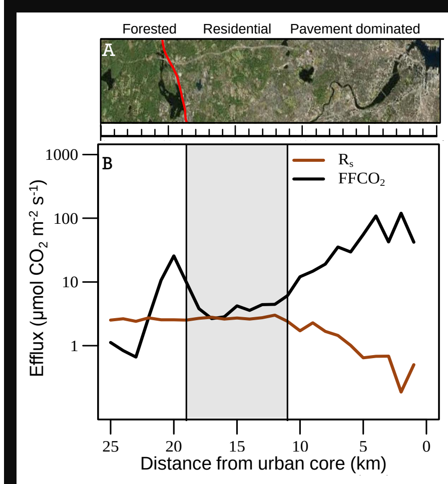




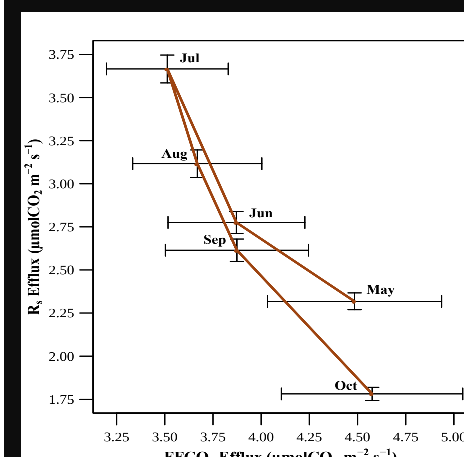
Decina et al. 2016

A different urban biogeochemistry
or a rediscovery of landscape ecology ?

2-3x ⇧ in urban respiration fluxes.



Seasonal hysteresis – July respiration exceed FFCO2 emissions.

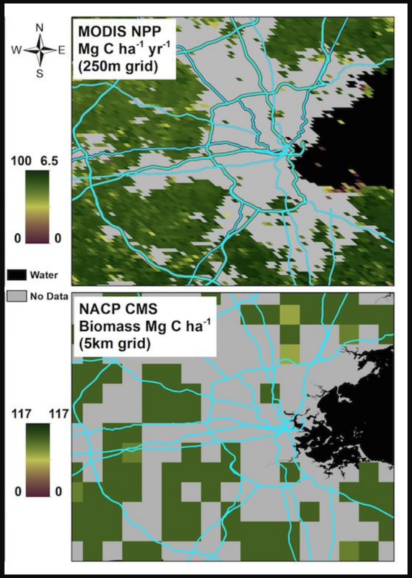


Decina et al. 2016

A different urban biogeochemistry or a rediscovery of landscape ecology ?

Ecosystem models typically don't include urban areas, effectively assuming them to be devoid of biological activity. The urban carbon densities of forest may be ~1/3 rural forests, but the fluxes per unit biomass may be 2-3x high!

Lucy's office has a view!



The urban carbon cycle: Uncertainties & surprises

- Globally/nationally $FFCO_2$ is well constrained, urban/regional estimates are still too uncertain
- Landscape fragmentation and urban development result in increased carbon fluxes! Carbon pools and fluxes are enhanced near forest edges. Respiration is enhanced in residential areas due to management … Rural forests are a poor analog for urban forests.
- A new urban biogeochemistry? I'm not sure. But, I am sure that we can not ignore the role of human management and cities within the carbon cycle.

Conor Gately

Andrew Reinmann

4.2 *High-resolution Emissions Modeling and Earth System Modeling*, Kevin Gurney, ASU

High-resolution GHG emissions, cities, and Earth System Models

Kevin Robert Gurney
Arizona State University
School of Life Sciences

Human-earth interactions in ESMs

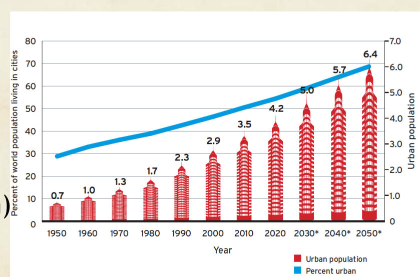
- GHG Emissions and Mitigation [managed bio, soils, <u>energy systems, infrastructure</u> (e.g. CH_4)]
- Adaptation/vulnerability
- Surface SH/LH budget
- Hydrology
- Geoengineering
- Surface radiation
- Radiative impacts aloft – contrails, etc
- .
- .

- What <u>scale</u>? Are pixels appropriate? Spatial gradients?
- How much determinism vs parameterization?
- How much do they change and is that important?

Cities as a shorthand

In the context of energy GHG emissions,
"Human activity" and "urban" are highly correlated

- The world has tipped over 50% urban pop…..and that is increasing.



- Urban areas (or "human settlements") ~tend to be emissions multipliers (but that is VERY sensitive to country, <u>accounting</u>, wealth)
- How we conceive of urban is tending to be more generous geographically and functionally

Consumption v production perspective

Human activity on the landscape

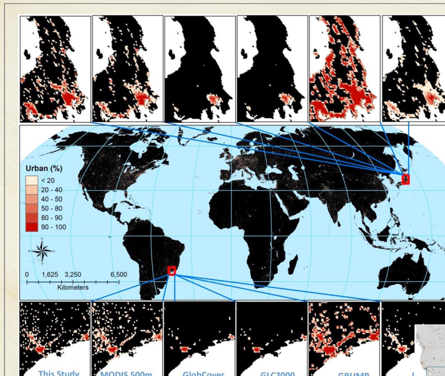
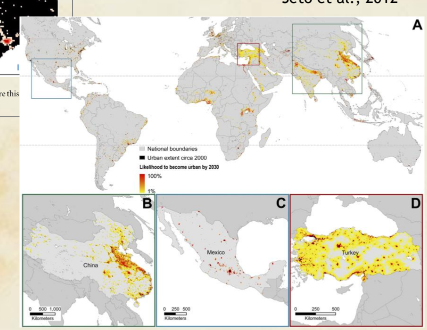


Figure 4. A global map of urban extent derived from DMSP nightlight data. The two enlarged example areas compare this product with the five previously published global urban maps.

Zhou et al., 2015

Seto et al., 2012



Emissions & Mitigation (FFCO_2)

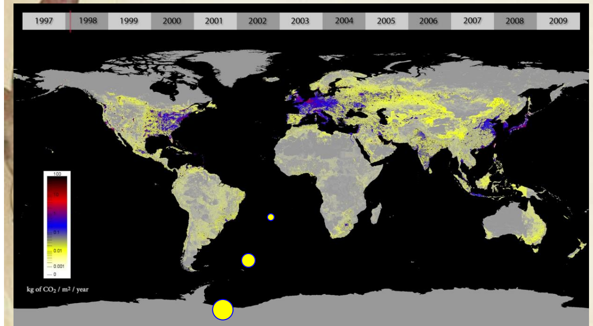
Resolved ("high"-resolution) characterization of emissions – a more ESM-style analytical approach

- Large growth in work over last 10 years (e.g. SOCCR1 v. SOCCR2)
- Partly enabled by *RS imagery/GPS/Google-way* of seeing the world
- Compute power, sub-grid now grid-resolved

➢ Geosciences: Aimed at linkage to atmos obs but evolving towards policy application
➢ Engineering/economics/geography: aimed at driver analysis (often in the urban space)

Consider three different resolutions/domains

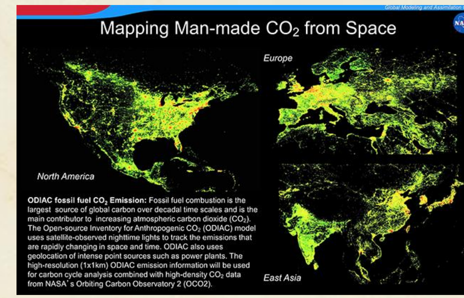
Global, gridded



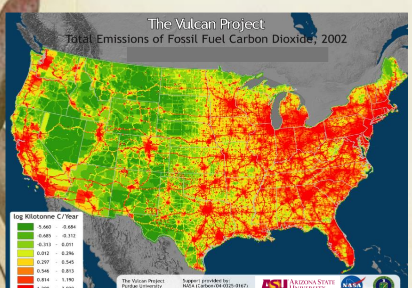
Also:
EDGAR
CDIAC

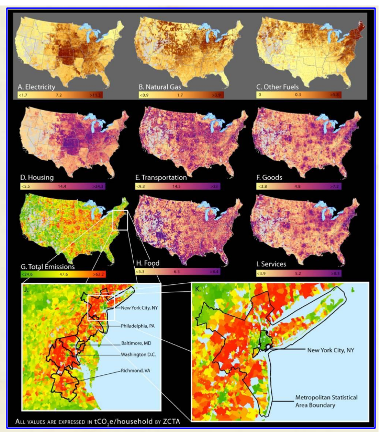
Primarily "climatology" of emissions used as BC to CC models

As a DA system with uncertainty, amenable to forecast



Nation-state gridded

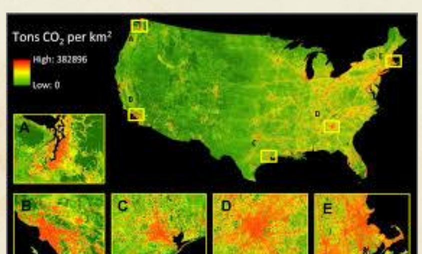




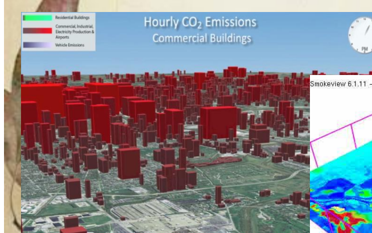
Techniques move towards more "bottom-up")

New China (CHREGD)

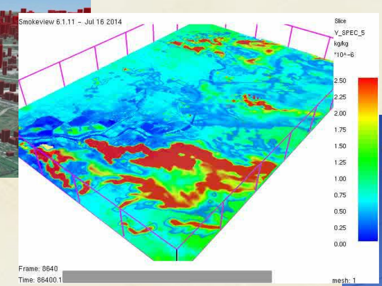
Europe effort



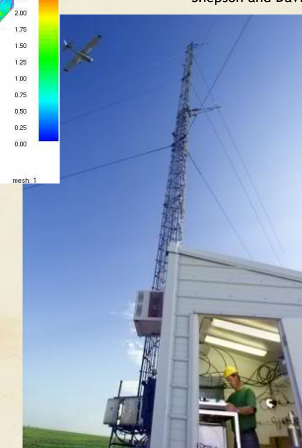
Urban emission quantification architecture



Gurney et al., 2012



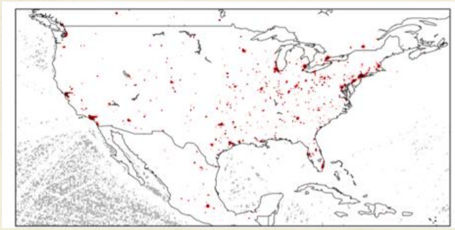
Shepson and Davis



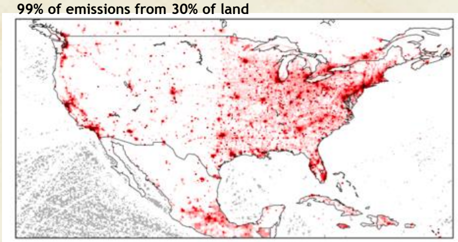
2 potential interests:
1) Verification capability
2) Mitigation guidance

The nature of $FFCO_2$ emissions

80% of emissions from <3% of land



99% of emissions from 30% of land



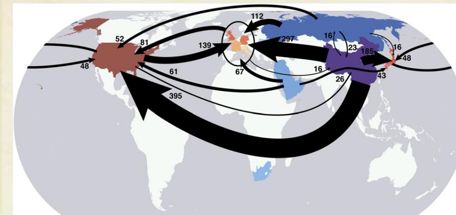
Duren and Miller

gC/m²/year

VERY large spatial gradients

flux sensitivity of 3,000 $gCm^{-2}yr^{-1}$ at 10km nets 80% of US FFCO2 emissions. flux sensitivity of 30 $gCm^{-2}yr^{-1}$ to get all (99%) total emissions. Intense sources (>3,000 $gCm^{-2}yr^{-1}$ at 10km) include medium to large cities and power plants.

Production versus consumption



Davis & Caldeira, 2010

Life Cycle engineering community very active

Focus is on responsibility and that can be defined a variety of ways…...not just "in-boundary" emissions.

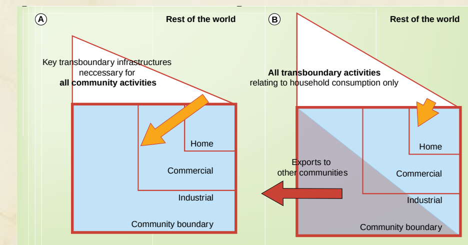


Figure 3. Transboundary infrastructure supply and consumption-based footprinting. Solid outline represents community boundary. Inf ow arrows represent material and energy inputs into the community. Outf ow arrow represents exports from the community (A) transboundary infrastructure supply footprint keeps the community together, accounting for all GHG emissions, and (B) consumption-based footprint divides the community, not accounting for GHG emissions from exports.

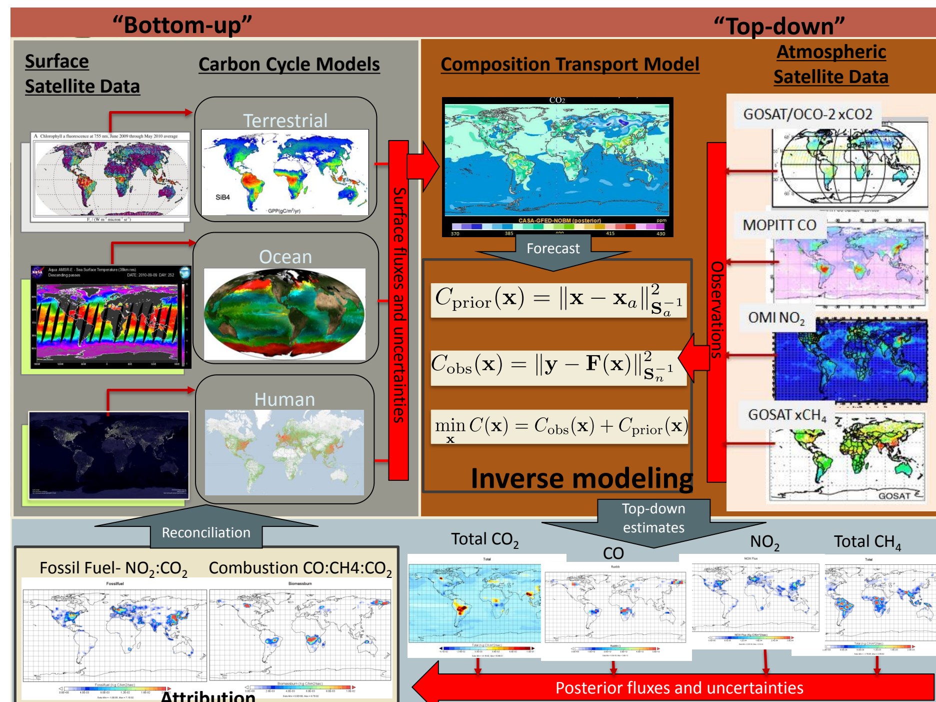
Chavez & Ramaswami 2011

Importance to ESMs?

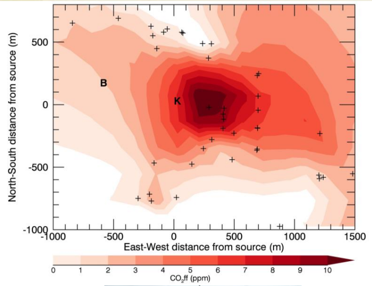
To the extent that ESMs are being used to solve CC problems (in inverse or forward mode), space/time-resolved human emissions matter.

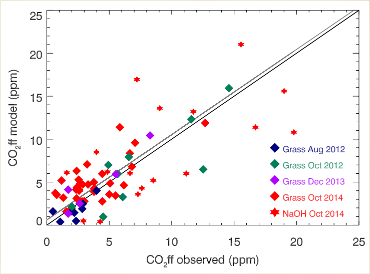
Inverse atmospheric methods rely on spatial gradients.

High-quality BC is critical - even for nation-state verification! We are not asking questions about the background any more.



Atmospheric verification of power plant CO_2ff emissions





	Slope	(r^2)	n
All data	1.00 ± 0.07	(0.6)	85
All grass	1.02 ± 0.05	(0.7)	64
Grass Aug 2012	1.01 ± 0.21	(0.5)	8
Grass Oct 2012	0.92 ± 0.08	(0.7)	9
Grass Dec 2013	1.14 ± 0.09	(0.9)	14
Grass Oct 2014	0.98 ± 0.10	(0.5)	33
NaOH Oct 2014	0.99 ± 0.11	(0.3)	21

Turnbull et al., in review 2016

Importance to ESMs?

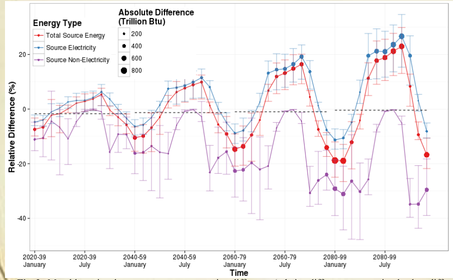


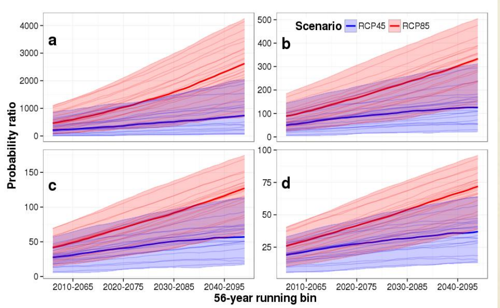
Fig. 2 Monthly national source energy consumption difference (relative difference on y-axis, absolute difference reflected in symbol size) between future time periods and the 2008–12 time period. Points represent the median, and the whiskers represent minimum and maximum relative difference values from the of 20 climate models. The dashed black lines indicate the annual relative source energy consumption differ

Huang and Gurney, 2016

Emissions projections: non-linear energy system feedbacks are space/time explicit phenomena

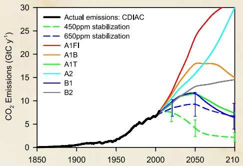
One in 56 year heat electricity demand events in response to heats waves increase 2600x in 2nd half of century (RCP 8.5)

Huang and Gurney, under review



"(un)Likely" scenarios

Likely in terms of *projected* emissions and *projected* mitigation



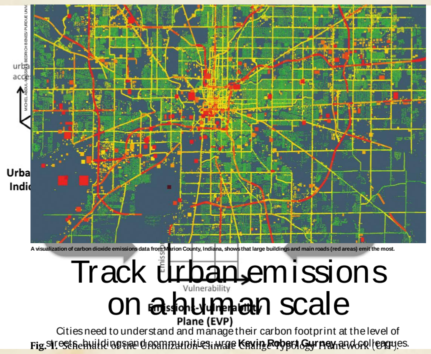
bounded by the national or regional scale, but significant constraints at "local" scale…..and some are understand

There are:

- physical constraints (geography, densities),
- social contraints (norms, HH structure, technology, transportation modes, policy),
- economic constraints (lock-in, investment)

Many of these characteristics may come with mitigation constraints

Place is critical – within country variation such as urban v rural is large



Solecki et al., 2015

CO2 and cities over time

Does Size Matter? Scaling of CO_2 Emissions and U.S. Urban Areas

Michail Fragkias[1]*, José Lobo[2], Deborah Strumsky[3], Karen C. Seto[4]

There may be urban CO2 "transitions" generated from empirical data……..

better emissions scenarios?

Large cities are less green

Erneson A. Oliveira[1], José S. Andrade, Jr.[1] & Hernán A. Makse[1,2]

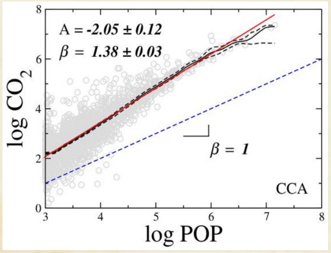
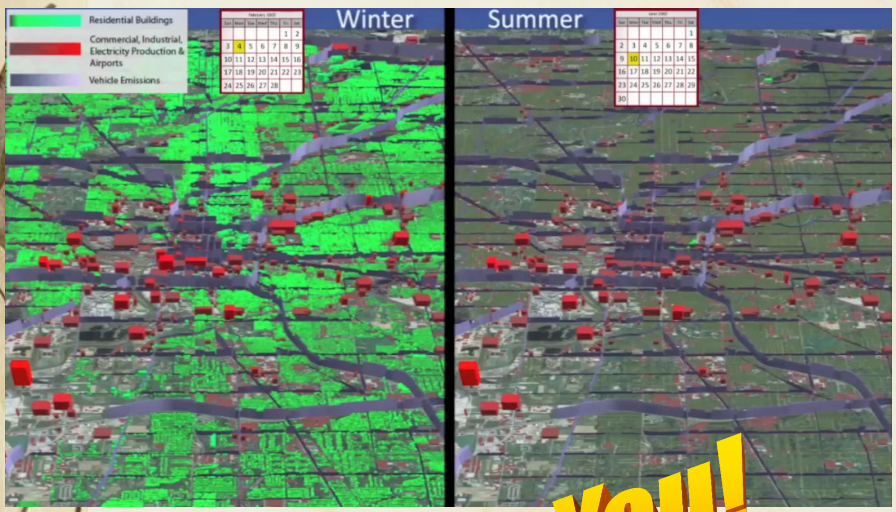


Figure 4 | Scaling of CO_2 emissions versus population. We found a superlinear relation between CO_2 (metric tonnes/year) and POP with the allometric scaling exponent $\beta = 1.38 \pm 0.03$ ($R^2 = 0.76$) for the case $\ell = 5$ km, $D^* = 1000$. The solid (black) line is the Nadaraya-Watson estimator, the dashed (black) lines are the lower and upper confidence interval, and the solid (red) line is the linear regression.

Conclusions

- Tremendous progress in last decade on modeling/estimating human GHG emissions in an ESM-ish mode
- A lot of the research has been advanced in service of the CC inverse/forward problem
- For that problem, highly-resolved, regularized emissions, accurate are essential
- Energy-related CO2 emissions are lognormally distributed with massive spatial gradients
- Feedbacks between climate change and energy/CO2 occur at the "human" scale – hourly/kms
- Opportunities exist to improve projections with likely/unlikely using learned constraints over the past 20 years



Thank You!

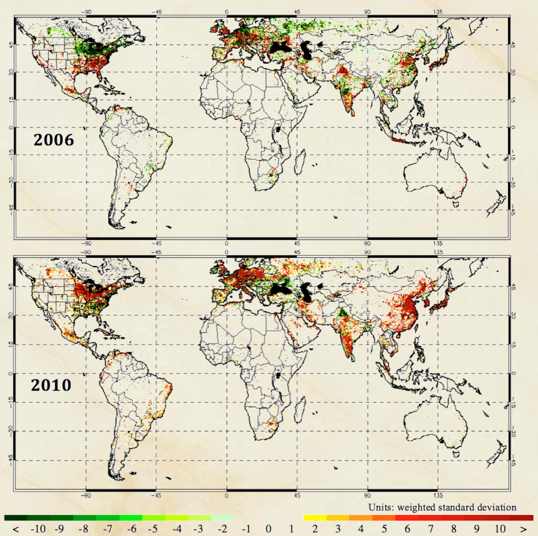
Thanks to Bedrich Benes & Yuyu Zhou

We see the global financial crisis

2009 CO_2 emission decline

2010 CO_2 emission recovery

US & EU sub-aggregate variation



negative

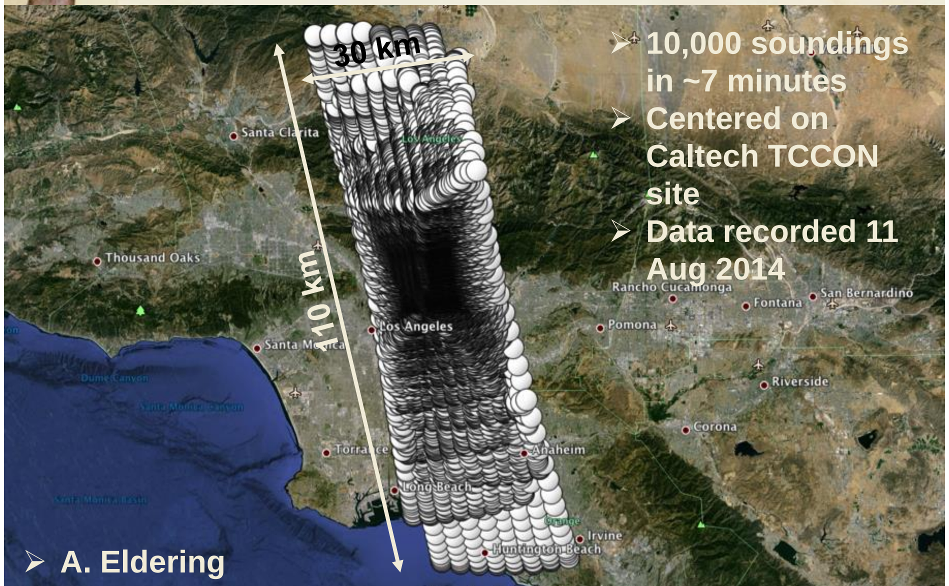
positive

Thoughts

Jianming's entropy

UHI as compound to CC, space/time matters and resolved. Waste heat extremely variable in space/time

OCO-2 Target Mode

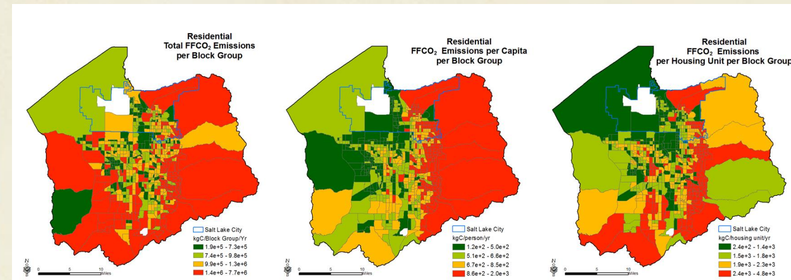


Driver analysis

STIRPAT regression:

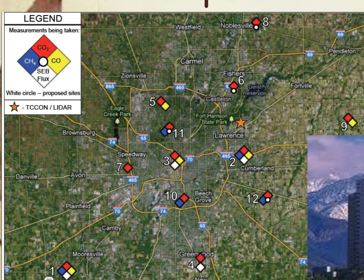
lnCO2(res) = intercept + ln(population) + ln(housing unit per capita) + ln(housing units per area) + ln(income per capita) + e

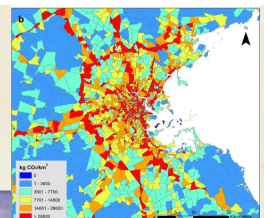
Subsets by income and geography

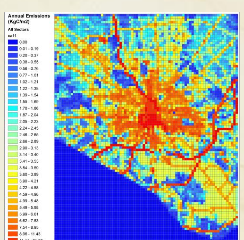


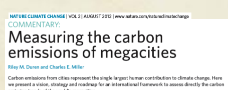
Multiple cities

Paris
Melbourne
Sao Paulo









Megacities Carbon Project

4.3 *Zero Energy Districts and URBANopt*, Ben Polly, NREL

(Slides not included due to proprietary nature.)

4.4 *Integrated Assessment Models in Earth System Models*, Peter Thornton, ORNL

(Slides not included.)

4.5 *Developments in high-resolution modeling that will improve efforts to understand human activity as related to climate change*, Katherine Evans, ORNL

High resolution climate modeling: Potential connections to Human Activity Modeling

Climate Change Science Institute

Computer and Computational Sciences

Oak Ridge National Laboratory

Presenter: Kate Evans

U.S. DEPARTMENT OF ENERGY

THE UNIVERSITY of TENNESSEE UT KNOXVILLE

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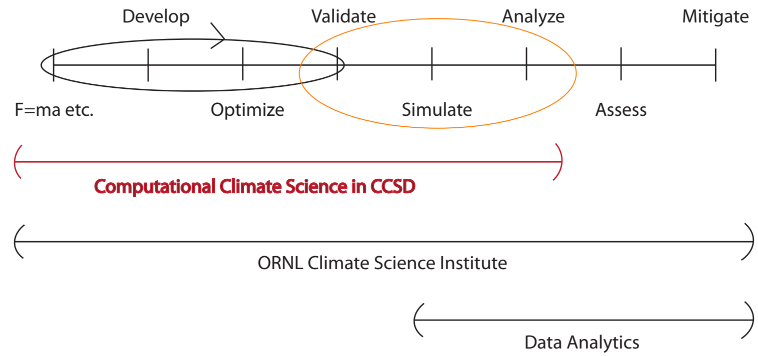
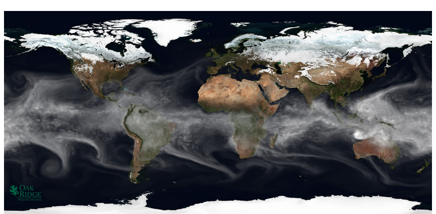
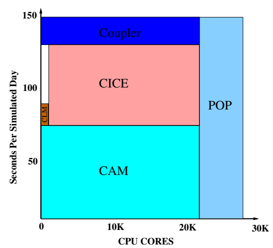
Span of large scale climate modeling at ORNL



Accelerated Climate Model for Energy (ACME)





Snapshot of water vapor from a coupled simulation with DOE/NCAR CESM (Jamison Daniel, NCCS). Current processor layout of CESM on titan (Pat Worley, CSMD)

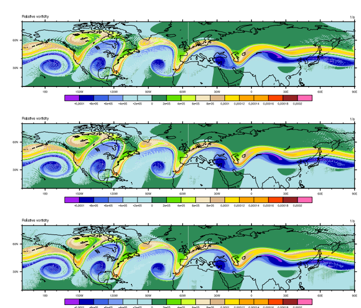
- Hypothesis-driven development of a global coupled Earth system model
- Tailored for DOE Office of Science needs for high-resolution coupled simulation
- Enhanced evaluation of the coupled system using coordinated workflows and metrics

ORNL is leading the workflow, land model, and performance groups and a task on evaluation of atmospheric dynamics

Performance analysis of implicit solvers within a spectral-element atmosphere model

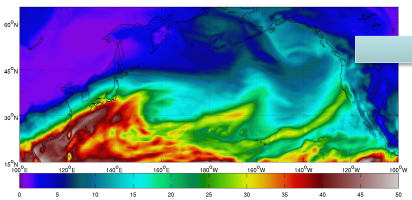
Objective	• Assess performance of implicit methods compared to other time-stepping schemes. • Apply implicit time stepping to a range of model configurations and parameter choices.
New science	• A library-based implicit solver that uses the GPU has been implemented • The solver provides accurate solutions for a range of problem types and scales to >86,400 cores. • This class of algorithms have not been evaluated at this scale of complexity for climate models.
Significance	• The implicit solver is able to use time-step sizes such that subcycling is removed. • The implicit solver shows equal performance to explicit for strongly regionally refined grids

K. Evans, R. Archibald, P. Worley, M. Norman, D. Gardner, C. Woodward, and M. Taylor. *Int. J. HPC Apps.*, in preparation.

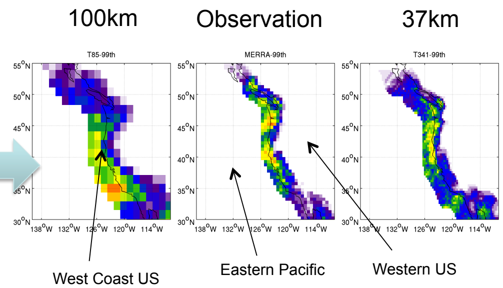


Vorticity field of the horizontal flow field at 6 days of simulation of a flow instability for three different layouts, all with a nominal resolution of a quarter degree but different spatial grids using the implicit solver, and it matches the explicit.

Using the high resolution models to better simulate extreme events: Atmosphere Rivers



A snapshot of the Total Water Vapor over the North Pacific on 1998/01/01 from CAM4 ~37km (1/3°) resolution (unit: mm).



Most precipitation on the Northern West Coast U.S. occurs as **atmospheric rivers** (red= highest ratio)*

As for global atmospheric models:

- Low res model places them too far South
- High res model matches observations more closely

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T. Jiang, (2014). JGR: Atmospheres

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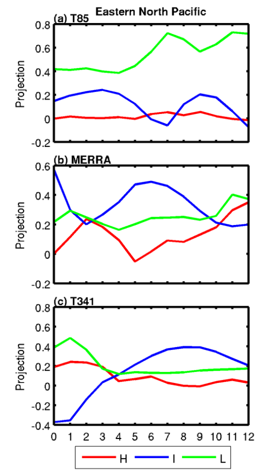
Using the model to better understand extreme events and why they do a better job with higher resolution



- Separate fluid flow scales into low, intermediate and high frequency components
- Atmospheric Rivers are modulated by flow upstream, over the Eastern Pacific
- This connection is due to an organization of water vapor, primarily through advection transport via intermediate scale eddies (blue)
- The high res simulation is better able to capture the intermediate scale, and therefore better captures the process.

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T. Jiang, et al. (2014). JGR: Atmospheres

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Using the high-res model to better simulate extreme precipitation events

- Demonstrated that the high-resolution model substantially improves the simulation of stationary precipitation extreme statistics particularly over the Northwest Pacific coastal region and the Southeast US.
- Implemented the framework in a parallel algorithm allowing a speed up of the analysis of extremes in global high resolution simulations by several orders of magnitude.

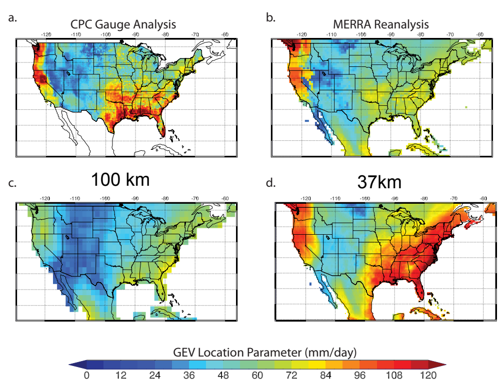

Figure: Simulation of precipitation extremes, 99.9 percentile. Extreme precipitation statistics are better represented in high resolution model as compared to low resolution model

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Mahajan S. et al. (2015), Procedia CS.

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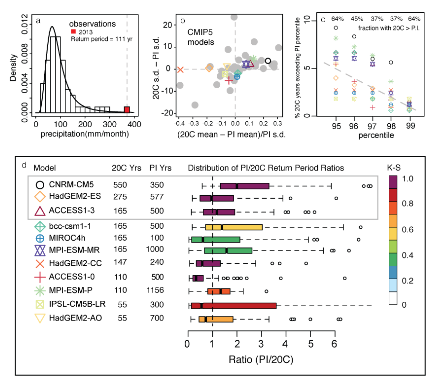
Attribution of a Severe Precipitation Event in Northern India in June 2013: Causes, Historical Context, and Changes in Probability



Singh D., **M. Ashfaq**, et al. (2014), *Bulletin of the American Meteorological Society*.

- Quantify the likelihood an **extreme hydrological event** could occur like the event in India 2013 (5800+ deaths)
- Develop and apply **new methods** to extreme events with observed and model datasets
- Analysis of June 2013 event dynamics within historical and pre-industrial climates **identified 4 interconnected proximal causes.**
- The extreme event was at least a century-scale event. Precise quantification of the likelihood of the event in the current and preindustrial climates is limited by the relatively short observational record.

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GFDL Geophysical Fluid Dynamics Laboratory

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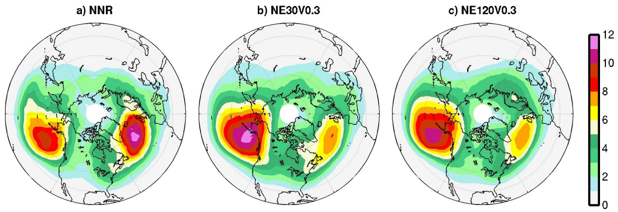
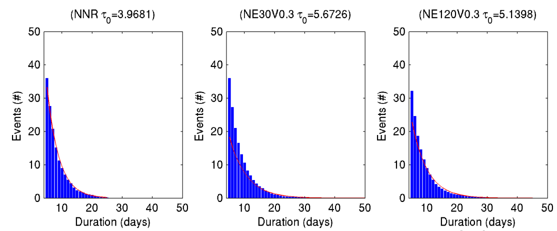
Northern Hemisphere Blocking characteristics of the ACME model v0.3



Observations | 100 km | 25km

Left: Winter Blocking frequency climatology (unit: *days per winter*).

Right: Histogram of blocking event duration in the Northern (blue bins). The red curves indicate the exponential fit of the distribution (e-folding time). τ_0 is the characteristic timescale



Observations | 100 km | 25 km

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Jiang, Evans et al. submitted

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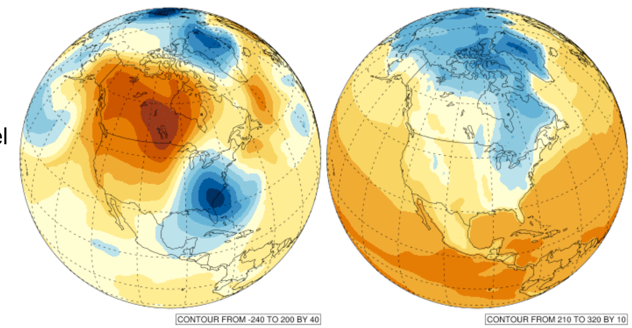
New DOE project: Large scale organization of extreme events: A dynamical pathway toward understanding and prediction

Upper level weather pattern



Surface Temperature

Animation of upper troposphere anomaly driving Arctic air intrusions to the South

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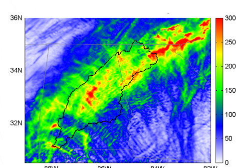
Connecting extremes to Impacts, Adaptations, and Vulnerabilities: CCSI

- **Develop an Integrated Energy-Water Risk Assessment Tool**
- **Downscale CMIP5 data over the United States at 4km horizontal grid spacing to assess the effects of future climatic changes on water supplies**
- **Understand the current state and motivate future work to combine simulations of climate change and vector borne diseases (Malaria, Zika)**

Review article on the state of the science for climate change and diseases
Parham et al. 2015

Simulation of extreme event over the Alabama-Coosa-Tallapoosa River Basin in Oct. 1995.



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Recent efforts to connect climate science to computer science, mathematics and computing facilities

- AGU 2016 planned presentation: "Making connections to translate climate research into effective action"
- Participation in a committee that provided information for the Earth Observing Assessment 2016
- Numerous sessions (as conveners, speakers, and posters) at AGU, AMS, and more
- 2 software releases and current ACME diagnostics development based on model evaluation metrics from our Earth System Science expertise.
- CCSI connections across themes, e.g. this workshop. Thanks to Melissa and other early career whipper-snappers!

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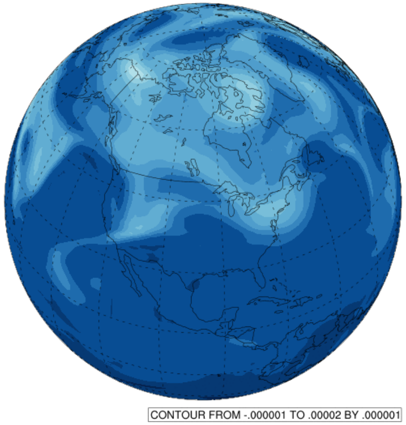
Questions?



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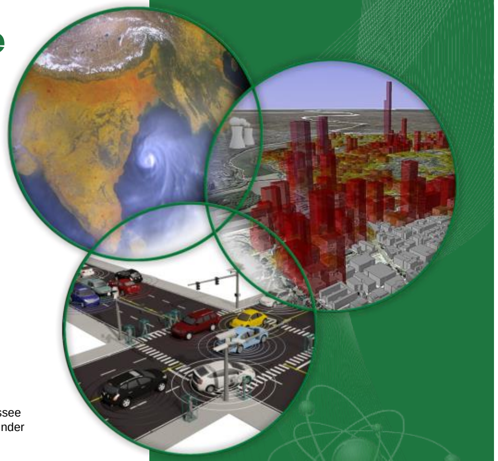
4.6 *From LandScan to Adaptive Population Agents: Modeling the Human Component*, Amy Rose, ORNL

From LandScan to Adaptive Population Agents: Modeling the Human Component

Amy Rose

Geographic Information
Science & Technology Group

Oak Ridge National Laboratory



Acknowledgment
Prepared by Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee 37831-6285, managed by UT-Battelle, LLC for the U. S. Department of Energy under contract no. DEAC05-00OR22725.

ORNL is managed by UT-Battelle
for the US Department of Energy

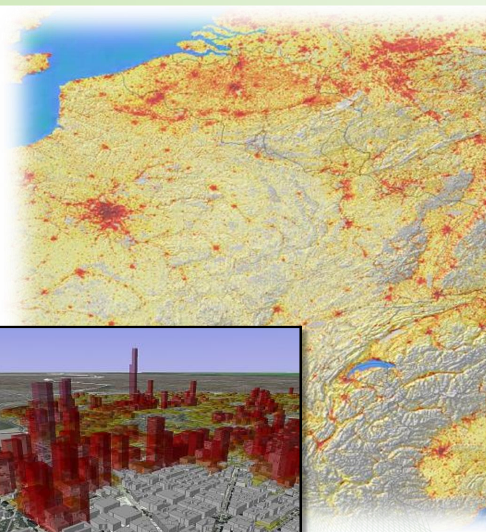
Outline

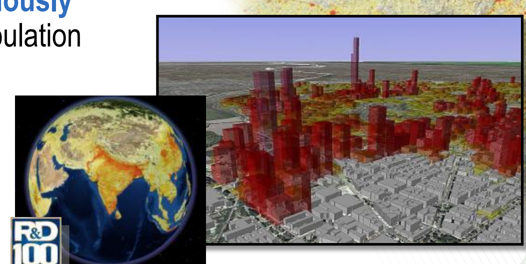
- Overview of LandScan and Related Programs
- Developing Population Agents
- American Population Simulator Example

LandScan

High Resolution Population Distributions at Global Scale

- The **finest resolution** population distribution data ever produced for the world (LandScan Global) and the U.S. (LandScan USA)
- The **community standard** for estimating population at risk
- Capturing **previously unmapped** population for the first time (LandScan HD)

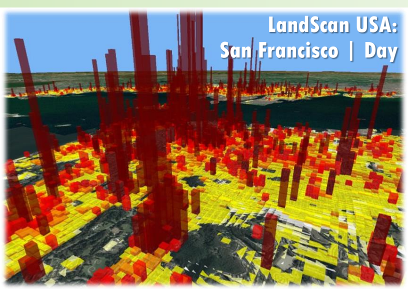


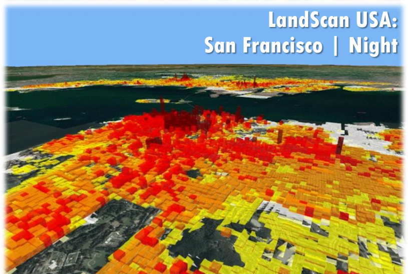


LandScan USA

High Resolution Spatiotemporal Population Distribution for the U.S.

- Captures **diurnal variations** of population:
  - Nighttime baseline includes residential and prisoner populations
  - Sub-models for daytime population components:
    - Workers, Students, Prisoners, Shoppers, Stay-at-home, Socioeconomic/Demographic Data
- **Extensible** for special events and tourist location scenarios
- Critical input for the **assessment, analysis, and visualization** of populations at risk
- ~90m resolution

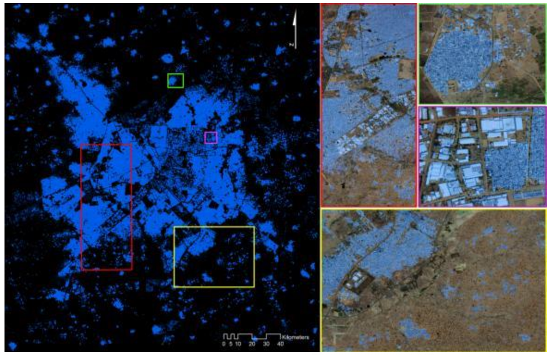


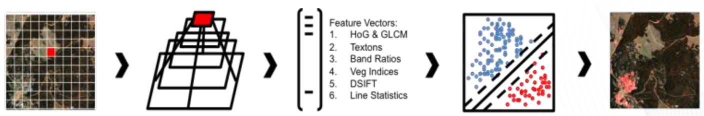


Settlement Mapping

Global mapping of human settlement at unprecedented resolution and speed

- HPC-based scalable framework that exploits parallel processing capability of GPUs
- Map sub-meter pixel data to unique structural patterns that correlate with the underlying settlements
- Foundational information for mapping population



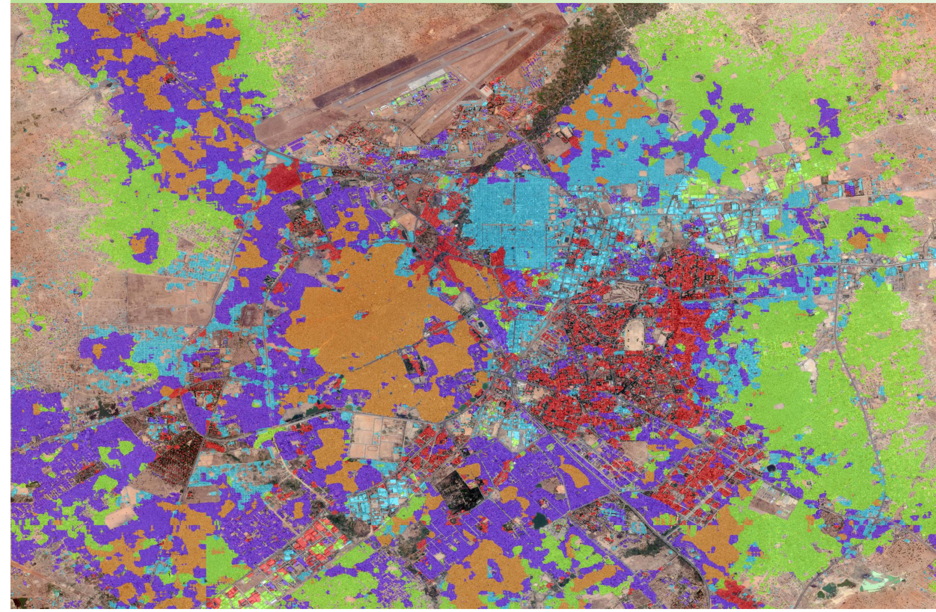


Divide Image into pixel blocks › Compute Multi-scale features for each pixel block › Each pixel block mapped to multi-dimensional feature vector › Apply linear SVM Model › Output Settlement Image

URBAN DYNAMICS INSTITUTE
OAK RIDGE NATIONAL LABORATORY

Neighborhood Mapping

Feature segmentation based on neighborhood typologies



Building Occupancy Modeling

Global open source data mining for facility occupancy estimates

Nearest	Day			Night		
Afghanistan (59)	1.73	3.10	4.81	2.82	5.29	8.13
Pakistan (15)	0.45	1.10	2.13	1.57	3.02	5.02
Tajikistan (7)	0.84	2.03	3.80	4.65	9.41	12.80
Turkmenistan	0.99	3.00	5.96	1.93	5.47	9.74
Uzbekistan	0.99	3.00	5.96	1.93	5.47	9.74
Iran (119)	0.33	0.75	1.39	1.81	3.11	4.82
Kyrgyzstan (8)	0.37	1.24	2.82	1.92	4.62	8.04
Disputed	0.45	1.40	3.10	1.63	5.00	10.90
United Arab Em...	0.99	3.00	5.96	1.93	5.47	9.74
Qatar (11)	0.00	0.04	0.68	0.04	0.62	2.72

- **Spatial Resolution**
  - **Region, Nation, City, Neighborhood**
- **Temporal Resolution**
  - **Diurnal**
  - **Workweek or weekend**
  - **Episodic, holidays, special event**
  - **Seasonal**

PDT Population Density Tables

Page 1 of 3

PDT OAK RIDGE CENTCOM Generated : 02-17

	Day			Night			Episodic		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
Residential									
Urban Upper/Middle Class	1.25	0.25	3.00	3.75	1.00	7.75			
Urban Lower Class/Slum	2.75	0.75	6.00	7.75	2.00	17.75			
Rural	2.00	0.75	3.75	6.00	1.25	13.25			
Multi-Family	1.25	0.25	3.25	3.25	0.50	9.50			
Refugee Settlement	7.50	0.75	22.75	10.50	0.75	36.00			
Tents	4.25	0.75	12.50	11.50	1.50	36.25			
Institutions/Public Service									
Religious	4.50	0.25	17.25	0.75	0.25	2.00	62.50	11.50	166.00
Museum - Urban	1.25	0.25	3.50	0.25	0.00	1.50			
Museum - Rural	0.50	0.25	1.00	0.00	0.00	0.25			
University Library	7.00	1.50	17.75	0.25	0.00	0.75			
Public Library	2.50	0.25	6.25	0.25	0.25	0.75			
School (D - 12)	13.75	2.50	39.50	0.25	0.00	0.75			
University	7.25	0.75	26.25	3.00	0.25	11.25			
Hospital/Clinic with beds	9.25	0.25	45.25	3.25	0.25	16.25			
Hospital/Clinic without beds	5.00	1.00	13.00	0.25	0.00	1.00			
Conference Centers	8.50	1.00	25.50	0.75	0.00	2.00	43.50	14.75	76.25
Fire Stations	4.00	0.75	10.25	1.50	0.50	3.25			
Courts	7.00	1.25	18.25	1.50	0.25	5.25			
Police Stations	3.50	0.50	10.00	1.50	0.25	4.75			
Post Office	3.50	0.75	8.50	1.25	0.25	4.00			
Public Service	7.75	0.75	24.50	2.25	0.75	5.00			
Radio Stations	4.00	1.25	7.25	3.75	0.25	8.50			
TV Stations	4.00	1.00	8.50	3.75	0.25	8.50			
Water Treatment	5.00	0.75	14.00	2.00	0.50	4.75			

Page 1 of 3

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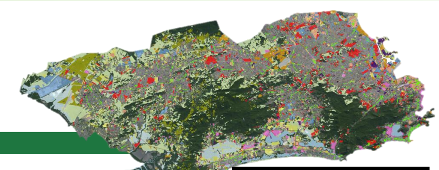
- **Average occupancy reported as people/1000 sq. ft. at national and regional level for day, night and episodic.**
- **Over 50 structural facility categories in 8 land use classes.**
- **PDT density inferred from available sources of information > 25K reports.**

Global Building Characterization

Data fusion across resolutions to capture spatial variability

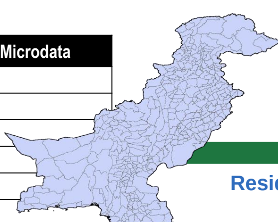
- Flexibly provide an improved, more detailed characterization of buildings
  - Fine resolution data on building materials
  - Myriad land use datasets
  - Customizable urban extents
- Classify using a unified taxonomy
  - Global Earthquake Model (GEM)



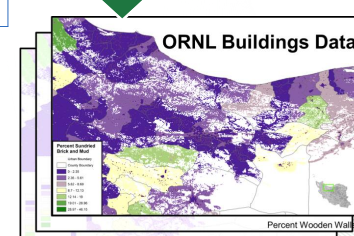
Non-residential

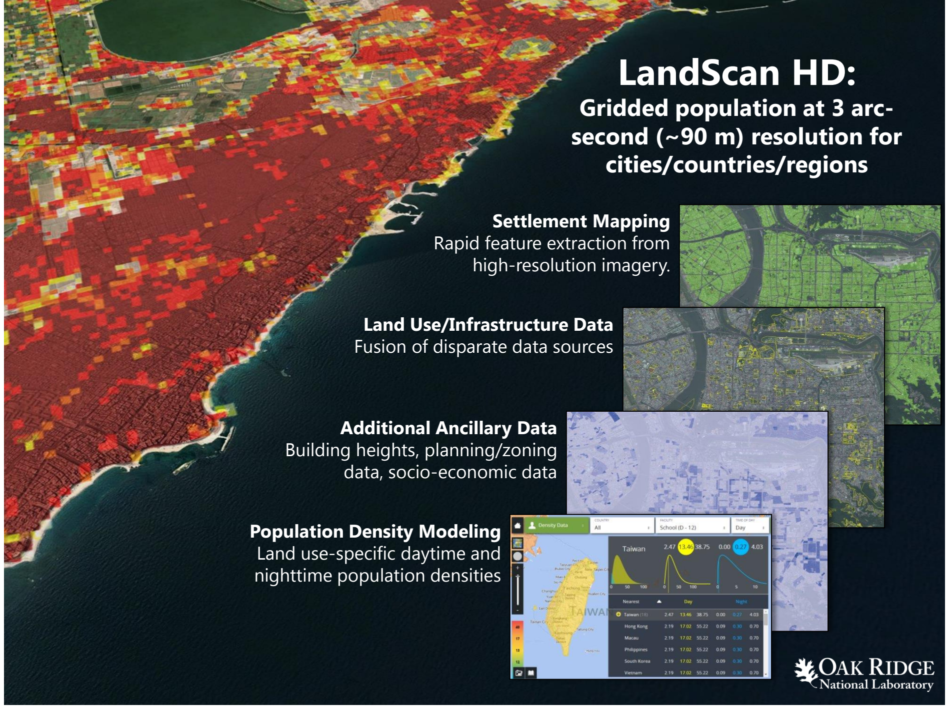
GEM Attribute Group
Structural System
Building Information
Exterior Attributes
Roof/Floor System

Census Microdata
Islamabad
Quetta
Karachi
Lahore
Kohat
Peshawar



Residential

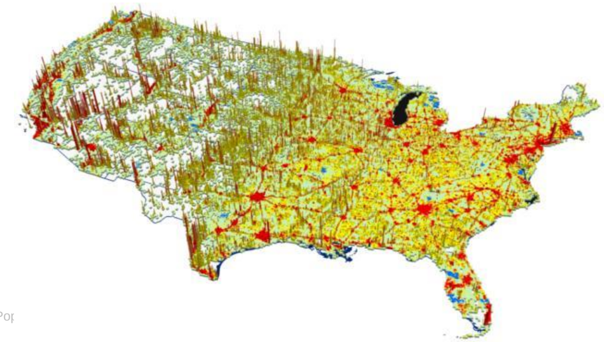


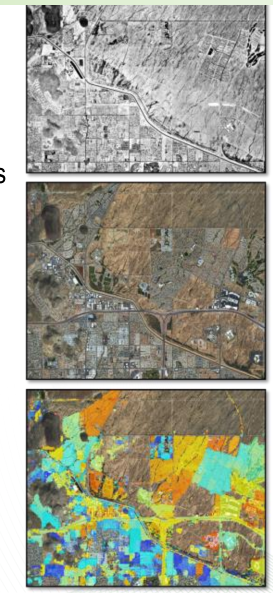


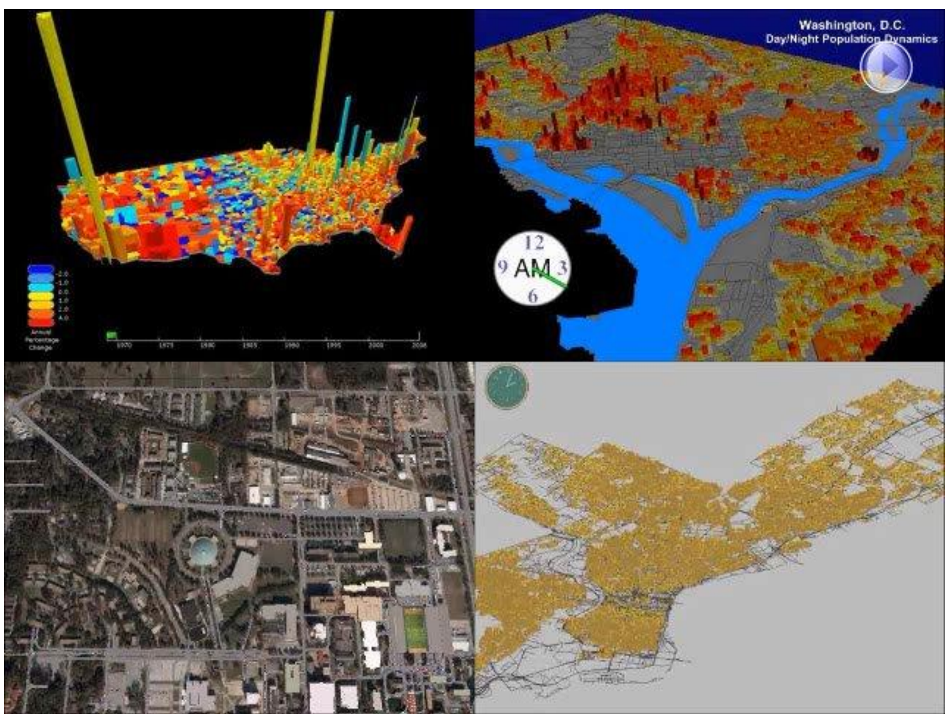
LandCast

Locally Adaptive, Spatially Explicit Projection of U.S. Population

- Understanding future population distributions is critical for **urban resiliency**, developing **sustainable infrastructure**, and assessing the impacts of **climate change**
- The first ever large scale, adaptive spatial algorithm for addressing local characteristics of unique geographic areas
- One of many potential **population futures**



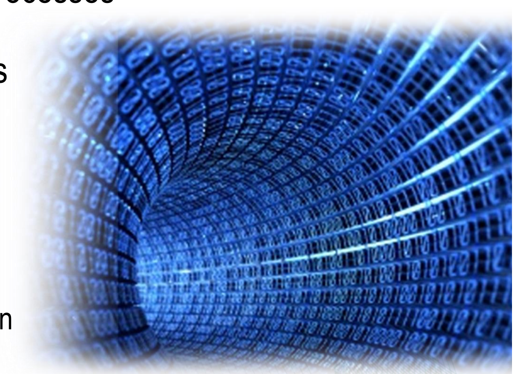




Moving from LandScan to Agents

What's Needed?

- High resolution distribution and dynamics data is critical to address the interdependencies between population, infrastructure, and physical processes
- Multi-simulation environments need to utilize population dynamics
  - Function of space and time
  - Geographically scalable and deployable
  - Interoperable among simulation environments



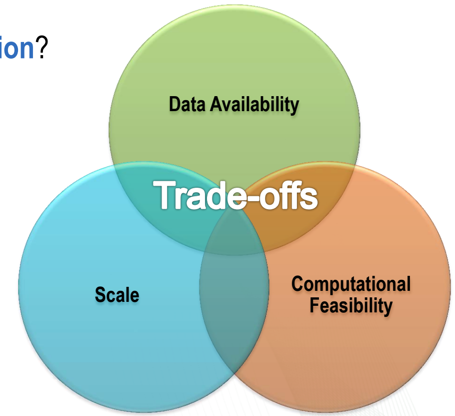
URBAN DYNAMICS INSTITUTE
OAK RIDGE NATIONAL LABORATORY

Developing Population Agents

Fundamental Issues

Scenario Driven: What question(s) are you trying to answer by injecting the human component?

- What is the **scale of representation**?
  - Individual
  - Household
  - Cohort
- What is the **spatial scale**?
  - Neighborhood
  - City
  - Region
- What is the **temporal scale**?
  - Static
  - Adaptive over time



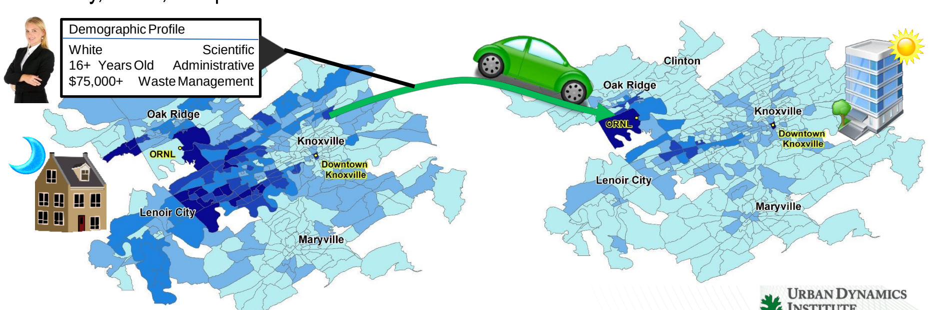
Process Flow

What are the critical decision points?

- Identify available **data sources** (global, regional, local) to support the simulation environment
- Characterize the **granularity** needed to model agents at the level required to support the simulation environment
- Describe **population agent attributes** required for a particular narrative
- Catalog all source data sets as **base information**
- Develop modeling techniques for **assigning attributes** to individual agents based on indicator data sets

American Population Simulator (APS)

- Produces population data with ***high* demographic detail** and ***high* spatial resolution** in response to the growing demand for fine scale urban modeling
- Using novel algorithms that fuse ACS microdata, summary data, CTPP data, and business location data to reconstruct and distribute likely sub-populations
- Providing full demographic detail for block group ***home and work* distributions** including quantitative measures of uncertainty
- Supporting neighborhood level decision support in energy consumption, transportation, mobility, crime, and public health.



Contact: Robert Stewart, stewartrn@ornl.gov, @drbobatornl

American Population Simulator

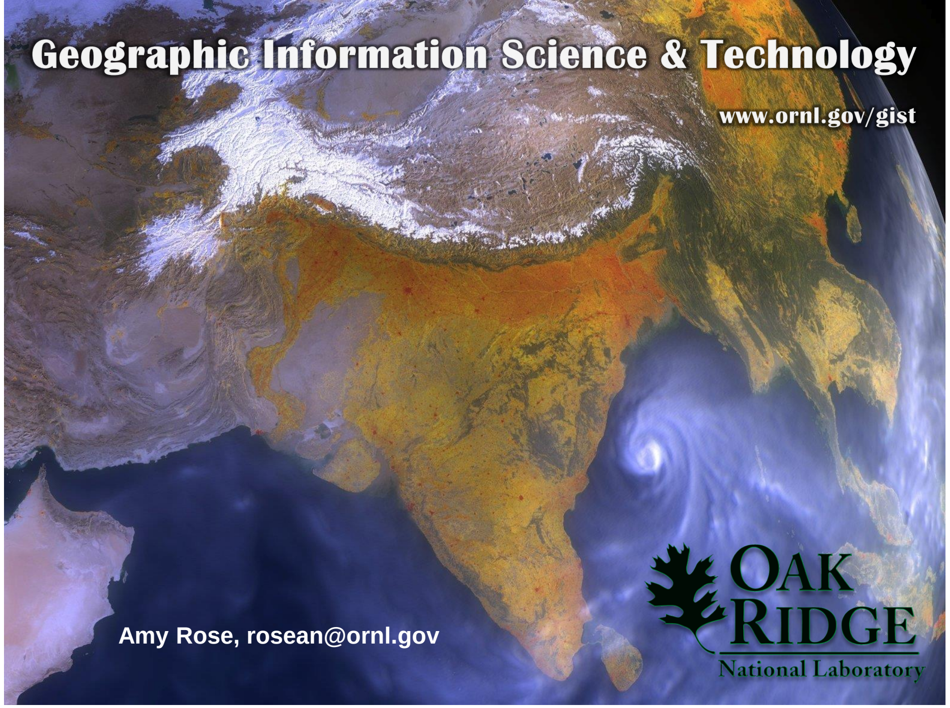
Current Implementations

- **DOE EPSA Solar Panel Project**
  Dr. Femi Omitaomu
  - Drawing important connections between solar panel investment and household characteristics
- **Toolkit for Urban Mobility (TUMS)**
  Dr. Cheng Liu
  - Increasing the resolution of traffic modeling in urban areas
- **Modeling Urban Energy System's Water Footprints**
  Dr. Ryan McManamay
  - Demography driven estimates of neighborhood (block group) energy consumption rates.

Summary

Considerations for Going Forward

- American Population Simulator
  - Demonstrates the adequacy of available public data sources to:
    - Characterize individual human behavior
    - Characterize overall social or economic phenomena
  - Demonstrates the fusion of disparate, multiscale, and potentially dynamic data sources
- Incorporating high resolution data allows small sub-populations to be identified
  - Large number of agents can reveal features important to course of action analysis
- **Trade-offs must always be considered**
  - Granularity of analysis vs. computational feasibility vs. data availability



4.7 *Science for Solutions: Climate Risk Management in a Post-Paris World*, Ben Preston, ORNL

Science for Solutions:
Climate Risk Management in a Post-Paris World

Benjamin L. Preston
Deputy Director, Climate Change Science Institute
Senior Research Scientist, Environmental Sciences Division
Oak Ridge National Laboratory

ORNL is managed by UT-Battelle
for the US Department of Energy

Human Activity at Scale in Earth System Models
September 19, 2016
Oak Ridge National Laboratory

Climate Change: A Human Condition

The new policy context for Earth system modeling

COP-21 (Paris)

- **Limiting global temperature increase well below 2°C (i.e., 1.5°C)**
- **Commitments by all parties to make "nationally determined contributions" (NDCs)**
- **Enhancing adaptive capacity, strengthening resilience and reducing vulnerability (including "loss and damage")**
- **Clean Development Mechanism v 2.0**

Sustainable Development Goals

- **End poverty, protect the planet, and ensure prosperity for all**
- **17 goals (one of which is "climate action"), each with multiple targets**

IPCC/Future Earth/PROVIA Workshop (August, 2016)

This is not your mother's "policy-relevant science"

- **Improved climate prediction continues to be a worthy science objective, but the questions are changing**
  - Gen 1: *What is the likelihood of warming of X°C?*
    - *Future demography?*
    - *Future rates of economic growth?*
    - *Future technology policy and innovation?*
    - *Future emissions?*
  - Gen 2: *How should I respond to a warming of X°C?*
    - *Future perceptions of risk?*
    - *What do people value?*
    - *What are people willing and able to do?*
  - Gen 3: *What will be the consequences of my response to warming of X°C?*
    - *What trade-offs are people willing to make?*
    - *How do people learn from experience?*

Behavior is the operationalization of choice

- **How do we evaluate choices using models where behavior is only minimally represented?**
  - Inherent Earth system elements are defined exogenously
    - Land use, emissions/radiative forcing
  - No people (beyond proxy land use types)
  - No feedbacks (of the human variety)
  - No infrastructure or economic assets (beyond proxy land use types)
  - No changes in values or preferences
  - No learning

So what do we do?

- **Don't worry about it**
  - *"you don't believe in any of that fate crap"*
  - Earth system models are designed (for good reason) to represent biophysical, not human, processes
- **Leverage integrated assessment models to fill the gaps**
  - IAMs were designed to do this kind of stuff
  - Yet, much continues to be defined exogenously (policy and technology constraints)
  - All choices assume maximization of economic utility (e.g., land use)
- **Dynamic human system modeling**
  - Incorporate those human system elements that matter (akin to the development of dynamic carbon cycle modeling)
  - Endogenize policy, technology deployment, land use change (particularly agriculture)

Thank You

Benjamin L. Preston
Climate Change Science Institute
Oak Ridge National Laboratory
865-574-6496
prestonbl@ornl.gov

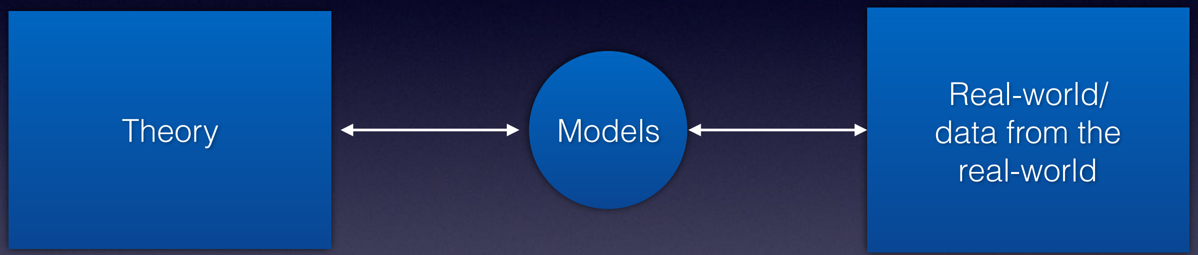
@adapt_to_change

4.8 *Big Ideas for Integrated Assessment Models using Large-scale Agent Computing*, Rob Axtell, GMU

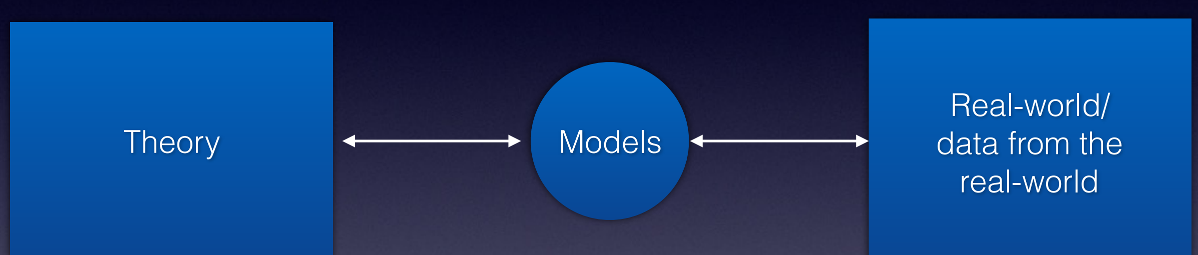
Full-Scale Agent Models for Earth System Science

Rob Axtell
George Mason/Computational Social Science/
Computational Public Policy Lab/Center for Social Complexity/
Krasnow Institute for Advanced Study
Santa Fe Institute
Northwestern/NICO

Philosophy of Social Science: Models Mediate

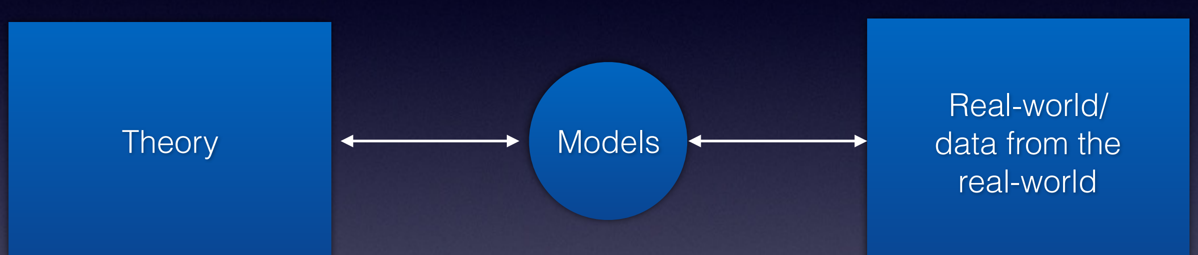


Philosophy of Social Science: Models Mediate



Positive models: how the social system works

Philosophy of Social Science: Models Mediate



Positive models: how the social system works
Normative models: how to make it work better

Archetypical Agent Story #1: Water Management in N. NM

- Distinct user types: Native rights, farmers, ranchers, industry, consumers, recreation…
- 1,000,000 line FORTRAN code run daily to control flows in the Colorado + Rio Grande rivers
- Normative goal: Water access for *people*
- How much of the code was behavioral/social
- 1 number: elasticity of demand!!!!!

Archetypical Agent Story #2: Fishery Management

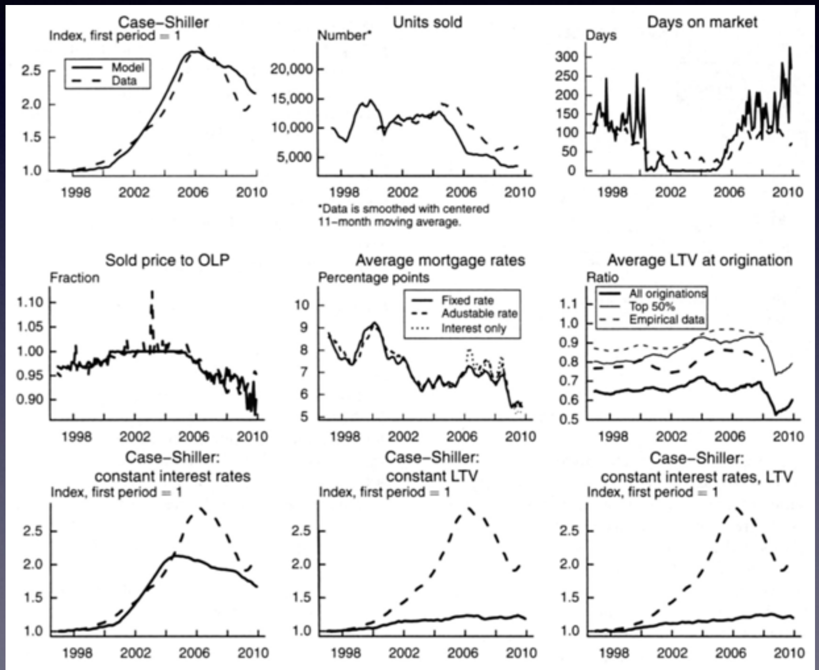
- Old way: top down
  - Exogenous biology (fish)
  - Aggregate fishing fleet
  - Optimal control of harvest
- Stock assessment => TAC
- Pathological outcomes:
  - Harvest as fast as possible
  - Global decline in harvests

- New way: bottom up
  - Endogenous biology
  - Individual fishers (data)
  - Individual tradable quotas
- Outcomes:
  - Emergent strategies: FTL
  - Sophisticated mgmt of choke species
  - Stabilization of harvests

Full-Scale Housing Bubble Model: Washington, DC

- Integrate the data on every:
  - household (Census, IRS)
  - house/housing unit (county tax records)
  - mortgage (CoreLogic)
  - real estate transaction (MLS)
- Create model for 2M people in Baltimore-Washington metro area for 1995-2010

Aggregate Results



Full-Scale Model of the U.S. Private Sector

- Data on ALL business firms (IRS)
  - ~30 million firms total
  - ~6 million firms with employees
  - ~100K firms enter, exit each month
- ~120 million employees
  - ~10 million in flux each month
- DSGE models used by Fed: 1 firm!

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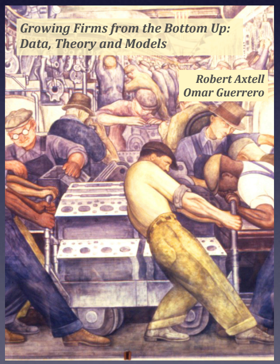
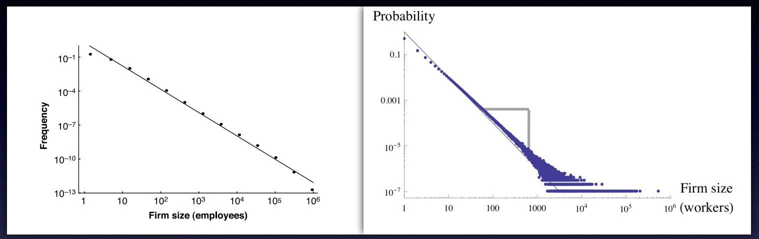


Firms: Results



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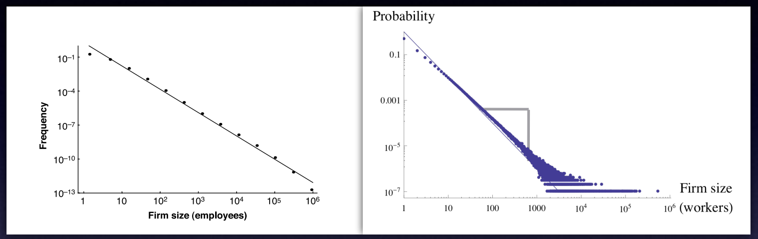
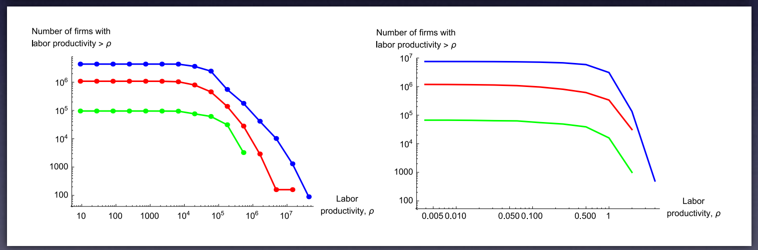
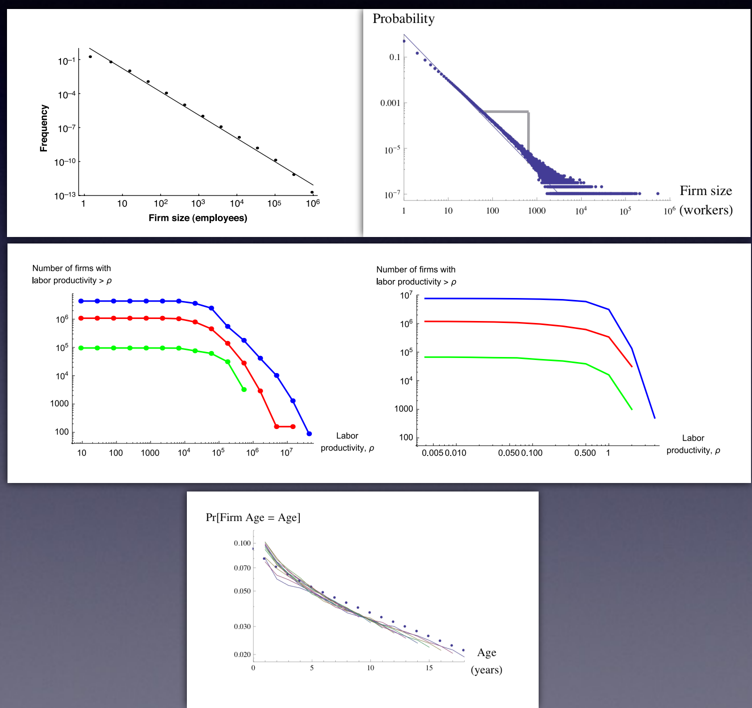
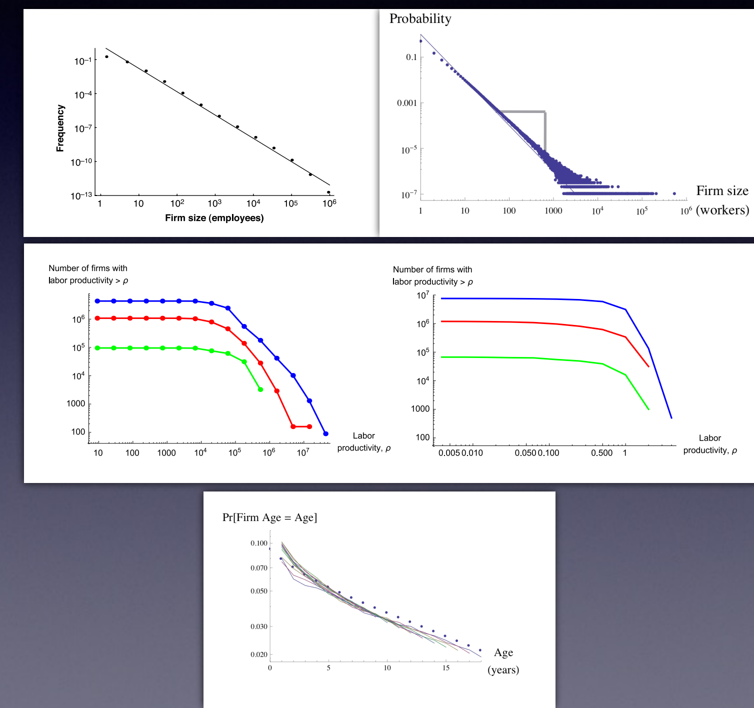


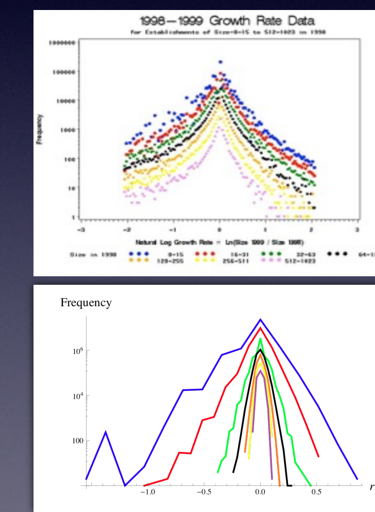


Firms: Results



Firms: Results





Rationale for Full-Scale

- *Fluctuations* are not Gaussian; not $\propto$ size$^{1/2}$
  - Not at full scale: either fluctuations are not right or reparameterize to get fluctuations right but then other aspects not likely to be right
- Social systems are hard to *aggregate*
- Social systems are *stiff:* at time *t* the only way to get to time *T* > *t* is to march through $(t+T)/2$

Rationale for Agents

- *Heterogeneity*: Beyond ‘representative’ agents
- *Bounded rationality*: Beyond *homo economicus*
- *Social networks*: Beyond ‘perfect mixing’
- *Nonequilibrium*: Beyond Walrasian and Nash eq (e.g., agent-level flux yet aggregate stationarity)
- *Space*: Beyond isotropy assumptions

Herbert Simon: “Social sciences are the *hard* sciences”

Economic conception	Simple	Complex
Quantity of agents	representative (one, few)	many (possibly full-scale)
Diversity of agents	homogeneous	heterogeneous (or types)
Agent goals, objectives	static, scalar-valued utility	evolving, other-regarding
Agent behavior	rational, maximizing, brittle	purposive, adaptive, biased
Learning	individual, fictitious play	empirically-grounded, social
Information	centralized, maybe uncertain	distributed, tacit
Interaction topology	equal probability, well-mixed	social networks
Markets	WMAD, single price vector	decentralized, local prices
Firms and institutions	absent or unitary actors	multi-agent groups
Governance	benevolent social planner	self-governance, emergent
Temporal structure	static, impulse tests, 1-shot	dynamic, full transient paths
Source of dynamism	exogenous, outside economy	endogenous to the economy
Solution concepts	equilibrium at agent level	macro steady-state (stationarity)
Multi-level character	neglected, dual fallacies	intrinsic, macro-level emerges
Methodology	deductive, mathematical	abductive, computational
Ontology	representative agent, *max U*	ecology of interacting agents
Policy stance	designed from the top down	evolved from the bottom up

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=> not COTS

Need a Basic Research Program on Agents

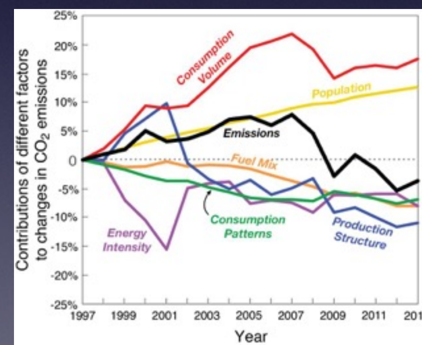
- Behavior: from experiments to software agents
- Parallel execution: from difficulty to easy
- Estimation of agent models
- Proposals:
  - ~$10M research center
  - ~$100M Office of Financial Research
  - $1B FuturICT

Going Forward…

- Representative agents deeply problematical

Going Forward…

- Representative agents deeply problematical
- Certain first-order effects dominate *most* others:
  - Economic conditions
  - Technological progress
  - Real estate values enormous



- Human adaptation endogenous: Lucas critique

Working papers

Pathologies of 'Integrated Assessments' of Climate Change:
Representative Agents vs Heterogeneous Populations,
Rational Response vs Behavioral Adaptation,
Homogeneous and Static Beliefs vs Diverse and Dynamic Perceptions,
Technological Stationarity in a Non-Stationary World,
Average Effects vs Extremes, and
Neglect of Poorly Understood Scientific Issues

Rob Axtell®
Department of Computational Social Science
Krasnow Institute for Advanced Study
George Mason University
Fairfax, Virginia 22030 USA

Version 0.5: 10 April 2014

Abstract

Conventional analyses of the social and economic impacts of climate change are often framed in terms of so-called integrated assessments. A cursory review of the methodology underlying such work clearly demonstrates them to be unsatisfactory on a variety of grounds. In this paper we first critique the use of such models and then suggest ways their current limitations can be relaxed.

I. Introduction: Integrated Assessments of the Net Costs of Climate Change

For more than 20 years it has been the norm for economists and policy analysts to sum up the costs and benefits of climate change, as they determine them, and render summary, normative assessments of how best to ameliorate the impending

Working papers

Pathologies of 'Integrate
Representative Agents vs Hete
Rational Response vs Beha
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Technological Stati
Average Effects
Neglect of Po

Rob Axtell®
Department of Computational S
Krasnow Institute for Advance
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I. Introduction: Integrated As

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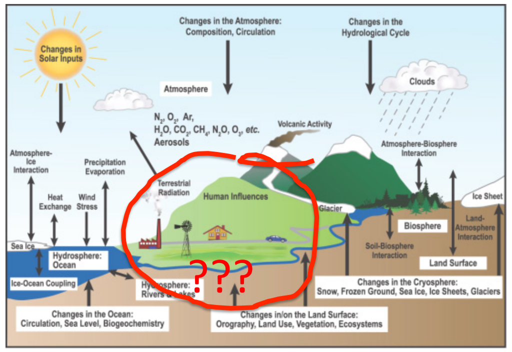
Next Generation Economy, Energy and Climate Modeling

Eric D. Beinhocker, J. Doyne Farmer, Cameron Hepburn

Prepared for the Global Commission on Economy and Climate
11 October 2013



Summary

- *Problem*: conventional social science models (e.g., CGE, DSGE, SD) not up to the task
- *Good news*: Agents are a way forward (e.g., in the 1980s there was no solution)
- *Bad news*:
  - No COTS, a basic research program is needed
  - No basic research program is in the cards
  - Solutions may be years in the making

Rerun the Tape?

- Imagine starting over on climate + social science:
  - Would we use IAMs with a few rep. agents? DICE?
  - Would we ask for/better micro-data?
  - Would we make *behavior* a primary focus?
- Start from human dimensions (impact/effects):
  - Would we we use GCMs?
  - Would we invert the funding pyramid?

4.9 *Modeling and Simulation of Large Biological, Information and Socio-Technical Systems: An Interaction Based Approach*, Chris Barrett, VT

Simulating Large Bio-, Info- and Socio- Technical Systems:

An integrative interaction-based approach

(& the end of monolithic models)

Christopher L. Barrett

Executive Director & Professor

VirginiaTech
Biocomplexity Institute

BIOCOMPLEXITY INSTITUTE

Why bother? Why wonder why?

- Understanding
- Design
- Policy and operational decisions
- Prediction….well, that depends, a nuanced thing
- We, science, are *chasing* implemented Instrumented Everything/ Computing Everywhere technology
- Science-as-research is not leading that technology
- Emerging consensus that very granular detail matters

Massively Interacting Systems

- Among many things

and

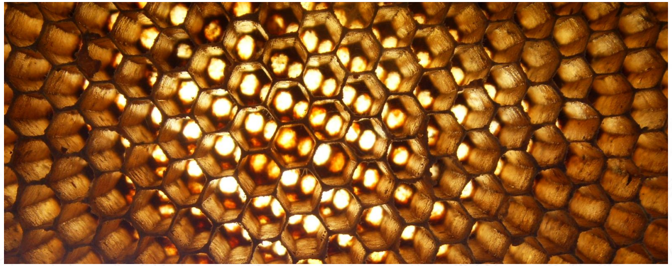
- Many properties of things

in

- An evolving interactum

For example, cities are made by/for/with people

- Literally, they are extended human forms
- Is this built infrastructure or bee biology? Detail



Practical meso-scale granular computation is here

- Now: 200 day ID epidemic with interventions and individual reactions; 315M people 145M locations:
  - 9 seconds, minutes and hours to set up
  - 2005: 48 hours, months and years to set up
- Now: (re)Compute entire global synthetic population "coordinate framework":
  - O(hour); hundreds/thousands of sources
  - In 2005: US population took 30 days to compute after a year setup
- etc

SITIS: Situated Synthetic Information Systems

- Scalable data-driven HPC application ecologies
- Situated app "mashups" vs monolithic models
  - Some "apps" can be large of course
- Explain and project: abduction and provisional decision making
- Integration of "All-Data", e.g., uncontrolled & controlled observation and including procedural facts as a data type

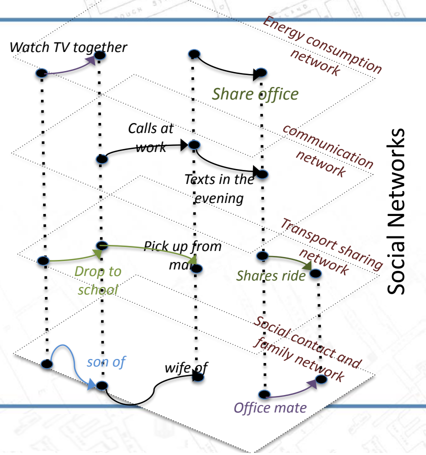
IoT, etc. Micro information trends

- This is new interaction media: meta-infrastructure
- All trends are going toward *individual/granular* information:
  - Mobility and transport
  - Communications and information
  - Personalized health and individualized public health
  - Advanced supply chain
  - Instrumented environment
  - Behavior and performance monitoring….
- All trending to decentralization

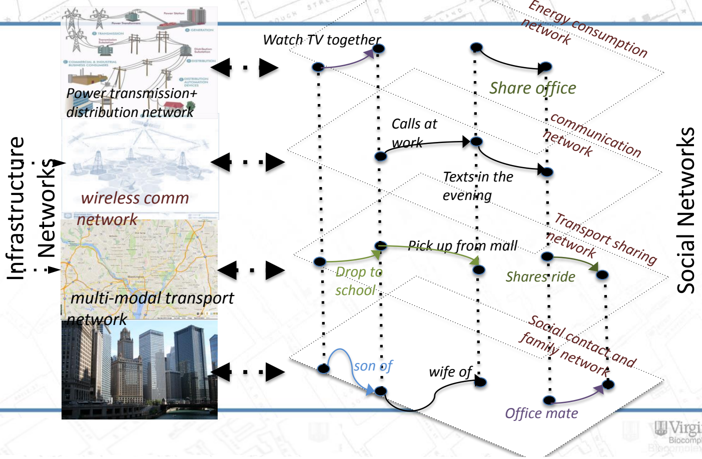
The unencapulated agent or other interactor

- Where is your money?
  - Your debt?
    - The processes by which your debt is serviced by your money?
- There is a problem with simple locality
  - Of self or item
    - Of interactions and properties

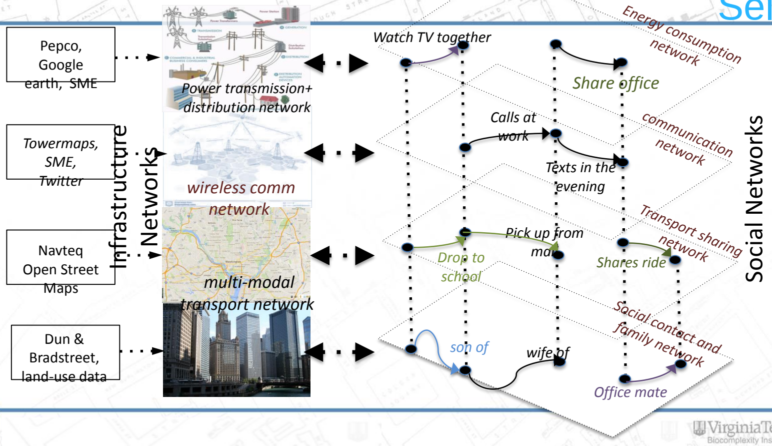
The Synthetic Interdependent Self



The Massively Interacting Self

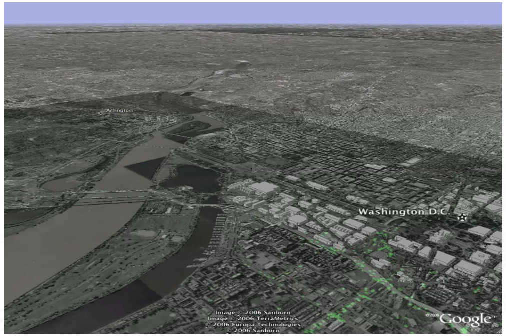


The Co-evolving Synthetic Interdependent Self



What is going on here?

State of art 1991

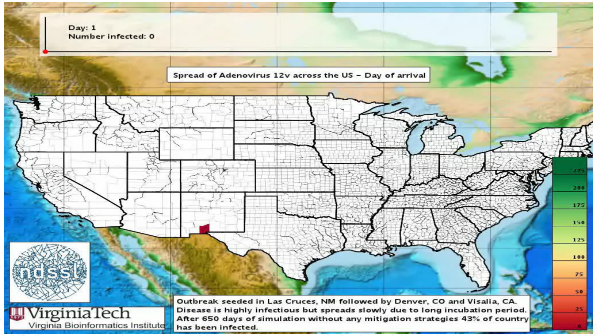


And here?

State of art 1996

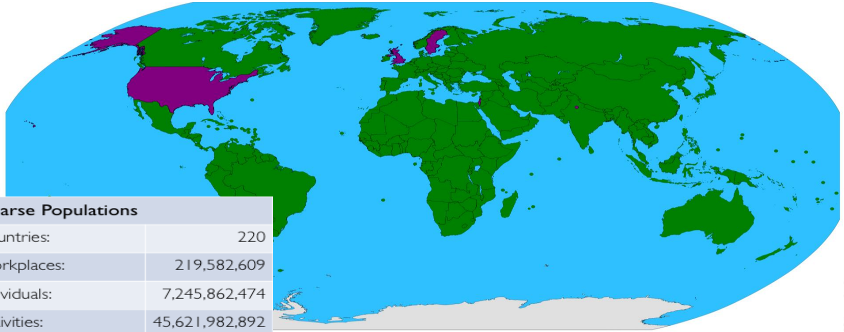
And here?

State of art 2010



Inveitably, here?

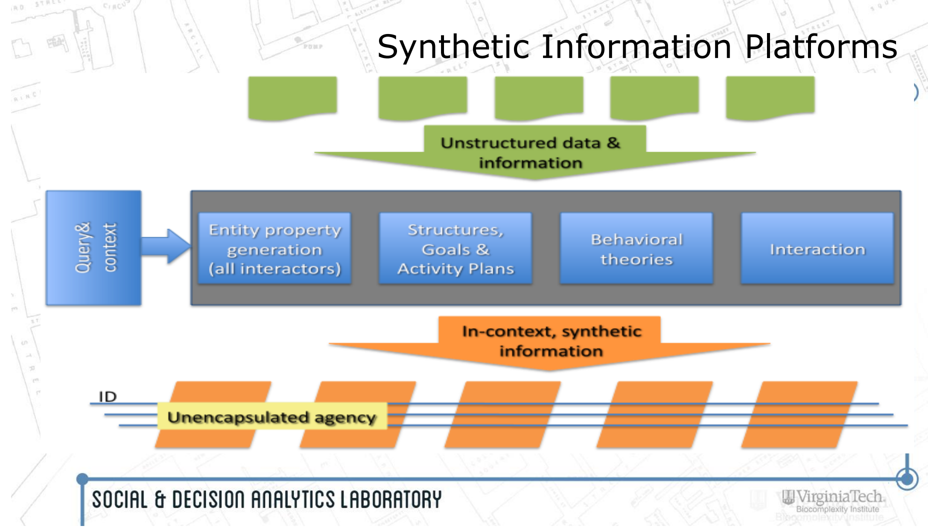
State of art 2015

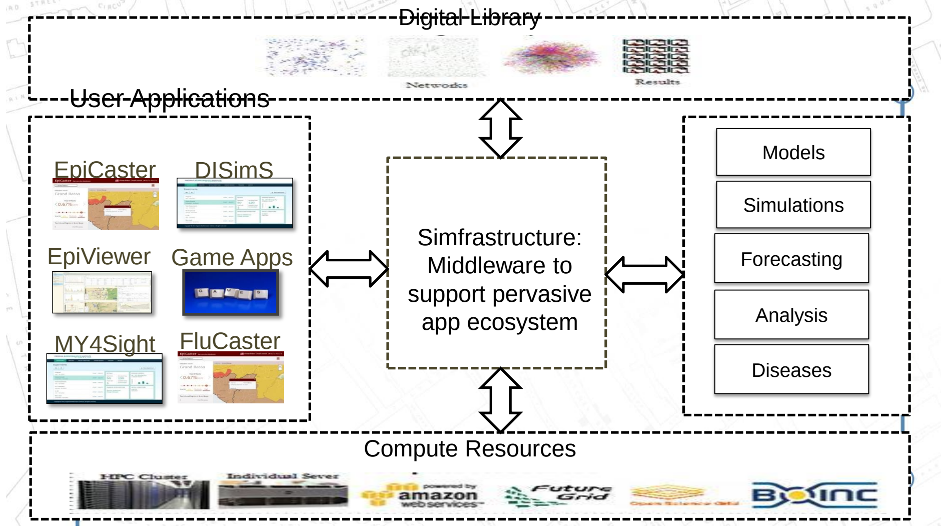


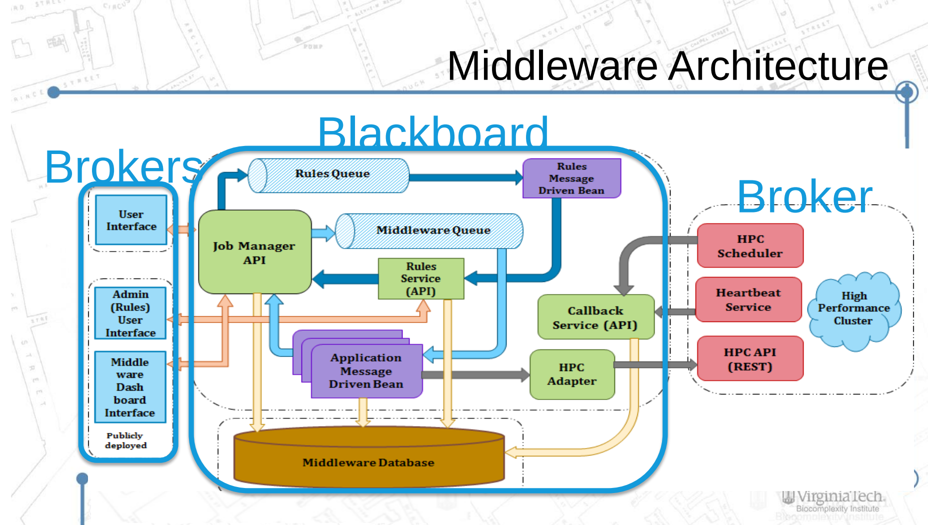
Coarse Populations	
Countries:	220
Workplaces:	219,582,609
Individuals:	7,245,862,474
Activities:	45,621,982,892
Households:	2,619,161,562
Schools:	51,609,085

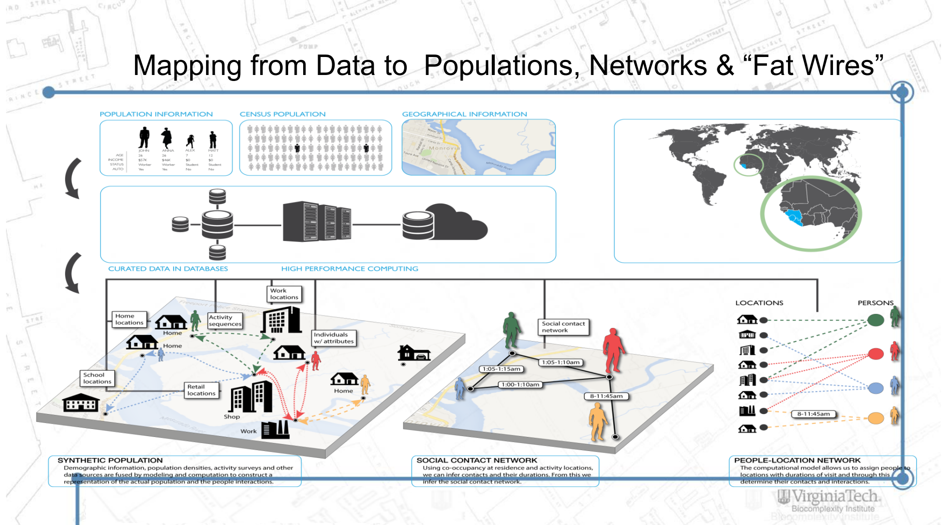
Big Data/ All Data methods

- Data that was not collected for the purposes you will use it for. Uncontrolled.
- Need integration methods
  - micro measurements, calibration & quality
  - “coordinate system”
  - procedural data type and dynamics
- Synthetic methods fit in here
  - base global person-activity location library data structure is ~7.7 TB


Synthetic Information Platforms
Unstructured data & information
Query& context
Entity property generation (all interactors)
Structures, Goals & Activity Plans
Behavioral theories
Interaction
In-context, synthetic information
ID
Unencapsulated agency
SOCIAL & DECISION ANALYTICS LABORATORY
VirginiaTech
Biocomplexity Institute


Digital Library
Networks
Results
User Applications
EpiCaster
DISimS
EpiViewer
Game Apps
MY4Sight
FluCaster
Simfrastructure: Middleware to support pervasive app ecosystem
Models
Simulations
Forecasting
Analysis
Diseases
Compute Resources
HPC Cluster
Individual Sever
amazon web services
Future Grid
BOINC


Middleware Architecture
Brokers
Blackboard
Broker
User Interface
Admin (Rules) User Interface
Middle ware Dash board Interface
Publicly deployed
Rules Queue
Rules Message Driven Bean
Job Manager API
Middleware Queue
Rules Service (API)
Application Message Driven Bean
Callback Service (API)
HPC Adapter
Middleware Database
HPC Scheduler
Heartbeat Service
HPC API (REST)
High Performance Cluster
VirginiaTech
Biocomplexity Institute


Mapping from Data to Populations, Networks & "Fat Wires"
POPULATION INFORMATION
CENSUS POPULATION
GEOGRAPHICAL INFORMATION
CURATED DATA IN DATABASES
HIGH PERFORMANCE COMPUTING
Work locations
Home locations
Activity sequences
Individuals w/ attributes
School locations
Retail locations
Home
Shop
Work
Social contact network
LOCATIONS
PERSONS
SYNTHETIC POPULATION
SOCIAL CONTACT NETWORK
PEOPLE-LOCATION NETWORK
VirginiaTech
Biocomplexity Institute

So: Integrated App Ecologies and “Complex Edges”

- Applications interact via the synthetic libraries wrt the “unecapsulated entities”/ integration coordinate system
- The SI system coevolves with (multiple) use
- Application ecologies and complex contexts
- SI is the fabric woven of interaction, relevant involvement of the system in the world and the evolving computation/information environment

Thanks

4.10 *Trade networks and climate change: Local effects-Global impact*, Shade Shutters, ASU

GLOBAL
SECURITY
INITIATIVE

Trade networks and climate change: Local effects-Global impact

Sep 19, 2016

Dr. Shade T. Shutters
Research Scientist

Core Faculty
Center for Social Dynamics & Complexity

Senior Sustainability Scientist
Global Institute of Sustainability

Faculty Affiliate
Center for Policy Informatics

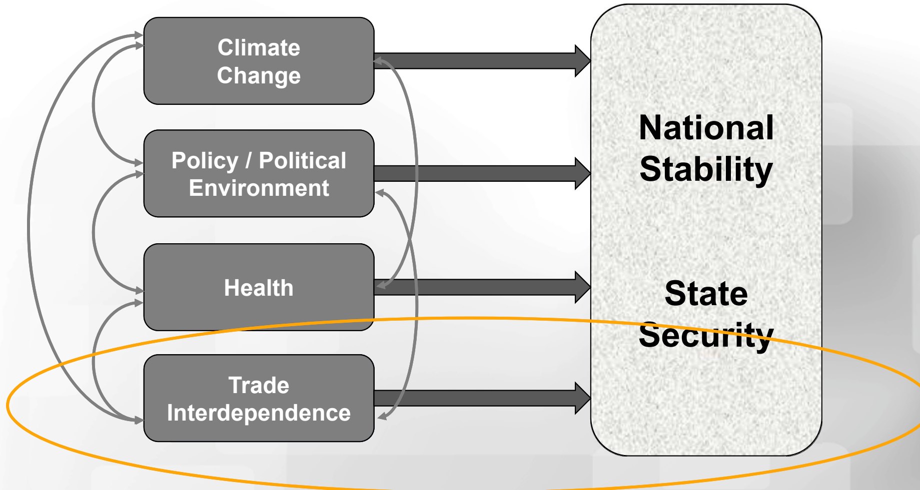
Adjunct Professor
School of Sustainability

Affiliated Faculty
Center on the Future of War

Arizona State University

Contact:
shade.shutters@asu.edu
www.public.asu.edu/~sshutte

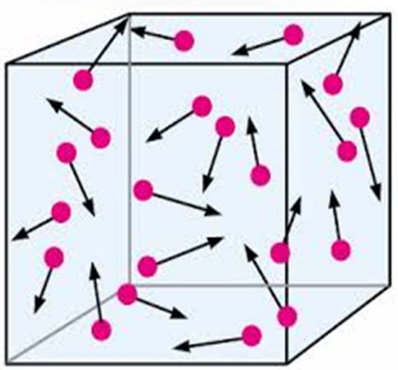
Drivers of Stability/Threats



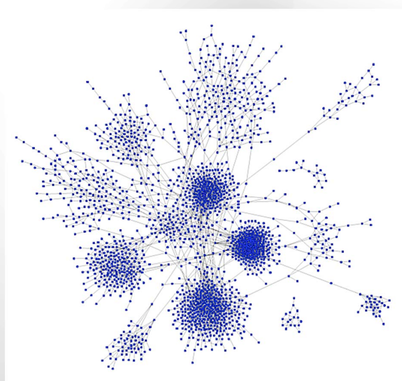
Trade has been studied in isolation
but its systemic role in integrated models is not well understood

A note on networks

Complicated System

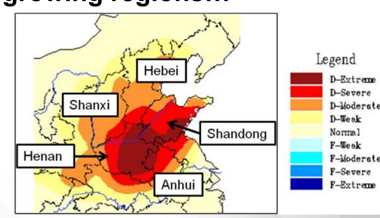


Complex Adaptive System



Systems with adaptive agents are typically structured by complex networks

In 2011, drought in China's wheat-growing regions…



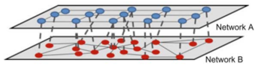
…contributed to revolution in Egypt and the fall of Mubarak…

…partly because of trade interdependencies.

Could we anticipate these situations in time to take action?

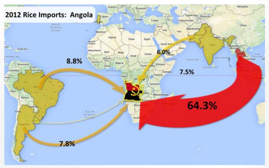
Research Agenda

Understanding and anticipating **cascading effects**



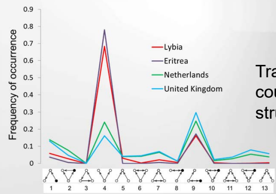
Bilateral trade links of food have doubled since the WTO's founding in 1995.

due to increasing trade **interdependence** and connectivity



In 124 countries at least half of rice imports come from a single country. In 37 countries, over 90% of rice imports come from a single source.

through novel application of **network** analytics to trade



Based on the global trade network for rice, 2010-2014

Trade networks of less stable countries have a significantly different structure than more stable countries.

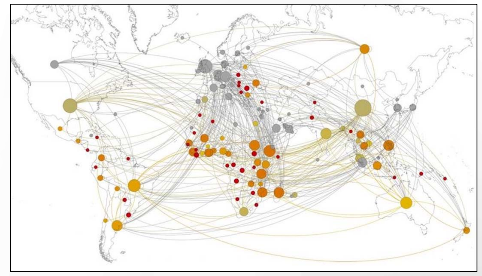
and visualization of potential food system **shocks**,

Our prototype interface can already highlight certain risks

potentially enabling proactive intervention

Analyzing Trade Structure

A two-pronged approach



Low risk/Quick insights

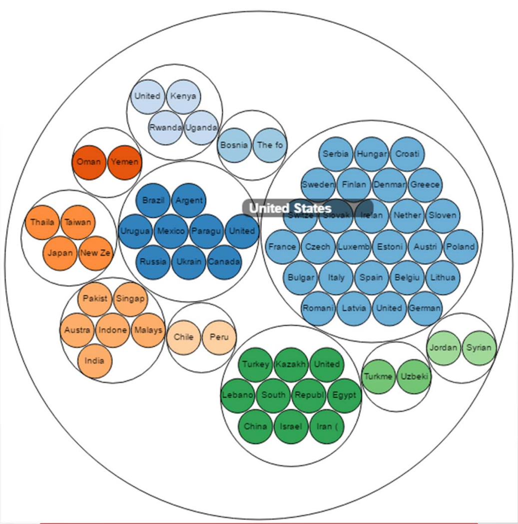
Quantify and visualize each country's dependency on others

Higher risk/Deeper insights

Quantify and analyze each country's local network structure

1. Triadic structure
2. Clustering coefficient

Visualizing Trade Similarity



Country Cluster for export pattern of wheat

- Countries can be clustered based on trade structure similarity
- Countries geographically close tend to have similar trade patterns

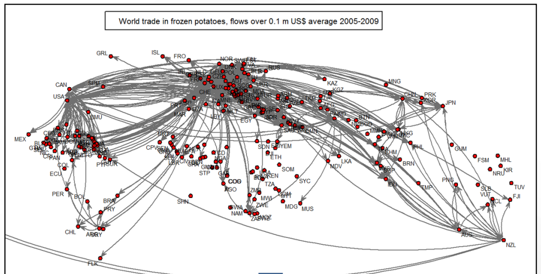
Network Topology Similarity

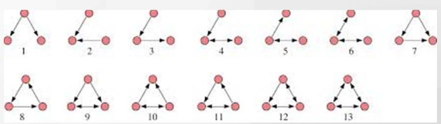
- Country: Egypt
- Food item: wheat
- Years: 2010-2014
- Structure: imports

Countries with most similar wheat trade network topology:

- Syria
- Libya
- Lebanon
- Jordan
- Chad
- Ghana

Triadic Analysis of Networks





Like DNA, networks can be decomposed into building blocks

Some of those building blocks are associated with conflict

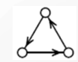
Structural balance theory predicts that nodes involved in too many “conflict” triads are less stable

Holland, PW and Leinhardt S. 1976. Local Structure in Social Networks. *Sociological Methodology* 7:1-45.

Facchetti G et al. 2011. Computing global structural balance in large-scale signed social networks. *Proceedings of the National Academy of Sciences* 108 (52):20953-20958.

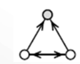
Preliminary Results

A cyclical triad



1. Iran
2. Ukraine
3. Israel
4. Guyana
5. Canada

A transitive triad



1. Italy
2. UK
3. USA
4. Germany
5. Spain

An unclosed triad

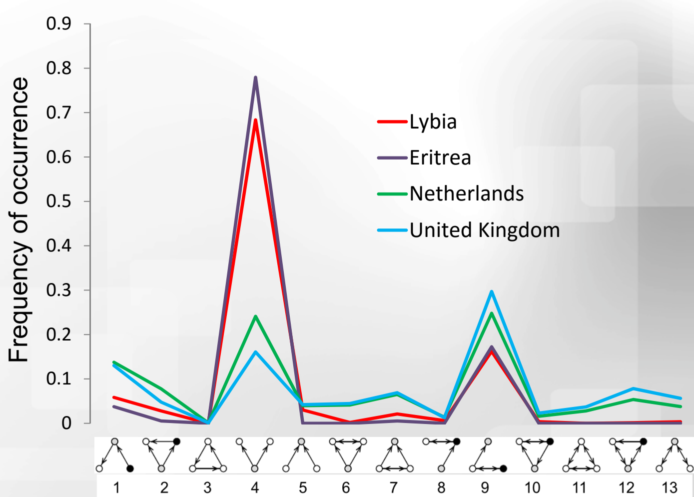
1. Bhutan
2. Lesotho
3. Laos
4. Macedonia
5. Myanmar

Relationship between triads and conflicts not as clear for trade networks as for human social networks

Thus we additionally analyze positions within triads, only the 2nd study, to our knowledge, to do so

Preliminary Results

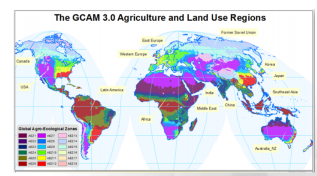
More stable countries have a different triadic signature than less stable countries



Based on the global trade network for rice, 2010-2014

Next Steps

- Tie to Climate Model

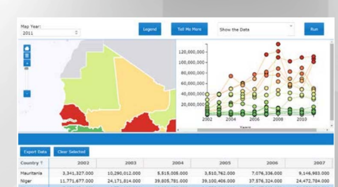


GCAM interface

- Inter-city trade
  - NSF INFEWs

- Integrate conflict data

The Correlates of War Project



World SpatioTemporal Analytics and Mapping Projects (WSTAMP) - Oak Ridge National Laboratory

Summary

- Local events can have global or far-off consequences
- When humans are involved, these effects are often transferred through networks
- Analyzing and modeling these networks can lead to anticipatory tools

4.11 *Individuals, Societies, and Climate: Modeling Motivations to Change*, Nina Fefferman, UT

Individuals, Societies, and Climate: Modeling motivations to change

Nina Fefferman, Ph.D.
University of Tennessee, Knoxville
Depts. of Mathematics &
Ecology and Evolutionary Biology
& NIMBioS

Individual Behaviors and Climate Change

Individuals are small, not powerless

- Individual choices
  - Green Behaviors
  - Voting in support of Green Policies
  - etc.
- Individuals form groups
  - Political parties
  - Grassroots organizations
  - Social Movements

Much of My Research is on Individual Behavior and the Social Construction of Risk, but Today I will Focus on Work with:

SESYNC/NIMBioS Working Group on
Integrating Human Risk Perception of Global Climate Change into Dynamic Earth System Models

Brian Beckage, Eric Carr, Nina Fefferman, Louis Gross, Travis Franck, Forrest Hoffman, Peter Howe, Ann Kinzig, Katherine Lacasse, Sara Metcalf, Adam Schlosser, Jonathan Winter, Asim Zia

Why and How can we expect Individuals to Change their **Minds** and **Behaviors** about Climate Change?

Two levels:

- Independent Individuals

  Individuals don't affect much alone, but lots of individuals acting in the same way make a difference

- Individuals as members of broader society

  Individuals purposefully act together to affect change

First Question: How much can incorporating individual behavior shift climate predictions?

Many models predict climate outcomes based on assumed average behaviors of populations.

Does anything shift meaningfully if we incorporate feedbacks between climate outcomes from behavior and human perceptions that change their behaviors?

First: How Do Humans Behave? Theory of Planned Behavior

Definitely not the only model of behavior, but widely accepted and a good starting place

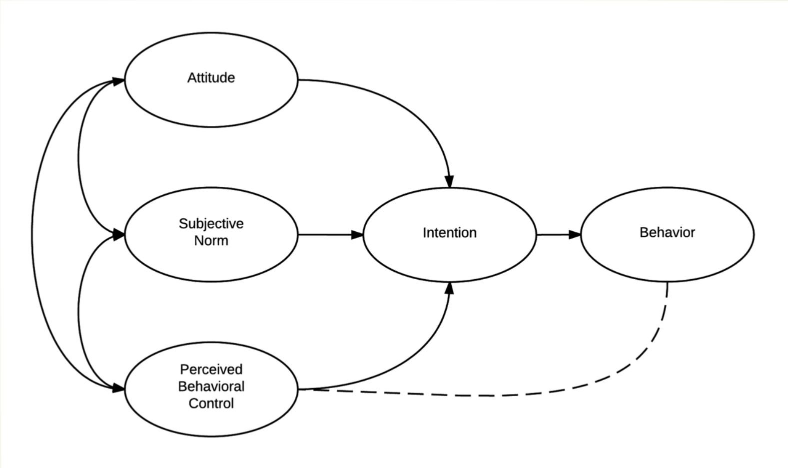
Actions are based on individual:

- *Attitude*
  - *Risk Perception* - How severe are the potential adverse effects?
  - *Perceived Efficacy* - How much can individual behavior influence outcomes?
- *Perceived Behavioral Control*

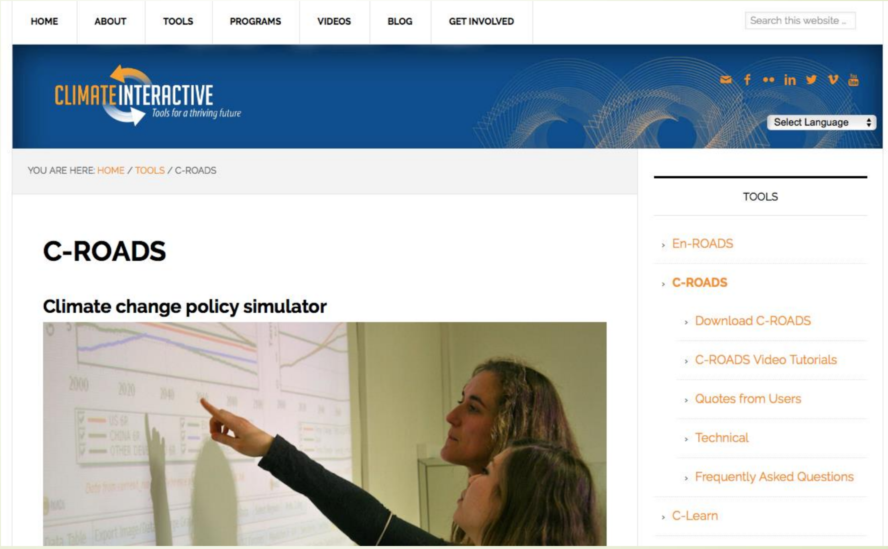
  How much control is there over whether or not to perform a behavior?
- *Perceived Social Norms*

  How much is the behavior performed or approved of by others in society?

Theory of Planned Behavior

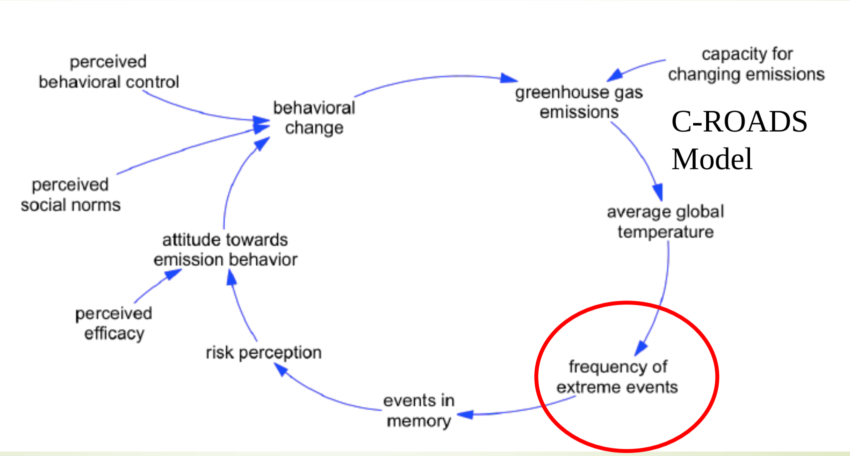


Next, we need Climate in response to behavior: C-ROADS: Climate Rapid Overview and Decision Support Simulator

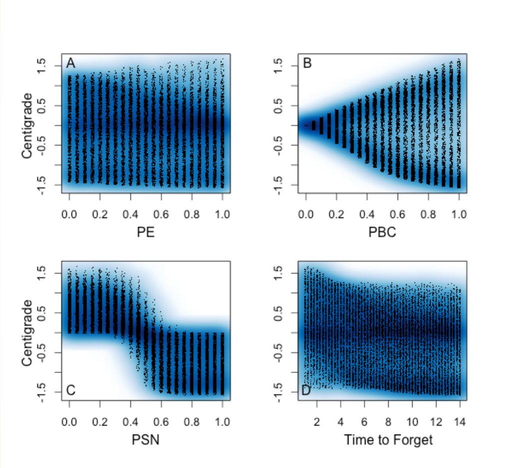


Again, not the only choice, just a reasonable place to start

From this, we build an integrated human-climate model: PACE (Perception, Attitude and Carbon Emissions)



Some model results
(more available – paper currently in revision)



Effect of parameter variation on difference in global mean temperature in 2100 with inclusion of human behavior compared to the baseline.

Other Model: How can PEOPLE recruit each other to Green Policies

Started under NSF EaSM, continued with NIMBioS/SESYNC group

No formal tie to climate, but focused on lobbying activities to change minds

- Lots of studies look at success of grass-roots strategies in social movements
- Few consider how to structure launching one

We ask:

- Can we construct a 'more effective' grassroots movement?
- How much information do we need to do so?

First question: Should we consider "global" network knowledge

Information that could be discovered by pretty easy polling data:

- Initial Ratio of Support for Cause (assumed Boolean)
- Initial Densities of Contacts Among Like-Minded Individuals vs Across Disagreeing Individuals

Next: How much "local" information do individuals need to persuade their friends?

Low Level: You always know your neighbor's beliefs

Medium Level: You always know your neighbor's beliefs, the strength of those beliefs, and what % of their friends agree with them

High Level: You know "medium level" information AND which of your neighbors others are also targeting.

This allows collaboration where individuals of the same belief can pool their collective efforts to collectively target a mutual neighbor.

Algorithms for Individual Agents Compared:

	Local Knowledge Level for each node	Which neighbors(s) are targeted; style	Persuasion Allocation per round	Round-Iteration Dependence
Model 0	None	All Neighbors	All Persuasion	One Round
Model 1	Low	Opposite Belief	All Persuasion	One Round
Model 2	Low	Opposite Belief	$\frac{Initial\ Persuasion}{\#\ of\ Rounds}$	Multiple Rounds
Model 3	Medium	Weakest Belief	Convert Target	Until Converges
Model 4a	Medium	Highest Disagreement Ratio; aggressive	Convert Target	Until Converges
Model 4b	Medium	Highest Disagreement ratio; defensive	Convert Target	Until Converges
Model 5a	High	Weakest neighbor; aggressive	Share Allocation	Until Converges
Model 5b	High	Weakest neighbor; defensive	Share Allocation	Until Converges

Results are REALLY complicated - Depends on what you want to know:

Potential Strategic Goals	Did Local Knowledge Help?	Did More Local Knowledge Help More?	Did Global Knowledge Help?
Maximize # individuals with target belief			
Maximize the average individual belief value			
Minimize the number of extremist individuals (of either belief			
Minimize segregation among individuals holding opposing beliefs			
Minimize isolation among minority belief holders			

Results are REALLY complicated - Depends on what you want to know: (further details available upon request)

Potential Strategic Goals	Did Local Knowledge Help?	Did More Local Knowledge Help More?	Did Global Knowledge Help?
Maximize # individuals with target belief	Somewhat	No	Yes
Maximize the average individual belief value			
Minimize the number of extremist individuals (of either belief	Yes	Yes	Somewhat
Minimize segregation among individuals holding opposing beliefs			
Minimize isolation among minority belief holders			

MORAL from both models so far:

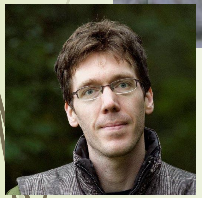
<u>What</u> individuals believe changes how they will behave which *CAN* influence climate outcomes.

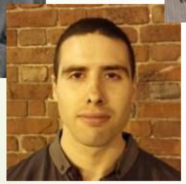
<u>Who</u> believes what will *CHANGE* how people react and how they try to persuade each other of social norms and movements.

<u>How</u> individuals try to persuade each other *AFFECTS* how successful a movement will be.

Widespread movements are how *INDIVIDUALS* affect global climate change.

Talented Researchers of the **Fefferman Lab**:





Post docs: Dr. Chris Stone, Dr. K. Myers, Dr. M. Quismondo, Dr. Nourridine Siewe

Grad Students: J. Beck, E. Chastain, N. Lemanski, A. Redere, S. Schwab