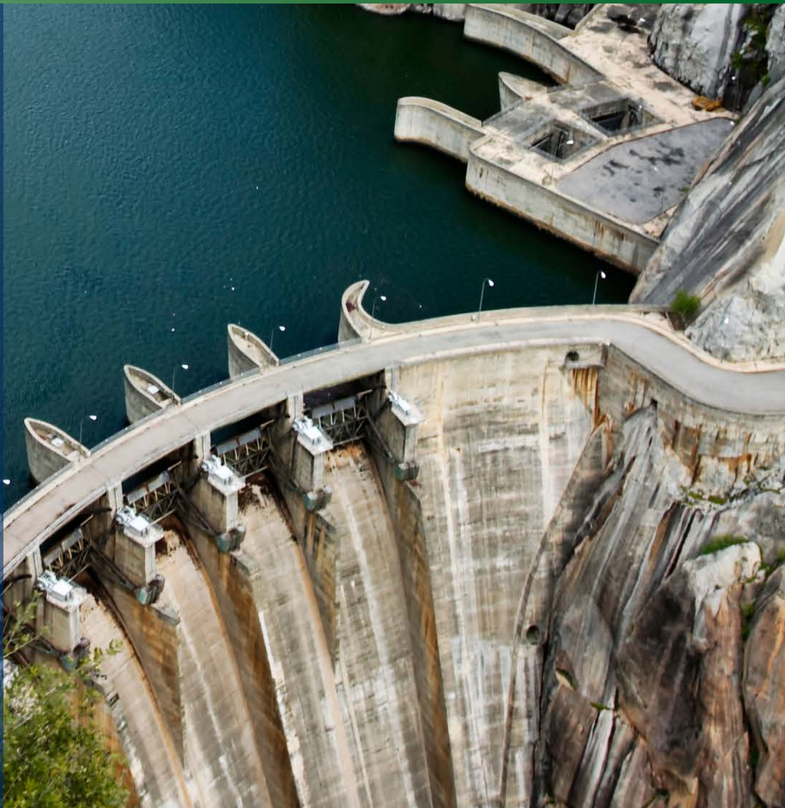
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

MIT JOINT PROGRAM ON THE SCIENCE AND POLICY of GLOBAL CHANGE

Global Changes

Fall 2014 In this Issue



MISSION AND OBJECTIVES

The Joint Program's integrated team of natural and social scientists studies the interactions between human and Earth systems to provide a sound foundation of scientific knowledge that will aid decision-makers in confronting the coupled challenges of future food, energy, water, climate and air pollution, among others. This mission is accomplished through:

- Quantitative analyses of global changes and their social and environmental implications, achieved by employing and constantly improving an Integrated Global System Modeling (IGSM) framework;
- Independent assessments of potential responses to global risks through mitigation and adaptation measures;
- Outreach efforts to analysis groups, policymaking communities, and the public; and
- Cultivating a new generation of researchers with the skills to tackle complex global challenges in the future.

IN THIS ISSUE:

Cover image: Aldeadávila Dam on the Duoro River, between Portugal and Spain.

Water Resources in a Changing World

Water has made headlines this year, whether it's too little water, in the case of the historic droughts parching California, or too much water, in the case of the devastating floods that hit Northern India in September. These examples represent extreme cases, but even subtle changes, like minor shifts in where or when precipitation falls, can have serious consequences, because with water timing and location are everything.

These considerations have led us to add a perspective on future water resources to our annual Energy and Climate Outlook. Climate change will alter global precipitation patterns by accelerating the hydrological cycle, leading to an increase in global precipitation, but not necessarily an increase everywhere. Our 2014 Outlook estimates that global freshwater supplies will increase by 15 percent by the end of this century, but, as the events of the last year prove, water is not always in the right place at the right time.

At first glance, an increase in precipitation might seem like it would bring relief to the many areas of the world that are under water stress, but regional hydrological change can upset the established balance of water resources in a region. Areas are adapted to a "normal" amount of precipitation, so any regional changes in precipitation are keenly felt. For example, if California received the amount of rain that usually falls in the Pacific Northwest, it would cause massive flooding and mudslides. If the American Southeast had rainfall like the desert Southwest, it would cause serious drought. So, what's normal for one place could be an extreme in another place.

In the 2014 Outlook, we map how socioeconomic growth will affect future water consumption in regions across the globe. Our estimates include changes stemming from population and economic growth, and increasing energy use and irrigation needs, among other factors. We find that total freshwater use will increase by 19 percent by the end of the century, meaning that humans will be withdrawing 6 percent of the total available water supply. It might seem like this will leave us with huge amounts of excess freshwater, but even with this apparently abundant resource we are already facing water stress. This is because water is not always where it's needed when it's needed. It's in rivers like the Amazon, a region that could never possibly use the amount of available water. Or it falls as rain during periods of heavy precipitation, so it runs off into the ocean where it can't be used.

Based on our projections, we see increases in potential water stress in several regions, including parts of India, China, Pakistan, Turkey, Northern Africa, South Africa, and the US. This is mostly the result of the pressures of population growth and economic growth, which are key drivers of change, especially in developing regions. Globally, most water is used for irrigation, but as populations become larger and wealthier, industry and household water use will expand, and begin to compete with irrigation at the same time that more water is needed to support the greater demand for food. As a result, developing countries face the unique challenge of trying to plan for growth, while simultaneously coping with changes in their water resources.

On average, climate change will make the world wetter, but its effect on precipitation will vary from region to region. In some regions, we project increased precipitation to alleviate pressures on water supply. India is projected to see an increase in water consumption, for example, and at the same time its freshwater resources will grow as the result of more precipitation. Conversely, in regions like China, we project a decrease in precipitation, magnifying pressures on water resources from socioeconomic growth.

These projections are far from certain, as one of the most difficult results of changing climate to project is where and when precipitation will occur. Of course the next step is to begin to ask: If faced with water stress (or excess water and flooding) what steps can be taken to minimize the adverse impacts? In general, there are several things we can do: We can build new and larger reservoirs, develop interbasin transfers, reduce water use, or move water-intensive activities to water-abundant areas. In more extreme situations we may look to reusing water, or to advanced desalinization of seawater. Some of these measures can be expensive, especially if we wait until there is a crisis to implement them. Understanding the risks presented by changes to our water needs and resources, and preparing for them now, will go a long way toward making sure that we are ready for the changes to come. A key element of that preparation is to put ourselves in a position to better predict those risks.

—John Reilly

Co-Director, Joint Program on the Science and Policy of Global Change

SAVE THE DATE: Upcoming Sponsors Webinar

Thursday, January 15, 2015, 10:30 A.M. EST
Theme: Oceans and Climate

2014 Energy and Climate Outlook

Photo: High altitude storage lake in Kaprun, Austria.

MIT Report: Without change in direction the future will be warmer, thirstier, still dependent on fossil fuels.

Global temperature is likely to rise 3.3-5.6°C by the end of this century, unless international climate negotiations in Paris next year are more effective than expected, according to a report released in September by the Joint Program on the Science and Policy of Global Change. The predicted temperature increase surpasses the threshold identified by the United Nations as necessary to avoid the most serious impacts of climate change, altering precipitation patterns and heightening the pressures of population and economic growth.

"Our world is rapidly changing," says John Reilly, co-director of the MIT Joint Program and a coauthor of the report. "We need to understand the nature of the risks we're facing so we can prepare for them."

Publication of the report, the *2014 Energy and Climate Outlook*, came on the heels of the UN Climate Summit in New York City, where more than 120 heads of state gathered in preparation for climate negotiations next year. The agreement that comes out of the 2015 talks will inform global climate action after 2020, when existing measures agreed to in Copenhagen and Cancun expire.

The *2014 Energy and Climate Outlook* extends the existing measures after they end to evaluate global changes under possible post-2020 climate action. It uses UN population data and projects economic growth to explore the connections between socioeconomic factors and changing climate, land use, and water.

"Population and economic growth are key drivers of change," Reilly says. "Developing countries like China and India are growing fast, and will play a big role in future emissions. They're also facing the unique challenge of trying to plan for this growth under a changing climate."

The MIT team expects world energy use to double by 2050, largely due to increased energy use in developing countries, where booming industry and larger, wealthier populations will have more access to personal vehicles. Globally, clean energy sources will make some headway, but energy use will continue to be largely dominated by fossil fuels. As a result, global emissions are expected to double by the end of the century. To stay below the warming threshold, global emissions need to peak soon, if not immediately, the report concludes.

The Outlook also examines a more ambitious climate agreement, based on expectations of what countries might pledge in the 2015 climate talks. The more ambitious pledges will further reduce greenhouse gas emissions, it finds, but even with the more ambitious pledges, the world will release enough greenhouse gases into the atmosphere by 2040 to make it unlikely that warming will stop at 2°C.

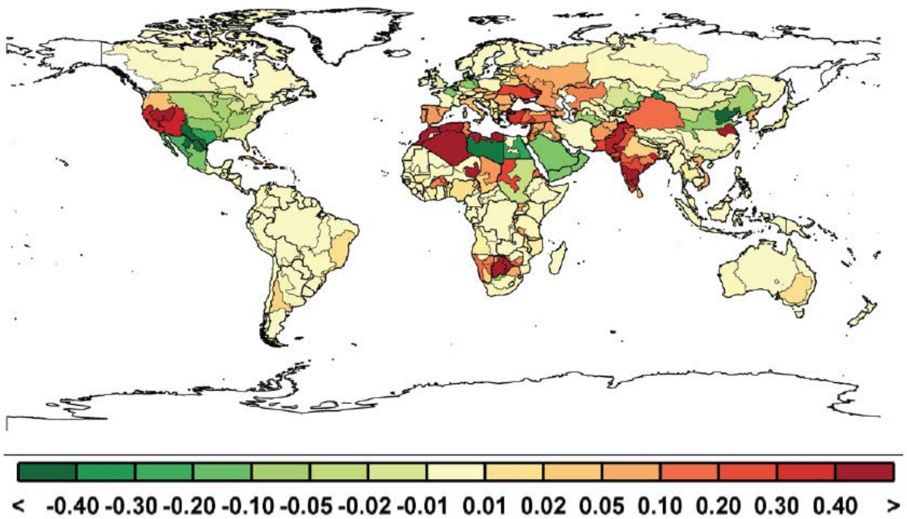


Figure: Change in water stress from 2010 to 2100.

"There is some uncertainty associated with these estimates," says Erwan Monier, a research scientist at the Joint Program and a coauthor of the report. "The fact is that there is uncertainty about future emissions, and also in the climate's response to those emissions. Yet, it is clear that we are not meeting the 2°C target based on current efforts alone."

New this year is a focus on how these changes impact water resources, which will have to support a growing population's need for food and energy. The Outlook evaluates water stress, or the amount of water used in an area for irrigation, industry, and household use, compared to how much freshwater is available in that area.

By the end of the century, freshwater supplies will increase 15 percent as hotter temperatures speed up the hydrological cycle, leading to more rain and snow. Global water use will keep pace, and is expected to increase 19 percent.

Water use is expected to skyrocket in India, China, parts of the Middle East, and North Africa, even though some of these countries, like India, will see more rain and snow. Hotter temperatures will lead to more precipitation, but it may fall at the wrong time of the year, after the growing season is over, or may run off into the ocean.

Globally, most water is used for irrigation. As industrial and household water use grow, they can edge out irrigation, just as more water is needed for irrigation to feed more people.

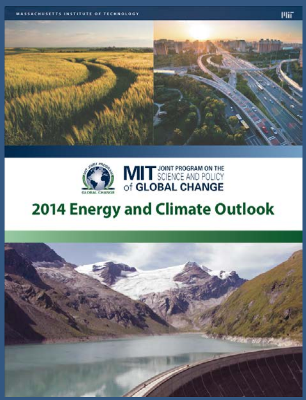
"These pressures on water will mean increased focus on making sure there is enough water where and when it is needed." says Charles Fant, a postdoctoral associate at the Joint Program and a coauthor of the report. "This can be done by transporting water to where it is needed, building more storage, or conservation and efficiency efforts."

Solutions like these are often difficult to put in place, Fant cautions, as they are expensive and may be damaging to the environment.

"Preparing for these issues now simplifies things quite a lot for the future," Fant says. ■

To read the *2014 Climate and Energy Outlook* visit:
http://globalchange.mit.edu/Outlook2014

To download figures from the Outlook visit:
http://globalchange.mit.edu/sponsors-only/programs



Pinpointing Climate Change

By Audrey Resutek and Erwan Monier

Reprinted from *World Meteorological Organization Bulletin*

MIT researchers explain how they account for different sources of uncertainty in climate modeling, and what they're doing to reduce it.

Photo: Researchers examine melt ponds in sea ice over the Arctic Ocean as part of NASA's ICESCAPE Mission; courtesy of NASA.

The US National Climate Assessment, released this spring by the White House, describes a troubling array of climate woes, from intense droughts and heat waves to more extreme precipitation and floods, all caused by climate change. The report also describes how climate change is expected to impact regions across the United States in the future, yet it notes that exact regional forecasts are difficult to pin down. At the larger scale, it is clear that climate is changing, but local predictions can disagree on the extent to which temperatures will increase, and what regions will be hit the hardest by precipitation changes.

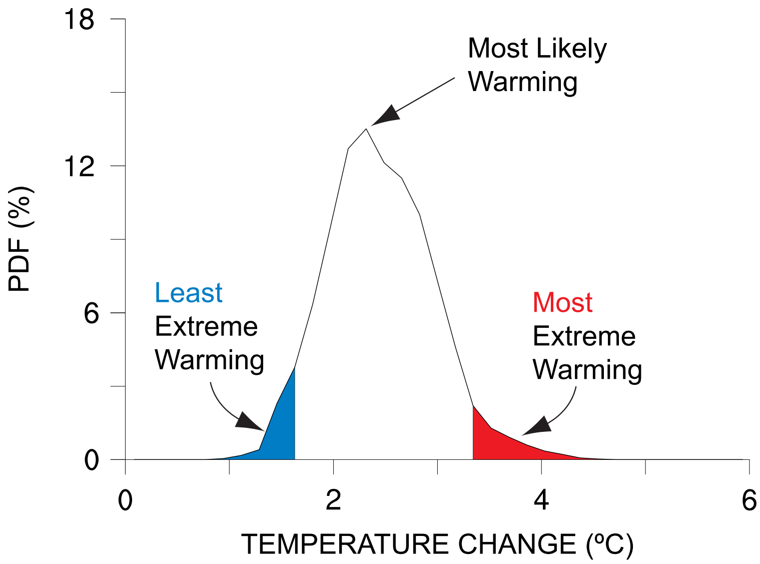


Figure: Example of a range of potential change in temperature.

Researchers at the Joint Program on the Science and Policy of Global Change examined four major factors that contribute to wide-ranging estimates of future regional climate change in the United States, with an eye toward understanding which factors introduced the most uncertainty into simulations of future climate. They find that the biggest source of uncertainty in climate modeling is also the only one that humans have control over—policies that limit greenhouse gas emissions.

In this context, the term "uncertainty" does not mean that there is a lack of scientific consensus that climate is changing. Instead, uncertainty refers to the fact that using different assumptions for the variables that go into a climate model—for example, the amount of greenhouse gases emitted over the next century, or how sensitive the climate is to changes in carbon dioxide levels—will produce a range of estimates. Overall, these estimates indicate that the Earth will be a warmer and wetter place over the coming century, but there is no single universally agreed on amount of climate change that will take place.

In fact, estimates that point to a single number for changes in temperatures and precipitation may be misleading, precisely because they do not capture this uncertainty. It is

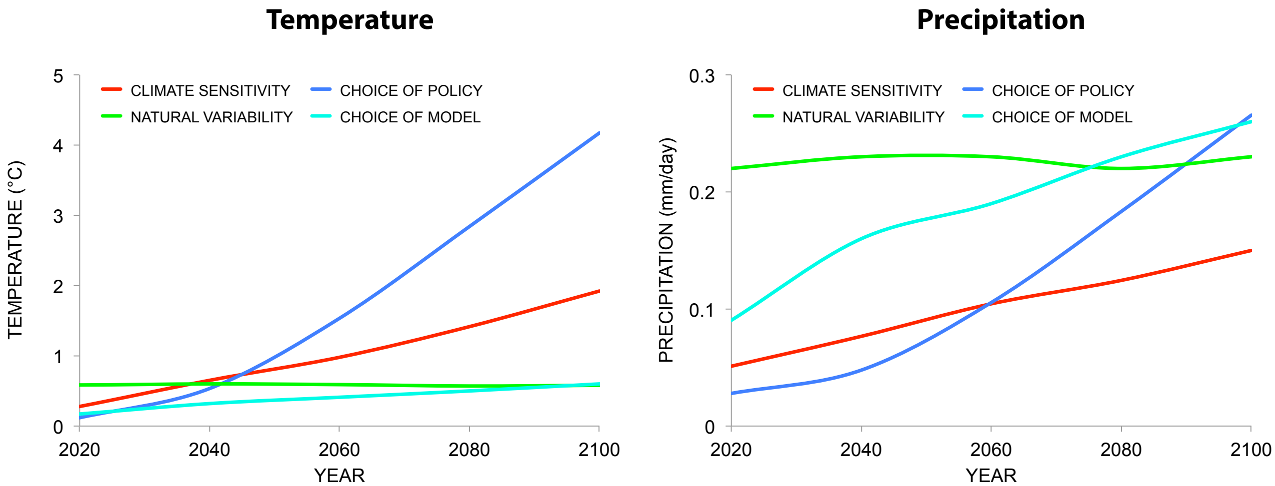


Figure: Mean range of temperature and precipitation change over time for each source of uncertainty. Lines represent how large the range in estimates of change is for each source of uncertainty. Lines show averages of two different modelling methods used to create regional forecasts.

more useful to think of estimates of future climate change as a range of possible effects. The range of potential warming, for example, follows a bell curve, with the most likely change in temperature falling at the highest point of the curve. The farther you travel from the curve's peak, toward the tails, the more unlikely the temperature change. While the extreme temperature increases at the curve's tails are unlikely, they still fall within the realm of possibility, and are worth considering because they represent worst-case scenarios.

The biggest source of uncertainty

The MIT study, published this spring in a special edition of *Climatic Change*, looked at how different sources of uncertainty affect estimates of future regional climate change in the United States—in other words, how do different factors affect the width of the range of estimates? The study concludes that lack of information about future climate policy is the biggest source of uncertainty over the next century for simulations of both temperature and precipitation change. Climate policy introduces uncertainty into the mix when researchers must try to predict what regulations will affect emissions in the future, leading to varying levels of global greenhouse gas emissions.

Not knowing the details of a future emissions policy, including the timing or magnitude of reductions, makes it difficult to estimate climate change—especially in certain regions. For example, the MIT team found that temperature increases in the Pacific Northwest and New England could range from 1°C to 6°C, depending on the policy studied. When climate policy to control greenhouse gas emissions was in place, no region experienced more than 3.5°C warming.

The MIT team used an Integrated Assessment Model, the MIT IGSM, to study the effects of different climate policies. The computer model links a simulation of the global economy with a simulation of Earth's climate. This makes it possible to study how climate policies affect activities that contribute to greenhouse gas emissions, such as electricity generation, transportation, industry and changing land use. The model then calculates the effect of the resulting changes in emissions on climate.

Such models are particularly useful for studying the effects of climate policy because they use one modeling framework to consistently take into account interactions between the climate and economic factors like population growth, economic development and changes in energy and land use. They can also be used to study the opposite relationship—how changes in climate impact economic activity, including what regions and areas of the economy are most likely to be affected.

The specific polices used in this study were selected based on the researchers' participation in the Climate Change Impacts and Risk Analysis (CIRA) Project, an effort led by the US Environmental Protection Agency (EPA) to understand the benefits of emissions mitigation. The EPA wanted to know how reducing greenhouse gas emissions would affect climate change impacts and damages in different regions of the country. Would stabilizing emissions produce the largest benefits compared to policy costs? Would a more drastic cut in carbon emissions lead to even bigger benefits, or just increase the costs associated with cutting emissions?

To study the scenarios identified by the EPA, researchers built three emissions scenarios, achieved through different climate policies, into the IGSM. In the first, nothing is done to slow global greenhouse gas emissions. In the second, global emissions are stabilized by enforcing a carbon tax. In the third, even more stringent checks on emissions are in place. The policies used are described in detail in a second article published in *Climatic Change*. The policies were then combined with the other sources of uncertainty to produce over 100 simulations of climate change through 2115.

Other sources of uncertainty

Though the choice of climate policy is the biggest source of uncertainty in simulations of climate change by the end of the century, it actually plays a much smaller role in influencing estimates for the immediate future. This is because once they are released into the atmosphere, greenhouse gases stay there for decades or even hundreds of years. So, past emissions continue to influence climate for decades after a climate policy is in place. Because of this lag time other sources of uncertainty, like the climate's response to changes in greenhouse gases levels (also called climate sensitivity), or the natural variability of the Earth's climate, introduce more uncertainty into near-term simulations.

Natural variability plays a big role in differing regional simulations of future climate change, at least through 2050. Basically, the Earth's climate is a complex system made up of many related processes—some of which, like circulation of currents in the deep ocean, take thousands of years to run from start to finish. On top of this, climate naturally varies from year-to-year, so it is normal for some years to be exceptionally hot or cold.

Climate processes and natural year-to-year variability are chaotic by nature and difficult to predict, complicating the process of climate modelling. Small errors in the initial conditions used in a simulation, such as temperatures, humidity or wind, can result in different paths for the entire climate system. This is reminiscent of the fabled butterfly effect analogy—where a butterfly flapping its wings in

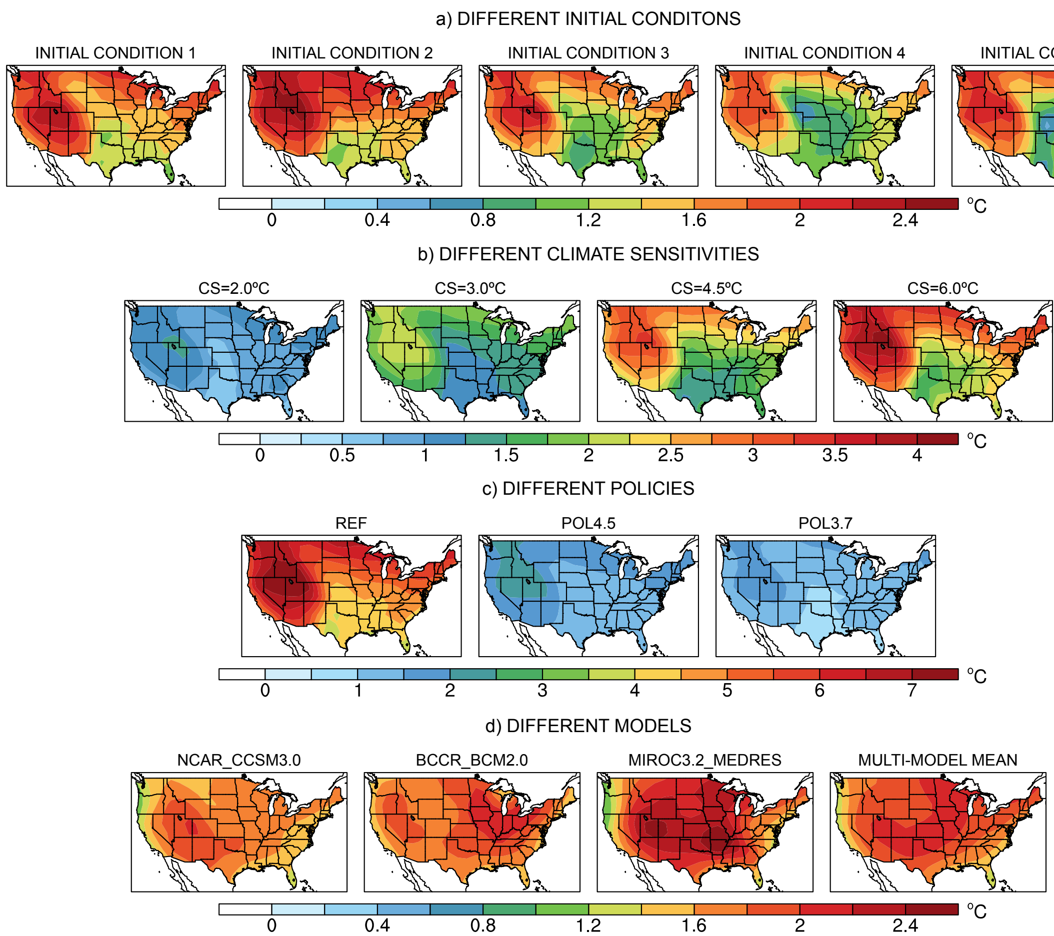


Figure: Simulated change in temperature over the next century under different sources of uncertainty: (a) Different initial conditions representing natural variability, (b) Different climate sensitivities, (c) Choice of policy, and (d) Different climate models.

one part of the globe leads to a hurricane weeks later, thousands of miles away. To work around this problem, climate scientists run the same model with different starting conditions, which helps to identify the natural variability in the climate system and quantify its uncertainty.

Using different starting conditions leads to surprisingly different regional simulations, especially when it comes to regional patterns of precipitation, the MIT study found. It can even cause conflicting projections about whether a region will become wetter, or drier. For example, in the Pacific Northwest two of the five starting conditions the researchers studied resulted in simulations of a much drier climate by 2100; two in somewhat drier climate for the area; and one actually led to an increase in precipitation.

Uncertainty about changes in regional precipitation is also the result of the tendency different climate models have toward either wet or dry projections. For example, precipitation simulations for the Southeastern United States are noticeably different depending on the climate model the researchers tested. By the end of the century, all four sources of uncertainty contribute about equally to the overall uncertainty in future changes in precipitation.

Increases in extreme weather

As part of the EPA's CIRA Project, the MIT team used the same method to study how different sources of uncertainty affect projections of changes in extreme weather. Climate change is often measured as the change in average temperature and precipitation levels. While this is a meaningful way to think about climate trends, using an average can hide changes in extreme weather like heat waves, cold snaps, and heavy snow and rain. These changes in extremes, perhaps even more so than changes in average climate, can have serious consequences for health, energy demand and agriculture.

The estimates of regional climate change in the United States varied according to the specifics of each scenario, but a clear pattern emerged: we can expect more intense and frequent hot days and heavy precipitation. Just how hot and wet depends more on what climate policy is in place than any other source of uncertainty. Accompanying the findings on extreme heat, researchers found that extremely cold days will decrease. As a result, it's likely that more areas of the country will remain frost-free year-round.

While these patterns did differ from region to region based on the representation of natural variability and climate sensitivity, policy again emerged as the driver of the largest differences in estimates of regional climate change. These findings show that none of the sources of uncertainty related to specific aspects of climate modeling has a bigger effect on simulations than the actual amount of emissions humans generate over the next century. This underscores how important it is, if we want to avoid the worst effects of climate change, to implement a global policy aimed at stabilizing greenhouse gas concentrations in the atmosphere. ■

Related Publications:

Paltsev, S., E. Monier, J. Scott, A. Sokolov, and J.M. Reilly, 2014: Integrated and Climate Projections for Impact Assessment. *Climatic Change*, online first, doi: 10.1007/s10584-013-0892-3 (Reprint 2013-38).

Monier, E., X. Gao, J.R. Scott, A.P. Sokolov and C.A. Schlosser, 2014: A framework for modeling uncertainty in regional climate change. *Climatic Change*, online first, doi: 10.1007/s10584-014-1112-5 (Reprint 2014-10).

Monier, E. and X. Gao, 2014: Climate change impacts on extreme events in the United States: an uncertainty analysis. *Climatic Change,* online first, doi: 10.1007/s10584-013-1048-1 (Reprint 2014-3).

AGAGE Launches New Website

The Advanced Global Atmospheric Gases Experiment (AGAGE) launched a new website this fall. The updated site features expanded information about network sites, news stories about AGAGE, publication highlights, and a publications archive.

Visit the new AGAGE Website:

http://agage.mit.edu

Photo: Cape Grim AGAGE station in Tasmania, Australia.

Solving the Polar Climate Conundrum

MIT researchers find ocean circulation explains why the Arctic is warming more quickly than the Antarctic.

Photo: Kulusuk, Greenland. Courtesy of NASA Earth Observatory.

New Research from Collaborators at MIT

By Genevieve Wanucha

Over recent decades, scientists have watched a climate conundrum develop at the opposite ends of Earth: The Arctic has warmed and steadily lost sea ice, whereas Antarctica has cooled in many places and may even be gaining sea ice. Now, MIT researchers have a better understanding of the elemental processes behind this asymmetric response of the polar regions to the effects of human-induced changes to the climate.

In a paper published in *Philosophical Transactions of the Royal Society A*, John Marshall, the Cecil and Ida Green Professor of Oceanography at MIT, and his group investigated this phenomenon by considering ocean dynamics. The ocean, because of its ability to absorb and transport enormous amounts of heat, plays a critical role in climate change. The authors argue that ocean circulation can explain why the Arctic has warmed faster than the Antarctic.

In MIT computer simulations of the ocean and climate, excess heat from greenhouse gas emissions is absorbed into the Southern Ocean around Antarctica and in the North Atlantic Ocean, but it doesn't linger. Instead, the moving ocean redistributes the heat. In the Southern Ocean, strong, northward-flowing currents pull the heat towards the Equator, away from Antarctica. In the North Atlantic Ocean, a separate northward-flowing current system shunts the heat into the Arctic. So while Antarctica warms only mildly, the Arctic Ocean's temperature increases quickly, accelerating sea-ice loss and warming the Arctic atmosphere.

The model results reveal the differing responses to greenhouse gases in each region, with the Arctic warming more than twice as rapidly as the Antarctic. They also add confidence to the existing predictions of enormous future changes up north. By midcentury, the Arctic may warm so much that the oceans could go sea-ice free in the summers.

Marshall's group also showed that the ocean's response to the ozone hole can help explain the lack of warming to date around Antarctica. The millions of square feet of deterioration in the ozone over Antarctica was caused by emissions of the man-made pollutants chlorine and bromine, and chlorofluorocarbons, which peaked at the turn of the century and are now slowly dwindling.

When they introduced an ozone hole into their model, the winds over the Southern Ocean grew faster and shifted southward, consistent with the observed wind changes around Antarctica. They found that this intensification of winds initially cools the sea surface and expands sea ice, but then a slow process of warming and sea ice shrinkage takes over. This warming happens, they suggest, because the stronger winds eventually dredge up to the surface relatively warm waters from the deep ocean. "Around Antarctica, the ozone hole may have delayed warming due to greenhouse gases by several decades," Marshall says. "I'm tempted to speculate that this is the period through which we are now passing. However, by 2050, ozone hole-effects may instead add to the warming around Antarctica, an effect that will diminish as the ozone hole heals."

The framework offers a new ocean-centric picture of the effect of greenhouse gases and the ozone hole on polar climates. The slight cooling measured around Antarctica today might be a consequence of the temporary cooling influence of the ozone hole. But as the century proceeds, both of the human-induced effects on the climate may combine to warm the waters around Antarctica. This MIT model joins several other recent demonstrations of the concerning, but uncertain, future effects of climate change on Antarctic sea ice and glaciers and, in turn, ecosystems and sea-level rise. ■

3 Questions: The Ocean's Changing Temperature

New Research from Collaborators at MIT

By Genevieve Wanucha

Carl Wunsch, professor emeritus of physical oceanography at MIT, has spent his career investigating the ocean's role in climate, from both observational and theoretical angles. Oceans at MIT asked Wunsch about the observational evidence that the ocean has warmed in recent years and how difficult it is to quantify.

Q. Is there evidence that the ocean has been warming?

A. Overall, the ocean does appear to have warmed over the last 20 years when, relatively speaking, there are enough data to do a reasonably accurate calculation. These recent observations come from Argo floats, altimetric satellite measurements, measurements made using elephant seals tagged with instruments that monitor ocean conditions, the World Ocean Circulation Experiment (WOCE) era and follow-up repeated high resolution shipboard data, and better meteorological estimates. Before 20 years ago, so few data exist that calculations remain highly uncertain.

It's plausible that modern ocean temperature changes are proceeding faster than earlier in the Holocene Epoch (a relatively warm period in Earth's history that began about 11,750 years ago at the close of the last major ice age), but that signal would be lost from the record if it had been present. Paleoceanographic data, which come from "proxies" such as planktonic shell measurements of oxygen isotope ratios, are very interesting sources of information about ocean temperatures thousands of years ago, but (A), they are so sparse that no one can compute an accurate global average, and (B), interpretation of these data means that the conversion to temperature makes the numerical values very uncertain. Furthermore, the time-spacing of those data that do exist make it almost impossible to detect rapid time changes in temperature. It's a different problem altogether from the modern one.

Q. You recently published a paper in the *Journal of Physical Oceanography* modeling temperature changes in the deep ocean. You found that parts of the ocean actually cooled. What mechanism could be responsible for the cooling?

A. We estimated the change in heat content of the ocean over a 20-year period using all of the many different kinds of data that are available in the interval from 1992–2011. Overall, we estimated that the ocean warmed over the past 20 years. The year-to-year variations in any given region are very large, sometimes warming, sometimes cooling, making it hard to compute an accurate average top-to-bottom. Over the 20 years, parts of the ocean appear to have cooled somewhat—despite the fact that on average we found a net warming. No contradiction exists because the ocean can take a long time to respond to heating and cooling, and parts of it are likely just beginning to change owing to atmospheric conditions from hundreds of years ago.

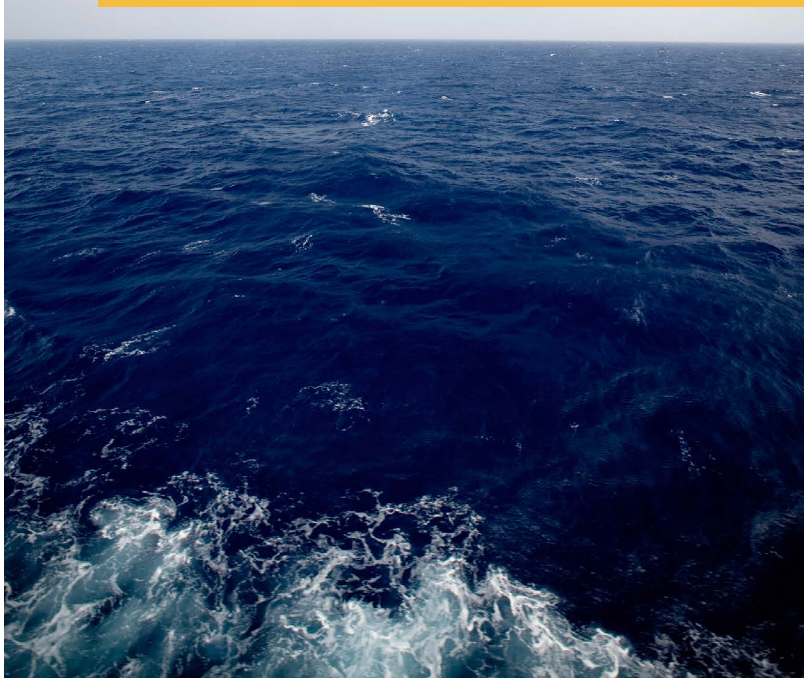


Photo: Atlantic Ocean.

An analogue is the way a large house responds to outside air temperatures: if the outside temperatures go up, some parts of the house will tend to heat up quickly, particularly if the sun shines directly through the windows. Other rooms may take hours or days to start to warm. If there is a deep basement, that might stay cool for weeks despite the rest of the house having warmed up, even when the attic is stifling. When the outside temperatures drop, parts of the house may still be warming up even as the more responsive rooms have started to cool down again. The ocean has many "rooms," many far removed from where the sun is directly shining.

Q. Do you believe that the observed warming is due to anthropogenic forcing from greenhouse gases?

A. That seems very likely—based upon some simple physical principles. If you add greenhouse gases to the atmosphere, it will warm up, and there is then a very powerful tendency for the ocean to warm as well, more slowly. Think of the house analogy again: if I turn on a heater in one room it's difficult to see why the adjoining rooms would not slowly warm up, and then the rooms next to them, etc. If the heated room were perfectly insulated, that wouldn't happen, but there's no such thing as perfect insulation, and the ocean has no analogue of that anyway. ■

Updated Economic Model Unveiled at Annual EPPA Workshop

Photo: 2014 EPPA Workshop attendees.

Joint Program researchers presented an updated version of the EPPA (Economic Projection and Policy Analysis) Model at the annual EPPA Workshop in Newry, Maine, on October 2–4. The updated model, known as EPPA6, uses the latest economic statistics to simulate the economic impacts of climate and energy policies.

Those who attended the workshop, including new graduate students, research staff, and sponsor representatives, received a crash course on new features in the model, which has been in development for the last two years.

New features

EPPA6 uses the latest global economy-wide database, and has an improved structure for modeling the consumption of food and agricultural products. Consumption of these products is closely related to agricultural production, so accurate modeling is crucial for capturing any implications for land-use change and greenhouse gas emissions.

The model also has improved representation of advanced power sector technologies, also known as backstop technologies. These are technologies that may not be commercially available yet, but could substitute for fossil energy when they become economically feasible. Including a realistic characterization of how these new technologies will be adopted by the energy industry allows EPPA to simulate how policy will speed or slow the uptake of new technology.

Other updates in EPPA6 include two new regions, South Korea and Indonesia, and a new economic sector, dwelling. The new sector makes it possible to study the effects of policy on household energy use associated with heating and cooling.

EPPA6 can be run as a standalone model, or it can be coupled with the MIT Earth System Model (MESM) to form the MIT Integrated Global System Modeling (IGSM) Framework for climate policy analyses. The updated model is currently being applied in several ongoing research projects. These include: evaluation of the effects of economic growth on energy use, greenhouse gases emissions, and food consumption; an update of the Joint Program's work on climate change uncertainty; simulation of the climate effects of greenhouse gas policies, specifically pricing policies related to the 2°C target identified by the IPCC; and work on how climate change and economic growth will impact land use.

Brushing up on the basics

The more than 40 workshop participants also brushed up on the basics of CGE (Computable General Equilibrium) modeling in a series of courses led by Joint Program research staff over the day-and-a-half conference.

Joint Program Codirector John Reilly kicked off the workshop with a broad introduction to the EPPA/IGSM, the linked set of models that are at the core of the Joint Program's research.

Niven Winchester, an environmental energy economist with the Joint Program, led the group through the process of constructing a simple CGE model from scratch.

Justin Caron, a postdoctoral associate with the Joint Program, presented on transitioning from a static to a dynamic CGE model, and described the process of adding advanced technologies to EPPA.

Y.-H. Henry Chen, a research scientist at the Joint Program, closed out the workshop by teaching the group how to run a simple simulation in EPPA.

The Joint Program holds the workshop every fall to teach new students how to use EPPA, the primary economic model used by the program. The retreat is also open to members of sponsoring organizations who would like to learn more about the details of the Joint Program's economic research. For information on how to attend, contact Frances Goldstein (fkg@mit.edu). ■

WATCH COURSES FROM THE EPPA WORKSHOP

Sponsors can watch video of courses and view the accompanying powerpoint presentations on the sponsors-only website: http://globalchange.mit.edu/sponsors-only/eppa2014

3 Questions: The Importance of Trade in Understanding CO_2 Consumption

Producing and transporting products for consumers creates CO_2 emissions at many points, from the emissions associated with manufacturing a product, to the emissions from generating the power used in manufacturing, to emissions from transporting the product to where it is consumed. By keeping track of all of these emissions, economists can compute the total "embodied" CO_2 associated with the final product and attribute it to the good's consumers. Postdoctoral Associate Justin Caron explains the Joint Program's latest work in this area.

Q. How does trade factor into estimating a region's CO_2 emissions?

A. The US is an open economy—it imports a substantial amount of the goods and energy it consumes from abroad. At the same time, there is a lot of trade between the states. So, a good portion of the goods and energy that households in a particular state consume might be imported from elsewhere. This makes it complicated to estimate the total amount of CO_2 emissions that a state is responsible for. When you include CO_2 embodied in the goods and energy consumed in the state, you get a different picture than if you were considering only emissions physically released in that state. So, it's important to carefully track trade when you're estimating emissions for a region.

Q. What did you find?

A. The difference in emissions estimates when you consider the CO_2 embodied in consumption are much larger than previously believed. In California, for example, emissions are over 25 percent higher. This also has implications for carbon policy. Regulation or pricing of CO_2 would increase the price of all goods by a small, almost imperceptible amount, but those changes can add up to a large share of the burden of a carbon tax. We find that this burden varies considerably across regions.

Q. What does this mean for climate policy?

A. Policymakers could craft legislation that takes the potentially unequal effects of a carbon tax into account. One option is to put redistribution mechanisms into place to more evenly distribute the impacts of the policy. Understanding the regional differences also helps explain varying regional levels of support for climate policy. As an example you can think about where in the process the CO_2 associated with making a car could be taxed. Some states might be better off if consumers paid a carbon tax when they purchase the car. On the other hand, some states might be better if the policy made the manufacturers of the car pay the tax. What's more, the amount of CO_2 associated with producing a dollar's worth of car in one state differs from the amount of CO_2 associated with producing the same dollar of car in another state. This depends on a number of factors, including how the electricity used to make the car was generated. So, it will take careful balancing to evenly distribute the effects of policy. ■

Related Publication:

Caron, J., G. Metcalf and J.M. Reilly, 2014: The CO_2 Content of Consumption Across US Regions: A Multi-Regional Input-Output (MRIO) Approach. *Joint Program Report 266.*

4th Annual John Carlson Lecture

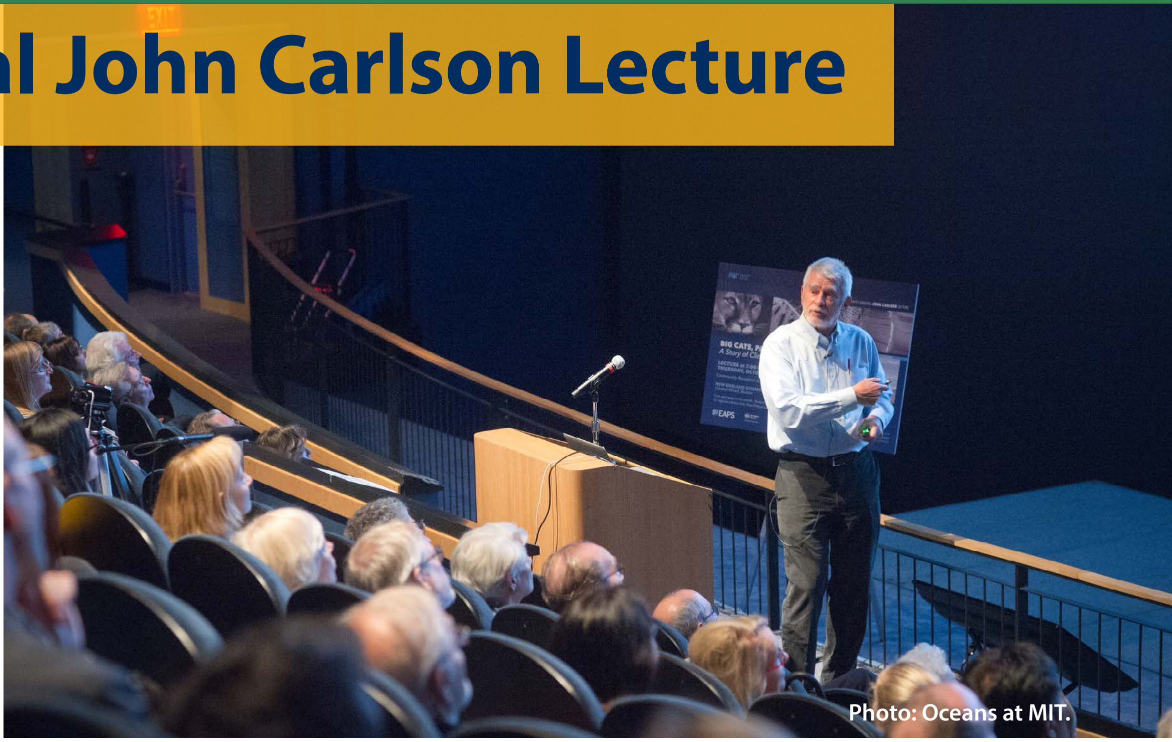


Photo: Oceans at MIT.

By Genevieve Wanucha

Approximately 3 million years ago, an enormous ice sheet pushed southward from the Arctic, covered what is now Canada and stretched down to modern-day Missouri, becoming the first ice age to occur in hundreds of millions of years. Ever since, Earth's climate has passed in and out of ice ages roughly every 40,000 years with the last ice sheet retreating about 20,000 years ago.

What triggered this enormous shift in climate? A commonly accepted explanation relies on the assumption that the Isthmus of Panamá closed at that time, creating a land bridge between North and South America that blocked the essential ocean currents keeping the ice ages at bay. At the MIT Lorenz Center's 4th John Carlson Lecture, prominent geophysicist Peter Molnar dismantled this long accepted explanation for why Earth's ice ages began when they did.

Molnar pulled up Wikipedia's entry for the Isthmus of Panamá, which presents a dramatic sequence of geological events: As continental plates collided 3 million years ago, a thin rib of land emerged, closing the gap between the North and South American continents. This major event separated the Atlantic and Pacific Oceans, and as a consequence, transformed ocean circulation in a way that allowed ice sheets to grow on the North American continent, giving us recurring ice ages.

Around that same time in Earth's history, fauna began to migrate across the continents in an event called the Great American Biotic Interchange. The emergence of the Isthmus of Panamá, as accepted scientific theory goes, created a land bridge that allowed the animals to cross the continents. Fossil evidence shows that North American natives such as bears, mastodons, ancestors of big cats, camels, and horses traveled into South America, while ancestors of modern-day armadillos, porcupines, sloths, anteaters, and opossums migrated into North America.

Molnar then proceeded to tear down this elaborate interpretation in minutes. "We can reject it," he said. "It has no foundation." He presented fossil findings that frogs, salamanders, and snakes crossed the continents between 6 and 19 million years ago, as well as new geological evidence that the Isthmus of Panamá actually emerged 20 million years ago—far before the commonly cited 3 million years. That's one hole in the story that the emergence of a land bridge directly enabled the Great American Biotic Interchange: It was already there.

Molnar's alternative explanation hinges on the slow global cooling that eventually sustained an ice sheet briefly, for no more than 20,000 years, on Canada 3 million years ago. During this ice age, the climate in Panama shifted from the hot, wet, mosquito-infested jungle we know today to a drier, cooler savannah grassland environment favorable to the migration of animals such as armadillos and saber-toothed cats. This change in Panama alone would have allowed animals to cross between continents.

"Did the emergence of the Isthmus of Panamá, whenever it occurred, have anything to do with Ice Ages?" asked Molnar, "I think it had nothing to do with it."

Molnar admitted that he did not answer the larger motivating question about what geological processes transformed Earth's climate from one with no ices ages to another with recurring ice ages. He will be working on that one for a long time. Rather, his talk proved the importance of challenging core assumptions in science. "The most important part of science is asking good questions," he told the young scientists and high schoolers in the audience.

Before the lecture, MIT and the aquarium hosted an exhibition of the iGlobe, a new tool for Earth science education. By projecting scientific data such as weather patterns, ocean circulation, and land temperature on a sphere, the iGlobe provides an intuitive, accurate, and fun way to represent the interconnectedness of Earth's systems. Researchers from MIT, led by Glenn Flierl, professor of oceanography in MIT's Department of Earth, Atmospheric and Planetary Sciences, recently partnered with iGlobe Inc. to educate students and the general public and improve the presentation of spatial information and computer model results on the iGlobe.

The John Carlson Lecture communicates exciting new results in climate science to the general public. The lecture is made possible by a generous gift from John H. Carlson '83 to the Lorenz Center in the MIT Department of Earth, Atmospheric and Planetary Sciences. ■

3 Questions: Launch of the MIT Climate Change Conversation

On Sept. 19, Maria T. Zuber, MIT's vice president for research, announced the membership of a community committee to plan and implement the MIT Climate Change Conversation. Roman Stocker, an associate professor of civil and environmental engineering and chair of the Committee on the MIT Climate Change Conversation, spoke with MIT News about the committee's charge, its progress to date, and its next steps.

New committee aims to catalyze discussion on how MIT can help address climate change.

Photo: Prof. Roman Stocker, courtesy Stuart Darsch, MIT News

Q. What does the Committee on the MIT Climate Change Conversation aim to achieve?

A. We aim to explore and assess the broad range of actions that MIT could take to make a significant positive contribution to address climate change. The global nature of this problem and the amount of debate and polarization that surround it are daunting, but the premise of the committee is that the complexity of the problem is uniquely suited for MIT, given our strong problem-solving ethos, and that a leading technical institution can have unique roles to play in responding to the climate crisis. Identifying and evaluating these potential roles is the purpose of the conversation.

Importantly, the committee will only be the catalyst of the conversation: Its main actor will be the MIT community! In other words, what we really aim to achieve is the engagement of the widest possible fraction of the MIT community in developing and debating bold ideas—MIT-style!—to help identify the pros and cons of different options. We believe that this approach will allow us, as a community, to identify a broad spectrum of action items; estimate the effectiveness of each action in addressing the problem; and thereby determine how our institute can most effectively drive forward the national and global agendas on climate change.

We will consider actions at all levels: from new educational initiatives at MIT and via its edX megaphone, to new opportunities for research that capitalize and expand on MIT's presence in the field, to improvements to campus infrastructure and operations aimed at reducing MIT's own carbon footprint, to leveraging MIT's visibility to drive more effective policy.

These are but examples, as we do not want to constrain the creativity of the MIT community. We will welcome any and all ideas through the multiple opportunities for input and feedback that we will construct. We look forward to this conversation as a catalyst for original ideas, debate, and sound analysis.

Q. What has the committee done to date, since its membership was announced on Sept. 19?

A. Devising the right ingredients to make this MIT conversation successful is what has kept us busy during this first month, and still is. Part of this effort consists of educating ourselves, within the committee, about the landscape of activities that already exist at MIT in the area of climate change, as some of these activities could represent important nucleation sites for bold ideas for action. At the same time, this knowledge will allow us to engage the MIT community in a more informed and meaningful way, through the conversation activities we have begun to plan for the fall and spring.

The committee is unanimous in its feeling not only of the urgency of the problem—expressed with particular emphasis by the younger generations—but also of the unique opportunity that this conversation represents for MIT to take on a visible leadership role in the solution of the problem.

Q. How can a member of MIT get engaged in this conversation?

A. We will create multiple opportunities for engagement throughout the current academic year. In the next few weeks, we will launch both an Idea Bank and a survey. The Idea Bank intends to capture the expertise and creativity of the MIT community and to engage it in a campus-wide brainstorm about what actions MIT could take to address climate change. We will welcome input on the full spectrum of possible actions that MIT could take. We will particularly welcome bold, creative ideas, because we feel that the spectrum of options for action available to a leading technical institution has not been fully explored to date.

We will carefully review the input we receive through both the Idea Bank and the survey, distill it into broad categories for potential action, and use it to inform the centerpiece of the conversation, a series of high-profile forums to be held in the spring term. These forums will focus on the different action categories that MIT can consider investing in to further its role in addressing climate change, including education, research, financial actions, policy, campus operations—with specifics that will be refined based on community input. ■

China: Local Incentives Drive Action on Global Climate Change

By Da Zhang, Valerie J. Karplus, and Zhang Xilang

Reprinted from *China Policy Institute Blog*, U. of Nottingham

Photo: Iron and steelworks near Beijing.

As countries ponder post-2020 action to halt global climate change, China has emerged as a more determined and prepared contributor. Why? The need to address climate change is closely linked to urgent domestic priorities such as cleaning up the air and steering the economy toward a path of sustainable growth. Environmental action is no longer a luxury but an imperative for China's citizens and policymakers, who recently declared war on the haze and smog they frequently wake up to. And because the severe air pollution problem and climate change share some common roots—burning coal and other fossil fuels—carefully planned countermeasures will address both. Recent policies enacted to address air quality combined with anticipated market-based approaches for enforcing future caps on emissions and pollution will deliver cuts in GHG emissions that could enable China to take a more ambitious position in post-2020 climate talks.

China's leaders already take their international commitments on climate change very seriously. The country is on track to meet its Copenhagen commitment to reduce the carbon intensity (CO_2 emission divided by GDP) by 40–45 percent in 2020, relative to 2005 levels. The carbon intensity reduction over the Eleventh Five-Year Plan (2005–2010) was 21 percent, and the 17 percent reduction targeted during the Twelfth Five-Year Plan (2011–2015) is considered achievable. A 16 percent reduction for the Thirteenth Five-Year Plan (2016–2020) will guarantee that China hits the higher end of its original commitment. However, post-2020 there are still huge uncertainties related to China's future growth, technological improvement, and most importantly, policy stringency that will influence the shape of China's emissions trajectory.

In recent research, we take a closer look at the impact of existing and proposed policy measures on China's future emissions trajectory. These measures include carbon pricing through an emissions trading system, a fossil fuel resource tax, a feed-in-tariff (FIT) for renewable electricity, hydro and nuclear capacity expansion according to government plans, and additional policies included in the National Air Pollution Action Plan (e.g., reducing the share of coal in primary energy below 65 percent by 2017 by implementing higher resource taxes or caps on coal use). We design two scenarios—Continued Effort (CE) and Accelerated Effort (AE) representing the existing policies and more aggressive efforts respectively and simulate them using an energy–economic modeling tool we developed to study the impacts of energy and climate policy in China. We find that China's emissions will peak around 2040 with current effort (CE scenario) and around 2030 with strong action (AE scenario). Coal use peaks earlier than CO_2 around 2020 and declines very gradually through 2050 in both policy scenarios. Of all the policies included in the package, the carbon price does the heavy lifting—and because coal is the main fuel displaced the carbon price has huge cobenefits in terms of air quality improvement. The economic impact of these policies constitutes less than 1 percent of total consumption in 2030, which is both very modest and in line with broader efforts to transition to slower, more sustainable economic growth. Our results suggest that introducing a national cap and price on emissions starting with the Thirteenth Five-Year Plan (2016–2020) offers an opportunity for China to transition to a cleaner growth path in line with domestic and global environmental policy goals.

"Looking ahead to the Paris conference next year we should expect a more determined and prepared China to take a more active role."

China is currently laying the foundation for such an approach known as an emissions trading system (ETS). The government is considering an ETS in order to minimize the costs of reducing carbon emissions while treating of equity issues through the initial allocation of emissions allowances. By mid-2014, all seven planned pilot-scale ETS programs had been launched in several provinces and cities, and five of them have already completed the compliance cycle for the first year, which has been viewed overall as smooth and successful. As the world's second largest ETS after EU-ETS, these ETS pilots offer important lessons for the future expansion of the system to a full-fledged national scale. The ETS pilot designs are as varied as the seven areas they cover. Tailored to the circumstances of the pilot area, the designs include different demographics, priorities and industries. Chinese policymakers believe this process of experimentation will allow the local communities to tailor the ETS to meet their diverse needs as heterogeneity within Chinese provinces is even more significant than that among the member states involved in EU–ETS. A remaining question is how these diverse designs can be linked and coordinated under a national ETS.

Compared to the decade or so required for the development of the EU–ETS, Chinese plans to build a national ETS by 2020 that covers most polluting sectors are ambitious. Better coordination between central and provincial governments as well as among the multiple agencies that are involved in energy and climate policy making is needed to help identify interactions between policies and avoid redundancies. There is also a strong need to develop legislation that sets penalties for exceeding CO_2 limits and enhances the transparency and independent reporting of carbon emissions. Capacity building at the local and national levels to train agencies to monitor, report and verify data will also benefit from more time to observe outcomes and incorporate lessons from existing ETS.

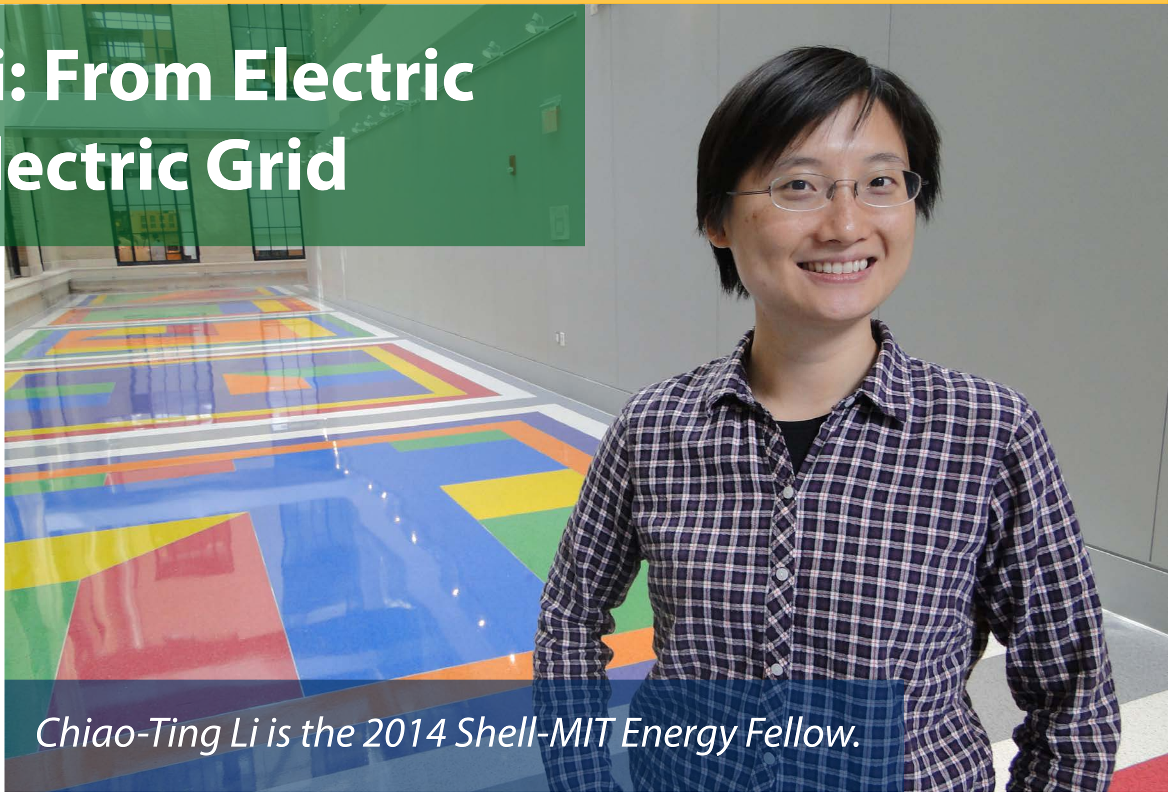
Looking ahead to the Paris conference next year, it is fair to expect a more determined and prepared China to take a more active role. However, we should not expect to see any miracles—China is still a developing country and any pledges to reduce emissions will be underpinned by—and not at odds with—its domestic agenda. The country still has a long way to go. Overseas support for technology transfer, knowledge sharing, and personnel training—especially as it relates to the construction and operation of an effective national ETS—will be crucial to build strong institutions that can support a low carbon transition within China's economy without undermining economic growth. China's readiness to consider emissions limits and market-based approaches to enforcing them should be both welcomed and supported by the global community. ■

Da Zhang is a postdoctoral associate at the MIT Joint Program on the Science and Policy of Global Change; Valerie J. Karplus is an assistant professor at the MIT Sloan School of Management; Zhang Xiliang is a professor at the Institute of Energy, Environment and Economy at Tsinghua University.

Crowds & Climate: From Ideas to Action

On November 6–7, John Reilly and Noelle Selin participated in panels at the 2014 MIT Climate Colab Conference—Crowds & Climate: From Ideas to Action. Building upon last year's successful conference, this year featured keynote addresses by Anthony Leiserowitz of the Yale Project on Climate Change Communication and Jeremy Grantham of the Grantham Foundation for the Protection of the Environment.
http://mitsha.re/1pWNdZQ

Chiao-Ting Li: From Electric Cars to the Electric Grid



Chiao-Ting Li is the 2014 Shell-MIT Energy Fellow.

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To understand big problems—like the challenges facing China's electricity grid—you have to ask big questions, says Chiao-Ting Li, a postdoctoral associate who joined the China Energy and Climate Project this summer. Li, who began her research career as an automotive engineering student focusing on electric vehicles, is now studying emissions and renewable energy in China.

At the China Energy and Climate Project, Li studies large-scale issues related to China's energy system, such as how the country can reliably add more wind power to its electricity generation mix, and the effect of policies limiting emissions in cities. But this focus on bigger picture problems is a recent development—she began her career by studying what goes on under the hoods of solar and plug-in electric cars.

"Mechanical engineers understand what's happening in one car very well, but they don't know about what's happening across multiple cars," says Li, who is the 2014 Shell-MIT Energy Fellow. "I eventually became interested in bigger picture questions, like how does the electric grid handle the increased load from plug-in vehicles."

During her graduate studies Li focused on automotive engineering, receiving a Master's Degree in Mechanical Engineering from National Taiwan University, and a PhD in Mechanical Engineering from the University of Michigan.

She put these engineering principles into practice at National Taiwan University—where she twice participated in the World Solar Challenge, an elite 10-day race across the Australian Outback. Competing against teams from universities and automakers across the globe, the National Taiwan University team scored well, in 12^{th}, and then 5^{th} places in the years that Li joined.

"It was the best experience an engineering student can ask for, to build a car and have it really work," Li says. "You're using these principles you've learned about in textbooks, and it's sort of an aha moment when it works exactly as you calculated."

Inspired by her hands-on experience at the World Solar Challenge, Li decided to pursue a PhD studying automotive engineering at the University of Michigan. Her research there focused on powertrain design in hybrid vehicles, but she didn't leave the race track behind. Li worked on race strategy optimization with the university's solar car team—studying whether it pays off to hedge in tough situations, say when the weather is bad, or if it is better to risk speeding up to power through a storm.

Li's doctoral thesis focused on problems that arise when large numbers of plug-in electric vehicles draw power from the grid. As electric vehicles become more popular, they have the potential to drastically change energy demand. If the electricity mix in a region is dominated by coal, the increase in energy generation needed to fuel the cars can actually increase emissions in the area.

Adding wind power to the electricity mix can solve this problem, Li found. In addition to being an emissions-free source of energy, wind is also available at night, which gives it an advantage over solar power for fueling electric cars. While it is available at night, wind is also intermittent, or in other words, there isn't always steady wind to power turbines.

Electric cars offer a potential solution to this issue, as they can vary when they charge to absorb fluctuating wind generation. The uneven charging doesn't affect driving performance, because the driving range depends on the lump sum of energy put into the battery and not how evenly the battery is charged. While theoretically feasible, this relationship would require careful coordination, she cautions.

"This is when I started to think about the energy system," Li says. "Talking with people in different disciplines gives you a different perspective. At Michigan, an electrical engineering faculty member encouraged me to look at what was happening on the electric grid. It was like stepping into a whole new world."

At MIT, Li studies whether or not regulations targeting emissions in cities on China's east coast will effectively control air pollution. She and the China Energy and Climate Project group are studying a phenomenon known as interprovincial transport, wherein emitting industries relocate from an area with emissions controls to adjacent areas with less strict regulations.

"We want to know how these policies will affect overall emissions in China," Li says. "The hiccup here is that they may not be as effective as intended. If these policies have a stringent grip on big cities, it's going to push industry into provinces that are less developed and have less access to advanced technology. So, you potentially end up with more pollution."

The work uses the MIT C-REM model, an economic model that can resolve the effects of policies on a provincial scale, to study how China's air pollution policies will affect economic activity and emissions. Li collaborates with Mingwei Li, a graduate student in MIT's Department of Earth, Atmospheric, and Planetary Sciences (who is unrelated), to model how these emissions travel through the atmosphere, and the resulting effects on regional air quality. They hope to present preliminary results of the work this winter.

Li is also working on wind integration in China. Over the last five years, China has made a big push to install large wind power plants. At the same time, it is replacing smaller coal plants with larger power plants, with up to 50 gigawatts of capacity. These megaplants take more time to power up, while at the same time, China's grid must compensate for the variability of wind power.

"On the face of things it looks like there is more variation coming in to the grid," Li says, "but the system is actually becoming less flexible. We are studying the consequences of this, and whether there are other options or technologies that China can use to plan for its future."

Li says that this sort of top-down policy analysis is just as important as the bottom-up technology development being done by automotive engineers. This is especially true in the energy industry, she says, where investments in generating capacity are made on a massive scale; because of this and the long lifetime of power plants, any policy put in place will affect the electricity system for years to come.

As for Li's future, she says she may someday return to her roots in automotive engineering. "If I can work in the F1 pit someday, that'd be great. That's actually my dream job." ■

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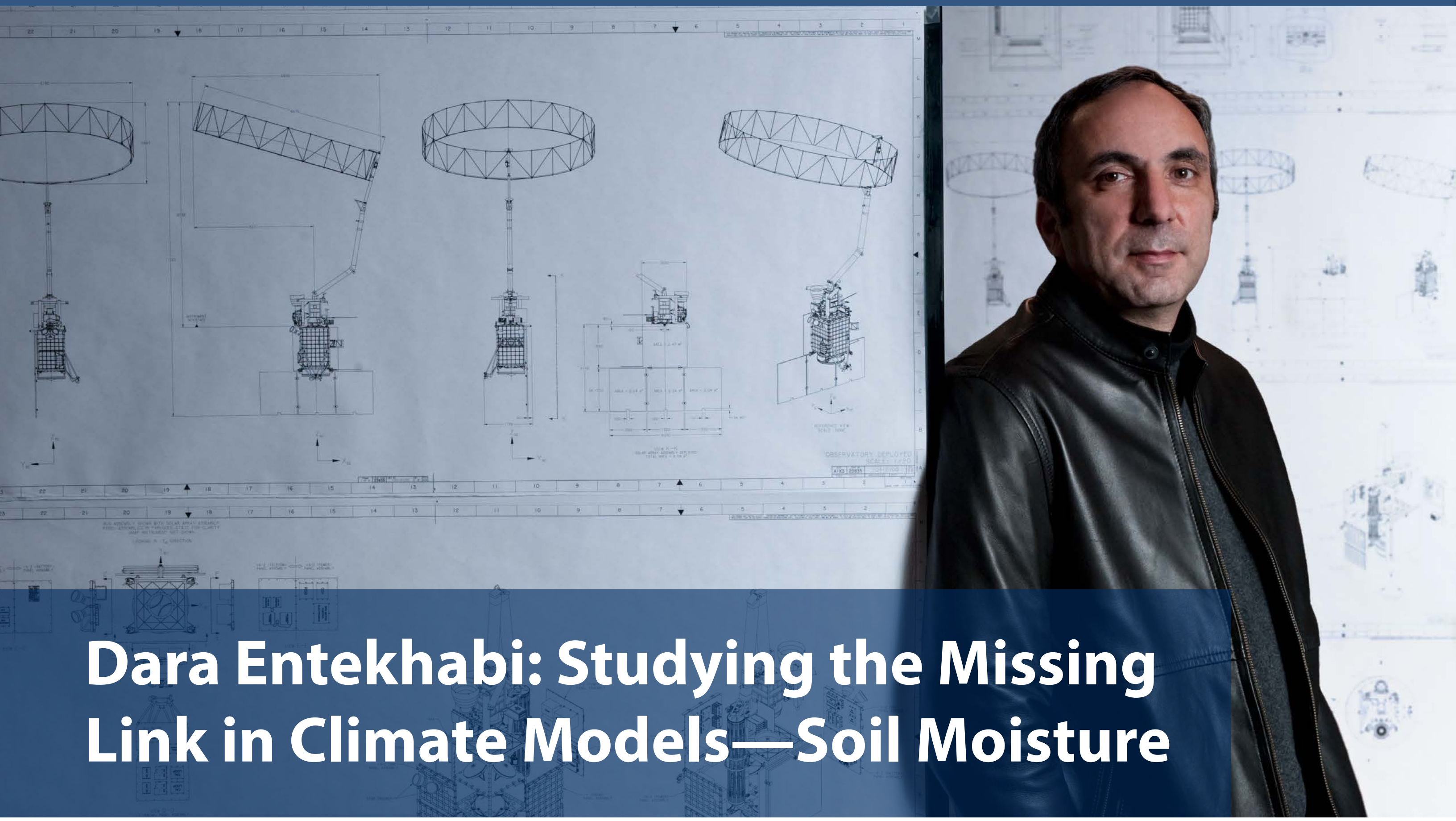
CECP @ MIT Energy Night

On Friday, October 17, 2014, a team from the China Energy and Climate Project participated in the event at the MIT Museum.

Hosted by the MIT Energy Club, Energy Night provides an ideal opportunity to see what energy research at MIT is all about. The CECP team presented two posters and interacted with hundreds of MIT students, faculty, energy companies, researchers and foreign business leaders.



Dara Entekhabi: Studying the Missing Link in Climate Models—Soil Moisture

Photo: Dara Entekhabi, courtesy of Len Rubenstein, MIT Spectrum

On January 29, 2015, a Delta II rocket launched from Vandenberg Air Force Base will carry the SMAP Observatory, the first satellite designed exclusively to monitor soil moisture, into orbit. Once there, the satellite will make a map of the Earth's soil moisture every three days—creating a measurement with the potential to dramatically improve weather forecasts and predictions of climate change.

It's been a long journey to get to this point, as Dara Entekhabi, the science team leader of the NASA mission and a researcher at the Joint Program on the Science and Policy of Global Change, can attest. SMAP, which stands for Soil Moisture Active Passive, was first conceived in 1999. Over the last 15 years, Entekhabi has led a team of researchers at MIT and other universities, the NASA Jet Propulsion Laboratory, and the NASA Goddard Space Flight Center working on the satellite.

"The team has stuck together," notes Entekhabi, who holds a joint appointment in the MIT's Department of Civil and Environmental Engineering and the Department of Earth, Atmospheric and Planetary Sciences. "It's almost the same people as when we started working on SMAP."

Once SMAP is in orbit it will measure moisture in the first five centimeters of the soil, using two instruments—active microwave radar and a passive microwave radiometer. The data transmitted back to Earth will represent a huge leap forward for scientists studying how the Earth works.

Unconventional Data

Entekhabi has spent his career learning about the Earth through collecting data, and the information collected by the SMAP Observatory will fill a major gap in our understanding.

"I was always into data and the environment, and reconstructing old records," says Entekhabi. "I eventually became interested in creating new sources of data—unconventional data. Which is how I became involved with SMAP."

SMAP is the first NASA mission dedicated to studying soil moisture and freeze/thaw data, which indicates the start and end of the growing season. Because of this, current records are spotty at best, and are based mostly on data from sparse ground stations and readings from satellites primarily designed for other uses.

The mission is somewhat unusual, Entekhabi says, because the long development period gave the mission team time to cultivate a community of early data adopters, who have already developed applications for the data. The information produced by SMAP will be tailored to fit these users' needs—allowing them to immediately put the data to use for forecasting and research.

"This is a path-breaking approach for NASA, because the applications are woven into the science of the mission. So, it's broad basic research, as well as application," says Entekhabi.

"This is a path-breaking approach for NASA, because the applications are woven into the science of the mission. So, it's broad basic research as well as application."

There is an impressive range of uses for soil moisture data. These include the obvious, like improving weather and climate forecasting; estimating agricultural productivity; tracking droughts, floods and landslides; to the less obvious, such as providing early warnings of famine in areas dependent on rain-fed crops; determining soil hardness on military transportation routes, and forecasting the density of the lower atmosphere, which determines how much lift an airplane has.

The lack of information about soil moisture is also a problem for basic Earth science research, because soil moisture links the three major cycles of the Earth system—the water, energy, and carbon cycles—together. Without accurate soil moisture data it's nearly impossible to accurately trace the movement of water through these three systems.

"These are basically three gears that are locked together," Entekhabi says. "If we don't get this right in models, because we don't know what the linkage is, it's a problem. Measuring soil moisture is important because it's the pivot that links these three gears."

Understanding soil moisture will likely greatly improve the accuracy of weather forecasts at a fraction of the cost of other measures, like beefing up computing power to support higher resolution weather models. It will also improve how models estimate how climate change will affect precipitation, which, up until now, has been notoriously difficult to pin down.

"All the models agree on global temperature; you can't get that wrong," Entekhabi says. "But what's going to happen with regional water availability, regional precipitation, the models don't even agree in sign—some of them are positive, some of them are negative—let alone magnitude."

Taking Extreme Weather's Fingerprint

Entekhabi's work on the water cycle and soil moisture spans decades, starting with his doctoral work at MIT, where he worked to improve how climate models account for land surface moisture. He joined MIT's faculty in 1991 and has been involved with the Joint Program since its creation in the early 1990s.

"A major question in the field today is what is climate change going to do to the water cycle?" Entekhabi says. "The real challenge is predicting the future of water availability at a regional scale."

To address this issue, Entekhabi worked with the Joint Program to create a new way of predicting how climate change will affect the frequency and severity of extreme precipitation. The method takes advantage of the fact that climate models do a good job of simulating the large-scale atmospheric events that lead to extreme precipitation, even though they're bad at predicting the precipitation itself. The method bypasses climate models' built-in precipitation parameterizations, and instead looks for the large-scale conditions that have been associated with extreme weather events in the past.

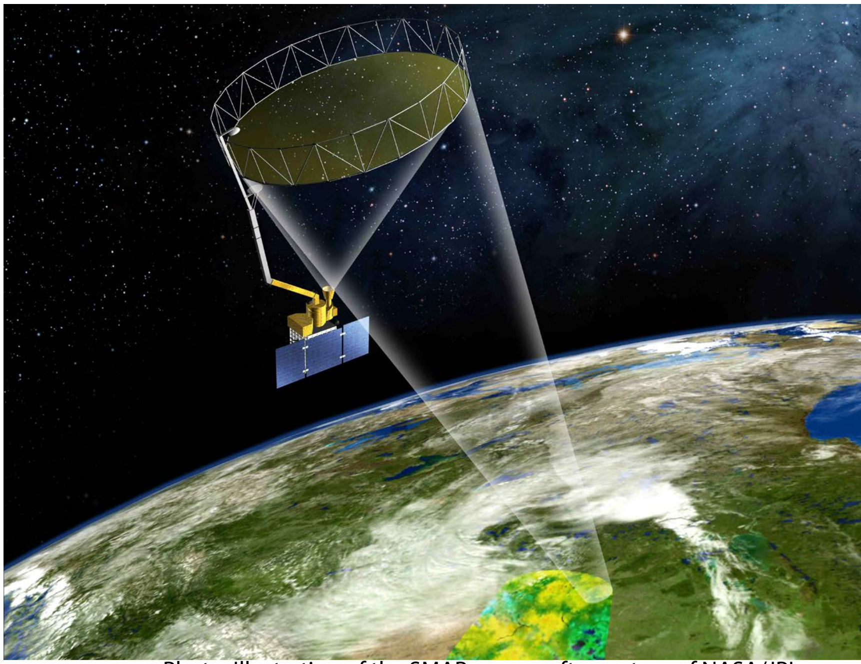


Photo: Illustration of the SMAP spacecraft, courtesy of NASA/JPL.

"What we're doing is basically fingerprinting," Entekhabi says. "We use the historical record to find a fingerprint, or pattern of what's going on in the large-scale climate that causes extreme weather.

"What we're doing is basically fingerprinting. We use the historical record to find a fingerprint, or pattern, of what's going on in the large-scale climate that causes extreme weather."

The technique, called an "analogue" method because it does not directly simulate precipitation within the model, gives more accurate reproductions of past extreme weather events than climate models alone. Once the patterns associated with extreme weather—either very wet or very dry—are identified, the next step is to look at future changes in these patterns in a climate model.

Entekhabi is currently working to identify these patterns across several regions. In one example, he studied over 100 years of precipitation data for the region around Mumbai, where the monsoon season can cause devastating floods in densely populated areas. The monsoons that caused the worst flooding left a distinct atmospheric fingerprint, he found.

"The fingerprint of the monsoon is much larger than the local flooding in Mumbai," Entekhabi says. "The circulation patterns extends all the way to the Arabian Sea and the coast of East Africa. Basically a long arc of vapor from the Arabian Gulf gets blocked, and it just sits there and rains a lot."

The method can be applied to any event in any region, as long as it is associated with changes in large-scale atmospheric conditions. Working with Adam Schlosser, a senior research scientist and assistant director for science research at the Joint Program, Entekhabi is currently applying the analogue method to West Africa, a region that relies on rain-fed agriculture for most of its food. Most of the rain in the region falls during a three-month rainy season in the summer, and what happens in the rainy season can make or break the area's food supplies.

"Models will always be uncertain once you start looking into the future," Entekhabi says. "SMAP is one way we're trying to improve the quality of models—by looking at how the water and carbon cycles fit together. The analogue approach is another way of attacking the challenge of regional water availability from an entirely different angle."

For now, Entekhabi is turning his attention skyward. In November, Entekhabi will travel to Southern California, where SMAP is being loaded into a rocket at the Jet Propulsion Laboratory. He'll remain there through the spring, while SMAP is being calibrated.

"It's been a long trek," Entekhabi says. "But every single screw on SMAP has been reviewed and reviewed and reviewed. Right now there's no more testing, no more touching the satellite. There's no looking back now." ■

Photo: SMAP lowered into place, courtesy of NASA/JPL-Caltech.

Related Research: An Analogue Approach to Identify Extreme Precipitation Events

Joint Program researchers applied the analogue approach developed by Entekhabi and collaborators to three regions in the United States—the Southern United States, California, and the Pacific Northwest. Research Scientist Xiang Gao describes the work, which was published in the Journal of Climate in August.

Q. Why aren't climate models good at detecting extreme precipitation?

A. Most models underestimate the frequency and intensity of present-day extreme precipitation events, especially on a regional level. This is the result of the coarse scale climate models are based on. Most models don't have a fine enough resolution to characterize the local phenomena and terrain that are involved in these events. Climate models are capable, however, of realistically simulating the large-scale conditions that are the precursors of extreme precipitation.

Q. How does an analogue approach work?

A. The first step was to identify widespread extreme precipitation events and the large-scale conditions associated with these events. Through the joint analyses of high-resolution observations and coarse-resolution NASA MERRA reanalysis from a 27-year period (1979–2005), we identified the atmospheric conditions such as air flow and moisture flow that were most likely to lead to extreme precipitation. We then created composite maps of these conditions for three regions: the South Central U.S., the North Pacific Coast, and the California Coast. Rather than using climate model-simulated precipitation to calculate the number of extreme events, we used the composite maps to evaluate against the daily large-scale atmospheric conditions from climate models to estimate the number of extreme events during the 27-year period.

Q. How good is the analogue approach at detecting extreme precipitation events?

A. This is a promising approach—overall, the analogue results are more consistent with observations than using climate model-simulated precipitation. We have tested this approach over the three regions in the United States in terms of characterizing the total number and interannual range of extreme days during the 27-year period. The results indicate that the approach is rather robust with satisfactory performance across various regions examined. We hope that this approach could be applied to any problem that requires bridging the gap between local problems and large-scale atmospheric conditions. For example, it could be used to study the effect of extremes on ecosystems, or extreme air quality events. ■

Related Publication:

Gao, X., C.A. Schlosser, P. Xie, E. Monier and D. Entekhabi, 2014: An Analogue Approach to Identify Extreme Precipitation Events, Evaluation and Application to CMIP5 Climate Models in the United States. *Journal of Climate*, 27(15).

FACTS Boston

On October 9, John Reilly, Susan Solomon and Kerry Emanuel participated in the Boston session of the FACTS: French Ameri-Can Climate Talks at MIT's Wong Auditorium. In partnership with MIT, the Embassy of France in the United States and the Consulate General of France in Boston organized the series of talks, which seek to mobilize French, American, and Canadian public opinion on issues related to climate change and discuss its economic impacts. The panel of scientific and policy experts outlined the main consequences of climate change and the risks it presents to the economy, particularly in the Northeast region.

http://mitsha.re/1xeKteO

Rebecca Saari: Exploring the Energy–Climate–Air Quality Nexus

Climate policies have traditionally been slow to gain political traction, possibly because the climate benefits of cutting carbon dioxide emissions aren't felt immediately or on the local level where cuts are made. However, there is one little-discussed side-effect of reducing emissions that does produce immediate local benefits—cleaner air.

Rebecca Saari, a doctoral student in MIT's Engineering Systems Division, studies the connection between policies that target greenhouse gas emissions, local air quality, and the accompanying health benefits. Climate policies lead to better regional air quality because the sources that emit carbon dioxide tend to be some of the dirtiest sources of air pollution, like the compounds that contribute to soot and smog. Cutting emissions from these sources lowers both types of pollution, which in turn lowers the rates of health problems like heart attacks and asthma.

"This connection might be surprising, because we don't often think about air pollution reduction as a major benefit of greenhouse gas mitigation," Saari says. "Mitigating climate change can be much more locally beneficial than we realize."

The drop in air pollution that accompanies a climate policy is often referred to as a cobenefit of the original policy, since the air pollution was not directly targeted by the policy. Considering these cobenefits can add new perspective to a discussion of the costs and benefits of climate policy, Saari says, because the effects of lower air pollution are mainly felt in the near term, and in the same region where cuts are made.

Creating Effective Policy

At the Joint Program on the Science and Policy of Global Change, Saari is working on an unusual sort of cost–benefit analysis. She compares the estimated costs of implementing climate policies to the resulting savings from avoided health expenses related to air pollution, like emergency room visits or missed work. Health problems like these end up costing the economy in healthcare costs, and lost economic productivity.

Modeling these costs and benefits across the economy is a huge undertaking, due to the multiple connected systems involved. Often, researchers studying this issue use separate modeling frameworks for each part of the issue, due to its complexity. Working with MIT Prof. Noelle Selin, Saari developed a method to evaluate both the costs and savings associated with different climate policies. The technique uses a single framework to calculate the effects across all of the areas affected by the policy.

"We're trying to create a more consistent framework, so we've integrated the health effects of cleaner air into the economic level of our framework." says Saari. "We look at the economic effects of having a healthier workforce. So we're really looking at impacts to labor and lost productivity."

Saari is also studying how the air pollution benefits of climate policies vary across regions and income levels. This is a complicated problem, since the answer depends on how many people are living close to emissions sources, what type of fuel is used in nearby power plants, and how states and regions choose to implement climate policies. Saari explains that there can be big benefits to looking at these connections holistically.

"Air quality is one component of a larger set of global sustainability challenges. It's one thing to try and improve air quality as an isolated issue. It's another to try to create useful, cost-effective policy that addresses multiple challenges like the economy, equity, and other environmental issues."

Saari is tackling this problem in her doctoral thesis, which evaluates the air quality impacts and health cobenefits of energy and climate policies, including CO_2 limits on existing power plants similar to the US EPA's Clean Power Plan. She is exploring how the magnitude and distribution of health benefits differ under different policy scales, from national to state-level implementation; and comparing when national or regional trading is allowed, and when states must make reductions locally. Preliminary results show that when national trading is allowed, the health benefits can outweigh the costs of reducing emissions. However, this effect appears to vary from region to region.

In addition to exploring the costs and benefits of reducing emissions, Saari is studying how climate policy influences air pollution hot spots, or areas where pollution levels are dangerously high. She is assessing if allowing regional trading will shift the location of hot spots, or even create new ones, compared to state-level trading.

"When it comes to carbon dioxide, it doesn't matter much where it's emitted. Its contribution to global warming is the same." Saari says. "But when it comes to air pollution, in terms of its health effects, it really matters where it's emitted. We want to know if the choice between regional and state-level trading can inadvertently lead to new hot spots."

Engineering Roots

The desire to address system-wide challenges brought Saari to MIT, but she wasn't always interested in such a large-scale approach. She began her career as an engineer designing technology for controlling pollution in power plants.

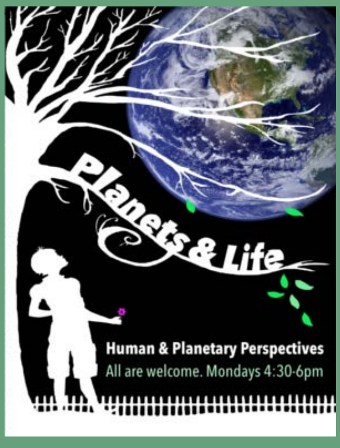
As a master's student at the University of Toronto Saari designed an optical sensor to improve combustion efficiency and pollution control in industrial furnaces. The sensor was tested at the Nanticoke Generating Station in Ontario, Canada, which was the largest coal-fired power plant in North America until it closed in 2013.

"We stuck it right at the furnace window, so the sensor had to be very robust and simple," she said. "It was basically a spectrometer that tried to use spectra to estimate ratios of carbon monoxide and carbon dioxide. It was meant to help monitor the steelmaking process, but we found it could be used to estimate emissivity in coal-fired power plants."

After graduation, Saari joined an engineering firm, where she worked as an air quality engineer on projects related to pollution control design and regulatory compliance. Working on projects in different regions, she noticed that regulations could vary vastly from place to place. She began to wonder why, and if policy grounded in science could address the bigger picture. The new interest made perfect sense to Saari, who sees her work on air pollution as an intuitive progression of her life-long interest in the environment, and her engineering background.

"I've always been interested in the natural environment, and while working on these engineering projects, you confront the intersection of the natural environment and the human environment," Saari says. "Air pollution is an interesting topic in natural science, but it's a human problem with human impacts. This is what brought me to exploring the human impacts of 'natural science' problems like air pollution."

Currently in her fourth year of studies at MIT, Saari hopes to complete and defend her thesis in the spring of 2015. After that, she hopes to continue studying the connections between energy, climate, and air quality. ■



Planets and Life: Human and Planetary Perspectives

In this Fall 2014 lecture series by MIT's Deopartment of Earth, Atmospheric and Planetary Sciences, a series of lectures and panel discussions will explore the grand environmental changes—from a natural planetary perspective—that might endanger the survival of the species Homo sapiens.

http://eapsweb.mit.edu/events/2014/planets-life

XXXVII MIT Global Change Forum Science and Policy Foundations of Post-2020 Actions 15–17 October, 2014 The Royal Sonesta Hotel, Cambridge, MA		
Wednesday	2:00–5:00 P.M.	**JP Sponsors Meeting**
Wednesday	7:00–8:00 P.M.	**Keynote Address**
Prof. Calestous Juma, *Harvard University*		
Thursday	8:30–10:00 A.M.	**Budget for Cumulative Carbon Emissions**
Prof. Myles Allen, *University of Oxford*		
Prof. Ronald G. Prinn, *Co-Director, Global Change Joint Program, MIT*		
Thursday	10:30–12:00 P.M.	**COP-21 Prospects**
Prof. Henry D. 'Jake' Jacoby, *Global Change Joint Program, MIT*		
Prof. David G. Victor, *UC San Diego*		
Thursday	2:00–3:30 P.M.	**Technology Options in Power and Transportation**
Dr. George C. Eads, *Senior Consultant, Charles River Associates*		
Dr. Sergey Paltsev, *Assistant Director for Economic Research, Global Change Joint Program, MIT*		
Thursday	4:00–5:30 P.M.	**Low Probability-High Impact Climate Risks**
Dr. Michael F. Wehner, *University of California, Berkeley*		
Prof. Tony Payne, *School of Geographical Sciences, University of Bristol*		
Friday	8:30–10:00 A.M.	**Risks and Options for Water, Food and Energy**
Prof. Wolfram Schlenker, *Columbia University*		
Prof. Paul Kirshen, *University of New Hampshire*		
Friday	10:30–12:30 P.M.	**Perspectives on a Prospective Post 2020 Agreement**
Dr. A. Denny Ellerman, *European University Institute, Florence; and Global Change Joint Program, MIT*		
Dr. Jeanne Chi Yun Ng, *Director, Group Sustainability, CLP Group*		
Dr. Jean-Yves Caneill, *Head of Climate Policy, Electricité de France*		
Mr. Reed Schuler, *Negotiator, Office of Global Change, U.S. Department of State*		

Coming and Going

Bertrand Delorme is a visiting student from the French engineering school ENSEEIHT and will be working with Erwan Monier.

Cléa Denamiel joined as a postdoctoral associate.

Simon Koesler returned to the Centre for European Economic Research.

Xiaohu Luo returned to Tsinghua University.

Shweta Mehta joined as the new BP Energy and Climate fellow.

Giacomo Schwarz is a visiting student from ETH Zurich and will be working on the China Energy and Climate Project.

Da Zhang joined as a postdoctoral associate with the China Energy and Climate Project.

Newly-Released Joint Program Reprints

2014-21: The ocean's role in polar climate change: asymmetric Arctic and Antarctic responses to greenhouse gas and ozone forcing, *Philosophical Transactions of the Royal Society A*

2014-20: The ocean's role in the transient response of climate to abrupt greenhouse gas forcing, *Climate Dynamics*

2014-19: Synergy between Pollution and Carbon Emissions Control: Comparing China and the U.S., *Energy Economics*

2014-18: Compact organizational space and technological catch-up: Comparison of China's three leading automotive groups, *Research Policy*

2014-17: Modeling U.S. water resources under climate change, *Earth's Future*

2014-16: The future of global water stress: An integrated assessment, *Earth's Future*

2014-15: Trend analysis from 1970 to 2008 and model evaluation of EDGARv4 global gridded anthropogenic mercury emissions, *Science of the Total Environment*

Peer-Reviewed Studies/Pending Reprints

Consumption-Based Adjustment of Emissions-Intensity Targets: An Economic Analysis for China's Provinces, *Environmental and Resource Economics*

How important is diversity for capturing environmental-change responses in ecosystem models? *Biogeosciences*

Leakage from Sub-national Climate Policy: The Case of California's Cap-and-Trade Program, *The Energy Journal*

The mercury game: evaluating a negotiation simulation that teaches students about science-policy interactions, *Journal of Environmental Studies and Sciences*

Understanding predicted shifts in diazotroph biogeography using resource competition theory, *Biogeosciences*

Influences of the Antarctic Ozone Hole on Southern Hemispheric Summer Climate Change, *American Meteorological Society*

A Systems Approach to Evaluating the Air Quality Co-Benefits of US Carbon Policies, *Nature Climate Change*

Newly-Released Joint Program Reports

Report 268: Characterization of the Solar Power Resource in Europe and Assessing Benefits of Co-Location with Wind Power

Report 267: Carbon emissions in China: How far can new efforts bend the curve?

Report 266: The CO_2 Content of Consumption Across US Regions: A Multi-Regional Input-Output (MRIO) Approach

Report 265: Coupling the High Complexity Land Surface Model ACASA to the Mesoscale Model WRF

Report 264: Expectations for a New Climate Agreement

Joint Program In the News

http://globalchange.mit.edu/news-events/news

July 29, *Reuters*, Curbing air pollution could help crops thrive

August 6, *The Hill*, Global climate pact won't keep warming below target, study says

August 7, *National Journal*, Why a Global-Warming Pact Won't Stop Global Warming

August 25, *International Business Times*, Health Care Savings Can Defray Climate Change Policy Costs, MIT Researchers Find

August 25, *Christian Science Monitor*, Climate change policies pay for themselves, study says

August 25, *CBC News*, Cap-and-trade carbon plans slash health costs

August 26, *The Atlantic*, If You Have Allergies or Asthma, Talk to Your Doctor About Cap and Trade

August 26, *Bloomberg BNA*, Any 2015 Climate Change Agreement Likely to Fall Short of Goals, Reports Say

August 27, *CBC News*, Cap and Trade Advocate

August 28, *National Journal*, The Head-On Politics of Going Around Congress on Climate Change

August 28, *Washington Post*, A climate for change: The U.S. can help drive a new round of global carbon cuts

September 30, *Environmental News Network*, New MIT report predicts serious future warming

October 1, *Climate Central*, MIT: Global energy use, CO_2 may double by 2100

October 1, *Business Green*, MIT: Prepare for worsening climate impacts

October 2, *Climate Central*, Climate Change Could Increase Global Fresh Water: MIT

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