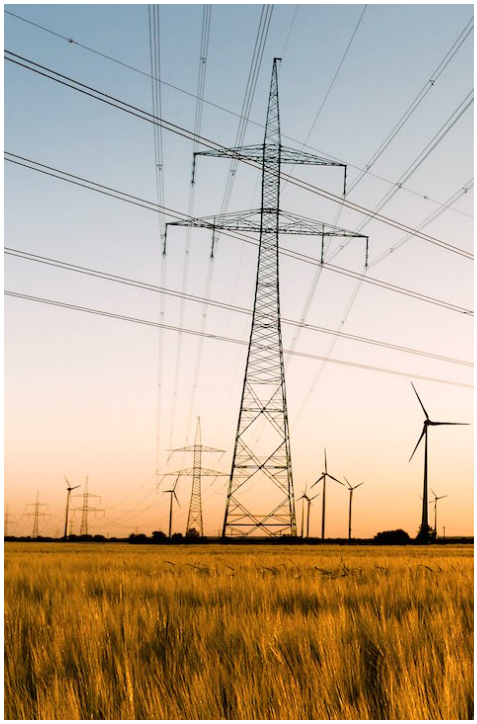
ANNUAL REPORT 2018



PURDUE UNIVERSITY

Purdue Climate Change Research Center
DISCOVERY PARK

The **Purdue Climate Change Research Center** (PCCRC) is a faculty-led, university-based research center on the campus of Purdue University. The PCCRC provides science-based, non-partisan, and collaborative analysis to support real-world decision making from the local to the global scales. A hub for people who want to work across disciplines on issues related to Earth's changing climate, the PCCRC serves to connect researchers, support collaborative projects, and share findings and expertise with stakeholders.

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Cover photos: From left to right: The center-led Indiana Climate Change Impacts Assessment released 7 reports in 2018, including, "Tourism and Recreation in a Warmer Indiana;" Professor Roshanak Nateghi uses multi-dimensional modeling to study the disaster resilience of critical infrastructure such as the electricity transmission grid; Graduate student Sarah Sams is studying how ice sheet thickness in Antarctica has changed since the last glaciation by analyzing the cosmogenic isotopes like 14C, 10Be, 26Al, and 36Cl in samples from western Dronning Maud Land, Antarctica.

DIRECTOR'S MESSAGE

As the PCCRC enters into its 15th year of existence, and Purdue enters its 150th, our faculty affiliates continue to do groundbreaking research that contributes to understanding and solving the global challenges presented by an increasingly disrupted climate.

Some highlights of the work done over the last year by our 90+ faculty affiliates, plus our students and staff, can be found in the pages of this report. For instance, you can read about our work on energy systems (pages 2, 11), tropical peatlands (page 5), and the role of gender in global climate negotiations (page 22). This report also covers research funded by some of our recent seed grants (pages 7, 12), and includes the first installment of our "Stories of Change" series of print and video stories (page18). As you will see, our researchers not only work on a wide variety of topics, but also in diverse locations, from the bottom of the ocean (Page 2) to the bottom of the world (page 23).

Here in Indiana, the PCCRC became more broadly known in 2018 than ever before, with the releases of seven reports from the Indiana Climate Change Impacts Assessment (see pages 14-17). These reports were widely covered by Indiana's local media outlets and served as the basis for many discussions with the public and with professional groups, on topics from agriculture to engineering to energy policy.

Our center is always evolving, and I hope you will take a minute to learn about our newest affiliates, who are introduced on page 27. And, if you're on social media, be sure to keep up with what we're doing by following or liking @PurdueCCRC.

Thanks for your interest in our work. We hope to see you in the year to come.

Jeffrey Dukes
Professor and Director

CONTENTS

RESEARCH BRIEFS

Reconstruction of past climate provides clues about future climate change

Sediment cores drilled from the seafloor by the JOIDES Resolution research vessel helped researchers create a timeline of temperature throughout the Eocene. New research results indicate that greenhouse gases were the main driver of climate change throughout the Eocene, a period of time between 56 million years and 34 million years ago, and a time that the Earth was at its warmest in the past 66 million years. The study, led by Margot Cramwinckel (*Utrecht University*) and professor Matthew Huber (*Earth, Atmospheric, and Planetary Sciences*) combined an analysis of these seafloor sediments with climate models to examine whether the extreme shifts in the global climate during that period were influenced by changing ocean circulation patterns or by carbon dioxide. Their research, which took 4 years of continuous computing to complete, found that rising carbon dioxide emissions were the cause of warming global temperatures—in this case, the emissions were likely from volcanoes. The study also points out that the polar regions experienced more severe warming than other parts of the planet. These findings should help scientists better understand the present-day changes in the Arctic and improve projections of future climate change impacts, like sea-level rise.


The JOIDES Resolution

Cramwinckel, M. J., M. Huber, I. J. Kocken, C. Agnini, P. K. Bijl, S. M. Bohaty, J. Frieling, A. Goldner, F. J. Hilgen, E. L. Kip, F. Peterse, R. van der Ploeg, U. Röhl, S. Schouten and A. Sluijs (2018). Synchronous tropical and polar temperature evolution in the Eocene. Nature, 559.

The growing risk to the U.S. electricity system

A secure and resilient electric grid is vital to national security, a strong economy, and critical services like those provided by water utilities and hospitals. As the demand for power continues to grow, the aging U.S. grid is being stretched to capacity. Moreover, supply risk can result from climate-induced shifts in electricity use and/or damaged infrastructure due to extreme weather events and climate change. A new analysis that focuses on the risks associated with climate-induced demand shifts finds that the power industry is dramatically underestimating how climate change could affect the medium- and long-term demand for electricity in the U.S.

The study, conducted by Sayanti Mukherjee (*PhD 2017, Civil Engineering; now an assistant professor at University of New York Buffalo*) and professor Roshanak Nateghi (*Industrial Engineering and Environmental and Ecological Engineering*) describes the limitations of prediction models currently used by electricity providers and regulators for energy forecasting, and presents a new model—a model that uses more accurate climate variables and climate change data to better predict future electricity demands in the residential, commercial, and industrial sectors. The researchers find that dew point temperature (the temperature at which air is saturated with water vapor) is the key predictor of climate-induced demand shifts for all the three sectors, with daily high temperature a second key variable for residential and commercial sectors, and daily minimum temperatures a second key variable for the industrial sector.

When the new model is used to predict future energy demands across the state of Ohio, the residential sector is most directly affected by climate variability and change. Even a moderate rise in dew point temperature could increase electricity demand up to 20% by the 2030s—the prediction jumps to 40% with a severe rise. By comparison, the Public Utility Commission of Ohio, which does not consider climate change in its models, predicts residential demand increases of less than 4%. The commercial sector is similarly affected by variations in dew point temperature, and demand could increase to 14%. The industrial sector is less affected. While the study was limited to Ohio, the model can be applied to evaluate the risks of climate change to electricity infrastructure in other states.

Mukherjee, S. and R. Nateghi (2019). A Data-Driven Approach to Assessing Supply Inadequacy Risks Due to Climate-Induced Shifts in Electricity Demand. Risk Analysis, 39, 3.

The ecology of peace: preparing Colombia for new political and planetary climates

Current efforts for achieving peace in Colombia and ongoing changes in global climate will combine to shape the future of Colombia's tropical forests, one of Earth's biodiversity hotspots. A new paper led by Alejandro Salazar (*PhD 2017, Biological Sciences; currently a postdoc researcher at the University of Iceland*) examines the potential impacts of these transformative events, emphasizing that ecosystem management decisions made within Colombia now can have local to global consequences. Co-authors include Purdue graduate student Maria del Rosario Uribe (*Biological Sciences*) and professors Jeffrey Dukes (*Forestry and Natural Resources and Biological Sciences*) and Qianlai Zhuang (*Earth, Atmospheric and Planetary Sciences and Agronomy*) along with an international team of researchers from Universidad del Rosario, Universidad de Antioquia, Universidad EIA, University of Exeter, Universidad Nacional de Colombia, University of Miami, Columbia University, EAFIT University, the Wallingford Centre for Ecology and Hydrology, and Max Planck Institute for Biogeochemistry.

In a nutshell, to prevent or mitigate ecological and environmental degradation, the research team recommends the Colombian government prioritize rural development in non-forested areas, strengthen environmental research (with a focus on intensive environmental monitoring), and engage scientists in decision-making processes.

Salazar, A., A. Sanchez, J. C. Villegas, J. F. Salazar, D. R. Carrascal, S. Sitch, J. D. Restrepo, G. Poveda, K. J. Feeley, L. M. Mercado, P. A. Arias, C. A. Sierra, M. del Rosario Uribe, A. M. Rendón, J. C. Pérez, G. M. Tortarolo, D. Mercado-Bettin, J. A. Posada, Q. Zhuang and J. S. Dukes (2018). The ecology of peace: preparing Colombia for new political and planetary climates. Front Ecol Environ, 16(9): 1–7.

In 2016, Colombia signed a peace accord with the country's largest rebel group, the Revolutionary Armed Forces of Colombia, or FARC (Fuerzas Armadas Revolucionarias de Colombia). Photos by Eliana Aponte: Members of FARC (left) and a sign calling for a cease-fire (right).

Pathways to smallholder adaptation to climate change

Smallholder farmers across the globe are vulnerable to environmental, climatic, and weather-related stress. Future changes in climatic conditions are expected to both exacerbate existing challenges and create new ones for smallholders. Adaptation strategies offer opportunities to adjust agriculture and agricultural livelihoods to the impacts of a changing climate, but professor Zhao Ma's (*Forestry and Natural Resources*) work shows that the success of a particular adaptation will depend on the social, political, economic, and institutional contexts that underpin them.

With her colleague Morey Burnham (*Idaho State University*), Ma conducted a study of smallholders in the Loess Plateau Region of China to analyze two adaptation strategies, planting maize and adopting drip irrigation. They found that planting maize persisted as an adaptation strategy because it allowed for the most amount of current and future risks to be managed. By planting maize and taking advantage of state-led agricultural advances (e.g., drought-tolerant seeds and plastic mulching) and economic incentives (fertilizer subsidies and crop insurance), farmers were able to reduce their vulnerability to environmental and climatic stresses, and also had more time to earn money as wage workers—growing maize requires less labor than other choices such as vegetables and watermelons. Drip irrigation, on the other hand, failed because it forced smallholder households to spend more time on irrigation and farming than they were willing to. This inhibited their ability to perform off-farm wage work as a strategy to reduce current and future risks associated with dependence on agriculture production.

Burnham and Ma's work highlight the complexities shaping adaptation decision making and the need to consider historical and ongoing multi-scale social-ecological change, and the need to find strategies that manage multiple risks.

Burnham, M. and Z. Ma (2018). Multi-scalar pathways to smallholder adaptation. World Development, 108, 249-262.

> To paraphrase former Speaker of the House Tip O'Neill, 'All climate change is local'—that is, society reacts most immediately to changes in local weather such as regional heat waves and heavy rainstorms.

High-resolution climate projections for New Hampshire

Earth system models are able to simulate the interactions of the atmosphere, ocean, land, ice, and biosphere to estimate the state of the global climate under a variety of conditions and for past, present, and future time periods. These models, however, are not able to provide detailed analysis of climate change at regional and local scales—the scales that are needed to support planning, mitigation, and adaptation efforts. In this study professor Matthew Huber and graduate student Paul Acosta (*Earth, Atmospheric and Planetary Sciences*), and researchers from MIT used a unique method to dynamically downscale global model projections to 3-km horizontal resolution, producing a high-resolution climate data set to support sustainable regional planning efforts in New Hampshire. This is the first and only study that has downscaled global model projections to such a high resolution for this region. Scientists and planners can use this improved climate data, which is publicly available, in smaller scale models to better anticipate and plan for future climate change impacts (e.g., flooding, drought, disease vector populations, heat waves, storm surge, and economic impacts).

Komurcu, M., Emanuel, K.A., Huber, M. and Acosta, R.P (2018). High-Resolution Climate Projections for the Northeastern United States Using Dynamical Downscaling at Convection-Permitting Scales. Earth and Space Science, 5 (11), 801-826.

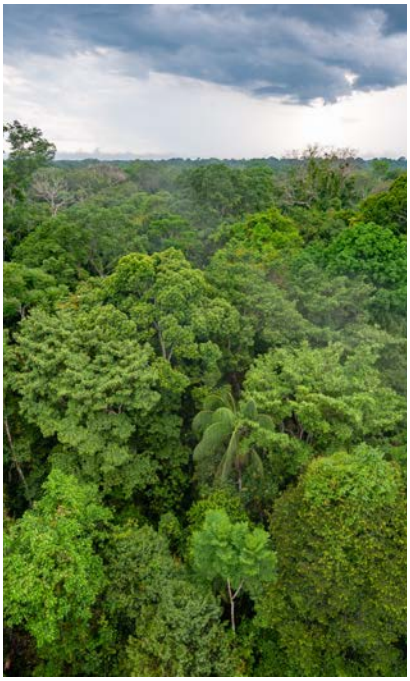
A rapid assessment of damaged residential buildings in the Florida Keys after Hurricane Irma

With maximum winds of 185 miles per hour, Irma was the most powerful hurricane in recorded history to exist in the Atlantic Ocean outside of the Caribbean and Gulf of Mexico. Irma sustained those maximum winds speeds for 37 hours and spent three consecutive days as a category 5 hurricane, making it the longest of any cyclone in the world to maintain that intensity.

Hurricane Irma made landfall near Cudjoe Key (lower Florida Keys) on 10 September 2017, as a Category 3 storm, and caused widespread damage to the Florida Keys. Shortly after the storm, a team of Princeton University and Purdue University researchers, including professor Dan Chavas and graduate student Jie Chen (*Earth, Atmospheric and Planetary Sciences*), conducted a field survey to investigate the damage to the Keys and to quantify the contribution of various hazard and vulnerability factors to the observed damage. Such post-event assessments can provide crucial information for implementing post-storm response measures and for developing vulnerability models.

To guide their efforts, the team used computer model simulations of the storm surge and wave heights along with post-storm satellite imagery and direct observations. They conducted a rapid damage survey for 1600+ residential buildings and found distinct factors governing damage at the two study areas. In Big Pine Key, proximity to the coast was a main factor, as severely damaged buildings were located near narrow waterways connected to the ocean. Building type and size were critical factors in Marathon, highlighted by the near-complete destruction of trailer communities there. These findings raise issues of affordability and equity that need to be considered in damage recovery and rebuilding for resilience. The raw and analyzed data from this study appear on DesignSafe, a web-based research platform of the National Science Foundation's Natural Hazards Engineering Research Infrastructure program.

Xian, S., K. Feng, N. Lin, R. Marsooli, D. Chavas, J. Chen and A. Hatzikyriakou (2018). Brief communication: Rapid assessment of damaged residential buildings in the Florida Keys after Hurricane Irma. Natural Hazards and Earth System Sciences, 18(7), pp. 2041-2045.

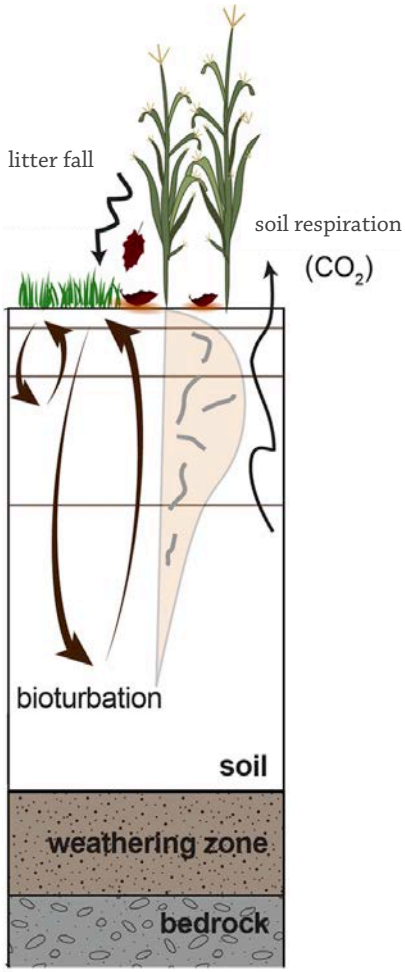


Amazonian peatlands could shift from a carbon sink to a carbon source under a changing climate

Amazonian peatlands store a large amount of soil organic carbon (SOC). These natural carbon "sinks" keep carbon dioxide (CO_2) out of the atmosphere, and, when left undisturbed, peatlands store more carbon dioxide than all other vegetation types on Earth combined. But when they are drained and deforested, they can release large amounts of heat-trapping gases like carbon dioxide (CO_2). Climate researchers are also concerned that a changing climate, higher temperatures in particular, may be accelerating SOC losses from intact peatlands.

Graduate student Sirui Wang (*Earth, Atmospheric and Planetary Sciences*) led a study looking at the impact of climate change on the Pastaza-Marañon foreland basin in Peru, which is the most extensive peatlands complex in the entire Amazon Basin. The research team, including Wang's advisor, professor Qianlai Zhuang and collaborators from Arizona State University, the Carnegie Institution for Science, and Florida International University, found that warming accelerates peat SOC loss while increasing precipitation accelerates peat SOC accumulation. With these impacts, their simulations suggest that the basin might lose up to 0.4 Pg of carbon by the year 2100, with the largest loss from palm swamps. If this loss rate is true for all Amazonian peatlands, the researchers project that these carbon-dense peatlands may switch from a current carbon sink into a future source in this century.

Wang, S., Q. Zhuang, O. Lähteenoja, F. C. Draper and H. Cadillo-Quiroz (2018). Potential shift from a carbon sink to a source in Amazonian peatlands under a changing climate. PNAS, 115 (49) 12407-12412.



3-D Modeling of the coevolution of landscape and soil organic carbon

Knowledge of how soil organic carbon (SOC) content changes within a landscape and over time will help improve our understanding of both how agricultural practices contribute to climate change and how climate change affects agriculture. Changes to both shallow and deep SOC result from belowground transformations such as microbial decomposition and addition of plant material, and from physical transport over the ground surface by erosion and deposition. The interactions between the two types of processes—transformation and transport—have been strongly perturbed by agricultural practices, but quantifying these interactions at the watershed scale is a challenge.

Agricultural practices have dramatically accelerated soil erosion and altered SOC dynamics. Soil erosion not only redistributes surface SOC but influences the biogeochemical transformations belowground. To study these complex interactions, a team of researchers from the University of Illinois and Purdue University (graduate student Tingyu Hou and professor Timothy Filley, *Earth, Atmospheric and Planetary Sciences*) developed a 3-D computational model that couples hydrological, biogeochemical, and geomorphological processes to simulate, for the first time, the coevolution of landscape and SOC dynamics at fine scales in space and time.

The model was applied to an agricultural watershed under a corn and soybean rotation. This watershed is a study site within the NSF-funded Intensively Managed Landscapes Critical Zone Observatory. The results show that in this setting, physical transport rather than biogeochemical transformation is the dominant driver affecting both the below ground profile as well as the stocks of SOC. The majority of upland, erosional sites were found to be a net local atmospheric carbon sink, and the majority of flood plain, depositional sites a net atmospheric carbon source. Interestingly, mechanical mixing by tillage was found to increase the SOC stock at erosional sites but reduce the stock at depositional sites. The study provides a better understanding of SOC dynamics, and the model could serve as an important tool for managing soil carbon.

Yan, Q. P. Le, D. K. Woo, T. Hou, T. R. Filley, and P. Kumar (2018) 3-D Modeling of the Coevolution of Landscape and Soil Organic Carbon. Water Resources Research, 55, 1218-1241.

Climate change implications for tourism in the U.S. Great Lakes and Midwest

Because the Great Lakes are so large and deep, they influence local and regional weather and climate, which, in turn, influence things like agricultural practices, shipping, and tourism. Winter tourism, for instance, is highly dependent on temperature, snow cover, snowfall, length of the snow season, and the presence or absence of snow during winter holidays.

During the 2009-2010 winter season, tourism added over $3.5 billion to Great Lakes states' economies and provided close to 63,000 jobs. The total gross annual revenue of downhill skiing and snowboarding areas in Great Lakes states is estimated at about $1.6 billion. Snowmobiling adds about $800 million annually to Michigan's economy alone.

A study led by Natalie Chin (PhD 2018, *Agricultural and Biological Engineering*) and professor Keith Cherkauer (*Agricultural and Biological Engineering*) and colleagues Kyuhyun Byun and Alan Hamlet (*University of Notre Dame*), set out to detail information about potential climate change impacts in the Great Lakes that is directly relevant to winter recreation and tourism and that can be used to help tourism managers think about climate change and adaptation strategies for the future. The work built on existing analyses by considering how climate change could impact winter weather and hydrology important to tourism for the U.S. portion of the Great Lakes region.

The study found that by the 2080s, climate change could result in winters that are shorter by over a month, reductions of over a month in days with snow depths required for many kinds of winter recreation, and declines in average holiday snow depths of 50 percent or more. The results also show reductions in the percent area of the study region that would be considered viable for winter tourism from about 22 percent to 0.3 percent. Furthermore, days with temperatures suitable for artificial snowmaking decline to less than a month, annually, making it potentially less feasible as an adaptation strategy. All of the region's current ski resorts are operating in areas that will become non-viable for winter tourism businesses under a high emissions scenario. Given the economic importance of the winter tourism industry in the study region, businesses and communities should consider climate change and potential adaptation strategies in their future planning and overall decision-making.

Chin, N., K. Byun, A. F. Hamlet and K. A. Cherkauer (2018). Assessing Potential Winter Weather Response to Climate Change and Implications for Tourism in the U.S. Great Lakes and Midwest. Journal of Hydrology: Regional Studies, 19, 42-56.

PCCRC Seed Grant: Lake Evaporation in the Atmosphere Project (LEAP)

As the climate continues to warm, better understanding of regional climate dynamics is becoming ever more important, both for improved severe weather forecasting and long-term climate projections. A key limitation in the Midwest region, however, is our ability to model the Great Lakes system. Because the Great Lakes are so expansive, they are a large source of the moisture and energy that fuels convective storms and lake effect snow. But we don't know enough about the interconnections between the land, water, and atmosphere to model the system. The Lake Evaporation in the Atmosphere Project (LEAP) is a collaborative effort between the Earth, Atmospheric, and Planetary Sciences and the Chemistry departments at Purdue working to better understand these interactions.

Photo credit: Thilina Karunarathna

Professors Lisa Welp, Paul Shepson, Mike Baldwin, and their research groups have teamed up to make direct measurements of lake influence by analyzing water vapor stable isotopes from instruments on-board Purdue's Airborne Laboratory for Atmospheric Research. The team flew upwind and downwind of Lake Michigan collecting data on the water content of the air as the wind blows it across the lake. Vertical profiles of water vapor mixing ratios and isotope ratios show that as an air mass crosses over an increasing large area of Lake Michigan, it increases in both water vapor concentration and deuterium isotope values, demonstrating the lake's influence on atmospheric moisture. Graduate student Ali Meyer is continuing to analyze and explore the isotopic measurements from these initial scouting flights to estimate the relative amount of lake influence on the downwind atmosphere and the extent to which that moisture influences higher levels of the atmosphere. These observations will ultimately be used to improve weather forecasting and regional climate modeling.

Impacts of climate change on soil erosion in the Great Lakes region

The U.S. Great Lakes region suffers from water quality degradation caused by agricultural nonpoint source pollution (e.g., from runoff and soil erosion). Understanding how climate change will impact future soil loss will allow areas susceptible to erosion to be identified and more sustainably managed.

Climate change studies project increases in both precipitation and air temperatures for the Great Lakes region. By the end of the 21st century, annual precipitation is projected to increase up to 20% across the region with precipitation increases in both winter and spring and decreases in summer. Mean annual air temperature is projected to increase by 2.2 °C to 5.8 °C with more frequently occurring extreme heat events and more common heavy precipitation events.

A study led by graduate student Lili Wang, with professor Keith Cherkauer (*Agricultural and Biological Engineering*) and Dr. Dennis Flanagan (*USDA-Agricultural Research Service, National Soil Erosion Research Laboratory*), examined the predicted runoff and soil loss to be expected under projected climate change conditions for the entire Great Lakes region. A macroscale soil erosion model, the Variable Infiltration Capacity—Water Erosion Prediction Project (VIC-WEPP) model was used to estimate soil loss under three climate change scenarios (A2, A1B, B1) using projections from three general circulation models (GFDL, PCM, HadCM3) for the Great Lakes region from 2000 to 2100.

Their findings suggest that to reduce soil loss in the Great Lakes region, soil conservation efforts should focus on reducing the impacts of increased precipitation on cropland and grassland areas in the fall and winter seasons. In future analyses, land cover changes need to be considered in soil loss prediction models and soil conservation strategies, as soil loss will increase at a greater rate if forestland is replaced with grassland in the northern study domain, and grassland is replaced with cropland in the southern reaches of this study.

Wang, L., K. A. Cherkauer and D. C. Flanagan (2018). Impacts of Climate Change on Soil Erosion in the Great Lakes Region. Water 10(6), 715.

Impacts of climate on the biodiversity-productivity relationship in natural forests

The biodiversity-productivity relationship (BPR) describes the effect of biodiversity on ecosystem productivity. This relationship forms the basis of our understanding of biodiversity loss and its impacts on the functioning of natural ecosystems, but there are few studies examining the forest BPR—and most of these studies report contrasting results. Some studies show a positive relationship between the number of species present and the productivity in an ecosystem while others show no correlation or a bell shape, in which productivity increases with biodiversity until a point at which more species lead to a decline.

Professor Songlin Fei (*Forestry and Natural Resources*) and colleagues from the United States, Sweden, China and New Zealand analyzed data from 2012-16 that included species composition, diameter, height, age and other attributes from more than 115,000 forest plots from the 48 contiguous United States. Their findings reveal that relationships between biodiversity and forest productivity actually depend strongly on climate. For instance, in dry, and especially in warm, climates, productivity increases along with species richness. But in areas that are humid, biodiversity and productivity increase together until a point at which more species begin to cause productivity declines. It is within a particular climate that other factors, including biotic (e.g., stand age and density) and abiotic (e.g., soil properties) can impact BPRs, which helps explain the contrasting results reported in previous studies.

The findings show that a one-size-fits-all approach to managing forests doesn't work and, depending on the climate, tradeoffs may need to be made when considering whether to maximize productivity or to conserve biodiversity. In addition, future climate change impacts should also be considered when making management decisions—a cool, wet forest today could look much different in the coming decades.

Fei, S., I. Jo, Q. Guo, D. A. Wardle, J. Fang, A. Chen, C. M. Oswalt, and E. Brockerhoff, (2018). Impacts of climate on the biodiversity-productivity relationship in natural forests. Nature Communications, 9: 5436.

Warming increases the sensitivity of seedling growth capacity to rainfall

Predicting the effects of climate change on trees is critical for understanding the future state of forested ecosystems. Warming air temperatures and shifting precipitation patterns are expected to increasingly affect the growth of tree seedlings, which will lead to long-term changes in the composition and productivity of forests. A new study set out to examine whole plant and leaf-level responses to warming and altered precipitation across a single growing season in the northeastern U.S. to study the climatic sensitivity of seedlings of six native tree species.

The research team, including Jeff Dukes (*Forestry and Natural Resources and Biological Sciences*) conducted a multifactorial climate manipulation experiment using 3 levels of precipitation (ambient, -50% ambient, +50% ambient) crossed with four levels of warming (up to a warming of 4°C) for 6 tree species: red maple, sweet birch, big-toothed aspen, black cherry, red oak, and American elm. These tree species all have large current and projected ranges that span much of the eastern and midwestern U.S.

The study showed that canopy warming dramatically increases the sensitivity of plant growth to rainfall across all species. Warm, dry conditions consistently reduced seedling growth in four species (red maple, sweet birch, black cherry, and American elm) by affecting leaf production. Interestingly, these conditions also harmed the other two species but in different ways, increasing either mortality (aspen) or herbivory (red oak). The results suggest that, in the northeastern U.S., dry years in a future warmer environment could have damaging effects on the growth capacity of these early secondary successional forests through species specific effects on leaf production, herbivory, and mortality.

Rodgers, V. L., N. G. Smith, S. S. Hoeppner and J. S. Dukes (2018). Warming increases the sensitivity of seedling growth capacity to rainfall in six temperate deciduous tree species. AOB Plants, 10(1).

Making use of marginal lands for biofuels production

The rapid expansion of biofuels industries in the early 2000s combined with the 2006-2008 world food crisis has focused global attention on agricultural lands and raised the question: is there enough land to both produce renewable biofuels and to meet food demands? One promising solution is to grow perennial grasses as biofuels crops on "marginal" land—land unsuited for food crop production. Focusing on 7 states in the Upper Mississippi River Basin (UMRB), a research team led by graduate student Qingyu Feng (*Agricultural and Biological Engineering*) used a computer model (the soil and water assessment tool model, SWAT) to estimate the potential for these marginal lands to produce biofuel crops and to evaluate the impacts of bioenergy crop production on the region's water resources.

The study concluded that the UMRB area could produce up to 37% of the ~35 billion gallons of renewable transportation fuel per year mandated in the 2010 Energy Independence and Security Act. However, more research, field work in particular, is needed to better understand the impacts of these crops on the environment. The research team included colleagues at Purdue (professors Jeff Volenec, *Agronomy*; Indrajeet Chaubey and Bernie Engel, *Agricultural and Biological Engineering*), Penn State University, and the Indian Institute of Technology Madras.

Feng, Q., I. Chaubey, R. Cibin, B. Engel, K. P. Sudheer, J. Volenec and N. Omani (2018). Perennial biomass production from marginal land in the Upper Mississippi River Basin. Land Degrad Dev, 29: 1748–1755.

Managing agricultural water in a changing climate

More than 30% of agricultural lands in the midwestern U.S. have subsurface drainage systems in place to remove excess water from soils. This technology allows aeration of the soil, better conditions for plant root development, and trafficable conditions for field operations, all of which have increased the productivity of farms. In any given year, however, this farmland is at risk to both flooding and drought, and projections of future climate change indicate that the Midwest is expected to experience more intense rainfall events along with an increased chance of drought. A research team led by professor Jane Frankenberger (*Agricultural and Biological Engineering*) is investigating the impact of retrofitting subsurface drainage systems for irrigation in times of water need.

In a changing climate, Midwest farmers are increasingly faced with both too much and too little water in a single growing season. Subsurface drainage systems have the potential benefit of addressing both issues. Retrofitting subsurface drains supplies water directly to crop root zones while also allowing for more efficient removal of excess water in response to large rainfall events. The research team used computer models to study the effects of this subirrigation practice on corn yields under historic and projected future climate conditions. Overall, their findings show that crop yield increases can be expected with subirrigation practice—on suitable soils—and may help alleviate the impacts of climate change.

Gunna, K. M., W. J. Baule, J. R. Frankenberger, D. L. Gamble, B. J. Allred, J. A. Andresen, L. C. Brown (2018). Modeled climate change impacts on subirrigated maize relative yield in northwest Ohio. Agricultural Water Management, 206, pp. 56-66.

"Sustainable" palm oil may not be so sustainable

Palm oil is found in products ranging from food to cosmetics and detergents. Demand for the oil has surged in the last decade, with global usage soaring from 37 million tons in 2006 to an expected 72 million tons in 2018. As the global palm oil market continues to grow, it is urgent to quantify the economic and environmental costs and benefits of current "sustainable" palm oil practice, especially in Southeast Asia. Industry has developed a "sustainable" palm oil certification process, but what are the real benefits of this certification?

In a short communication, research associate Roberto Cazzolla Gatti, professor Jingjing Liang (*Forestry and Natural Resources*) and colleagues from Tomsk State University, Russia, briefly discuss why palm oil certifications may have failed as an effective means to halt forest degradation and biodiversity loss. Using multiple new datasets, the researchers analyzed recent tree loss in Indonesia, Malaysia, and Papua New Guinea, and discovered that, from 2001 to 2016, about 40% of the area located in certified concessions suffered from habitat degradation, deforestation, fires, or other tree damage. In fact, certified concessions have been subject to more tree removals than non-certified ones. They also detect significant tree loss before and after the start of certification schemes. In other words, the sustainability certification for palm oil appears to be meaningless.

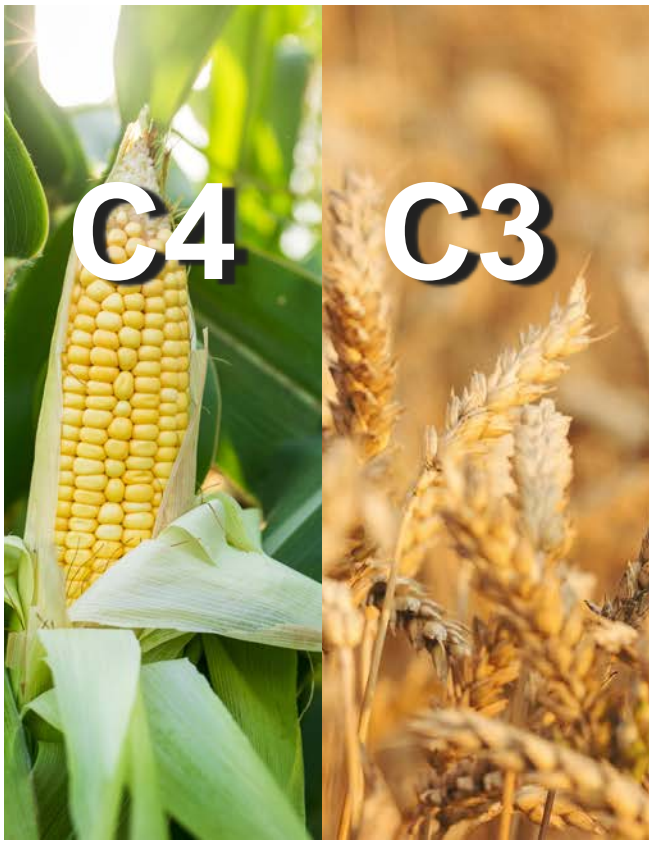
Gatti, R. C., J. Liang, A. Velichevskaya, M. Zhou (2019). Sustainable palm oil may not be so sustainable. Science of the Total Environment, 652, 48-51.

Dry conditions helped C4 plants emerge during the mid-Oligocene

The period between 30 million years ago to about 5 million years ago (the mid-Oligocene) saw the emergence of a new form of photosynthesis in a subset of plants, the C4 pathway. Researchers have long believed that falling carbon dioxide levels were the cause, but a new study based on biochemical modeling by a group of University of Pennsylvania biologists and paleoclimate modeling by a group at Purdue University, led by professor Matthew Huber (*Earth, Atmospheric and Planetary Sciences*), indicates that water availability may have been the critical factor behind the emergence of C4 plants such as corn, sorghum, and sugar cane.

The researchers used a coupled photosynthesis–hydraulic optimal physiology model in conjunction with paleoclimate modeling to examine the primary selective pressures along the ecological trajectory of C4 photosynthesis and to determine the geographic origins and expansion of the C4 pathway. This modeling system included four factors that could either favor the C3 or the C4 lineage: carbon dioxide (CO_2) concentration, light, temperature and water availability. The findings suggest that water limitation was the primary driver for the initial ecological advantage of C4 over C3 in the mid-Oligocene until CO_2 became low enough to, along with light intensity, drive the global expansion of C4 in the Miocene. This work helps explain how different plant lineages came to be distributed on the planet today and gives some insight into how they might respond to future conditions.

Zhou, H., Helliker, B. R., Huber, M., Dicks, A. and Akçay, E. (2018). C4 photosynthesis and climate through the lens of optimality. Proceedings of the National Academy of Sciences, 115 (47), 12057-12062.



Agriculture, trade, and climate change adaptation: an analysis for Morocco and Turkey

Agricultural production, which is among the most climate-dependent economic activities, is likely to be the economic sector most vulnerable to climate change. Climate change is a global phenomenon with specific impacts and implications for different countries. The extent to which agricultural trade liberalization (removing or reducing barriers and restrictions) can be an adaptation strategy in the face of climate change remains an open discussion.

Professor Wally Tyner, *Agricultural Economics*, and colleagues from Sweden, Spain and Turkey analyzed the potential impacts of climate change at the country level, and evaluated how tariff elimination could serve as an adaptation strategy. The study focused on Turkey and Morocco—both countries face similar climate change impacts to their agricultural sector, are open to international markets and have significant trade in agricultural commodities. However, they differ in terms of the pace and structure of economic development, which directly impacts their respective competitiveness.

The study found that in a scenario where all tariffs are eliminated, for all regions and all commodities, the welfare loss associated with climate change impacts to agriculture would be offset, globally. Total elimination of tariffs is not likely a realistic scenario, so the analysis focused on a series of trade liberalization schemes at regional and sector levels. The researchers find that the scope of the tariff elimination at these levels does matter in determining how successful trade liberalization will be in mitigating the losses associated with climate change. The more trade is liberalized, the higher the global welfare gains are, however, in all the various scenarios analyzed, the net welfare gains are not large enough to offset the loss from climate change impacts on agricultural productivity globally. For Morocco, agricultural trade liberalization, on average, induces additional welfare losses, whereas for Turkey, trade liberalization results in net welfare gains under all scenarios. The research team identifies several important factors that account for these differences, and outlines several areas for continued research, including better understanding the linkages of non-tariff barriers to trade.

Ouraich, I., H. Dudu, W. E. Tyner, and E. H. Cakmak (2018). Agriculture, trade, and climate change adaptation: a global CGE analysis for Morocco and Turkey. The journal of North African Studies: https://doi.org/10.1080/13629387.2018.1463847.

Resilience in hurricane-prone electric power distribution systems

Reliable energy, water and transportation services are an essential part in ensuring national security and sustaining economic productivity and social well-being. This critical infrastructure and the communities that rely on their services are growing increasingly more vulnerable to climatic shocks—the US Department of Energy revealed that severe climate events were among the most frequent cause of power outages since the early 2000s. The recent devastation caused by hurricanes Harvey, Irma, Jose, and Maria further highlights the need for accurate and holistic disaster resilience modeling for proactive preparation, response, and mitigation planning to help minimize the large-scale costs that are typical of natural hazards like tornadoes and hurricanes.

Professor Roshanak Nateghi (*Industrial Engineering and Environmental and Ecological Engineering*) has proposed a new approach to conceptualize the disaster resilience of our critical infrastructure. Rather than looking at resilience as a 1-dimensional concept (e.g., resilience as a function of the fraction of customers without power or the number of protective devices activated during disaster impacts), Nateghi uses a multivariate framework to model the complex interplay between climate hazards, system topology, and the topography of the region to approximate the multidimensional resilience of a system. She then applied the model to estimate the number of power outages, the number of customers without power and the time it took to restore power. The model also established which variables are critical for approximating the resilience of the system. In this analysis, she focused on an electric utility company that serves the central Gulf Coast region of the U.S. This service area was heavily impacted by Hurricane Katrina with more than 80% of the customers affected and outage restorations taking up to 12 days. The model performed well and was found to be a powerful tool for assessing the effectiveness of alternative investment decisions in improving the various dimensions of the resilience of the system.

Nateghi, R. (2018). Multi-Dimensional Infrastructure Resilience Modeling: An Application to Hurricane-Prone Electric Power Distribution Systems. IEEE Access, vol. 6, 2018.

Building political support for carbon pricing

New insights from professor Leigh Raymond (*Political Science*) on the benefits of a carbon pricing policy appeared in a policy brief from the Smart Prosperity Institute, a national research network and policy think tank based at the University of Ottawa, Canada. The brief draws from Raymond's fall 2018 research in Canada as a Fulbright Fellow as well as his earlier work. The brief's main message? "Long running carbon pricing programs tend to generate tangible public benefits beyond emissions reductions that are distributed among citizens in a way that is broadly perceived as fair." Raymond concludes that finding the policy design and communication strategy that will best improve public support for the policy requires careful attention to what concerns are most salient for particular groups affected by the new policy. For example, the Regional Greenhouse Gas Initiative (RGGI), which was the first major carbon pricing policy in the U.S., created and promoted tangible "consumer benefits" by investing in energy efficiency and other programs that lower consumers' energy bills. In California, "public health benefits" aimed at improving local air quality and economic opportunity in disadvantaged communities were more important co-benefits to emphasize for passing carbon pricing legislation. In the European Union Emissions Trading System, revenues were focused on enabling greater "climate benefits" by investing in the development and adoption of no/low carbon technology. Here, reducing the threat of climate impacts was the most important public concern.

PCCRC Seed Grant: Using P-band signals of opportunity for biomass remote sensing

Forests serve as important "'sponges" of atmospheric carbon dioxide, absorbing CO_2 from the atmosphere and storing it in forest biomass. This stored carbon is released during wildfires, controlled burning, and deforestation; however, it is still difficult to assess how much these events are affecting the carbon cycle. This knowledge of carbon flows between forests and the atmosphere is critical to our understanding of future climate change. It is also essential for the development and implementation of mitigation programs, such as the United Nation's Reducing Emissions from Deforestation and forest Degradation (REDD+) program. Despite the importance, monitoring of biomass globally, and especially in underdeveloped areas, is quite inaccurate.

Satellite remote sensing would be the most efficient approach for estimating biomass globally and in difficult to access areas (which includes many regions with the highest biomass density). Although biomass can be estimated through measurements of canopy height or forest extent using lidar or multispectral methods, only microwave observations in P-band or lower frequencies (< 500 MHz) are able to penetrate through dense biomass and provide observations directly related to the forest structure. Satellite measurements of P-bands have several limitations including radio frequency interference, high power requirements, and the need for large antennas. Despite these limitations, several airborne systems (AirMOSS, EcoSAR) are now operational, and investment in global biomass mapping using satellite remote sensing continues including from the European Space Agency for the BIOMASS satellite (scheduled for deployment in 2021).

An alternative method for microwave remote sensing was first proposed by Prof. James Garrison (*Aeronautics and Astronautics*) in the late 1990's using Global Navigation Satellite Systems (GNSS) signals. This technique, now known as "signals of opportunity" (SoOp), re-utilizes existing transmissions (usually deployed for communications or navigation purposes) as illumination sources. In addition to overcoming issues with signal interference, this method allows for measurements to be made with small, omni directional antennas and lower power.

With a PCCRC seed grant, professors Janes Garrison, Brady Hardiman (*Forestry and Natural Resources*), John Couture (*Entomology and Forestry and Natural Resources)*, and Dr. Lola Agues (*NASA Goddard Space Flight Center*), are conducting the first experimental demonstration of the sensitivity of P-band SoOp reflectivity to observe changes in forest biomass. The team is outfitting drones for observations over Martell Forest in West Lafayette, Indiana.

A DJI Matrice 600 pro drone is being used for this study. Left: configuration on the ground; Right: configuration in flight.

Methane emissions from the Baltimore-Washington area based on airborne observations

The value of local, observation-based greenhouse gas estimates is the focus of a recent paper co-authored by PCCRC graduate student fellow Olivia Salmon (*PhD 2018, Chemistry*) and professor emeritus Paul Shepson (*Chemistry*), and led by Xinrong Ren (*University of Maryland*). Their study finds that estimates of methane emissions from cities are dramatically underrepresented—a significant problem given that methane is a more potent greenhouse gas than carbon dioxide. To quantify emissions, the researchers used the Purdue Airborne Laboratory for Atmospheric Research (ALAR) to collect data on methane, carbon dioxide, carbon monoxide, ozone, and black carbon for the Baltimore-Washington region. They report that methane emissions from landfills and natural gas systems are up to 2.8 times higher than what is inferred from the national and state inventories, highlighting the need to reconcile state and national inventories with local observational data.

Ren, X., O. E. Salmon, J. R. Hansford, D. Ahn, D. Hall, S. E. Benish, P. R. Stratton, H. He, S. Sahu, C. Grimes, A. M. F. Heimburger, C. R. Martin, M. D. Cohen, B. Stunder, R. J. Salawitch, S. H. Ehrman, P. B. Shepson,and R. R. Dickerson: Methane Emissions From the Baltimore-Washington Area Based on Airborne Observations: Comparison to Emissions Inventories. J. Geophys. Res. Atmos: https://doi.org/10.1029/2018JD029690, 2019.

The Global Stocktake

When 195 countries signed the Paris Agreement on Climate Change, they committed to keeping global mean temperature increase below 2 degrees Celsius from pre-industrial levels by the end of the century and to make efforts to limit the rise to below 1.5 degrees.

Instead of setting legally binding emission reduction targets, however, the agreement relies on countries' voluntary pledges and actions, monitored by regular reviews to ensure progress towards these goals. This new pledge-and-review global governance model will be reviewed by an equally novel assessment mechanism—the global stocktake.

In addition to assessing collective progress over time, the global stocktake (GST) is also expected to act as an ambition mechanism, inspiring and driving new activities to further reduce emissions over time. Professor Manjana Milkoreit and graduate student Kate Haapala (*Political Science*) analyzed which characteristics of the GST would maximize the chances for its effectiveness and offered suggestions for designing this unprecedented review and ambition mechanism.

Their study included an analysis of the closest available precedent to the GST, the Periodic Review. Created in 2010 by the Parties to the United Nations Framework Convention on Climate Change Conference along with a long-term temperature goal of 2 degrees Celsius, the goal of this new review process was to regularly assess the adequacy of the long-term global temperature goal and the overall progress toward achieving it. The First Periodic Review (FPR) was conducted between 2013-2015, and was used to inform the negotiations in Paris. Milkoreit and Haapala identified success criteria related to three dimensions of the FPR—the nature of the process, procedural characteristics, and outputs and outcomes—and used this analysis to develop a series of lessons for designing the GST.

They suggest that the most important feature of the GST will be its ability to serve as a collective learning and engagement platform for the Parties. In addition to promoting peer-learning, this aspect of the GST could also drive ambition and serve as an enabling mechanism for transformative action and for involving non-state stakeholders. Other key characteristics of the GST include allowing for flexibility and adaptation over time; ensuring inclusiveness, transparency, and fairness; focusing on efficiency in terms of time, funds, and knowledge; and emphasizing the technical work of assessment and learning to keep discussions focused on science and expertise, rather than on negotiations.

Milkoreit, M. and K. Haapala (2018). The global stocktake: design lessons for a new review and ambition mechanism in the international climate regime. Int Environmental Agreements: Politics, Law and Economics, 1-18.

PUTTING GLOBAL CHANGE INTO LOCAL PERSPECTIVE

Weather observations over the last century show that Indiana's climate is already changing. The best available science says these changes will continue and intensify. The Indiana Climate Change Impacts Assessment (IN CCIA) is designed to help Indiana's residents and businesses understand current and upcoming climate change risks so they can plan for a better future. With a series of seven sector-based reports released throughout 2018 (and more scheduled for 2019), the IN CCIA put global change into local perspective.

IN CCIA
Indiana Climate Change Impacts Assessment
www.IndianaClimate.org

Past & Future Climate
Topics include: annual and seasonal temperature and precipitation, length of growing season, plant hardiness zones, heating and cooling demand, snowfall, humidity, and extreme events.

Forest Ecosystems
Topics include: forest regeneration, forest composition and tree habitat suitability, tree growth and harvest, impacts to habitat and ecosystem services, and effects on forest products.

Urban Green Spaces
Topics include: habitat suitability for urban trees, impacts on green drainage infrastructure, urban prairie composition, gas emissions from lawns, and management strategies for protecting urban green infrastructure in a changing climate.

Aquatic Ecosystems
Topics include: changes in water temperature, seasonal shifts in the amount and timing of water, impacts to endangered freshwater mussels, agriculture and nutrients, invasive species, Lake Michigan impacts, and strategies for managing changes in aquatic systems.

March April May June July August September October November

Health
Topics include: health impacts from extreme heat, air quality issues from elevated ozone and allergens, insect-borne illnesses, water-based problems, mental health impacts, and how social vulnerabilities compound future climate impacts.

Agriculture
Topics include: agronomic crops, specialty crops, outdoor laborers, livestock and poultry, soil health and water resources, and pests and disease. In addition to assessing risks, the report also provides strategies for coping with projected changes.

Tourism & Recreation
Topics include: water-based recreation, land-based activities, agritourism, sports and events, impacts to winter tourism and recreation, and a discussion about preparing Hoosier businesses and communities for a future climate.

Selected findings from the IN CCIA

Hoosiers Heating Up

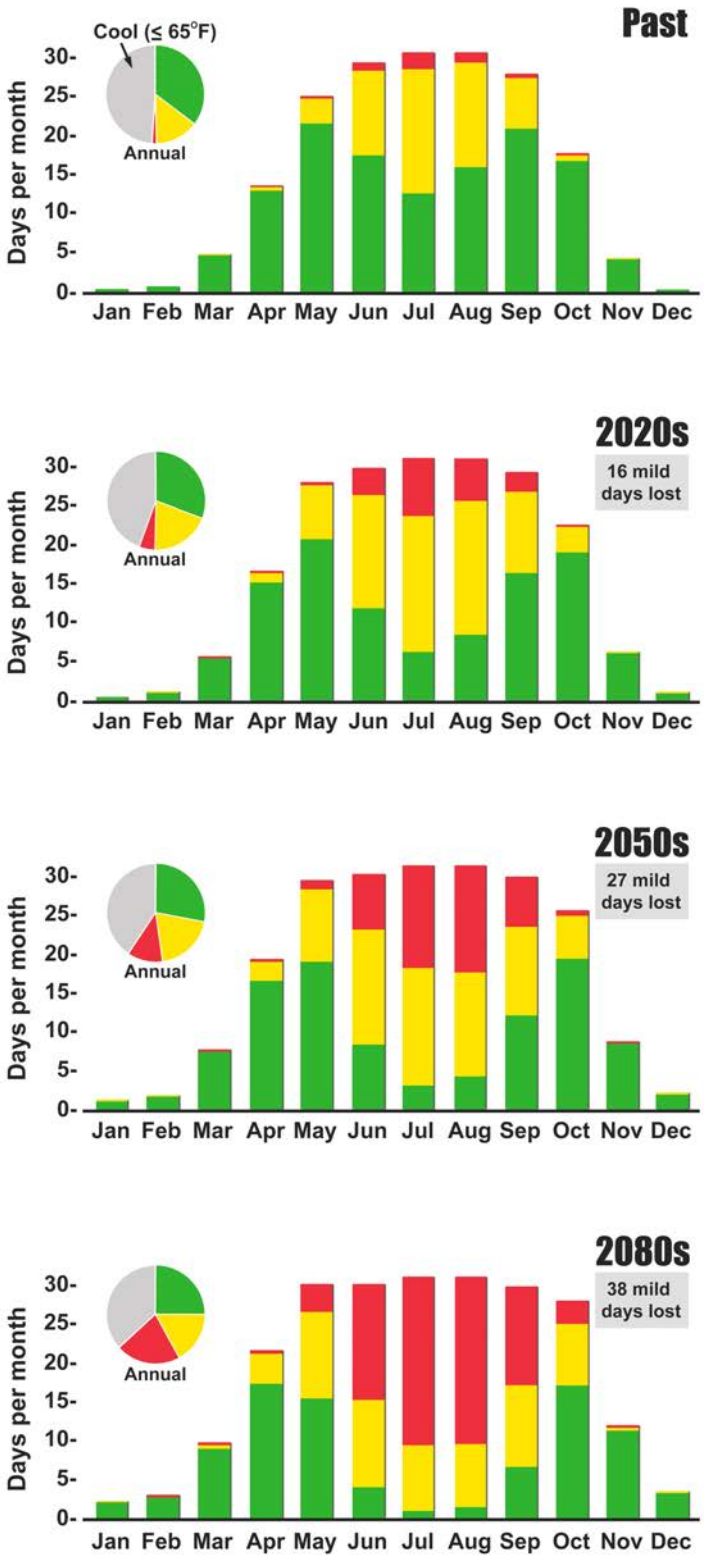
As temperatures increase, Indiana will see a growing number of warm days with temperatures above 65°F, but with notable shifts in the occurrence of mild, hot and extremely hot days. Mild-weather days are defined as those in which the high temperature is above 65°F but at or below 85°F – essentially, warm enough to be outdoors but not uncomfortably hot.

Key Findings

- **Mild days decline and shoulder seasons shift:** comfortable days from May to September are replaced with hot and extremely hot days. Months with predominantly mild weather will start earlier and end later in the year.

- **Summer heat on the rise, lasting longer:** extremely hot days dominate summer months by end of century. Hot weather days in spring and fall increase.

In this analysis, the "past" represents an average for the time period 1915 to 2013. The "2020s" represents the average 30-year future period 2011 to 2040; the "2050s" represents the average 30-year period 2041-2070; and the 2080s represent the 30-year period 2071-2100. Future projections are based on average results from 10 climate models based on a high emissions scenario. These results appear in the IN CCIA report, "Tourism and Recreation in a Warmer Indiana."



Mild (> 65°F and ≤ 85°F)
Hot (> 85°F and ≤ 95°F)
Extreme (> 95°F)

Selected findings from the IN CCIA

Cisco in a Changing Climate

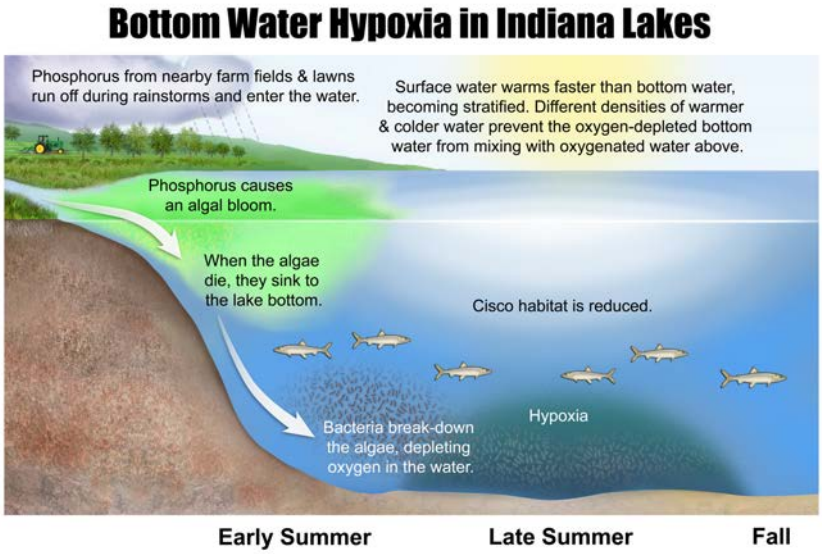
Cisco, a coldwater fish native to northern Indiana's glacial lakes, can only tolerate a narrow range of relatively cool temperatures and needs oxygen-rich water. While cisco inhabit many locations across the Great Lakes region, Indiana is the southernmost extent of its habitat range. Cisco was present in around 50 northern Indiana lakes at the beginning of the 20th Century, but today is found in only six.

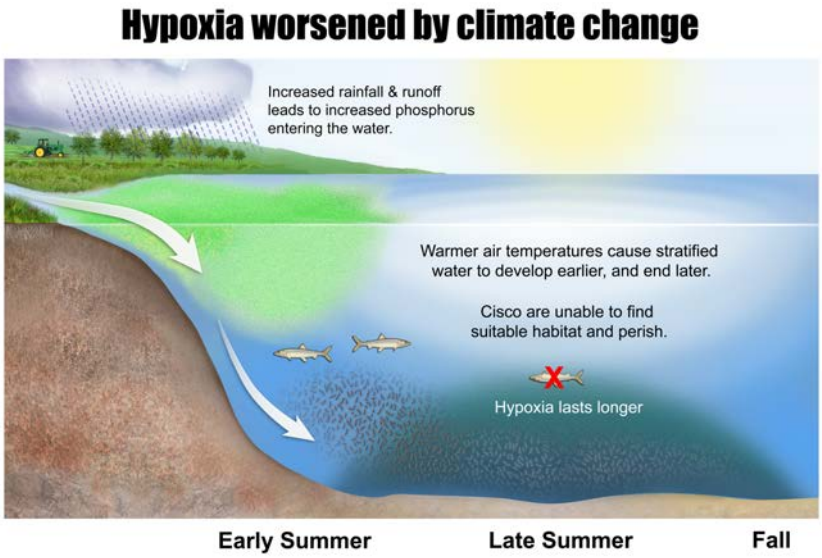
In stratified lakes—where warm surface water and cold bottom water are unable to mix—cisco normally move to cooler bottom waters during the summer. However, in many Indiana lakes, bottom waters become hypoxic (oxygen-depleted) as bacteria decompose algal blooms that develop in response to human-related nutrient runoff (specifically phosphorous).

With warm surface temperatures and limited oxygen in bottom waters, cisco are squeezed between a rock and hard place, and may only be able to occupy a very narrow layer in the middle of the water column. If this suitable layer becomes too narrow, cisco can experience massive die-offs and can disappear entirely from a lake. Studies suggest this phenomenon has contributed to the loss of cisco from many of the Indiana lakes they previously occupied.

With warming temperatures contributing to a longer stratified period and increasing precipitation leading to more phosphorus entering waterways and more intense algal blooms, hypoxic conditions in the bottom waters of Indiana's lakes are expected to become worse in the future. Cisco and other coldwater fishes are likely to find themselves without livable conditions and such species may be lost from Indiana's lakes over this century.

From the IN CCIA report, "Aquatic Ecosystems in a Changing Climate."





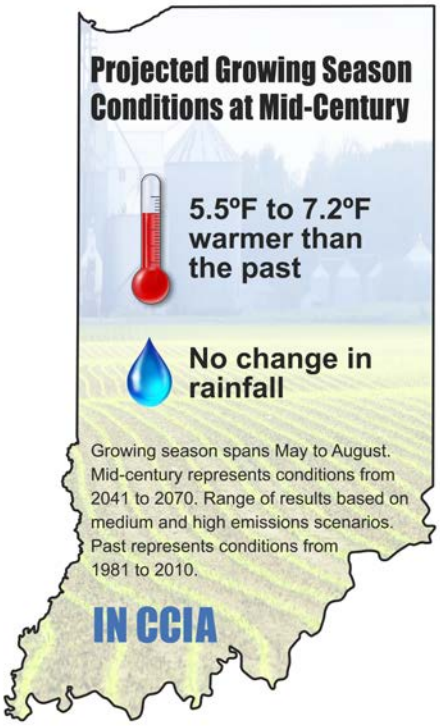
Selected findings from the IN CCIA

Agricultural Water Management

About half of Indiana cropland contains subsurface tile drainage. These buried, permeable pipes drain excess water away from fields, improving soil conditions and field access for farmers. As Indiana's climate changes, so too will soil moisture conditions and subsurface drainage patterns, requiring farmers to rethink water management.

Indiana is projected to become warmer and wetter during the winter and spring months, which is the time of year when subsurface drainflow peaks. With increasing precipitation and more falling as rain instead of snow, Indiana's spring drainage is projected to increase by 32 to 48 percent by mid-century. This will cause more nitrate and other nutrients applied to farm fields to be washed into waterways, costing farmers in lost yield and threatening water quality downstream.

Mid-century climate projections show significant warming in summer and fall, but with no change or slight declines in rainfall. This combination is expected to cause a doubling of growing season water deficits—the difference between growing season precipitation and water demand—increasing statewide demand from 3.7 inches historically to 7.6 to 8.1 inches in the future. Alternative water management approaches that allow farmers to remove and store excess water for use during dry periods later in the season could help farmers cope with Indiana's changing climate. These findings appear in the IN CCIA report, "Agriculture in a Changing Climate."



Climate Conversations

In 2018 the PCCRC engaged over 3,000 Hoosiers in conversations about Indiana's changing climate through dozens of webinars, conferences and community gatherings around the state. Using localized information from the Indiana Climate Change Impacts Assessment (IN CCIA), we are talking about what we can expect if we slow climate change and what would happen if we do nothing. Our goal is to help Hoosiers understand the specific ways climate change affects us here at home and how slowing emissions could reduce future impacts.

What do Hoosier adults think about climate change?

51%
think climate change is mostly caused by humans

35%
think climate change will harm them personally

31%
discuss climate change at least occasionally

[Source: Yale Climate Opinions Maps 2018]

For years, the images shown to us and the language we've used has made it really difficult for Hoosiers to see climate change as an urgent local issue. With the Indiana Climate Change Impacts Assessment, we're changing the conversation and helping Hoosiers understand the ways a shifting climate affects our day-to-day lives.

STORIES OF CHANGE

In his youth, Barny Dunning and his fellow Boy Scout friends made a goal of earning all the nature-related merit badges the program offered. After poring over the requirements for each, they decided to start with Bird Study. It was the easiest of the badges, Dunning recalls, so the thought was to pick the low-hanging fruit and move on. Dunning remembers walking with a guide through a local park, spotting birds he'd never noticed and memorizing their vocalizations. He jotted down observations in a small notebook and finished the requirements for the badge.

The scouts moved on to other badges, but Dunning found himself back in that park and others. Fascinated by birds, Dunning became a wildlife ecologist and is now a full professor at Purdue. That's in addition to countless hours he's spent in his free time with binoculars and notepad in hand.

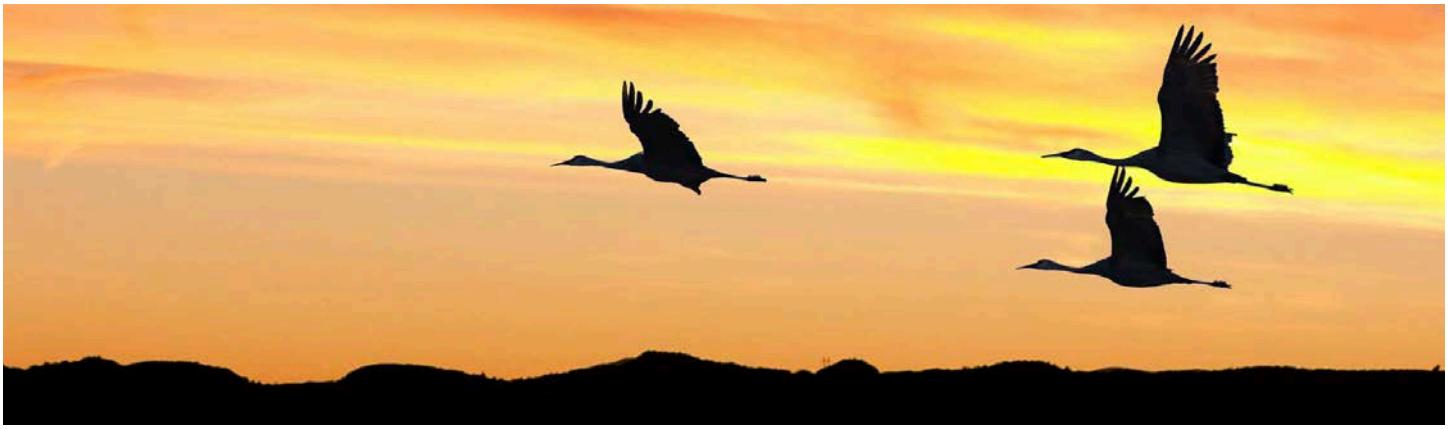
"I've described my career as a Boy Scout merit badge gone horribly wrong," joked Dunning. "I still have the notebook from those first bird sightings. It's from June of 1970."

Since 1994, when Dunning came to Purdue, those notebooks have included notes from Purdue Horticulture Park and West Lafayette's Celery Bog, where he has led weekly tours for bird enthusiasts and the local chapter of the National Audubon Society for more than 20 years now. He still looks forward to every walk and the field trips he leads around the state.

"The intrigue of birding is like stamp collecting. It's seeing something new, getting a new thing to put in an empty space on a page," Dunning said. "You never know what you're going to see, and we know that because of the change of the seasons, we may see something new every time we go out."

For every new thing Dunning sees, and even the more routine things, he takes notes in the same type of notebook he did as a Boy Scout. He has records on bird locations, weather conditions and other observations for all his excursions. Dunning hasn't counted the notebooks, but he once dumped them on his dining room table, and they covered it.

One major thing he can pull from those decades of notes—Indiana's climate is changing rapidly, and it's having a real effect on birds.



Flocking Cranes

One of the annual trips Dunning leads for his graduate students and local bird enthusiasts is up to the Jasper-Pulaski Fish & Wildlife Area each fall to see a gathering of thousands of sandhill cranes. The birders might come with as little as a pen or pencil and a notebook to jot down details from the trip. But others have binoculars, spotting scopes, cameras and lenses, and devices that attach smartphones to the spotting scopes to improve photo-taking capabilities.

These people are a fraction of the 1.2 million birders the U.S Fish & Wildlife Service estimates there are in Indiana. There are 47 million people across the country that count bird watching as a hobby, and they spent $41 billion on it in 2011 from equipment to trips and hotel rooms to see sites like where the sandhill cranes congregate in Indiana. And once at the wildlife area, it's clear to see why. It's a stunning sight.

Birds in pairs or small flocks call to each other as they descend on the fields, their silhouettes a contrast on the pinks, blues, oranges and yellows of the sky as the sun sets. They're in Indiana to feed on leftover grain in harvested fields, usually a pit stop on the way to Georgia or Florida for the winter.

They leave their northern habitats as marshes start to freeze, staying in Indiana until the same happens here. They'll slip from the fields to nearby marshes as the sky grows dark, the water a protection from predators that will make splashing noise should they try to attack during the night.

"It's one of the most spectacular things we can see in this area," Dunning said.

But the scene has changed in two distinct ways since Dunning started taking the trips to Jasper-Pulaski in the 1990s.First, there used to be upwards of 25,000 cranes at Jasper-Pulaski at one time. These days, Dunning's group might see 5,000 or fewer.

"What's really dramatic is seeing hundreds, to thousands, sometimes ten thousand in one place at one time. We don't see those concentrations anymore," Dunning said.

Second, Dunning led this most recent trip in late November, around Thanksgiving. But back in the 1990s, the cranes were in Indiana by late October. The difference? Northern marshes are freezing later and later each fall. The cranes don't have to leave to find a safe habitat by October. And in some cases, Indiana marshes might not freeze at all, meaning cranes are spreading out to more places and might even stay year-round in years where marshes never freeze here.

Changes

A warming climate is playing a central role in the migration habits of sandhill cranes, and there are both costs and benefits associated with that. Positively, having cranes in less-dense groups decreases the likelihood that a disease or accident, such as an oil tanker overturning and contaminating the habitat, would devastate the birds' population. With more hospitable habitats available, the birds are a little more protected. But dispersing the birds makes their gatherings less spectacular. That means fewer people might be interested in traveling to places like Jasper-Pulaski. They'll spend their money elsewhere or on different hobbies. And if interest in birding declines, so too will interest in protecting birds and their habitats.

"When we think back to the kinds of things that got us birders interested when we were young, it was these kinds of events that just capture people's imagination and get them started," Dunning said. "We're losing the kind of experiences that get people into nature."

In a more direct way, Dunning sees ways in which birds are dangerously threatened by a warming climate.

The red knot starts its spring migration from South America to the Chesapeake and Delaware bays based on the length of the days. There, it feeds on the eggs of horseshoe crabs laid on the beaches.

Those crabs come to the beach based on the temperature, and as it warms, they lay their eggs earlier. By the time the red knots appear, the eggs have hatched and the food source is gone, leading to dwindling numbers of the birds.

"We think the horseshoe crabs are responding to local weather conditions and coming out earlier and earlier. But the red knots, since they're in South America, don't know what the weather conditions are in Delaware Bay, so they're using different cues to migrate," Dunning said.

Closer to home, climate may be a factor for the loss of American golden-plovers. The birds have long congregated in the spring in White and Benton county fields. There, they feed on earthworms while molting into their breeding plumage. In the 1990s, Dunning said there were as many as 30,000, perhaps even 90,000 golden-plovers in the area. Today, informal estimates put the number at around 3,000. In that time, Indiana's climate has been volatile. Periods of drought and others where rain has been abundant make the conditions inhospitable for the golden-plover and may be the reason so few are seen these days.

"Changes in the right conditions to support the birds on their movement north is one of the possibilities," Dunning said. "They need something in the middle — between drought or really wet springs. We think one of the advantages of being in these great big agricultural fields is there is a lot of variation and they'll find the right conditions somewhere. But they don't seem to be anywhere here in the numbers we used to see."

The birds could be spreading out or finding new places to congregate. But Dunning hasn't seen reports of golden plovers in adjacent counties or states. So he's left wondering what has happened. Recent surveys suggest population declines in a large number of Arctic-breeding shorebirds, which includes the American golden-plover. So the problems may involve more than just this species. It's possible that there are birders out there just like Dunning who are thrilled to see a golden plover where it's never been before. But that thrill comes with some regret for Dunning.

"I still have the same excitement over all these years when something pops up and I haven't seen it for a long time, or it shows up and it's never been here before," Dunning says. "But it's also depressing to see something that's really cool, and it's cool because it's not supposed to be there. You know it's probably not really good for the birds."

It's a situation that's playing out all over the country, and it's happening to many of the 400 or so species of birds in Indiana. Based on data from the U.S. Forest Service that shows how bird migratory patterns are changing, Dunning estimates that 30 percent of bird species are benefiting from climate change. But the rest are worse off.

"If there is one thing I would tell the bird-watching public: 'yes under climate change there will be winners and losers. But all the evidence we see so far says there will be a lot more losers than winners,'" he said.

"As far as I can tell, that has never happened prior to the 1990s," Dunning says.

Story by Brian Wallheimer for the Stories of Change series. See a video version of this story at www.purdue.edu/climate.

STUDENT TRAVEL GRANTS

The PCCRC Student Travel Grant Program supports the professional development of our students by helping to defray the costs of presenting their scholarly work at professional conferences and meetings. The program also supports student travel to workshops or to field sites related to their research program. This year, the center provided 28 travel grants to students representing 12 different departments in 4 colleges. Here are some of their stories.

Listening to changing social-ecological systems through the sounds of penguins

By Dante Francomano, Forestry and Natural Resources

After five months living at "the end of the world", I have often found myself in closer proximity to penguins than I ever could have imagined. One doesn't just run into live penguins on the streets of Ushuaia, Argentina, but Avenida San Martín, the central commercial street, is lined with tourist shops selling all manner of penguin paraphernalia, and I did recently look up from my coffee, rather unsurprised at the human-sized penguin mascot strolling—or waddling as it were—along the sidewalk. The immense sociocultural significance of penguins in Ushuaia is just one part of the social-ecological story in a growing city that bills itself as the gateway to the Antarctic and an ecotourism destination in its own right.

If one can look beyond the plush toys and stone statuettes, one would notice that the closest place to consistently observe live (non-mascot) penguins is on Isla Martillo, some 60 km east of Ushuaia. Isla Martillo and Isla de los Estados (further to the east) have been two of the principal research sites for my dissertation fieldwork, which has been generously supported by a PCCRC Graduate Student Travel Grant. Along with local scientists from the Centro Austral de Investigaciones Científicas who have been monitoring these Magellanic and rockhopper penguins for years using various methods including camera trapping and censuses, we have installed acoustic recorders from Purdue's Center for Global Soundscapes on each island and conducted observations to determine rates of sound production in individual penguins. At the conclusion of my fieldwork in April 2019, I will begin to look for relationships between my acoustic data, local population densities, and patterns of attendance in the colonies.

The importance of penguins extends beyond their role as ecotourism attractions in places like Ushuaia and their status as charismatic, iconic megafauna that can inspire conservation efforts. Penguins also play important trophic roles in Antarctic and Subantarctic food webs, and due to their reliance on land, sea, and ice habitats, they can be viewed as "sentinel species" that indicate a variety of environmental changes—including those stemming from anthropogenic pressures like climate change, pollution, and fisheries. This sensitivity, while dangerous for penguin populations, presents a valuable opportunity for researchers interested in monitoring ecosystem change in the southern hemisphere.

Women and gender groups at COP24

As an observer to the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) since 2007, the PCCRC has sent a delegation to these international climate negotiations with the overarching goal of better understanding the challenges and opportunities presented in the global negotiation process. This year, graduate student Bi Zhao, *Political Science*, was among those who attended the United Nations Framework Convention on Climate Change (UNFCCC) 24th Conference of the Parties (COP24) in Katowice, Poland. Zhao studies interactions and collaborations among non-governmental organizations, with a focus on women and gender groups. Here are some highlights she recorded from her trip.

Bi Zhao on the her first day at COP24.

On the international day of human rights, civil society groups gathered inside the COP24 venue to commemorate the 120 environmental rights defenders that were killed in 2018.

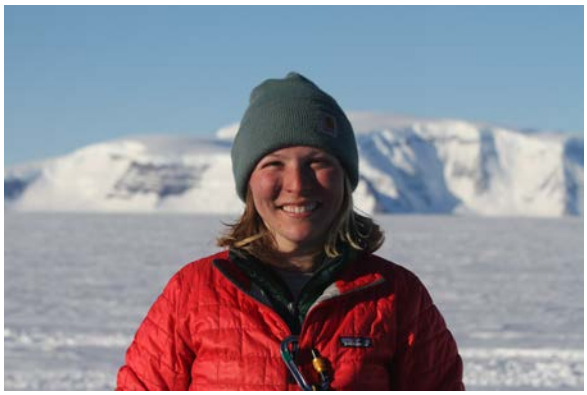
Titilope Akosai is the executive director of the Centre for 21st Century Issues based in Lagos, Nigeria. She shared with Zhao details about her work at the COPs—especially efforts to ensure gender-responsive climate policy and women's leadership in the decision-making processes of the UNFCCC.

The Women and Gender Constituency organized a day to highlight the efforts of women in the Global South. Various groups shared inspiring stories of how they are implementing solutions and empowering women to tackle climate change in their communities.

Each year, the Gender-Just Climate Solution Awards celebrates real solutions for a more just, equal and healthy planet. Honorees at COP24 included Dorothee Linsenga, Congo DRC, for her work on women's access to land and forest rights; Clive Chibule, Zambia, for his work training 537 women in project management and climate resilience; and Trupti Jain, India, for developing new technology to tackle the severe impacts of excessive rain water from storms.

Mapping, measuring, and modeling Antarctica

By Sarah Sams, Earth, Atmospheric and Planetary Sciences



My ongoing research as a Master's student at Purdue University is focused on ice sheet thickness changes in western Dronning Maud Land, Antarctica since the Last Glacial Maximum. This research is being conducted as part of a large international collaborative project known as Mapping, Measuring, and Modeling Antarctic Geomorphology and Ice Change in Dronning Maud Land (MAGIC-DML). My involvement in the project is participating in recent fieldwork in DML to collect rock samples exhibiting past glaciation and analyzing the resulting samples at the Purdue Rare Isotope Measurement Laboratory. Due to the large number of researchers involved and the interdisciplinary nature of the project, it is necessary for all team members to meet annually to discuss the ongoing work and future goals. During June 2018, I attended the annual MAGIC-DML project team meeting and POLAR/Scientific Committee on Antarctic Research 2018 General Assembly in Davos, Switzerland.

As part of the team meeting, I led discussions about the samples I helped collect during the 2017-2018 field season, focusing on the reasoning for selection and prioritization within what was collected. I also participated in discussions on new data, budgeting analyses, and scientific outreach. Others in MAGIC-DML led discussions surrounding analytical techniques, ice sheet modeling, and method development. Being present at this team meeting was critical to my knowledge of the ongoing research within MAGIC-DML and provided guidance on the future of my own work.

Fortunately, the 2018 team meeting coincided with the POLAR/Scientific Committee on Antarctic Research 2018 General Assembly. At this conference, I had the opportunity to meet other polar researchers and learn about both my field and other fields of Antarctic research. Being present at a variety of lectures, talks, and posters allowed me to frame the research I am doing in the broader context of glacial geomorphology and Antarctic science.

Receiving the PCCRC graduate student travel grant allowed me to collaborate with other MAGIC-DML team members and learn about the forefront of polar science. I am very grateful for the PCCRC affording me this opportunity and look forward to applying what I learned in my research.

2018 Travel Grant Recipients

Spring 2018

- Michelle Helmer, *Forestry and Natural Resources*
- Heather Cann, *Political Science*
- Laura Ploughe, *Biological Sciences*
- Dante Francomano, *Forestry and Natural Resources*
- Sarah Sams, *Earth, Atmospheric and Planetary Sciences*
- Becca Nixon, *Forestry and Natural Resources*
- Sushant Mehan, *Agricultural and Biological Engineering*
- Feixiong Huang, *Aeronautics and Astronautics*
- Mustafa Lokhandwala, *Industrial Engineering*
- Jessica Eise, *Communication*
- Akane Ota, *Forestry and Natural Resources*
- Maria del Rosario Uribe, *Biological Science*
- Nehika Mathur, *Environmental and Ecological Engineering*

Fall 2018

- Leonardo Bertassello, *Civil Engineering*
- Bithi Di, *Earth, Atmospheric and Planetary Sciences*
- Reyes Espinoza, *Philosophy*
- Kayenat Kabir, *Agricultural Economics*
- Huan Fang, *Earth, Atmospheric and Planetary Sciences*
- Jason Hawes, *Forestry and Natural Resources*
- Nagisa Ishinabe, *Industrial Engineering*
- Jacob Klaybor, *Forestry and Natural Resources*
- Jianghanyang Li, *Earth, Atmospheric and Planetary Sciences*
- Zhaoyu Kou, *Environmental and Ecological Engineering*
- Mayra Rodriguez-Gonzalez, *Forestry and Natural Resources*
- Licheng Liu, *Earth, Atmospheric and Planetary Sciences*
- Tariq Usman Saeed, *Civil Engineering*
- Franklin Wagner, *Forestry and Natural Resources*
- Xinyue Wang, *Earth, Atmospheric and Planetary Sciences*

CAMPUS SPECIAL EVENTS

Realistic Climate Solutions: Local to Global Policy

What are some of the most cost-effective, realistic, and equitable options for addressing climate change? The PCCRC partnered with the Purdue Policy Research Institute to organize a panel discussion featuring the perspectives of four individuals who have worked on realistic and equitable policy solutions to climate change at every level of governance: local, state, national, and global. The event was held on April 2, 2018 to a full house in Krannert Auditorium.

Moderated by professor Leigh Raymond, Political Science, the panel offered diverse perspectives for making progress on the challenge of climate change across political scales, based on the substantial experience of each panelist working on the issue. In the first half of the program, each speaker described their experience and ideas for creating realistic solutions to climate change in their particular political context. The second half of the program featured a discussion among the panelists as well as questions from the audience.

Congressman Robert Inglis, Former congressman from South Carolina, and executive director of RepublicEN, an organization promoting free-enterprise solutions to climate.change.

Janet McCabe, professor of practice at the Indiana University McKinney School of Law and Former Assistant Administrator EPA-Office of Air and Radiation.

Assembly Member Eduardo Garcia, California assembly member and co-sponsor of the bill to renew California's groundbreaking cap and trade program through 2030.

Mayor Greg Ballard, former mayor of Indianapolis who created the city's first Office of Sustainability and the SustainIndy Initiative.

The Road From Paris: An Update on the International Climate Change Negotiations

In 2015, countries gathered under the United Nations Framework Convention on Climate Change adopted an international agreement to address the threat of climate change. The Paris Agreement was praised as an historic success after many years of contentious and failed negotiations. On February 7, 2018, the center hosted a panel discussion to recap the key achievements but also weaknesses of the Paris Agreement and reflect on the progress made since 2015. Purdue professors Manjana Milkoreit and Robert Marzec were joined by graduate students Kate Haapala, Roberta Weiner, and Bi Zhao for this special presentation.

Toward a Sustainable Environment in a Changing Climate

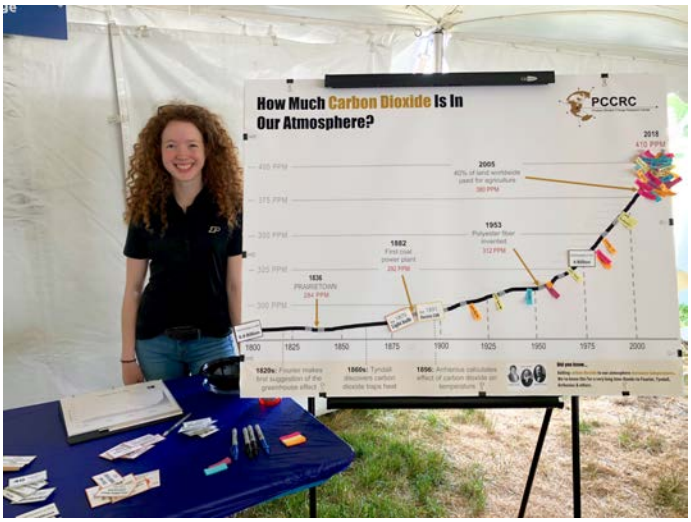
In partnership with the Center for the Environment, the PCCRC co-hosted a series of campus events featuring leading figures within the science, journalism, and public communities highlighting important topics in the area of climate change and environmental sustainability.

- January 24: Dr. Joe Fargione, chief scientist for North America with The Nature Conservancy presented, "Natural Climate Solutions."
- February 4: Dr. Dennis Todey, Director of the USDA Midwest Climate Hub shared details about the Hub and discussed opportunities for collaboration.
- March 5: Dr. Ben Santer, atmospheric scientist, Lawrence Livermore National Laboratory presented, "How a Sentence Changed Climate Science."
- March 6: Dr. Andrew Light, professor of philosophy and public policy, George Mason University, presented, "The Roads to and from the Paris Climate Agreement."
- April 11: Mr. David Roberts, author and journalist at Grist presented, "The key to tackling climate change: electrify everything!"
- April 12: Mr. Bill McKibben of 350.org, presented, "Hot Times: Reports from the Front Lines of the Climate Fight."
- April 13: Dr. Susan Crate, professor of anthropology, George Mason University, and Kathryn Yerogov-Crate discussed their new film *The Anthropologis*t after an on-campus screening.
- April 23: Dr. Janet McCabe, professor of practice, Indiana University McKinney School of Law, presented, "Rolling Back an Environmental Agenda: Will it Stick?"

THE LARGER COMMUNITY

2018 Curiosity Fair at Conner Prairie in Fishers, Indiana

In June, 2018, the PCCRC was in the Science Big Top at Conner Prairie talking about CO_2, rising temperatures and Indiana climate impacts. Conner Prairie, located in Fishers, Indiana, is a living history museum that recreates life in the early 1800s in central Indiana. Their annual Curiosity Fair, which draws in nearly 4,000 visitors over a two-day period, gives families of all ages an opportunity to play, create, and investigate the mysteries of the world around them. PCCRC operations manager Melissa Widhalm and student intern Iris O'Donnell Bellisario hosted an interactive booth where visitors could learn about carbon dioxide, rising air temperatures, and lifestyle choices that contribute to our changing climate.



Climate Science Day on Capitol Hill

Each year since 2011, scientists gather in Washington, D.C. to meet with members of Congress and congressional staff to have conversations about the importance of climate science and its role in protecting jobs, infrastructure, agriculture, and public safety— among other so many other things.

PCCRC director Jeff Dukes spoke with some of our Indiana legislators and their staff, including Representatives Jackie Walorski and Todd Rokita, Congressman Jim Banks, Congresswoman Susan Brooks, and Senators Todd Young and Joe Donnelly.

Making Climate Assessments Work

States, counties, cities, and local stakeholders are increasingly taking the lead on climate change assessments. On August 14th, the National Academies hosted a 2-day workshop in Washington, D.C. exploring subnational climate assessments. The program considered questions such as: What are the key elements of success? What challenges do decision makers face in implementing proposed interventions? What strategies are most effective in engaging utilities and other key stakeholders? PCCRC Director Jeff Dukes joined the discussion and offered insights from the IN CCIA. The event was sponsored by the California Energy Commission and the Electric Power Research Institute.

Courage, Brains, and Muscle: Our Environmental Champions

Former First Lady Judy O'Bannon traveled the state in search of environmental champions, discovering creative individuals who are successfully improving sustainability and reducing pollution in Indiana. At Purdue, Judy met with director Jeff Dukes, affiliates Jim Garrison, Mike Baldwin, and their students to learn more about the work we're doing for the state, our country and the world. O'Bannon's interviews were aired in a special program on WFYI, Indianapolis.

Alumni Conversation Series

This year, as Purdue celebrates 150 years of Giant Leaps, the PCCRC has kicked off a new alumni program to promote awareness of the work underway on campus on important climate change topics, from the state of the science to the state of possible solutions, and from the local to the global scales.

The Alumni Conversation Series, a collaboration with the Purdue Alumni Association, is designed to engage our alumni—where they live—with thought-provoking content and an opportunity to network with faculty, friends and other alumni. Our first event was hosted by the Purdue Alumni Club of Washington, DC and was a designated Ideas Festival special event: **What IF We Ignore Climate Change?**

A team of Purdue climate change experts discussed this question, in the context of an alarming new report issued by the United Nations warning that we must limit temperature rise to 1.5 degrees Celsius or risk a "life-or-death situation" for hundreds of millions of people and for ecosystems around the world. Jeff Dukes moderated the conversation among professors Manjana Milkoreit, *Political Science*; Dan Chavas, *Earth, Atmospheric, and Planetary Sciences*; Linda Prokopy, *Forestry and Natural Resources*; and Matthew Huber, *Earth, Atmospheric, and Planetary Sciences*. Over 40 alumni from the greater Washington, D.C. area joined the conversation.

The majority of Americans recognize that climate change is happening, but many do not understand how it will impact them directly and why there is a sense of urgency to do something about it.

This year, the center has directly reached over 3100 people through workshops, panel discussions, lectures, meetings and presentations—in cities all across Indiana. We're sparking conversations in our state because if we are not talking about the problem, we are not going to solve it.

In 2019, we will continue our outreach to communities, businesses, and civic organizations around the state, while also expanding our engagement with Purdue alumni across the country.

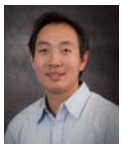
Newest faculty affiliates

Michele Buzon, *Anthropology*, investigates the social and cultural perceptions of, and experiences with, climate change in Bronze and Early Iron Ages in the Near East.

Natalie Lambert, *Brian Lamb School of Communication*, studies climate change communication in developing countries, analyzing the climate change attitudes and beliefs of coffee farmers in Pereira, Colombia.

Alexander Laskin, *Chemistry*, studies atmospheric aerosols and their impacts on climate and public health.

Jingjing Liang, *Forestry and Natural Resources*, is focused on studies of global forest resources and ecology, terrestrial biodiversity, and forest carbon dynamics.



Catharine Searle, *Biological Sciences*, studies disease ecology, community ecology, host-parasite interactions, and freshwater biology.

Faculty affiliates by department

Aeronautics & Astronautics: James Garrison

Agronomy: Laura Bowling, Sylvie Brouder, Melba Crawford[1], Richard Grant, Cliff Johnston[2], Dev Niyogi[2], Ronald Turco, and Jeffrey Volenec

Agricultural & Biological Engineering: Indrajeet Chaubey[2], Keith Cherkauer, Jane Frankenberger, Margaret Gitau, Sara McMillan, and Shweta Singh

Agricultural Economics: Joseph Balagtas, Otto Doering, Alla Golub, Thomas Hertel, Paul Preckel, Jacob Ricker-Gilbert, Juan Sesmero, Gerald (Jerry) Shively, Nathanael Thompson, Wally Tyner, Dominique van der Mensbrugghe, and Michael Wetzstein

Agricultural Sciences Education and Communication: Linda Pfeiffer

Anthropology: Michele Buzon, Jennifer Johnson and Laura Zanotti

Biological Sciences: Catherine Searle

Building & Construction Management: Kirk Alter

Communication: Natalie Lambert

Chemistry: Alexander Laskin

Civil Engineering: Brandon Boor, Samuel Labi, Larry Nies, Suresh Rao[4], Amisha Shah, Cary Troy, and David Yu[6]

Curriculum and Instruction: Dan Shepardson [2]

Earth, Atmospheric and Planetary Sciences: Ernest Agee, Michael Baldwin, Dan Chavas, Timothy Filley [4], Alexander Gluhovsky[3], Harshvardhan, Matthew Huber, Nathaniel (Nat) Lifton, Greg Michalski, Wen-wen Tung, Lisa Welp, and Qianlai Zhuang[4]

Economics: Timothy Cason

English: Robert Marzec

Entomology: Grzegorz Buczkowski, John Couture [7]

Forestry and Natural Resources: Jeffrey Dukes[5], Songlin Fei, Reuben Goforth, Brady Hardiman, Tomas Höök, Douglass Jacobs, Jingjing Liang; Zhao Ma, Rick Meilan, Bryan Pijanowski, Linda Prokopy, Guofan Shao, Robert Swihart, and Pat Zollner

Health Sciences: Jennifer Freeman and James McGlothlin

Health and Kinesiology: David Klenosky

Hospitality and Tourism Management: Jonathan Day

Industrial Engineering: Hua Cai, David Johnson[6], and Roshanak Nateghi

Mechanical Engineering: Jay Gore

Philosophy: Daniel Kelly

Physics: Marc Caffee

Political Science: Manjana Milkoreit, Leigh Raymond, and Mark Tilton

Psychological Sciences: Erin Hennes

Statistics: Hao Zhang

Technology Leadership and Innovation: Brett Crawford

Visual and Performing Arts: Charles Gick

Faculty Executive Committee: Michael Baldwin, Laura Bowling, Otto Doering, James Garrison, Shweta Singh, and Qianlai Zhuang

Staff: Jeffrey Dukes, Director; Iris O'Donnell Belisario, Student Intern; Cindy Fate, Administrative Assistant; Rose Filley, Managing Director; Melissa Widhalm, Operations Manager.

[1]joint appointment in Civil Engineering; [2] joint appointment in Earth, Atmospheric and Planetary Sciences; [3] joint appointment in Statistics; [4] joint appointment in Agronomy; [5] joint appointment in Biological Sciences; [6] joint appointment in Political Science, [7] joint appointment in Forestry and Natural Resources.