2019 NCAR ANNUAL REPORT

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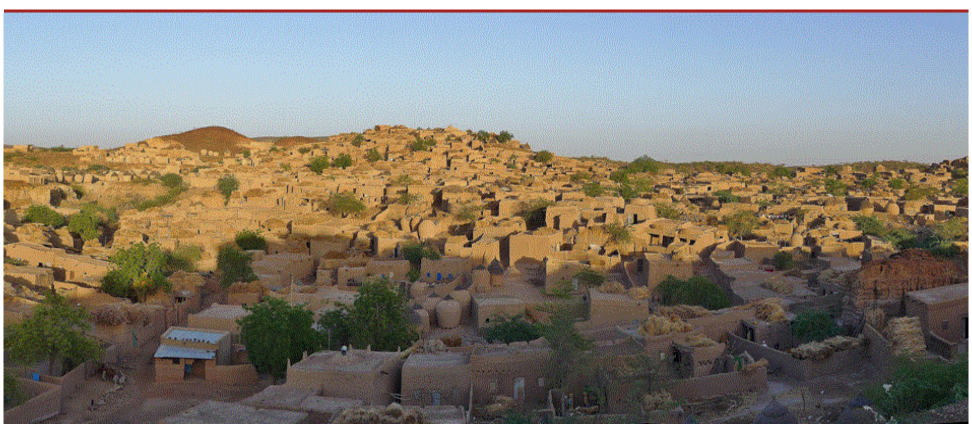
A MESSAGE FROM THE NCAR DIRECTOR

Coming Soon!

BIG DATA PROJECT EXPLORES PREDICTABILITY OF CLIMATE CONDITIONS YEARS IN ADVANCE

DECADAL PREDICTION LARGE ENSEMBLE IS FREELY AVAILABLE TO THE COMMUNITY



A panoramic shot of Bouza, Niger, in the Sahel region of Africa. With the help of the Decadal Prediction Large Ensemble, scientists have determined that it may be possible to predict wetter- or drier-than-average conditions in the Sahel years in advance. (Image: Teseum, Flickr.)

As scientists work to forecast climate patterns from years to as much as a decade in advance, the National Center for Atmospheric Research (NCAR) has created a vast new set of computer simulations to help identify the types of events that are most predictable.

For example, an early analysis of the data set, which contains a staggering 24,800 simulated years of climate information, finds there is potential to predict sea surface temperatures in the North Atlantic, which are tied to climate conditions across Europe and Asia. The analysis also finds that multi-year precipitation anomalies — wetter- or drier-than-average conditions — over parts of Africa, including the Sahel, as well Europe and Eurasia, may be predictable as well.

The NCAR scientists who led the effort, called the Decadal Prediction Large Ensemble (DPLE), expect other areas of predictability to emerge as experts from across a wide range of fields begin to dig into the data set, which is freely available to the research community. For example, the DPLE contains data on ocean biogeochemistry, which will allow scientists to search for predictability in aspects of the ocean that affect fisheries and the global carbon cycle.

The massive new data set, which is described this month in the Bulletin of the American Meteorological Society, was created using the NCAR-based Community Earth System Model (CESM). For each year between 1954 and 2015, the scientists used historical observations to create initial conditions for 40 model simulations and then allowed the simulations to run forward 10 years. The bulk of the simulations were run on the Cheyenne system at the NCAR-Wyoming Supercomputing Center.

"There are groups all over the world working on using observations to initialize decadal predictions," said NCAR scientist Stephen Yeager, the lead author of the paper. "What makes our effort unique is the number of model simulations and the sheer computational resources it took to generate this data set. Having a data set this size allows you to explore a lot of unanswered questions in this field that no one else can."

The creation of the data set was funded by National Science Foundation, which is NCAR's sponsor, the National Oceanic and Atmospheric Administration, and the U.S. Department of Energy.

FINDING SIGNALS IN THE NOISE

In recent decades, scientists have improved short-term, localized weather forecasts that go out about a week or a little longer, but the natural chaos of the atmosphere makes it impossible to predict precise weather conditions at a particular time and place more than about two weeks in advance.

Scientists, however, are interested in whether regional climate patterns — from unusually cold winters in Europe, for example, to multi-year droughts in northern Africa — might be predictable months, years, or even a decade in advance. Such long-term forecasts would be invaluable for farmers, utility managers, and many industries that could benefit from extended planning.

The DPLE offers scientists a new tool, unprecedented in scope, to examine the possibility of making these kinds of long-term predictions on time scales of a few years to a decade out. The DPLE comprises 62 individual ensembles (or sets of simulations), one for every year between 1954 and 2015. Each ensemble consists of 40 members running forward a decade in simulated time.

The ensembles were kicked off using real-world historical observations for Nov. 1 of the year they were started, but the initial temperature conditions for each of the 40 members were tweaked ever so slightly — by less than a trillionth of a degree. Those tiny differences create striking variety across the ensemble, representing the natural variability in the climate system. By averaging together the individual members of the ensemble, however, the scientists can also pick out signals from the noise. Those signals point to areas of potential long-term predictability.

For example, if scientists analyze the average of the 40 ensemble members from one particular year and find a trend — perhaps drier-than-average conditions over a particular land area for multiple years — they can then look to see if the trend actually occurred in the historic record.

"The 40 ensemble members evolve differently, producing a spread of results over time, due to the chaotic nature of the climate system," Yeager said. "But when you take the ensemble mean, you average out all those chaotic variations and what you are left with is the signal. If that signal corresponds with observed reality, you have a skillful prediction."

Aside from its incredible size (the DPLE clocks in at roughly 600 terabytes), it has another unique advantage compared to other decadal prediction efforts. The DPLE builds on and complements another big data project at NCAR known simply as the Large Ensemble. The Large Ensemble, which also uses CESM and is based on the same protocol, consists of a single 40-member ensemble stretching from 1920 to 2100. Unlike the DPLE, it is not initialized using real-world conditions. Instead, its ensemble mean "signal" reflects the impacts of human-caused climate change as well as variations in the amount of solar radiation driving the climate system.

Being able to compare the DPLE and the Large Ensemble allows researchers to determine whether apparently skillful DPLE predictions are connected to an actual ability to forecast natural, internal cycles — such as changes to large ocean currents that transport heat around the globe — or rather to changes related to human-caused climate change, including a general warming of global surface temperatures.

"No one else in the world has these two large ensembles that can be compared and contrasted in this way," Yeager said.

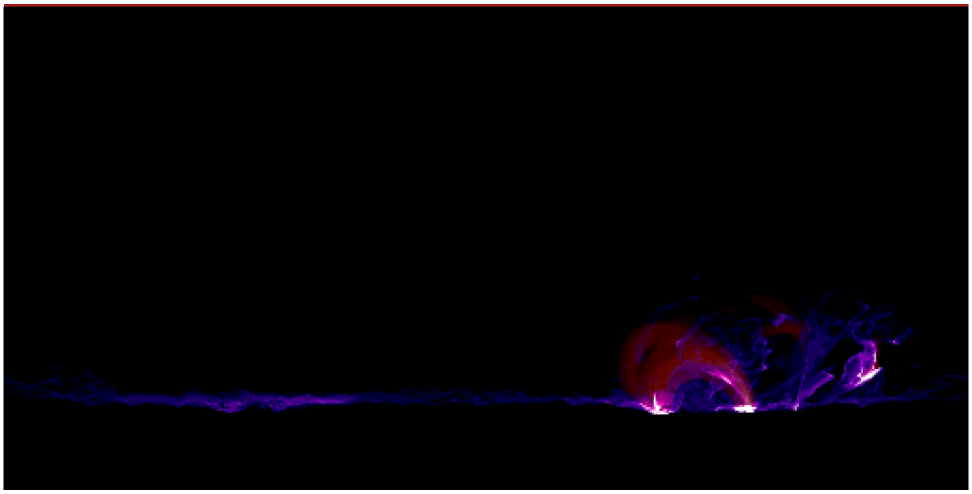
ABOUT THE ARTICLE

Title: Predicting near-term changes in the Earth system: A large ensemble of initialized decadal prediction simulations using the Community Earth System Model
Authors: S. G. Yeager, G. Danabasoglu, N. A. Rosenbloom, W. Strand, S. C. Bates, G. A. Meehl, A. R. Karspeck, K. Lindsay, M. C.

Long, H. Teng, and N. S. Lovenduski
Journal: *Bulletin of the American Meteorological Society*

SOLAR FLARES: FROM EMERGENCE TO ERUPTION

COMPREHENSIVE MODEL CAPTURES ENTIRE LIFE CYCLE



This visualization is an animation of the solar flare modeled in the new study. The violet color represents plasma with temperature less than 1 million Kelvin. Red represents temperatures between 1 million and 10 million Kelvin, and green represents temperatures above 10 million Kelvin. (Image: Courtesy Mark Cheung, Lockheed Martin, and Matthias Rempel, NCAR)

Editor's note: An outreach video about the simulated solar flare is available at https://youtu.be/kyhsBqB2x_Y.

A team of scientists has, for the first time, used a single, cohesive computer model to simulate the entire life cycle of a solar flare: from the buildup of energy thousands of kilometers below the solar surface, to the emergence of tangled magnetic field lines, to the explosive release of energy in a brilliant flash.

The accomplishment, detailed in the journal Nature Astronomy, sets the stage for future solar models to realistically simulate the Sun's own weather as it unfolds in real time, including the appearance of roiling sunspots, which sometimes produce flares and coronal mass ejections. These eruptions can have widespread impacts on Earth, from disrupting power grids and communications networks, to damaging satellites and endangering astronauts.

Scientists at the National Center for Atmospheric Research (NCAR) and the Lockheed Martin Solar and Astrophysics Laboratory led the research. The comprehensive new simulation captures the formation of a solar flare in a more realistic way than previous efforts, and it includes the spectrum of light emissions known to be associated with flares.

"This work allows us to provide an explanation for why flares look like the way they do, not just at a single wavelength, but in visible wavelengths, in ultraviolet and extreme ultraviolet wavelengths, and in X-rays," said Mark Cheung, a staff physicist at Lockheed Martin Solar and Astrophysics Laboratory and a visiting scholar at Stanford University. "We are explaining the many colors of solar flares."

The research was funded largely by NASA and by the National Science Foundation, which is NCAR's sponsor.

BRIDGING THE SCALES

For the new study, the scientists had to build a solar model that could stretch across multiple regions of the Sun, capturing the complex and unique physical behavior of each one.

The resulting model begins in the upper part of the convection zone — about 10,000 kilometers below the Sun's surface — rises through the solar surface, and pushes out 40,000 kilometers into the solar atmosphere, known as the corona. The differences in gas density, pressure, and other characteristics of the Sun represented across the model are vast.

To successfully simulate a solar flare from emergence to energy release, the scientists needed to add detailed equations to the model that could allow each region to contribute to the solar flare evolution in a realistic way. But they also had to be careful not to make the model so complicated that it would no longer be practical to run with available supercomputing resources.

"We have a model that covers a big range of physical conditions, which makes it very challenging," said NCAR scientist Matthias Rempel. "This kind of realism requires innovative solutions."

To address the challenges, Rempel borrowed a mathematical technique historically used by researchers studying the magnetospheres of Earth and other planets. The technique, which allowed the scientists to compress the difference in time scales between the layers without losing accuracy, enabled the research team to create a model that was both realistic and computationally efficient.

The next step was to set up a scenario on the simulated Sun. In previous research using less complex models, scientists have needed to initiate the models nearly at the moment when the flare would erupt to be able to get a flare to form at all.

In the new study, the team wanted to see if their model could generate a flare on its own. They started by setting up a scenario with conditions inspired by a particularly active sunspot observed in March 2014. The actual sunspot spawned dozens of flares during the time it was visible, including one very powerful X-class and three moderately powerful M-class flares. The scientists did not try to mimic the 2014 sunspot accurately; instead they roughly approximated the same solar ingredients that were present at the time — and that were so effective at producing flares.

Then they let the model go, watching to see if it would generate a flare on its own.

"Our model was able to capture the entire process, from the buildup of energy to emergence at the surface to rising into the corona, energizing the corona, and then getting to the point when the energy is released in a solar flare," Rempel said.

Now that the model has shown it is capable of realistically simulating a flare's entire life cycle, the scientists are going to test it with real-world observations of the Sun and see if it can successfully simulate what actually occurs on the solar surface.

"This was a stand-alone simulation that was inspired by observed data," Rempel said. "The next step is to directly input observed data into the model and let it drive what's happening. It's an important way to validate the model, and the model can also help us better understand what it is we're observing on the Sun."

ABOUT THE ARTICLE

Title: Predicting near-term changes in the Earth system: A large ensemble of initialized decadal prediction simulations using the Community Earth System Model
Authors: S. G. Yeager, G. Danabasoglu, N. A. Rosenbloom, W. Strand, S. C. Bates, G. A. Meehl, A. R. Karspeck, K. Lindsay, M. C. Long, H. Teng, and N. S. Lovenduski
Journal: *Bulletin of the American Meteorological Society*

FIELD CAMPAIGN FLIED THROUGH ICY WEATHER

SCIENTISTS STUDY DANGEROUS FLIGHT CONDITIONS


Ice buildup on the NRC Convair 580 can be seen on the aircraft nose and windows after a flight to collect data on ice-prone weather conditions. (©UCAR. Image: Scott Landolt/NCAR)

Winter in the United States can produce some of the most dangerous weather for the aviation industry, including freezing rain, freezing drizzle, and sleet. Those are the ideal conditions for a field campaign focused on collecting in-flight data in some of the most treacherous North American icing conditions.

The program is led by the Federal Aviation Administration (FAA), in partnership with the National Center for Atmospheric Research (NCAR) and other organizations, and will help improve weather models and forecasts for those who work in aviation.

"Icy weather conditions are a hazard to pilots, crew, and passengers around the world," said Scott Landolt, an NCAR scientist and co-lead principal investigator for the field campaign. "This research will help make flight transportation safer, especially for smaller aircraft that fly at lower altitudes where they are at a higher risk of ice buildup during flight."

Scientists with the In-Cloud Icing and Large-Drop Experiment (ICICLE) have been flying through extreme winter weather conditions since Jan. 28 using the National Research Council of Canada's (NRC) Convair 580, a twin-engine research aircraft. Based in Rockford, Illinois, the scientists and Convair crew will travel to Wisconsin, Michigan, Iowa, and other neighboring states for another two weeks, chasing icy weather conditions.

This project is part of the FAA's Aviation Weather Research Program, which sponsors research that will help minimize the impact of weather on the National Airspace System, including turbulence, ceiling and visibility, thunderstorms, and aircraft icing. "Aviation users can only operate in icing conditions for which the aircraft is certified. If an aircraft demonstrates it can operate safely in a particular icing environment, it can become certified for flight into those icing environments," said Stephanie DiVito, the FAA ICICLE program lead and terminal area icing project lead. "Any icing environment outside of those provisions must be avoided. In order to avoid icing, the user must know it exists."

"The data from ICICLE will help develop and validate icing diagnosis and forecast tools for the identification of icing conditions an aviation user may encounter, both in the terminal and en route environments, to enable safe operations in the National Airspace

System," said Danny Sims, the FAA in-flight icing weather project lead.

ICE IN THE SKY

The data collected during ICICLE will be used to improve weather models and tools used in icing diagnosis and forecasting. Improving and drawing upon the strengths of these weather tools the aviation industry relies on could help pilots avert risky situations, like ice buildup.

Ice buildup on the surface of an aircraft can occur on the ground or in-flight. When it happens on the ground, an aircraft must be de-iced before takeoff. During a flight, ice can form when an aircraft flies through supercooled liquid water — water that remains liquid in the atmosphere at temperatures well below freezing.

"The risk to aviation in these conditions is that as soon as an airplane flies through this cloud, the supercooled droplets will freeze on impact," said Julie Haggerty, who leads the in-flight icing program at NCAR and is co-lead principal investigator for ICICLE. "Airplanes are shaped to be aerodynamically functional, and when you add ice this changes the shape of the airplane and the airflow. Suddenly the airplane doesn't fly as it is supposed to."

The goal of the field campaign is to capture the various environments in which supercooled liquid water can exist in winter conditions aloft and to produce a data set that cannot be gathered from weather stations on the ground. The scientists are particularly interested in studying large water drops, typically bigger than what is seen in foggy weather.

Instruments and sensors are attached to the wing of the NRC Convair 580 to gather data on supercooled liquid water and ice crystals during flight. (Image: National Research Council of Canada)

"Getting something correct at the surface is insufficient. We need the observations in the sky as well because that is where the water droplets affect the airplanes once they are off the ground," said Greg Thompson, an atmospheric scientist at NCAR who is working on ICICLE.

While the focus is on the in-cloud conditions, the scientists will be collecting data through the entire flight process, said Landolt. "We are trying to cover the full spectrum of what a pilot goes through when they are doing their planning — what the conditions are at their current airport location, what to expect during takeoff, en route, and then landing," he said.

Throughout the field project, scientists and flight crew begin work on the flight plan in the early morning. Forecasters start looking at weather conditions as early as midnight and, through university partnerships, occasionally release weather balloons to analyze the cloud structure. The team uses the forecasts to plan the flight altitude and route to best capture the in-cloud conditions. Even if there is no precipitation, the crew will be flying.

"The majority of clouds you see outside aren't producing precipitation, but when an aircraft takes off it has to fly through the cloud, and it will encounter ice-prone conditions there," said Landolt.

Throughout takeoff, flight, and landing, instruments mounted on the airplane are collecting measurements. A suite of sensors, provided by the NRC and Environment and Climate Change Canada, measures a range of particle sizes while optical sensors count the number of droplets and ice crystals in the cloud along the flight path. In addition, an onboard cloud radar will allow the scientists to characterize the clouds above, below, and ahead of the aircraft.

This in-flight data will be compiled with NCAR's Earth Observing Laboratory field catalog, a suite of tools that record ancillary data each day of the campaign. Scientists from around the world can use the catalog in real time and long after the field campaign is finished to help visualize the entirety of the project. The catalog includes maps, satellite and radar observations, and surface conditions among many other products.

ICICLE includes essential participation by NCAR, a major facility of the National Science Foundation, as active icing researchers in support of FAA icing projects and participating in ICICLE as support scientists, forecasters, and operations directors. In addition, Ben Bernstein, a consultant with Leading Edge Atmospherics, LLC is a critical part of the team, serving as science lead for the team and primary operations director, while providing expertise in identifying and sampling conditions that cause ice buildup. ICICLE further includes collaborators from the National Oceanic and Atmospheric Administration as well as groups in England, France, and Germany.

ABOUT THE ARTICLE

Title: Field Campaign Flies Through Icy Weather
Author: Ali Branscombe

GLOBAL FORESTS SOAKING UP CARBON AT QUICKENING RATE

INCREASED UPTAKE NOT KEEPING PACE WITH FOSSIL FUEL EMISSIONS

An aerial shot shows the contrast between forest and land that has been cleared for agricultural use near Rio Branco, Acre, Brazil. Despite widespread deforestation in the tropics, the remaining forests are taking up increasingly more carbon, according to a new study. (Image: Kate Evans/Center for International Forestry Research)

The world's forests are taking up increasingly more carbon, partially offsetting the carbon being released by the burning of fossil fuels and by deforestation in the tropics, according to a new synthesis of model simulations.

The findings, published in the journal Biogeosciences, suggest that forests are growing more vigorously, and therefore, locking away more carbon. Even so, the concentration of heat-trapping carbon dioxide in the atmosphere is still on the rise.

"Every decade, Earth's forests are taking up carbon faster than the previous decade," said Britton Stephens, a scientist at the National Center for Atmospheric Research (NCAR) and a co-author of the study. "The same is true of the oceans. But even together, the ocean and the land are not keeping up with industrial carbon emissions, and the global concentration of carbon dioxide in the atmosphere is increasing at an accelerating rate."

The increased plant growth in global forests could be due to a variety of factors, including higher concentrations of carbon dioxide in the atmosphere, warmer temperatures, or increased availability of nitrogen.

The new study also contributes to a mounting body of evidence that tropical forests might take up more carbon — and northern temperate forests might take up less carbon — than many scientists once thought.

"The forests we aren't cutting down in the tropics are taking up a lot of carbon," Stephens said.

The study was authored by an international group of researchers, led by NCAR scientist Benjamin Gaubert. The scientists were funded by the National Science Foundation, which is NCAR's sponsor, as well as NASA, the European Union's Copernicus Atmosphere Monitoring Service, Japan's Environment Research and Technology Fund of the Ministry of Environment, Climate Change Canada, and the Canadian Space Agency.

"This team of scientists has significantly improved our knowledge of how much carbon dioxide gets into the atmosphere," said Sherri Hunt, a program director in the National Science Foundation's Division of Atmospheric and Geospace Sciences. "Understanding what factors control the amount of this important greenhouse gas is critical for predicting future climate conditions and estimating the contribution of human actions."

A CONVERGENCE OF MODELS

The new study relies on a synthesis of results from 10 different "inverse transport models," which are atmospheric models run in reverse. To use them, scientists input the "results" — the actual levels of atmospheric carbon dioxide measured all over the world during the past several decades — and force the model to predict how much carbon dioxide must have been emitted and reabsorbed in different parts of the Earth system to match the measurements.

This effort is the third inverse transport model comparison project of this scale. In the first comparison, published in 2002, the model results diverged from one another significantly, but the average pointed toward the presence of a large carbon sink in the Northern Hemisphere outside the tropics.

Since the original comparison, the model results have begun to come together.

"We find that the models now agree a lot better with each other and with independent aircraft data," said Gaubert. "Collectively, they are telling us that both the tropics and the northern temperate region are taking up more carbon than in the past, but the amount being taken up by intact tropical forests is a bigger surprise."

The remaining disagreement among the models is mostly related to uncertainty about how much carbon is being emitted into the atmosphere by the burning of fossil fuels. Previously, the uncertainties most affecting model spread were related to sparse observations and the physics contained in the models themselves.

"Despite the fact that all the models we used in the analysis are built differently, they come to similar solutions, which reflects our increased understanding of how carbon moves through the Earth system," said Gaubert. "To further zero in on where the carbon is going, we need better inventories of society's carbon emissions to feed into the models."

The new study finds that, averaged over the past decade, the carbon flux in the tropics is about zero — meaning the additional amount of carbon being released by deforestation (an estimated 1.5 billion metric tons a year) is being compensated for by increased uptake in the remaining forest. This expanded capacity of intact forests to act as a carbon sink suggests that the additional carbon dioxide in the air may be fertilizing those forests, allowing them to grow and store carbon more quickly, though changes in precipitation, temperature, and deforestation could also be playing important roles.

The researchers said it isn't clear how long Earth's land areas will be able to keep increasing carbon uptake in the face of ongoing deforestation and continued emissions of fossil fuels, even with the help of fertilization.

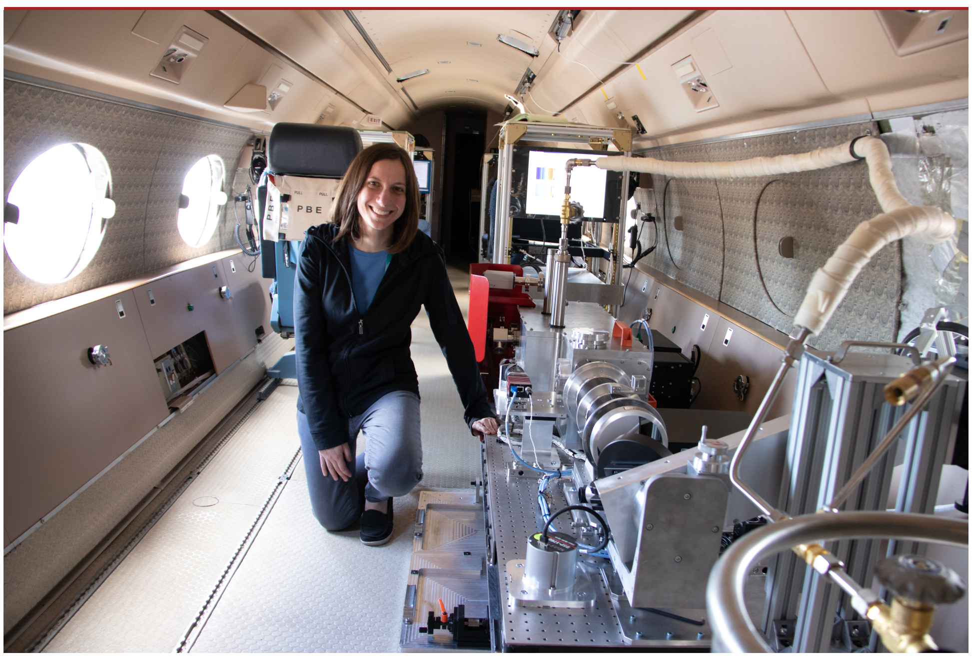
"The limits of carbon fertilization aren't yet well understood," Stephens said. "But we do know that fossil fuel emissions are outpacing Earth's ability to take up carbon, and the gap may widen in the future."

ABOUT THE ARTICLE

Title: Global atmospheric CO2 inverse models converging on neutral tropical land exchange, but disagreeing on fossil fuel and atmospheric growth rate
Authors: Benjamin Gaubert, Britton B. Stephens, Sourish Basu, Frédéric Chevallier, Feng Deng, Eric A. Kort, Prabir K. Patra, Wouter Peters, Christian Rödenbeck, Tazu Saeki, David Schimel, Ingrid Van der Laan-Luijkx, Steven Wofsy, and Yi Yin
Journal: *Biogeosciences*

SCIENTISTS TO CHASE SOUTH AMERICAN TOTAL ECLIPSE WITH RESEARCH AIRCRAFT

SPECIALIZED ECLIPSE-VIEWING INSTRUMENT TO TAKE A SECOND FLIGHT



Instrument scientist Jenna Samra kneels next to the Airborne InfraRed Spectrometer (AIR-Spec), an instrument that will be used to view the 2019 South American solar eclipse and measure infrared wavelengths from the Sun's corona. The instrument is mounted on the NSF/NCAR GV research aircraft. (©UCAR. Image: Simmi Sinha)

A scientific instrument specifically designed to study the Great American Eclipse of 2017 will soon be making its second journey through the shadow of the moon. On July 2, scientists from the National Center for Atmospheric Research (NCAR) and the Center for Astrophysics | Harvard & Smithsonian (CfA) will be sending a high-altitude research jet through the path of totality of a solar eclipse, taking place in the Southern Hemisphere, to capture data that could unveil mysteries about the Sun's magnetic field.

During the flight, scientists on board will be aiming the Airborne InfraRed Spectrometer (AIR-Spec) instrument at the Sun's corona, which is the outermost part of the solar atmosphere, to measure infrared radiation. The eclipse, caused when the moon passes between the Sun and Earth, offers a brief window to view the corona, which is usually obscured by the bright solar surface. The research aircraft, the NSF/NCAR HIAPER Gulfstream V (GV), is owned by the National Science Foundation and operated by NCAR.

Super-heated, charged particles of plasma hold clues to the Sun's invisible magnetic fields. "The corona gives us information about the temperature and density of the plasma at the solar surface," said Edward DeLuca, an astrophysicist at CfA and a principal investigator for the field campaign. "Observing these in the infrared is relatively new and challenging because the Earth's atmosphere gets in the way."

Flying along the path of totality as the eclipse makes its way across the South Pacific Ocean will give the researchers eight minutes of total eclipse observing, twice the amount of time of the 2017 eclipse campaign. The aircraft will fly above 40,000 feet, an altitude that puts the AIR-Spec above the clouds and most of the infrared-blocking water vapor in Earth's atmosphere. While NCAR scientists have a history of observing solar eclipses with ground-based instruments stretching back decades, the 2017 eclipse was the first time the GV was used to chase an eclipse with an instrument on board.

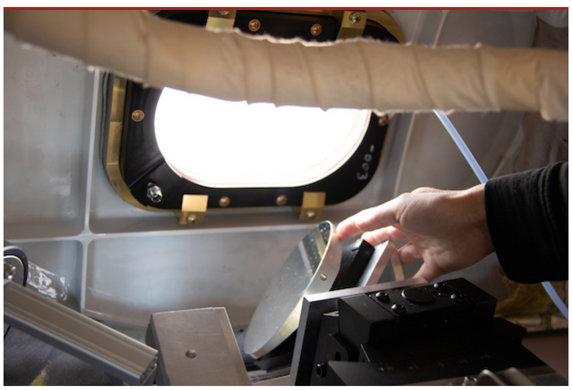
The AIR-Spec is mounted on the NSF/NCAR GV, a research aircraft with the ability to reach altitudes above infrared-blocking water vapor in Earth's atmosphere, giving the instrument a clearer image of the solar eclipse. (©UCAR. Image: Simmi Sinha)

"The benefit of having the GV is the ability to fly above any clouds, and the ability to take full advantage of the eclipse at its longest duration, longer than anywhere on the ground," said Cory Wolff, who is the NCAR project manager for the field campaign.

A total solar eclipse occurs approximately once every 18 months on Earth, and this year's eclipse will mainly pass over the South Pacific Ocean. The field campaign, funded by NSF, will be based out of Lima, Peru. Scientists from NCAR and the CfA will accompany the aircraft during the project, and provide educational opportunities for local media and scientists to learn more about the campaign.

GETTING 20 TIMES MORE DETAIL

Since the 2017 eclipse, the AIR-Spec has undergone two major improvements, said Jenna Samra, the instrument scientist on the project who works at CfA. The instrument has several mirrors that direct the image of the solar eclipse into a telescope, which then focuses onto a spectrometer held in a vacuum chamber. One of these mirrors is steered electronically to compensate for the motion of the aircraft. One improvement to the design is to have this mirror automatically track the edge of the moon, in order to keep the image of the Sun's corona steady as it enters the spectrometer.



The AIR-Spec uses a series of mirrors to direct the image of the solar eclipse to a telescope. This first mirror is steered electronically to keep the image stabilized while the aircraft is in motion. (©UCAR. Image: Simmi Sinha)

"The 2017 image of the Sun was very jittery," said Samra. "Now we'll be able to have a very stable image."

The biggest improvement is additional cooling inside the vacuum chamber that contains the spectrometer. Infrared wavelengths are captured as heat, and a cooled instrument is able to better "see" the infrared contrast of the Sun's corona. Now the corona will appear about 20 times brighter.

The ultimate scientific goal of this field campaign is to better understand the corona's magnetic field, which cannot easily be measured with an instrument. Like a detective who must reverse-engineer a crime scene, the scientists will focus on five infrared wavelengths as the clues to derive the characteristics of the corona's magnetic field. "The wavelengths we are seeing in the AIR-Spec could be used as a diagnostic," said Samra, who did the optical design on the instrument. "In the presence of a magnetic field, the infrared wavelengths will change."

Scientists have long been interested in better understanding the Sun's magnetic system, which is responsible for space weather events that can affect technology on Earth. The resulting impact of space weather on Earth can block radio communication, interrupt GPS signals, and even influence the weather.

"An eclipse, seen through the AIR-Spec, offers an opportunity to study the Sun's atmosphere in a new way," said Wolff. "We know the eclipse is going to happen, and it is not going to wait for us, so now we have to go out and capture it."

This material is based upon work supported by the National Center for Atmospheric Research, a major facility sponsored by the National Science Foundation and managed by the University Corporation for Atmospheric Research. Any opinions, findings and conclusions or recommendations expressed in this material do not necessarily reflect the views of the National Science Foundation.

CONFRONTING THE UNPREDICTABLE

METEOROLOGISTS CAN'T FORECAST THE WEATHER MORE THAN 2-3 WEEKS IN ADVANCE. AND THEY NEVER WILL.

The Sun will not start setting in the east. Niagara can't begin flowing uphill. And the weather's not going to become predictable more than a couple of weeks away.

Even with the ideal computer model and nearly perfect observations, new research confirms what meteorologists have long thought: there's a limit to how far in advance we can forecast the weather.

"The atmosphere has a finite level of predictability," said Falko Judt, a scientist at the National Center for Atmospheric Research (NCAR) and the author of a recent paper on the subject. "If we want to predict the day-to-day weather, then we're stuck with two to three weeks."

For decades, scientists have concluded that the maximum range for a specific forecast is about a couple of weeks. But Judt, using an exceptionally detailed weather model and powerful supercomputer to run it on, returned to the issue to see if modern technology could move the forecasting needle.

The answer in a word: no.

Judt tested the limits of forecasting with high-resolution simulations created using the NCAR-based Model for Prediction Across Scales (MPAS), a powerful weather model developed over the past several years. In an idealized experiment, he found that the forecasts noticeably began deteriorating after six days. After 17 days, they were no better than relying on climate averages.

The reason has to do with the chaos of the atmosphere: even a slight perturbation, such as an unusually powerful thunderstorm in the tropics or a temporary kink in the jet stream over North America, will have impacts that gradually ripple out through the air worldwide. This makes it impossible to accurately forecast the weather at a specific point on the globe more than about a couple of weeks out, regardless of future prediction technologies.

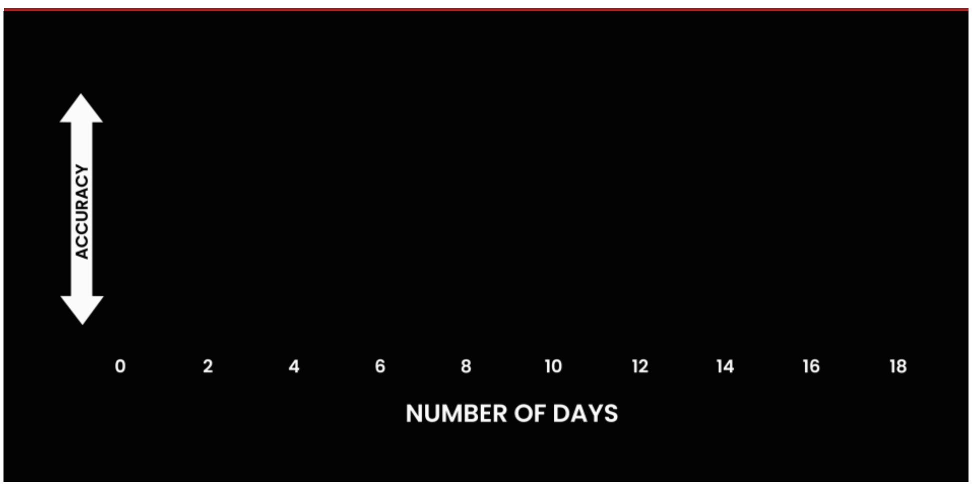
The research was supported by the National Science Foundation.

Judt's conclusion reinforces other meteorological studies. As far back as 1969, a paper by Massachusetts Institute of Technology mathematician and meteorologist Edward Lorenz found that atmospheric models will have entirely diverged after two weeks because of tiny disturbances in the atmosphere, a theory that has become known as the "butterfly effect." Last year, scientists at Pennsylvania State University concluded that current 10-day forecasts can be extended by no more than about five days.

Despite such limits, Judt emphasized that researchers can make substantial improvement to shorter-term forecasts, potentially making them highly accurate about a week in advance. Scientists are also working on developing reliable subseasonal to seasonal predictions, providing residents and businesses with such information as the probability of the upcoming spring being particularly wet or warm.

But those hoping for longer-term deterministic forecasts — the kind that would inform parents if their town is going to be sunny with a high of 70 for the school picnic in six weeks — are doomed to be disappointed. Despite the impressive strides in weather prediction over the years, the physical world has constraints.

TWIN SIMULATIONS



This animation illustrates how weather forecasts inevitably become less accurate over time. An idealized experiment with an advanced computer model shows that weather forecasts can be highly accurate for about a week out. But the inherent chaos of the atmosphere means that all predictability is lost after about 17 days, even with the most powerful weather models and accurate observations. (©UCAR. Animation: Simmi Sinha. This animation is freely available for media & nonprofit use.)

To examine the limits of predictability, Judt ran two nearly identical simulations with the MPAS model. The first was a 20-day control simulation that began with actual observations on a day in late October. For the purpose of the study, Judt assumed that this simulation perfectly described the weather for that 20-day period.

Then he ran an alternative 20-day simulation that began with starting conditions that differed from the control simulation by only the tiniest amount — on the order of a thousandth of a degree — a change too small to be detected by a standard weather station. This second simulation played the role of a forecast for the idealized experiment.

Judt was interested in how closely the "forecast" with nearly perfect starting conditions (the second simulation) could track the "actual weather" (the first simulation).

Both simulations, run on the NCAR-Wyoming Supercomputing Center, had a highly detailed resolution of 4 kilometers (about 2.5 miles).

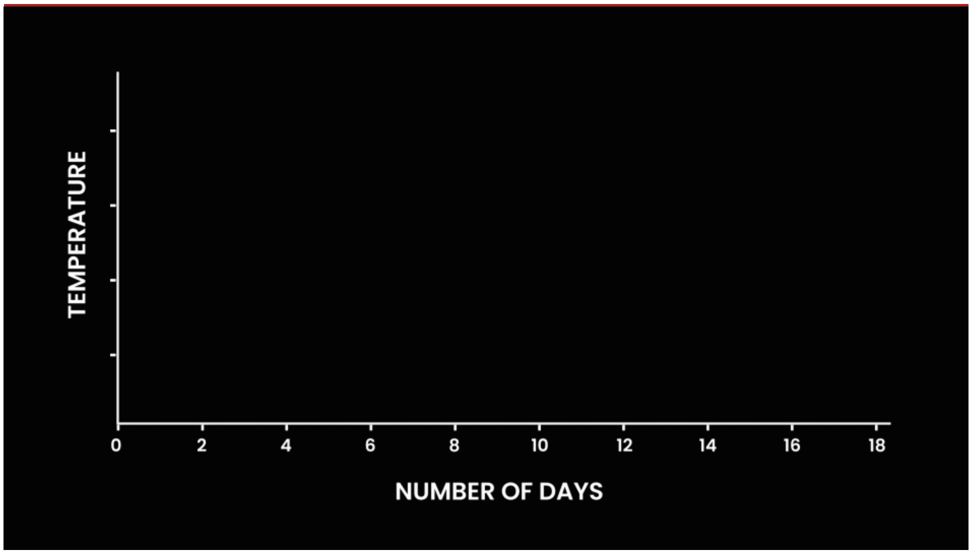
For the first six days, the simulations tracked closely. After that, the "forecast" simulation began to deviate increasingly from the control simulation. Driving the deviation were small-scale events, such as thunderstorms, which over time began influencing larger-scale, regional atmospheric patterns until, after 17 days, the weather patterns in the two model simulations were no longer linked in a predictive way.

The paper was published last year in the Journal of the Atmospheric Sciences. Judt described it as a thought experiment.

"This helps us make decisions about where to focus our research," he said. "If we had perfect observations, we could make almost perfect forecasts of the day-to-day weather out to six or seven days. If we want to develop models that will accurately forecast the weather a month into the future, that's not a realistic goal."

ABOUT THE ARTICLE

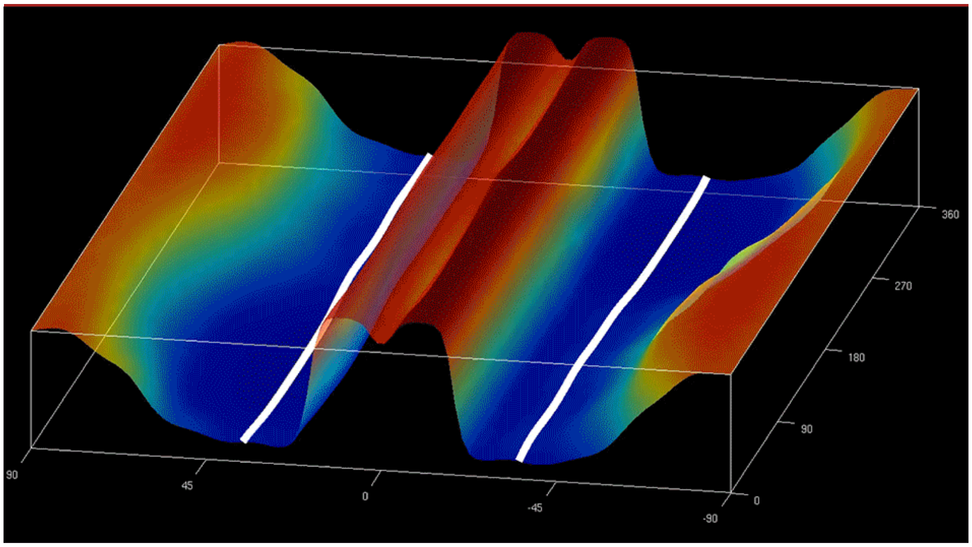
Title: Insights into Atmospheric Predictability through Global Convection-Permitting Model Simulations
Authors: Falko Judt
Journal: *Journal of the Atmospheric Sciences*



This animation provides another way of looking at the inevitable decline in forecast accuracy over time. Two computer model simulations of weather conditions in Boulder, Colorado, start with nearly identical conditions and begin to diverge sharply in about six days because of the atmosphere's chaotic conditions. Even with future advances in forecasting technology, it will never be possible to predict weather conditions more than about 17 days in advance, but scientists can focus on improving predictions within that 17-day window. (©UCAR. Animation: Simmi Sinha. This animation is freely available for media & nonprofit use.)

'TERMINATORS' ON THE SUN TRIGGER PLASMA TSUNAMIS AND THE START OF NEW SOLAR CYCLES

THE NEXT SOLAR CYCLE IS PREDICTED TO TAKE OFF WITHIN A YEAR



In a pair of new papers, scientists paint a picture of how solar cycles suddenly die, potentially causing tsunamis of plasma to race through the Sun's interior and trigger the birth of the next sunspot cycle only a few short weeks later.

The new findings provide insight into the mysterious timing of sunspot cycles, which are marked by the waxing and waning of sunspot activity on the solar surface. While scientists have long known that these cycles last approximately 11 years, predicting when one cycle ends and the next begins has been challenging to pin down with any accuracy. The new research could change that.

This visualization of a computer model simulation shows a solar tsunami, which is initiated at the equator. As the tsunami travels toward the poles it buoys the toroidal magnetic fields (white lines) traveling deeper in the solar interior. As these bands are lifted to the surface, they erupt as sunspots on the solar surface. (©UCAR. Visualization: Mausumi Dikpati, NCAR. This animation is freely available for media & nonprofit use.)

In one of the studies, which relies on nearly 140 years of solar observations from the ground and space, the scientists are able to identify "terminator" events that clearly mark the end of a sunspot cycle. With an understanding of what to look for in the run up to these terminators, the authors predict that the current solar cycle (Solar Cycle 24) will end in the first half of 2020, kicking off the growth of Solar Cycle 25 very shortly after.

In a second study, motivated by the first, scientists explore the mechanism for how a terminator event could trigger the start of a new sunspot cycle using a sophisticated computer model. The resulting simulations show that "solar tsunamis" could provide the connection and explain the Sun's remarkably rapid transition from one cycle to the next.

Both studies were led by the National Center for Atmospheric Research (NCAR).

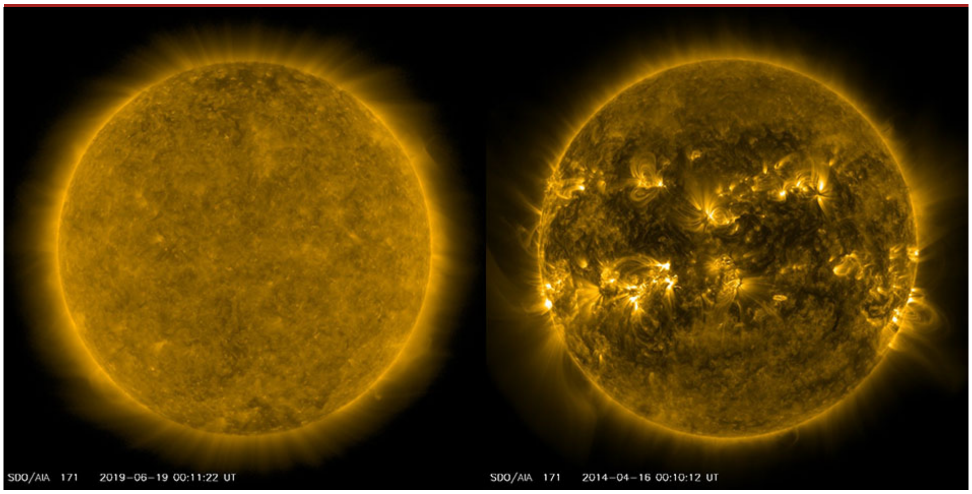
"The evidence for terminators has been hidden in the observational record for more than a century, but until now, we didn't know what we were looking for," said NCAR scientist Scott McIntosh, who directs the center's High Altitude Observatory and worked on both studies. "By combining such a wide variety of observations over so many years, we were able to piece together these events and provide an entirely new look at how the Sun's interior drives the solar cycle."

The research was funded by the National Science Foundation, which is NCAR's sponsor, NASA's Living with a Star program, and the Indo-US Joint Networked R&D Center.

FLICKERS OF LIGHT REVEAL MYSTERIES

Sunspot cycles are born after solar minimum, a period when the face of the Sun is quiet. As the cycle continues, more and more sunspots emerge, first appearing at about 35 degrees latitude in both hemispheres and slowly marching toward the equator over a decade before they fade again into the next solar minimum. The rough midpoint of this progression is solar maximum, when sunspots are the most abundant.

Predicting the timing of sunspot evolution is a major scientific goal, in part because sunspot activity is tied to the solar storms that can disrupt Earth's upper atmosphere and affect GPS signals, power grids, and other critical technologies. But such predictions have proven challenging.



Images of the Sun from NASA's Solar Dynamics Observatory. The left image was taken last month during the current solar minimum. The image on the right was taken in April 2014 during the last solar maximum. (Images: NASA)

For example, the Sun is currently in a solar minimum. Scientist know the relative peace means that the current solar cycle is wrapping up, but it has been difficult to say whether the new cycle will begin in a few months or a few years. McIntosh and his colleagues think their studies can provide more clarity, both into the timing of cycles and also into what drives the cycles themselves.

The researchers began by studying the movement of coronal bright points – ephemeral flickers of extreme ultraviolet light in the solar atmosphere. By observing bright points, which occur even in the relative calm of a solar minimum, the scientists think they have gained a more complete view of the solar cycle than if they focused only on sunspot activity.

The bright points first appear at higher latitudes than sunspots (around 55 degrees) and migrate toward the equator at approximately 3 degrees latitude per year, reaching the equator after a couple decades. The paths traced by the bright points overlap with sunspot activity in the mid-latitudes (around 35 degrees) until they both reach the equator and disappear. This disappearance, which the researchers call a terminator event, is followed very shortly after with a large burst of bright point activity at the mid-latitudes, marking the beginning of the next sunspot cycle.

In the new study that identifies terminator events, published in the journal Solar Physics, the scientists corroborate the bright point observations with a number of other observations from a variety of spacecraft- and ground-observing facilities stretching back over

13 solar cycles.

“We were able to identify these terminators by looking at data from a whole range of different measures of solar activity – magnetic fields, spectral irradiance, radio flux – in addition to the bright points,” said University of Maryland scientist Bob Leamon, a co-author of the paper who is also a researcher at NASA’s Goddard Space Flight Center. “The results demonstrate that you really need to be able to step back and use all the available data to appreciate how things work – not just one spacecraft or one observation or one model.”

TSUNAMI CONNECTIONS

McIntosh and his team have identified that coronal bright points allow them to better “see” the solar cycle unfolding. But why does the sunspot cycle start surging in the midlatitudes a few weeks after the terminator?

The paper on solar tsunamis, led by NCAR scientist Mausumi Dikpati and published in Scientific Reports, explores the possible mechanisms behind the observations. It suggests that coronal bright points are markers for the movement of the Sun’s “toroidal magnetic fields,” which wrap around the Sun like rubber bands stretching in the east-west direction and migrate slowly toward the equator over the same two decades.

When these toroidal magnetic fields bob to the surface, they create sunspots along with the bright points they were already producing. As they travel, they also act as magnetic dams, trapping plasma behind them. When the toroidal magnetic fields from the Sun's northern and southern hemispheres touch in the middle, their opposing charges cause their mutual annihilation, releasing the pent-up fluid behind them in a tsunami. This fluid rushes forward, collides, and then ripples backward, traveling toward the poles at a rate of about 300 meters per second.

As the solar tsunami reaches the Sun's mid-latitudes, it encounters the toroidal magnetic fields of the next cycle, which are already marching toward the equator (this progression is marked by the path of coronal bright points) but traveling deeper within the Sun's interior. The tsunami buoys those magnetic fields, lifting them toward the surface and producing the remarkable surge of bright points – and accompanying sunspot activity – that marks the beginning of the new sunspot cycle.

"We have observed the sunspot cycle for hundreds of years, but it's been a mystery what mechanism could transport a signal from the equator, where the cycle ends, to the Sun's mid-latitudes, where the next cycle begins, in such a relatively short amount of time," said Dikpati.

As a body, the research provides a new way of thinking about the workings of the solar interior that challenges some of the conventional thinking about processes on the Sun. Whether or not the research is on the right track – and could improve our predictive capabilities – will soon get its first test.

There are a number of instruments that are ideally suited to observe the inevitable end of the current solar cycle and the start of the next, according to the authors. These include the Parker Solar Probe, which launched last August, the STEREO-A spacecraft, the Solar Dynamics Observatory, the Daniel K. Inouye Solar Telescope, and other assets.

“In the next year, we should have a unique opportunity to extensively observe a terminator event as it unfolds and then to watch the launch of Sunspot Cycle 25,” McIntosh said. “We believe the results, especially if the terminator arrives when predicted, could revolutionize our understanding of the solar interior and the processes that create sunspots and shape the sunspot cycle.”

ABOUT THE ARTICLES

Title: What the sudden death of solar cycles can tell us about the nature of the solar interior
Author: Scott W. McIntosh, Robert J. Leamon, Ricky Egeland, Mausumi Dikpati, Yuhong Fan, and Matthias Rempel
Journal: *Solar Physics*

Title: Triggering the birth of new cycle's sunspots by solar tsunami
Author: Mausumi Dikpati, Scott W. McIntosh, Subhamoy Chatterjee, Dipankar Banerjee, Ron Yellin-Bergovoy, and Abhishek Srivastava
Journal: *Scientific Reports*

COMMUNICATING COASTAL STORM RISKS THROUGH A SENSE OF PLACE

SCIENTISTS STUDY VISUAL TOOLS TO HELP LOCAL RESIDENTS MAKE DECISIONS ABOUT SAFETY

As hurricane forecasts become more accurate, scientists are increasingly turning their attention to communicating those forecasts to vulnerable communities in a meaningful way. The goal is to enable residents and local officials to see how the incoming storm could affect specific areas so they can make critical decisions about protecting their lives, homes, and businesses.

The National Center for Atmospheric Research (NCAR) is leading a new, two-year project to study the use of maps and other visualizations to characterize and communicate risks related to coastal surge and flooding. The project, funded by the National

Science Foundation (NSF), brings together scientists at NCAR and leading universities across a range of disciplines to better understand how certain types of geovisualizations will resonate with particular populations.

The researchers will focus on a concept known as "sense of place" — essentially how residents identify with the area where they live, including the emotional connection they form with their local community and environment. For inhabitants of a barrier island, that might be an environmental feature such as a river or inlet. For those living in urban areas or smaller towns, it might be schools, parks, or historic landmarks.

"By focusing on local features that coastal communities identify with, visualizations can help the residents locate themselves in relation to the potential threats from storm surge," said Olga Wilhelmi, an NCAR geographer who is leading the project. "This communicates the risks in a way that's most meaningful to residents so they can make informed decisions, such as whether to evacuate or shelter in place."

FOCUS GROUPS AND SURVEYS

The research team will conduct focus groups to better understand localized sense of place. They will then create specialized maps, 3-D animations, and other visualizations that incorporate sense of place representations to assess how they differently convey information to people about risk of storm surge.

For example, a map could highlight local schools and highways that would be flooded from an incoming hurricane. An animation could show rising waters approaching the types of houses that local residents live in.

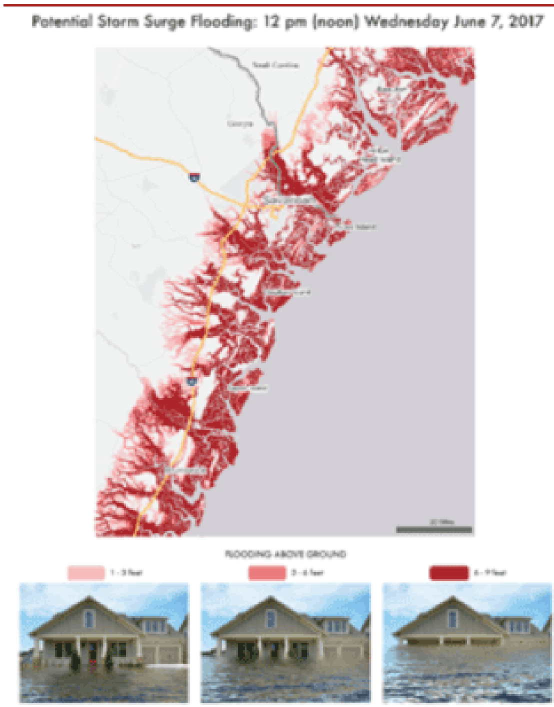
The scientists will then survey coastal residents to test the effectiveness of the various visual approaches.

The research will concentrate on coastal Georgia and South Carolina, which have been repeatedly affected by hurricanes and associated storm surge in recent years. But the results will be broadly applicable to other populated areas that are at risk from storm surge or other disasters.

The project brings together scientists from a range of disciplines, including experts in Geographic Information Systems (GIS), cartography, storm surge, social vulnerability, and risk communication. It builds on prior work at NCAR that has analyzed how visualizations can communicate risks to vulnerable residents, although without an emphasis on a sense of place. That work was also funded by NSF, which is NCAR's sponsor.

"We want to bridge the gap between the ways that geophysical scientists convey information about storm surge and how the public interprets and uses the information," Wilhelmi said. "The end goal is to reduce the devastating effects that storm surges can have on the safety and well-being of vulnerable communities."

In addition to NCAR scientists, the research team includes scientists from Utah State University, University of Georgia, and University of North Carolina Asheville. The project's advisory panel includes experts with the National Oceanic and Atmospheric Administration's National Hurricane Center and National Weather Service, South Carolina Emergency Management Division, City of Savannah, Skidaway Institute of Oceanography, and Emory University.



An example of a visualization of a hypothetical storm surge forecast. (©UCAR. Image: NCAR geographer Olga Wilhelmi and collaborators.)

ABOUT THE ARTICLE

Title: Communicating Coastal Storm Risks Through a Sense of Place
Author: David Hosansky

FACIAL RECOGNITION TECHNIQUE COULD IMPROVE HAIL FORECASTS

SCIENTISTS USE MACHINE LEARNING TO RECOGNIZE POTENTIALLY DAMAGING STORMS

The same artificial intelligence technique typically used in facial recognition systems could help improve prediction of hailstorms and their severity, according to a new study from the National Center for Atmospheric Research (NCAR).

Instead of zeroing in on the features of an individual face, scientists trained a deep learning model called a convolutional neural network to recognize features of individual storms that affect the formation of hail and how large the hailstones will be, both of which are notoriously difficult to predict.

The shape of a severe storm, such as this one, is an important factor in whether the storm produces hail and how large the hailstones are, but current hail-prediction techniques are typically not able to take the storm's entire structure into account. NCAR scientists are experimenting with a new machine-learning technique that can process images to weigh the impact of storm shape and potentially improve hail forecasts. (©UCAR. Image: Carlye Calvin. This image is freely available for media and nonprofit use.)

The promising results, published in the American Meteorological Society’s Monthly Weather Review, highlight the importance of taking into account a storm’s entire structure, something that’s been challenging to do with existing hail-forecasting techniques.

“We know that the structure of a storm affects whether the storm can produce hail,” said NCAR scientist David John Gagne, who led the research team. “A supercell is more likely to produce hail than a squall line, for example. But most hail forecasting methods just look at a small slice of the storm and can’t distinguish the broader form and structure.”

The research was supported by the National Science Foundation, which is NCAR's sponsor.

“Hail – particularly large hail – can have significant economic impacts on agriculture and property,” said Nick Anderson, an NSF program officer. “Using these deep learning tools in unique ways will provide additional insight into the conditions that favor large hail, improving model predictions. This is a creative, and very useful, merger of scientific disciplines.”

THE SHAPE OF STORMS

Whether or not a storm produces hail hinges on myriad meteorological factors. The air needs to be humid close to the land surface, but dry higher up. The freezing level within the cloud needs to be relatively low to the ground. Strong updrafts that keep the hail aloft long enough to grow larger are essential. Changes in wind direction and speed at different heights within the storm also seem to play a role.

But even when all these criteria are met, the size of the hailstones produced can vary remarkably, depending on the path the hailstones travel through the storm and the conditions along that path. That's where storm structure comes into play.

“The shape of the storm is really important,” Gagne said. “In the past we have tended to focus on single points in a storm or vertical profiles, but the horizontal structure is also really important.”

Current computer models are limited in what they can look at because of the mathematical complexity it takes to represent the physical properties of an entire storm. Machine learning offers a possible solution because it bypasses the need for a model that actually solves all the complicated storm physics. Instead, the machine learning neural network is able to ingest large amounts of data, search for patterns, and teach itself which storm features are crucial to key off of to accurately predict hail.

For the new study, Gagne turned to a type of machine learning model designed to analyze visual images. He trained the model using images of simulated storms, along with information about temperature, pressure, wind speed, and direction as inputs and simulations of hail resulting from those conditions as outputs. The weather simulations were created using the NCAR-based Weather Research and Forecasting model (WRF).

The machine learning model then figured out which features of the storm are correlated with whether or not it hails and how big the hailstones are. After the model was trained and then demonstrated that it could make successful predictions, Gagne took a look to see which aspects of the storm the model’s neural network thought were the most important. He used a technique that essentially ran the model backwards to pinpoint the combination of storm characteristics that would need to come together to give the highest probability of severe hail.

In general, the model confirmed those storm features that have previously been linked to hail, Gagne said. For example, storms that have lower-than-average pressure near the surface and higher-than-average pressure near the storm top (a combination that creates strong updrafts) are more likely to produce severe hail. So too are storms with winds blowing from the southeast near the surface and from the west at the top. Storms with a more circular shape are also most likely to produce hail.

BUILDING ON RANDOM FORESTS, TESTING WITH ACTUAL STORMS

This research builds on Gagne's previous work using a different kind of machine learning model – known as a random forest – to improve hail prediction. Instead of analyzing images, random forest models ask a series of questions, much like a flowchart, which are designed to determine the probability of hail. These questions might include whether the dew point, temperatures, or winds are above or below a certain threshold. Each "tree" in the model asks slight variants on the questions to come to an independent answer. Those answers are then averaged over the entire "forest," giving a prediction that's more reliable than any individual tree.

For that research, published in 2017, Gagne used actual storm observations for the inputs and radar-estimated hail sizes for the outputs to train the model. He found that the model could improve hail prediction by as much as 10%. The machine learning model has now been run operationally during the last several springs to give on-the-ground forecasters access to more information when making hail predictions. Gagne is in the process of verifying how the model did over those few seasons.

The next step for the newer machine learning model is to also begin testing it using storm observations and radar-estimated hail, with the goal of transitioning this model into operational use as well. Gagne is collaborating with researchers at the University of Oklahoma on this project.

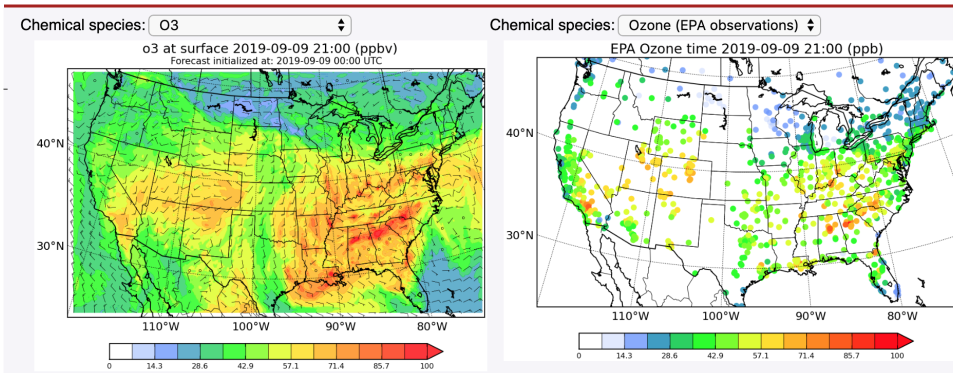
"I think this new method has a lot of promise to help forecasters better predict a weather phenomenon capable of causing severe damage," Gagne said. "We are excited to continue testing and refining the model with observations of real storms."

ABOUT THE ARTICLE

Title: Interpretable Deep Learning for Spatial Analysis of Severe Hailstorms
Authors: David John Gagne II, Sue Ellen Haupt, Douglas W. Nychka, and Gregory Thompson
Journal: *Monthly Weather Review*

NCAR GENERATES EXPERIMENTAL 48-HOUR FORECASTS OF U.S. AIR QUALITY

PREDICTIONS CAN HELP DECISION MAKERS AND THE PUBLIC, ACCELERATE NEW RESEARCH



This NCAR experimental forecast shows predicted levels of ozone pollution across the United States, as well as observations by the U.S. Environmental Protection Agency. The EPA generally considers ozone to be at an unhealthy level if it persistently exceeds 70 parts per billion over an average 8-hour average period. (©UCAR. This image is freely available for media and nonprofit use.)

The National Center for Atmospheric Research (NCAR) is now generating high-resolution, experimental, 48-hour forecasts of air pollutants across the contiguous United States. The predictions, which are freely available online, can help decision makers anticipate episodes of unhealthy air as well as accelerate research into the factors that influence air quality.

The system, which draws on observations of pollutants, weather forecasts, and advanced computer modeling, will complement existing operational air quality forecasts issued by the National Oceanic and Atmospheric Administration (NOAA). The NCAR forecasts are primarily for research purposes, but they are based on different techniques than those used by NOAA and can provide state and local officials who are trying to safeguard public health with a more complete picture of air quality.

"It provides decision makers and also the public with an additional piece of information," said NCAR scientist Gabriele Pfister. "If two forecasts tell you the same thing, that gives you more confidence. If they do not agree, this means that conditions are harder to predict but you should be prepared for the possibility of unhealthy air quality."

The forecast maps, publicly accessible on an NCAR webpage, show anticipated levels of ozone, particulates, and other damaging pollutants as well as near-real time measurements from Environmental Protection Agency Airnow sites. Users can view the pollutants at different heights in the atmosphere, they can view the entire United States or take a closer look on Colorado, and they can also focus on pollutants from fires. The forecasts are updated once a day and continuously compared to observations.

The work builds on a new forecasting system that NCAR has developed for New Delhi and other heavily polluted parts of northern India. The system can be readily adapted for other regions of the world as well.

Pfister and her colleagues say the forecasts, in addition to helping to protect the public, will support and advance research into air quality by providing scientists with daily examples of pollution levels across the country.

"Scientists can take the output, separate out different sources of the pollutants, and evaluate the forecasts in light of actual levels of pollutants," said NCAR scientist Rajesh Kumar. "This is really useful for fingerprinting the sources of emissions."

The research for the system is funded by NASA and the National Science Foundation, which is NCAR's sponsor.

A MAJOR HEALTH AND ECONOMIC ISSUE

Although meteorologists have long been able to forecast the weather days in advance, predicting air quality is more challenging. That's because air quality forecasts rely on accurate predictions of weather conditions (which affect air quality) as well as detailed assessments of ever-changing emissions of pollutants and how they evolve and move in the atmosphere.

Air pollution is a significant health and economic issue. Poor air quality in the United States causes as many as 60,000 premature deaths each year, and the annual costs of air pollution-related illnesses can be as high as $150 billion, according to NOAA estimates.

Accurate forecasts can enable vulnerable residents, such as those with asthma or pulmonary or cardiovascular diseases, to better protect themselves by planning ahead and limiting outdoor exposure on highly polluted days.

The NCAR forecasting system incorporates satellite and ground-based measurements of particles and gases in the atmosphere, as well as inventories of emissions from transportation, industry, and other human activities. This information is combined with forecasts of meteorological conditions and fed into a specialized NCAR-based atmospheric chemistry computer model known as WRF-Chem (the chemistry component of the Weather Research and Forecasting model), which then simulates air quality conditions over the next 48 hours.

Even though the system focuses on the United States, it incorporates observations and computer simulations of pollutants flowing into the country from outside regions, such as Asia, by incorporating global air quality predictions from the NCAR-based Whole Atmosphere Model. The system also has a highly advanced fire modeling component that simulates emissions from wildfires and prescribed burns, recreating their impacts on local and regional air quality as well as on atmospheric conditions such as cloud cover, which in turn influence levels of air pollution.

The NCAR team is continually evaluating the system and working on upgrades, such as improvements to the ways that observations are fed into the model.

NCAR has generated accurate forecasts in the past for specialized field experiments that deploy research aircraft to study atmospheric chemistry, Pfister said. By using similar technology to make the research forecasts every day, the scientists can help decision makers and the public, as well as other researchers.

"We are taking what we have already been doing for research campaigns and using it to benefit not just the specific campaigns, but everyone," Pfister said. "This will provide important information now as well as lead to enhancements of air quality predictions in the future."

ABOUT THE ARTICLE

Title: NCAR Generates Experimental 48-Hour Forecasts of U.S. Air Quality
Author: David Hosansky

NCAR 2019 METRICS & PUBLICATIONS

FISCAL YEAR 2019 NCAR METRICS

The metrics featured below offer qualitative and quantitative measurements and assessments of the productivity, quality, and impacts that NCAR staff, programs and activities have on our research community, sponsors, and society in general for data reported in the Metrics Database, Workday and iVantage HRIS systems and OpenSky Database as of October 31, 2019 for fiscal year 2019 (October 1, 2018 - September 30, 2019). Staff continue to update their entries and expand their contributions throughout the year so visit the Metrics Database for the most current data. (2019 METRICS AS OF OCTOBER 31, 2019). Date stamp 10/30/19.

LAB/OBSERVATORY/PROGRAM-LEVEL METRICS

NCAR-Hosted Community Events

In FY19, a total of 138 events were hosted: 31 workshops, 62 tutorials, 42 conferences, and 3 colloquia with an average audience of 34 colleagues per event and estimated total audience of 13,250. Event co-sponsor groups included Colorado State University, the National Science Foundation and the Clean-Air Society of Australia and New Zealand, to name a few.

Date Range	Total Hosted	Workshops	Tutorials	Conferences	Colloquia
FY19	138	31	62	42	3

Field Campaigns

NCAR's geosciences research facilities, instrumentation and field support services support field campaigns around the globe.

Date Range	Total Campaigns	Institutions	PIs	Undergraduate Students	Graduate Students
FY19	6	98	42	65	80

In FY19, NCAR participated in six field campaigns ranging in duration from 87 to 986 operational field days. A total of 98 institutions, including 20 UCAR member institutions participated in these campaigns. The projects involved 42 investigators, 65 undergraduate students, and 80 graduate students. The field campaigns for FY19 are:

Campaign Acronym	Campaign Full Name
SAVANT	Stable Atmospheric Variabilitiy and Transport
RELAMPAGO	Remote sensing of Electrification, Lightning, And Mesoscale/microscale Processes with Adaptive Ground Observations
OTREC	Organization of Tropical East Pacific Convection
Eclipse 2019	Observations of 2019 Eclipse
CHEESEHEAD	Chequamegon Heterogeneous Ecosystem Energy-balance Study Enabled by a High-density Extensive Array of Detectors
FIREX-AQ	Fire Influence on Regional to Global Environments and Air Quality

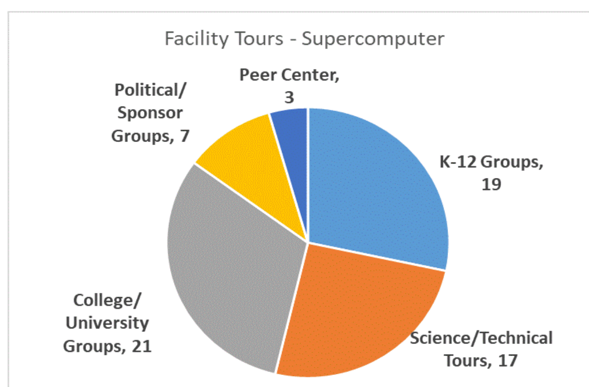
One example is the Stable Atmospheric Variabilitiy and Transport (SAVANT) project, an NSF sponsored field campaign focused on quantifying the effects of converging shallow cold air drainage and background flow on aerosols transport and dispersion. The novel aspect of this work was the ability to identify turbulent events and features with aerosol lidars to add the missing spatial component to our current understanding.

Facility Tours

Each year, NCAR facilities host tours organized for a specific organization or group. This year, NCAR hosted a total of 114 tours, between the NCAR-Wyoming Supercenter, the NCAR Research Aviation Facility, the High Altitude Observatory, EOL laboratory and the Mesa Lab.

NCAR-Wyoming Supercomputer

The NCAR-Wyoming Supercomputer Center (NWSC) is based in Cheyenne, Wyoming. The Center provides advanced computing services to scientists studying a broad range of disciplines, including weather, climate, oceanography, air pollution, space weather, computational science, energy production, and carbon sequestration. The Center is open to the public for self-guided tours, field trips for school groups, and non-school group special tours. In FY19, the Center received 922 walk-in public visitors, and averaged 83 visitors per month.



Date Range	Hosted Tours	K-12 Groups	Science/Technical Tours	College/University Groups	Political/Sponsor Groups	Peer Center
FY19	72	19	17	21	7	3

NWSC hosted 72 tours in FY19, for groups ranging in size from 1 to 400 people. Nineteen tours were for K-12 groups, including Afflerbach Elementary School (Colorado) and various local school visits. Seventeen groups took science- or technical-related tours, including a group from Microsoft . There were 21 college or university groups, ranging from the Smithsonian Institute to Western Nebraska Community College. There were seven tours by political/sponsor groups, including the British Government and the U.S. Senate Committee and three peer centers visited, ranging from European Centre for Medium-Range Weather Forecasts to TGS. There were also 3 engineering and 2 green building and design tours.

NCAR Research Aviation Facility at the Rocky Mountain Metropolitan Airport

Date Range	Total Hosted Tours	K-12 Groups	Science/Technical Tours	College/University Groups	Political/Sponsor Groups	Engineering Groups
FY19	31	3	15	5	5	3

The Rocky Mountain Metropolitan Airport hosted a total of 31 tours in FY 2019. Five tours were for college and university groups, including STEM undergraduates and the University of Colorado. Five tours were for political and sponsor groups, including a congressional deligation and the Colorado State representative. There were also three tours provided to K-12 groups, including one from the Broomfield Workforce Teen Program. This year there were fifteen science/technical tours provided to groups ranging from the Ball Corporation to Earth Works. There were also 3 engineering groups that toured the Rocky Mountain Metropolitan Airport.

The High Altitude Observatory

Date Range	Total Hosted Tours	Engineering Groups	Science/Technical Tours	College/University Group	Political/Sponsor Groups
FY19	6	1	3	1	1

The High Altitude Observatory hosted a total of 6 tours in FY19. One tour was for the University of Rochester and another was for visiting scientists from NOAA.

In addition to the NCAR-Wyoming Supercomputer, the NCAR Research Aviation Facility and the High Altitude Observatory tours, there were also 2 tours of EOLs laboratory and 3 tours at the Mesa Lab.

INDIVIDUAL STAFF METRICS

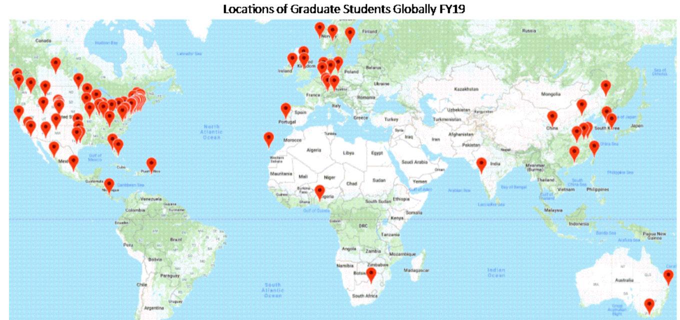
Contributions to Individual Graduate Student Education

NCAR staff members serve as research advisors and thesis committee members for graduate students around the world.

Date Range	Total Students	International Service	U.S. Service
FY19	202	27%	73%

In FY 2019, NCAR staff served as graduate advisors or committee members for 202 graduate students. Eighteen of those are working on their M.S. degree and 184 are working on their Ph.D. Seventy-three percent of students attend U.S. universities, whereas 27% study at schools in 24 different countries world-wide including a PhD student from Pennsylvania State University who was advised by Guido Cervone, a PhD student from the Chinese Academy of Science advised by Hanli Liu, and a Master’s student from the University of Costa Rica, advised by Joanie Kleypas.

Locations of Graduate Students Globally FY19



Editorships

NCAR staff members serve as publication editors. These positions recognize the appointee's leadership in the field and serve a critical role in developing a given field's future focus.

Date Range	Total Editorships	Different Publications/Journals
FY19	177	105

91 NCAR staff served in editorial roles for 105 different publications or journals. Falko Judt served as a Reviewer for the Monthly Weather Review while Federico Gasperini served as a Reviewer for the Journal of Geophysical Research. Publications included top-tier journals such as the Monthly Weather Review and the Journal of Climate.

External Awards

Every year a significant number of NCAR Staff are honored for their scientific excellence and community contributions to the Atmospheric and related sciences.

Date Range	Total External Awards
FY19	42

Rich Rotunno (MMM) received a Lifetime Achievement Award from the American Meteorological Society. This award recognizes individuals who have made outstanding contributions to the theory and/or application of knowledge about Severe Local Storms during their career.

In FY19 there were 4 NCAR staff awarded the American Meteorological Society (AMS) Fellows: Wen-Chau Lee (EOL), Tammy Weckwerth (EOL), Jenny Sun (RAL) and Michael Ek (RAL). Additionally, Bob Sharman and Peter Gent won the Outstanding Contribution to the Advance of Applied Meteorology and the Sverdrup Gold Medal award, respectively, both presented by AMS. Astrid Maute received the AGU 2018 Editor's Citation for Excellence in Refereeing, Eric Gilleland received the Editor's Award from the Monthly Weather Review and Peter Gent was awarded a Fellow appointment from the American Geophysical Union (AGU).

Fellowships

A fellowship is typically a special appointment granting support for a term in order to support advanced research or study.

Date Range	Total Fellowships
FY19	7

Seven NCAR staff received fellowships in 2019. Among the highlights: Sarah Gibson (HAO) was awarded the Instituto Nazionale di Astrofisica (INAF) Associateship offered by the Instituto Nazionale di Astrofisica and James Done (MMM) was awarded the Willis Senior Academic Fellow from the Willis Research Network.

K-12 Outreach

Staff across NCAR work directly with classes and groups of K-12 students to develop or deliver lectures, conduct tours, and lead or participate in field trips and other educational activities.

Date Range	Total K-12 Outreach	Schools/Events	Communities Reached
FY19	43	58	27

Forty-three NCAR staff worked with K-12 students from 58 schools or other school based organizations. Activities included a kindergarten clouds session at Alpine Elementary School in Longmont, Colorado, helping teachers, mentoring, and field trips reaching 27 different communities. Examples range from volunteering at the Wyoming State Science Fair in Laramie, Wyoming to conducting a presentation to 6-12th grade students at the Northern Lights Community School in Warba, Minnesota.

Additional highlights include: Mark Miesch (HAO) was on the Advisory Board, Mobile Earth and Space Observatory in middle schools across Colorado which serves approximately 300 students; Lorena Medina Luna was an educator at the Wow! Children's Museum Girls in Science event, sponsored in Lafayette, Colorado and Scot Colburn was a science fair judge at the Colorado Science and Engineering Fair in Fort Collins, Colorado.

K-12 Global Outreach for FY19

Mentoring

NCAR staff participate in mentoring colleagues and students.

Date Range	Total Mentoring
FY19	173

During this year, 104 staff members mentored mentees both inside and outside of NCAR. Stephen Yeager (CGD) was a mentor to a student from Scripps Institute of Oceanography at the University of California San Diego; Heather Lazrus MMM) was a science mentor for a student from the University of Oklahoma; Melissa Bukovsky (CISL) met with students during the Undergraduate Leadership Workshop at various colleges while Alessandro Fanfarillo (RAL) was a science and software engineer mentor for a machine learning-based method for wind resource assessment at the University of Iowa.

Talks and Posters

NCAR Staff give presentations about data, models, theories, hypotheses, reviews, and results around the world in talks and posters to audiences ranging from scientists and engineers to the general public.

Date Range	Audience Totals	NCAR Staff - Talk & Poster Presentations
FY19	82,000+	985

Many thousands of people were in the audience when 228 NCAR staff presented 866 talks globally, from Savannah, Georgia to Kobe, Japan. Examples range from Anders Jensen's (RAL) talk on "Toward improving finescale forecasts with UAS ensemble data assimilation using NCAR's Data Assimilation Research Testbed (DART)" at the International Society for Atmospheric Research using Remotely-piloted Aircraft conference in Lugo, Spain; to Bill Lipscomb's (CGD) talk "Atmospheric forcing strategy for Greenland" at the Ice Sheet Model Intercomparison Project for CMIP6 in Washington, DC.

Presentations Globally FY19

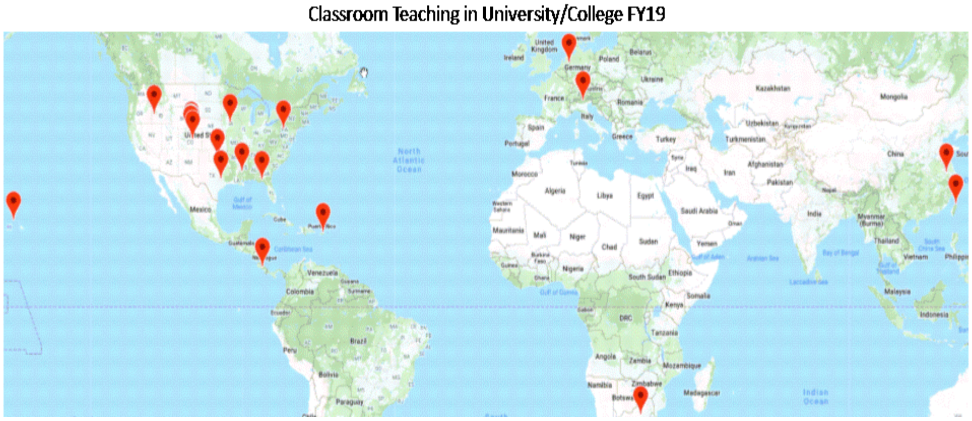
Eighty-seven NCAR staff made more than 119 poster presentations globally, from Bethesda, Maryland to Leuven, Belguim. Examples include Giuliana de Toma's (HAO) poster "Linear Polarization Observations of Coronal Pseudostreamers" in Boulder, Colorado at the SHINE Conference 2019 and Julie Haggerty's (EOL) poster "Characterization of mountain waves in the tropopause region using MTP measurements" in Kyoto, Japan at the SPARC General Assembly.

Teaching in University/College Classroom

Date Range	Total Teaching Appointments	Countries	U.S. States
FY19	47	17%	83%

NCAR staff members make important contributions through teaching appointments at institutions of higher education in different positions ranging from Graduate Faculty to Professor.

Classroom Teaching in University/College FY19



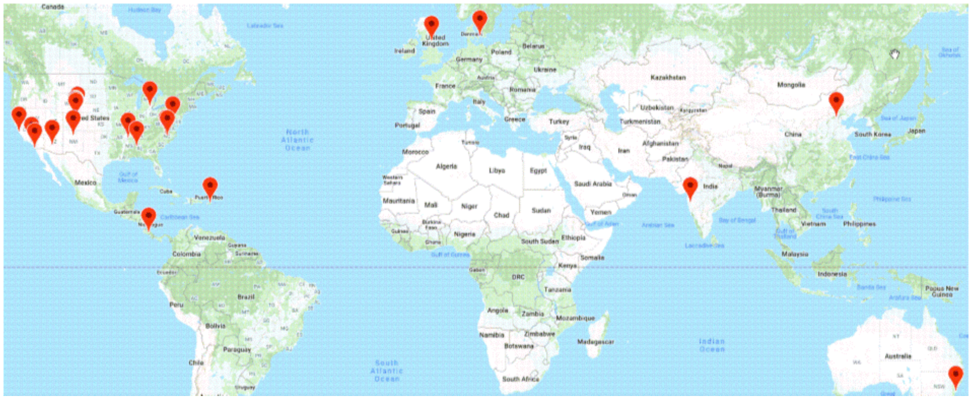
Teaching appointments at institutions of higher education currently number 47. Seventeen percent of these appointments occur in 6 international countries; 83% took place in 10 U.S. states. The longest term is 34 years, by Grant Branstator (CGD) who is an Adjunct Professor at Iowa State University. The class sizes range from 4 to 350 students.

Teaching or Training at Workshops/Tutorials/Colloquia

NCAR staff teach classes and offer training in workshops, tutorials, and colloquia to colleagues and students ranging from model users, to scholars, to fellow researchers.

Date Range	UCAR Staff Members	Workshops/ Tutorials/ Colloquia	# of Classes	# of Participants	Countries	U.S. States
FY19	79	138	386	13000+	10	9

Teaching or Training at Workshops/Tutorials/Colloquia FY19



During this year, 79 staff members taught at a total of 138 workshops, tutorials, and colloquia. In all, 386 individual classes were taught, with class sizes ranging from four to 300 people. Nine percent of these events occurred in the following 8 international countries: Australia, China, Costa Rica, Denmark, India, Japan, Malaysia and the United Kingdom; 91% took place in fifteen U.S. states, including Michigan and Alabama. Examples range from Jim VanDyke's (CISL) presentation at the STEM Computers Day hosted by the Univeristy of Wyoming in Cheyenne, Wyoming to Michael Ek's (RAL) instructing at NASA Summer School on Satellite Observations and Climate Models in Pasadena, Californa.

External Committee Service

NCAR staff are called upon to participate in and often lead external scientific, technical, policy, and educational committees. These committees are instrumental to advancing and promoting the work of the scientific and technical community.

Date Range	Total External Committees	NCAR Staff Served	Service on more than one committee
FY19	512	182	60%

This year, 182 NCAR staff served in a multitude of roles on 512 external committees (an average of 2.8 committees per participating staff member) for national and international scientific, education, and governmental organizations, including entities such as the European Geosciences Union, the Boulder Public Library, and the University of Utah.

Staff Collaboration Visits to Universities

NCAR staff take leaves to visit other institutions for two weeks or more for intellectual growth, professional development, collaboration with research community peers, community support, teaching, or sabbatical. Examples of work include teaching courses or workshops, lecturing, giving tutorials, working with graduate students on dissertation-focused research, student mentoring, collaborative research, and participating in the host institution's outreach to community colleges, minority-serving institutions, and high schools.

Date Range	NCAR Staff Members	Institutions
FY19	6	6

This year, 6 NCAR staff members took leaves to 6 different institutions, ranging from the University of Hawai'i to Monash University. Among the highlights: Moha Gharamti (CISL) worked a on state-parameter estimation for biogeochemical models at the University of Leeds. The modeling framework is based on NCAR's CESM and the goal is to provide global estimates of various biogeochemical states and parameters which can be useful for climate projections and reanaly and Angeline Pendergrass (CGD) was on a collaborative leave at ETH Zurich where she was collaborating on the hydrologic cycle and its changes with NCAR Affiliate Professor Reto Knutti.

Staff Leaves and Visits FY19

APPOINTMENT METRICS

Special Appointments

NCAR Affiliate Scientists

Select university and research-community scientists are invited to carry out long-term, highly interactive, collaborative work with UCAR scientists and are appointed as Affiliate Scientists with three-year terms (see list). This appointment is particularly suitable for parties who desire an extended, close-working relationship on scientific problems of mutual interest. Currently, 44 scientists hold appointments including Dr. Kevin Repasky of Montana State University. Dr. Repasky is collaborating with scientists in the Earth Observing Laboratory(EOL) on developing a deployable version of a low-cost water vapor differential absorption lidar (WV DIAL).

NCAR Affiliate Scientist	Home Institution
Dr. Elliot Atlas	University of Miami
Dr. Bernard Aumont	Laboratoire Interuniversitaire des Systemes Atmospherieques (LISA)
Dr. Dale Barker	United Kingdom Meteorological Office
Dr. Alan Blyth	University of Leeds
Prof. Lance Bosart	State University of New York Albany
Dr. James Brasseur	University of Colorado
Dr. Natalia Calvo	Universidad Complutense de Madrid
Dr. Guido Cervone	Pennsylvania State University
Dr. Shuyi Chen	Pennsylvania State University
Prof. Philip Chilson	University of Oklahoma
Prof. Cathy Clerbaux	CNRS
Dr. Enrique Curchitser	Rutgers University
Dr. Ineke de Moortel	University of St. Andrews
Dr. Leo J. Donner	NOAA GFDL
Dr. James Doyle	U.S. Naval Research Laboratory
Dr. Veronika Eyring	German Aerospace Center
Dr. Jerome Fast	Pacific Northwest National Laboratory
Dr. Michael Ferrari	aWhere
Dr. Paul Field	Met Office
Dr. Silvano Fineschi	Osservatorio Astrofisico di Torino
Dr. John Finnigan	CSIRO, Australia
Dr. Mary Hayden	University of Colorado
Dr. Song-You Hong	Yonsei University
Dr. Joseph Huba	Naval Research Laboratory
Dr. Harm Jonker	Delft University of Technology
Dr. Reto Knutti	ETH Zurich, Switzerland
Dr. Vincent Larson	University of Wisconsin - Milwaukee
Dr. Hao-Sheng Lin	University of Hawai'i Manoa
Dr. Elisabeth Lloyd	Indiana University
Dr. Jakob Mann	Technical University of Denmark
Dr. Marty Mlynczak	NASA Langley Research Center
Dr. Phiippe Naveau	Laboratoire des Sciences du Climat et I'Environnement (LSCE) CNRS
Dr. Bart Nijssen	University of Washington
Prof. Lorenzo Polvani	Columbia University
Dr. Marilyn Raphael	University of California, Los Angeles
Dr. Mark Rast	University of Colorado
Dr. Kevin Repasky	Montana State University
Dr. Alfonso Saiz-Lopez	Ministerio de Ciencia e Innovaction, Madrid
Dr. Banjamin Sanderson	CERFACS
Prof. Gunilla Svennson	University of Stockholm
Dr. Laurent Terray	CERFACS
Prof. Javier Trujillo-Bueno	Instituto de Astrofisica de Canarias
Dr. Lian-Ping Wang	University of Deleware
Prof. Mei Zhang	Chinese Academy of Sciences

Emeritus/Emerita

Scientific and Research Engineering staff who have made significant contributions to NCAR through long and distinguished service in senior positions in research may be granted emeritus or emerita status (see list). This designation confers a life-long honorary distinction. Approval of the President and the Board of Trustees is required. Currently the ranks of Emeritus/Emerita number 32.

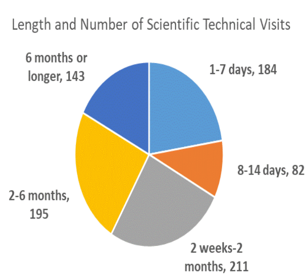
Emeritus/Emerita	Year of Appointment
Jack Calvert	2002
Rit Carbone	2016

Al Cooper	2013
James Dye	2003
Fred Eisele	2009
John Firor*	1999
Brant Foote	2017
John Gille	2015
Peter Gilman	2009
Roy Jenne*	2013
Maura Hagan	2015
Jackson Herring	1998
Greg Holland	2018
James Hurrell	2019
Richard Katz	2013
Charles Knight	2013
Michael Knoelker	2019
Joachim Kuettner*	2007
Margaret Lemone	2009
Donald Lenschow	2011
Bruce Lites	2013
Roland Madden	2002
William Mankin	2003
Nychka, Doug	2018
Annick Pouquet	2013
Art Richmond	2017
Brian Ridley	2007
Raymond Roble	2009
Bob Serafin	2001
Smolarkiewicz, Piotr	2018
Paul Swartztrauber*	2004
David Williamson	2014
Jim Wilson	2014

*deceased

SCIENTIFIC AND TECHNICAL VISITS TO NCAR

Date Range	Total Scientific/Technical Visits	1-7 days	8-14 days	2 weeks-2 months	2-6 months	6 months or longer
FY19	815	184	82	211	195	143



Each year students, scientists, engineers, weather forecasters, and other professionals from around the country and world receive special visitor appointments from labs and programs across NCAR to collaborate with scientific, educational, or technical staff; conduct independent research; or participate in and/or oversee a professional project. Many receive financial support for their visits and some visitors temporarily join the NCAR staff.

This year, colleagues visited NCAR 815 times and hailed from 342 institutions, located in 46 different U.S. states and 40 different countries.