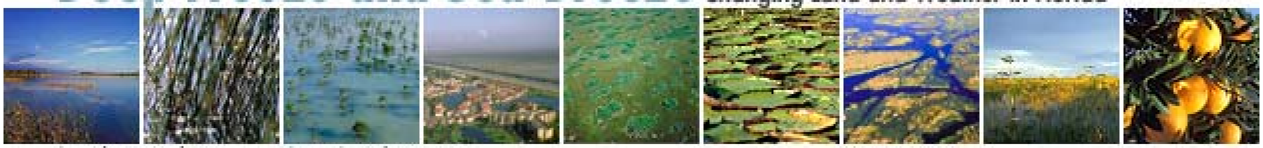
FEATURES

Deep Freeze and Sea Breeze

Changing Land and Weather in Florida



by Rebecca Lindsey design by Robert Simmon May 17, 2005

The first interesting thing about talking with Roger Pielke on the subject of land cover and climate change is that he simultaneously gives the impression that everything he is saying, he has said before, and yet it is all still incredibly fascinating to him. The second interesting thing is that, even before he brings up the subject directly, you get the clear impression that not only has he made these same points before, he is also used to them being misunderstood. It's not impatience or irritability that gives him away, but the directness of his words, the way he pauses as he talks to allow for questions, and the frequency with which he says things like "I'm *not* saying... What I *am* saying is..."

"Whenever you talk about factors other than carbon dioxide or other greenhouse gases that may be playing a role in global climate change," Pielke says, "people immediately accuse you of trying to divert attention away from the human-influence-on-climate problem. But when I say to people that enacting the Kyoto Protocol isn't going to solve our climate problems, I don't mean that carbon dioxide isn't a problem. What I mean is that, unfortunately, it may not be our worst problem."

Three decades of research have brought Pielke to the conclusion that when it comes to the kinds of climate change people experience where they live, land surface changes like deforestation, urbanization, and the draining of wetlands are at least as important—and maybe more important—than increasing atmospheric greenhouse gases.

Most of Florida's wetlands have been drained and converted into croplands in the past 100 years. According to computer simulations, this large-scale transformation modified the regional climate in unexpected ways. In the present-day landscape, Florida days are warmer in summer, nights are colder in winter, and inland rainfall has decreased. (Photograph courtesy Deb Willard, USGS)

In 2004, Curtis Marshall (a former student of Pielke's), Pielke himself, and their colleagues Louis Steyaert and Debra Willard published two papers in which they demonstrate how the transformation of Florida's wetland ecosystems in the last century may have changed the state's climate in unexpected ways. Using present-day land cover based on Landsat satellite data, historical documents and vegetation maps, and the types of pollen found in deep soil samples, the team meticulously reconstructed how the landscape has changed in the last century. Then they used a regional climate model to compare the climate that exists with the climate that might have existed if the natural landscape had remained undisturbed.

Combining their diverse expertise in climatology, environmental modeling, ecology, geography, geology, and remote sensing, the team ended up with an explanation for how land cover change in central and southern Florida could simultaneously be responsible for hotter, drier summers and wintertime deep freezes that are longer-lasting and more severe.

▶ Florida Before Farming

Florida Before Farming

Before humans constructed drainage canals, dams, dikes, and reservoirs, much of central and southern Florida was covered with one kind of wetland or another. From swampy forests dominated by giant cypress trees, to bogs and various types of marshes, to the tree-island-dotted Everglades, almost every ecosystem on North America's southeastern tip was under the sway of water.

Human-made structures now control the flow of water in the Everglades, disrupting natural cycles. (Photograph courtesy South Florida Water Management District)

Runoff from the north kept the Kissimmee River Floodplain in the central part of the peninsula almost perpetually under water. From there the water flowed south into Lake Okeechobee. The spillover from the lake glided slowly over the Everglades in a slow-moving, horizontal sheet. Today's flow is dramaticallyreduced, and the Everglades are only about half the size they once were.

The natural landscape of southern Florida was dominated by wetlands. Rainfall in central Florida feeds the Kissimmee River, which flows into Lake Okeechobee. The southern extent of Lake Okeechobee spills over into the seemingly endless Everglades, which join with coastal mangrove forests. (Map courtesy USGS National Water-Quality Assessment Program)

The change has had profound ecological consequences, but could the transformation of this world of free-flowing water into the agricultural and urban lands of today have actually changed the weather? After the soaking that Florida got from four hurricanes in 2004, it's easy to forget that between 1997 and 2001, Florida suffered through five consecutive summers of drought, much of it extreme.

In January 1997, a surprising freeze event caught Florida farmers off guard, causing the near-total loss of winter crops in the cultivated areas south of Lake Okeechobee. The increased public perception that droughts and freezes in Florida were becoming more frequent and severe focused Pielke's thoughts on the question of whether, if that were true, land cover might have had something to do with it.

Experiments with the Weather

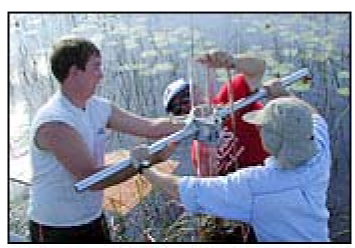
It was an idea that had grown in Pielke's mind over the course of his career, with the seed planted as far back as 30 years ago, when he worked with cloud-modeling pioneer Joanne Simpson. Pielke's task was to develop a model of Florida's weather behavior that they could use to better understand the results of cloud "seeding" experiments, in which scientists tried to entice clouds to produce rain.

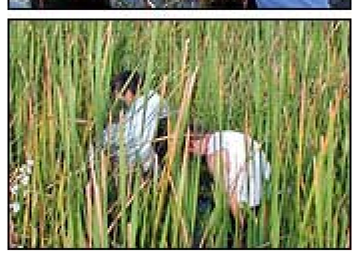
Roger Pielke began studying Florida's weather to support weather-modification experiments in the early 1970s. In this photograph he adjusts a remote weather station in Florida marshland. (Photograph courtesy Roger Pielke)

Pielke's three-dimensional model of Florida's weather evolved over the years. Fifteen years ago, he consolidated his model with a model developed by fellow Colorado State University atmospheric scientist Bill Cotton and colleagues Craig Tremback and Bob Walko. They called the modeling system the Regional Atmospheric Modeling System, or RAMS.

To figure out if the weather that existed with the present-day landscape was different than the weather that would have occurred if the natural landscape had remained required two main ingredients: a model of how the land and atmosphere interact to produce the weather, and a detailed map of land cover in Florida—not just for the present but for the past as well. The study would require expertise in climatology, remote sensing, ecology, hydrology, and geology.

The need for interdisciplinary expertise is what brought Pielke and Curtis Marshall, a meteorologist from the NOAA National Centers for Environmental Prediction and Pielke's student at the time, together with Lou Steyaert of the U.S. Geological Survey (USGS) and NASA, and paleobotanist Deb Willard of the USGS, who has collected and analyzed pollen in soil samples cored out of Florida's wet and dry lands for the past 10 years.





Deb Willard and her colleagues extract pollen samples from the

It was Steyaert who wrote the proposal for funding for the project and arranged for Pielke to be the lead scientist. Pielke planted the idea in the head of

Marshall. Marshall's interest in the link between the land surface and weather developed out of his storm-chasing days at the University of Oklahoma. "While I was studying tornados and severe storms," he explains, "I began to get curious about how land surface properties could influence where and when thunderstorms would form."

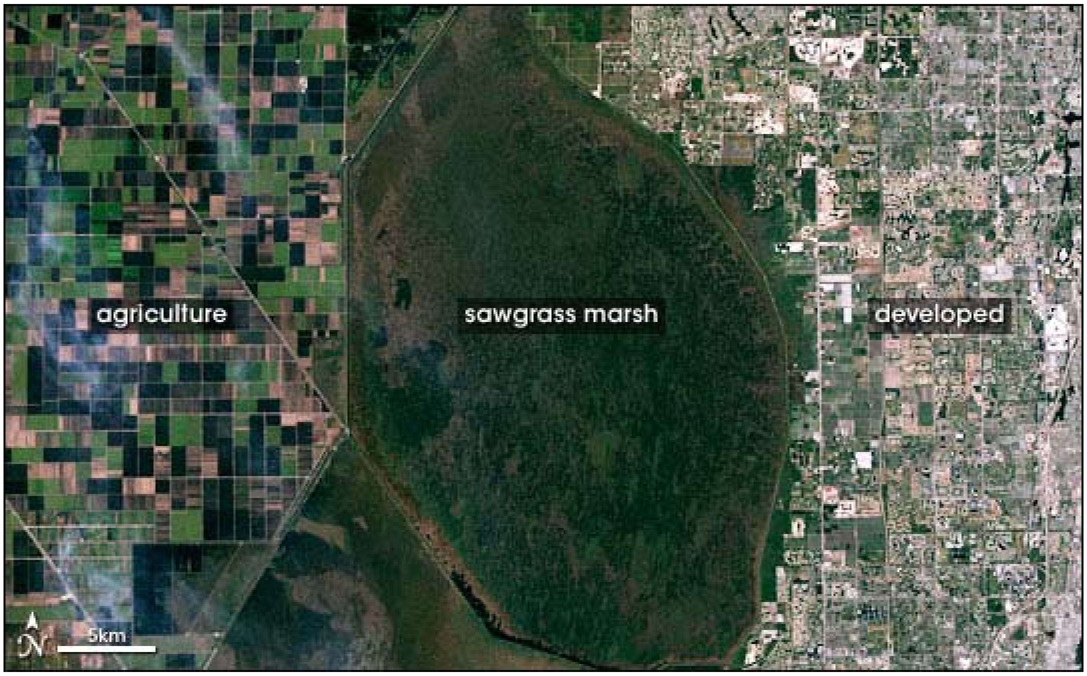
thick bottom peat that underlies marshes and swamps. The work occurs far from the lab in waist-high water and tall marsh plants. (Photograph courtesy Deb Willard, USGS)

The idea of applying the RAMS model to Florida wasn't Marshall's initial plan for a Ph.D. project. "Roger is one of those people with lots of ideas, and he will just come and chit chat about them with you, see if he can get you interested. He doesn't really tell you what to do or how to do it, so I was able to work very independently." Before long, Marshall was hooked on the idea, too.

"The biggest challenge," says Marshall, "was getting historical land cover. You can use satellite data to describe today's land surface, but there are no satellite data for pre-1900." The challenge of creating the two land cover data sets the RAMS model would need for input—a present-day one and a historical one—fell to Steyaert. The approaches he used for creating the two maps couldn't have been farther apart on the technological spectrum.

The Landscape of History

Steyaert based the modern land cover map on satellite data collected in the early 1990s by the Thematic Mapper sensor on NASA's Landsat 5 satellite. As a first step, Steyaert used the USGS National Land Cover Dataset developed from 1992-93 Landsat scenes. To get additional detail on the types of wetlands, he added land cover data based on Landsat scenes from 1993-94, which were produced by the "Florida GAP" project.



Landsat images clearly show different types of landcover in southern Florida. (NASA image by Robert Simmon, based on Landsat 7 data provided by the UMD Global Land Cover Facility)

The ability of satellites to map large areas at once was a benefit sorely missing from historical descriptions of Florida land cover. To get a complete map of the pre-1900 natural vegetation for the area the team wanted to study, Steyaert had to pull together information from books, natural vegetation maps, and papers published as far back as 1943 that he could use in a Geographic Information System (GIS) analysis. Even with all those sources of information, the picture still wasn't complete.

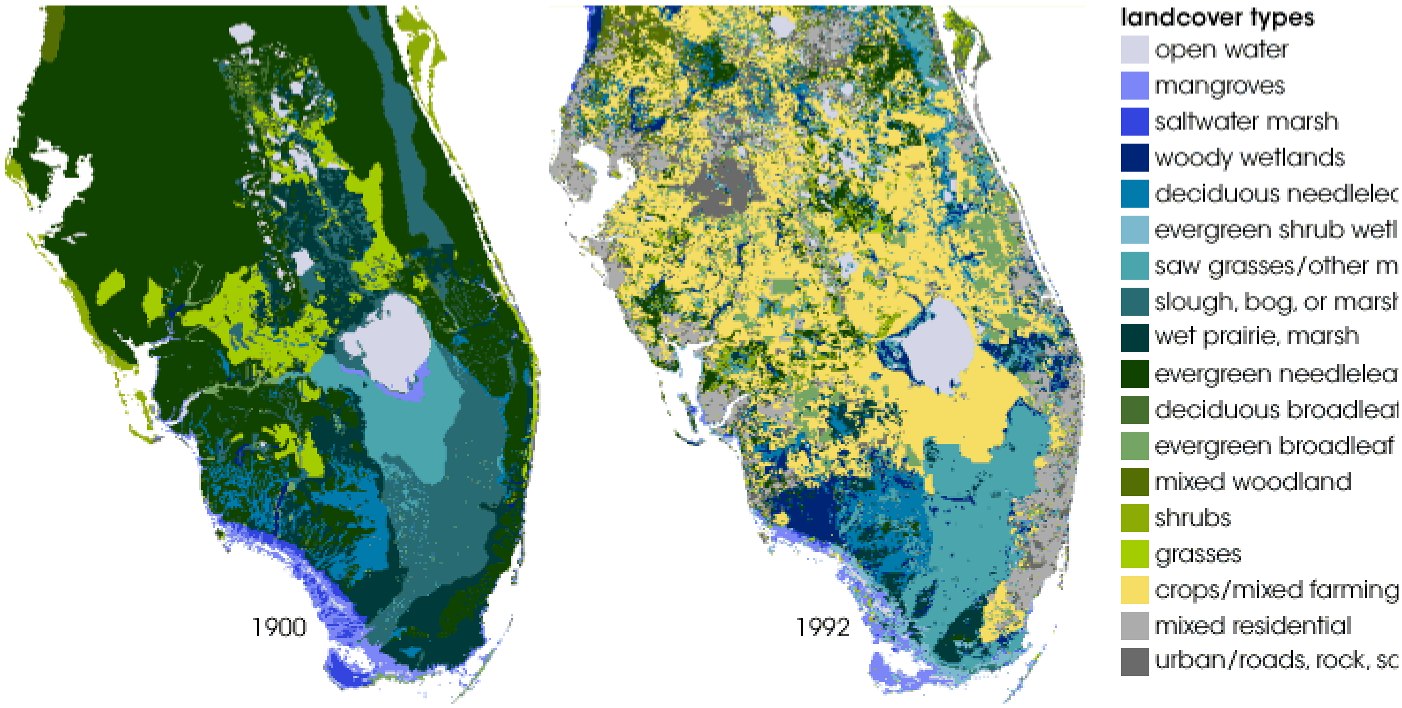
Critical details about the different types and sizes of historical wetlands came from Deb Willard, a paleobotanist who had been "collecting the dirt" on southern Florida since the mid-1990s. She started working in the area after continuing agricultural and urban pollution, disrupted water cycles, and other ecological problems motivated Congress to pass the Comprehensive Everglades Restoration Act, a thirty-year, multi-billion-dollar project to restore the "River of Grass" to a more natural condition.

Beneath the open water sloughs and sawgrass marshes of the Everglades, a thick layer of peat preserves a record of past vegetation—ancient pollen grains. (Photograph courtesy Deb Willard, USGS))

Willard is working to figure out what the "natural condition" would be—what types and amount of vegetation would exist, how deep the water would be, and how the level would vary at different times of the year. She collects cores of soil from locations all over the Everglades, from bogs, to lakes, to tree islands. The pollen trapped in the layers of soil reveal what plants and trees were around hundreds, even thousands, of years ago.

Microscopic pollen grains retrieved from the Everglades act as a fingerpint for past ecosystems. (Micrographs courtesy Deb Willard, USGS)

The Everglades haven't been in a natural state for a long time, says Willard, with efforts to drain them beginning in the late 1800s. Current conditions are unlike anything else in the past 3,000 to 4,000 years. There is much more pollen of sawgrass and weedy plants because it's drier, and there are vast areas of cattails that never existed in the past. Tree islands that had built up over hundreds of years on isolated pockets of higher ground were allowed to remain flooded for more than a decade, and many died within a few years. Willard's pollen work filled in crucial details about the distribution of different kinds of wetlands during the Everglades' past.



Human influence has transformed southern Florida. The transformation occurred not only on land converted to cropland or cities, but even in protected and undeveloped areas like the Everglades. Changes in water flows transformed deep-water sloughs into drier sawgrass marshes, and mangrove forests have shrunk dramatically. (Maps adapted from data provided by Lou Steyaert, USGS and NASA GSFC)

Speaking RAMS language

Getting the land cover maps completed was only the first hurdle. A model needs more information than “Over here there used to be a freshwater marsh, and over there was a cypress swamp forest.” What’s equally important to the model is how each of those surfaces responds to solar heating and interacts with the atmosphere.

In describing how the RAMS model works, Marshall says, “In Nature’s daily cycle, the Sun comes up in the morning and begins heating the Earth. The incoming energy gets partitioned basically one of three ways: some evaporates water, some heats the land surface (which then heats the air), and some is conducted downward into the soil. Mostly, it’s land cover that determines which of those things happens.” RAMS performs all the mathematical calculations to determine the net result of all the different energy-balance characteristics of all the different land cover types, and then predicts what the effect on the weather would be.

The main things that determine how the energy gets split up at the surface are the vegetation (what type and its biological and physical characteristics), soil (what kind and how moist), and water (how deep). These characteristics are known as a surface’s biophysical parameters. Steyaert used the default biophysical parameters for RAMS 20 standard land cover classes as the basis for the 40 land cover categories in their maps. Most of the new categories were different kinds of wetlands, so Steyaert added in estimates of the seasonal depth and duration of standing water, which is called the hydroperiod. Developing the land cover maps, the biophysical profiles, and the hydroperiod information for use in the RAMS simulations occupied Steyaert for the better part of a year.

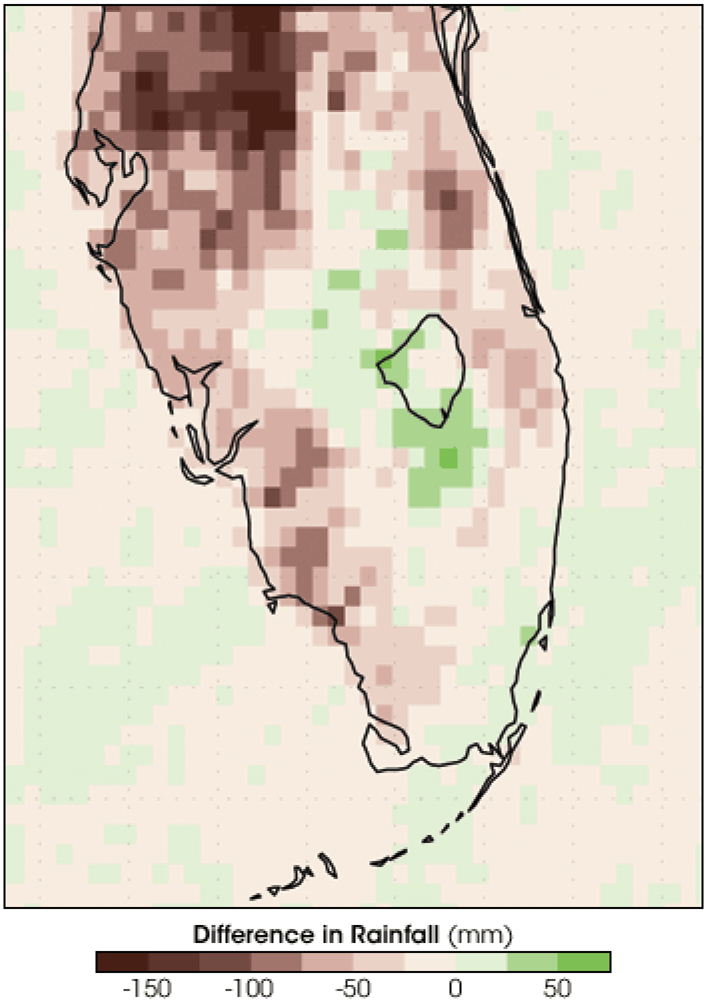
Warm Weather Experiments

To test how land cover change might have influenced summer climate, the team used the RAMS model to create pairs of climate simulations for three July-August periods: 1973, 1989, and 1994. The 1973 and 1994 seasons were wetter than normal, while 1989 was an unusually dry year.

Marshall explains the concept behind the paired scenarios. “To test whether changing the land cover could have changed the weather, you first define the area you want to model, and then you use meteorological observations from the time period you are interested in to identify the large-scale meteorological influences that were acting on your modeling area at that time. You hold those external influences constant and run two simulations: one with the old land cover, and one with the present land cover.”

For all three time periods, the team discovered significant differences in the intensity and location of precipitation when the pre-1900 land cover was replaced with the present-day land cover. South of the latitude of Tampa, two roughly parallel strips of decreased rainfall ran north to south on either side of the heart of the peninsula. Rainfall increased somewhat in a strip down the center of the state. When averaged across the region, the modeled rainfall totals for all three periods were 10-12 percent less with the present-day land cover than they would have been with the pre-1900 land cover.

The draining of many of Florida’s wetlands did more than transform the landscape—it also changed the climate. This map shows the difference in rainfall calculated by a computer model using landcover data from 1993 compared to model results using the pre-1900 landcover. Areas that are now

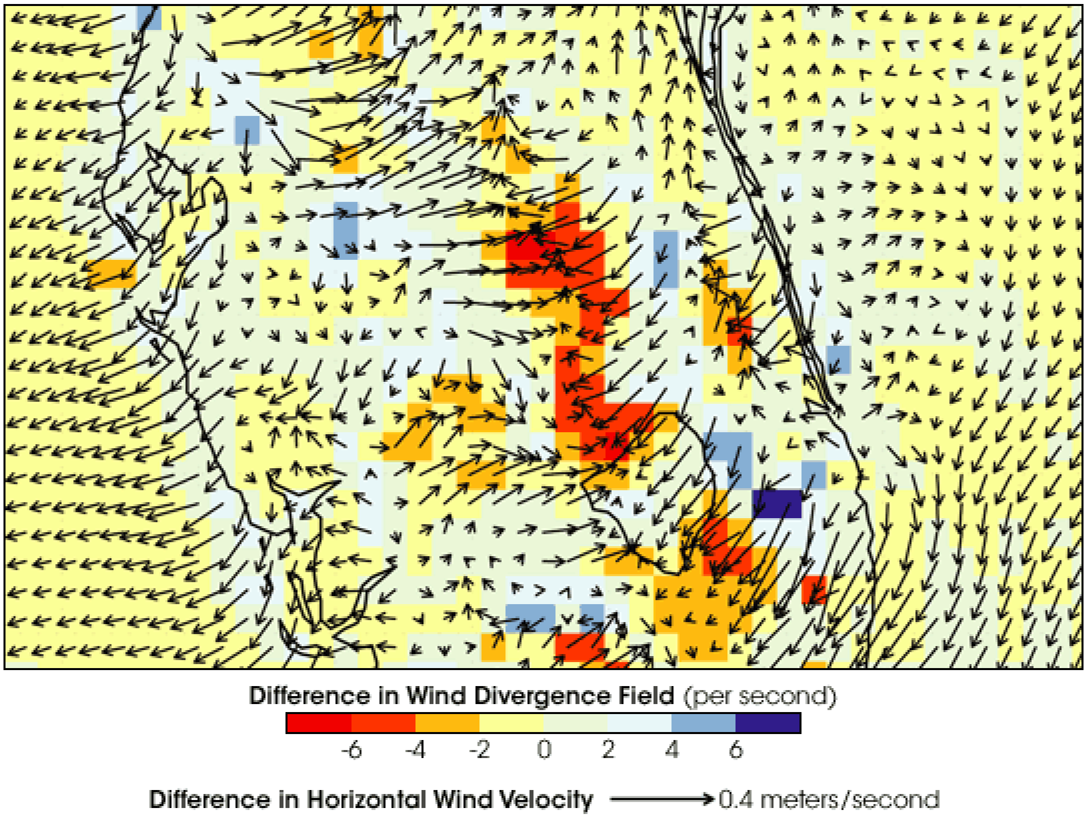


drier are brown, and wetter areas are green. Averaged across the entire state, precipitation may be as much as 12 percent less than it would have been if Florida's pre-1900 landscape still existed. (Map courtesy Curtis Marshall, Colorado State University/NOAA)

Temperatures were affected, too. Urbanization increased maximum daily temperatures by several degrees, particularly around the Miami-Ft. Lauderdale area on the state's southeastern tip. In the center of the peninsula, the daily temperature differences were amplified, with daytime high temperatures up to four degrees Celsius warmer with the present-day land cover, and nighttime lows up to 4 degrees cooler.

One reason for this, Pielke explains, is the draining of the Kissimmee River Floodplain in the center of the peninsula. In the absence of other large-scale meteorological influences, the afternoon sea breeze determines where, when, and how much it rains in Florida. The sea breeze occurs each day as the Sun heats the land more than it heats the ocean. The air above the land warms and rises, and cooler air from over the Gulf of Mexico and the Atlantic Ocean flows inland.

In the past, the standing water in the Kissimmee Flood Plain would have been like an inland sea, and the air over the floodplain would have been cooler than the areas on either side, between the interior and the coasts. When the dry land on either side heated up in the daytime, cool air would have flowed outward from the floodplain and collided with the onshore sea breezes, enhancing convection and rainfall.

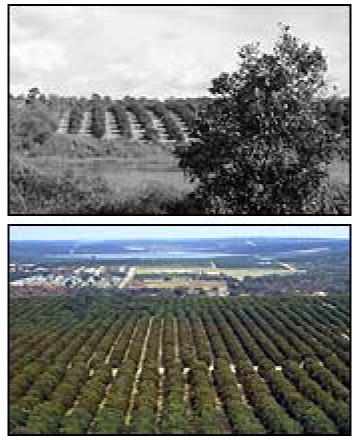


This map shows model simulations of how Florida's wind patterns have changed since humans converted much of the state's wetlands to croplands. Arrows indicate the change in wind speed and direction, while the colors indicate the change in *divergence*—air flowing outward from an area. Red areas show where divergence (outward flow) has decreased most dramatically, while blue areas show where divergence has increased. The large red area north of Lake Okeechobee, in the center of the state, is where the Kissimmee River floodplain and its extensive wetlands once existed.(Map courtesy Curtis Marshall, Colorado State University/NOAA)

"Overall, what we see with the current land cover is a weakening of the sea breeze, less evaporation, less rainfall, and higher temperatures," says Marshall. By converting the wetlands of central and southern Florida into one of the nation's most productive agricultural areas, we may have inadvertently caused the summer climate to get warmer and drier.

Cool Weather Experiments

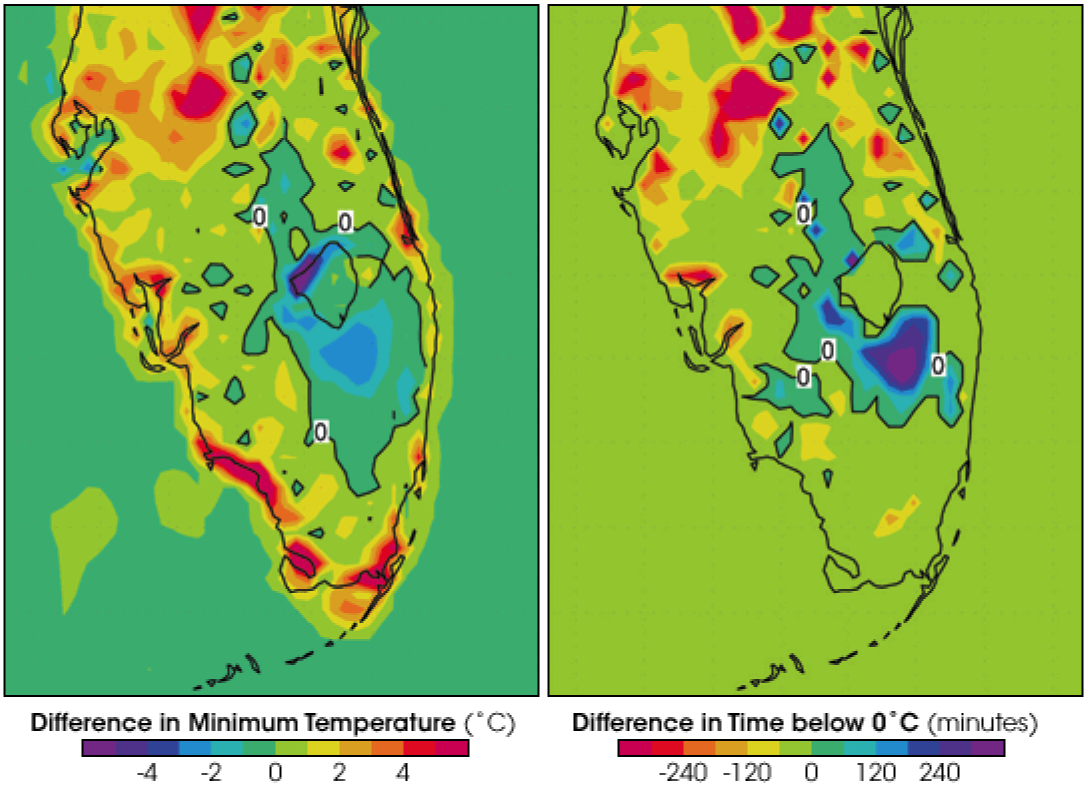
A warmer, drier summer would not have been on the wish list of any of the region's farmers, but the results of the team's cold-season experiments are what really got people's attention. Florida is one of the few places in the country where fruits and vegetables can be grown year round. The mild winter and ample rainfall is precisely why the Florida settlers appealed to Congress in the early part of the 20th century for the federal government's help in converting the state's "worthless" swamps into peat-rich farmlands. Winter vegetable and citrus farmers in the northern and central part of the state, however, still had to fear the occasional winter cold snap that was cold enough and long enough to ruin crops. For the past 150 years, the citrus industry, first established in the less disease-prone soils of northern Florida, has progressively moved southward to escape tree-killing freezes. A major southward migration shifted production into central Florida in the early 1900s, and production flourished. But several catastrophic freezes there in the 1980s drove many citrus farms even farther south, in particular to the southwest of Lake Okeechobee.



Orange groves migrated southward throughout the twentieth century to escape damaging frosts. [Photographs courtesy Library of Congress Prints and Photographs Online Catalog (top) and USDA Online Photography Center (lower)]

And then in 1997 came an overnight freeze that dipped down to citrus and vegetable farms in locations farther south than Lake Okeechobee. Was the occurrence of such a devastating freeze event so far south simply a random “blip” in Florida’s climate history? Was it just a coincidence that as the citrus farms moved south over the past century, the winter freezes they were trying to escape seemed to be right on their heels?

The team reviewed the historical record of severe freeze impacts on the Florida citrus industry and pulled together a second experiment to answer the question. Using their pre-1900 and present-day land cover data, they created a series of paired comparisons of the modeled weather at the time of three damaging freezes: December 26, 1983; December 25, 1989; and January 19, 1997. According to the model results, the southward creep of the winter freeze line was neither a fluke nor a coincidence. It appeared to be the direct result of moving the farms farther south.



The most damaging aspect of landcover-related climate change in Florida is the decrease in nighttime winter temperatures in the Kissimmee River floodplain and around Lake Okeechobee. These areas, largely planted with orange groves and sugarcane, experience colder temperatures (left), and longer freezes (right). Purple and blue areas represent regions with increased risk of damaging freezes, while yellow and red represent areas less likely to freeze. (Maps courtesy Curtis Marshall, Colorado State University/NOAA)

The team's warm-season experiments had demonstrated that in the summer, evaporation from the standing water in Florida's wetlands would have kept daytime temperatures down, explains Marshall. But the cold-season experiments demonstrated another way the wetlands acted as a thermal regulator. In the winter, the standing water in wetlands would have acted like a hot water bottle, holding on to the daytime heat and radiating it back into the night air.

The model told the scientists that areas where wetlands had been converted to agriculture experienced nighttime temperatures that were as much as 2 degrees Celsius colder than they would have been. Two degrees may not seem like much, the scientists wrote in their article on their results, but it's the difference between a light freeze and devastating one. In all three cases, not only were the temperatures colder in the converted areas, but they stayed below zero for longer periods.

Local or Global Problem?

Though their results drew national media attention from many sources, all the scientists involved in the research agree that the scientific arena is where the results should be evaluated. Pielke hopes these results will convince scientists to give the land cover-climate connection more attention. In the past, he has been frustrated by the lack of attention to the topic.

Gordon Bonan is a climate modeler for the National Center for Atmospheric Research in Boulder, Colorado. “It’s definitely true that historically, the emphasis in global climate change research has been on other climate forcings—greenhouses gases, solar variability, aerosols—and that the role of land cover has been neglected. Roger’s work, his persistence, has really played a large role in bringing people around to the importance of it.” Bonan thinks people are finally beginning to listen.

So far, what research has been done on the global-scale influence of land cover change on climate seems to suggest it plays a minor role. That’s not surprising, says Bonan, considering how small the Earth’s land surface is compared to its oceans and that our most common metric for climate change is global mean temperature. Even significant changes in the temperature where we live can get “washed out” (at least for a while) in the global average of a world mostly covered by oceans.

“Nobody experiences the effect of a half a degree increase in global mean temperature,” Bonan says. “What we experience are the changes in the climate in the place where we live, and those changes might be large. Land cover change is as big an influence on regional and local climate and weather as doubled atmospheric carbon dioxide—perhaps even bigger.” That’s the idea Pielke says he has been trying to get across for years. “Climate change is about more than a change in global temperature,” he says. “It’s about changes in weather patterns across the Earth.” Even if it turns out that land cover change doesn’t significantly alter the globally-averaged surface temperature of the Earth, it’s still critically important. “The land is where we live. This research shows that the land itself exerts a first order [primary] influence on the climate we experience.”

If land cover change can cause Florida to have hotter, drier summers and chillier, longer-lasting cold spells, then that is a perfect example of why, Pielke says, “we can’t keep looking solely at increasing carbon dioxide as the only important forcing of climate by people.”

References

Davis, Steven M., and John C. Ogden. 1994. Everglades: The Ecosystem and Its Restoration. Delray Beach, FL: St. Lucie Press.

Marshall, C.H. Jr., R.A. Pielke Sr., L.T. Steyaert, and D.A. Willard. 2004. The impact of anthropogenic land-cover change on the Florida peninsula sea breezes and warm season sensible weather. *Monthly Weather Review.* 132: 28-52.

Marshall, C.H., R.A. Pielke Sr., and L.T. Steyaert. 2004. Has the conversion of natural wetlands to agricultural land increased the incidence and severity of damaging freezes in south Florida? *Monthly Weather Review.* 132: 2243-2258.

Links

South Florida Information Access Website

The Pielke Research Group at Colorado Sate University

The Florida GAP Project Website

The Landsat Project Website

USGS EROS Data Center's Land Cover Characterization Project Website

National Centers for Environmental Prediction Website

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