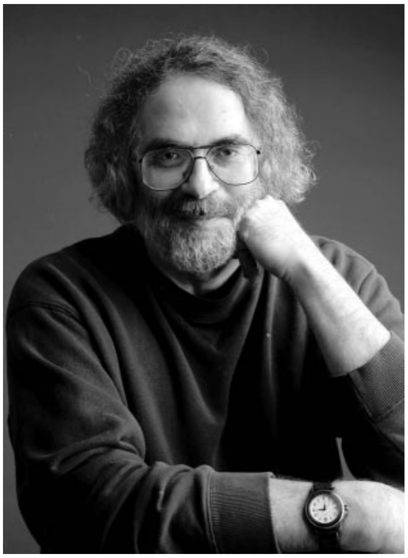
Profile of Isaac M. Held

Stories about global warming pepper the covers of magazines and newspapers on a weekly if not daily basis. But when Isaac Held entered the field of climate studies in the early 1970s, researchers were just beginning to publicize claims that human activities were generating pollutants that could dramatically change the Earth's climate. Motivated by a desire to understand climate change, Held, now a senior research scientist at the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, NJ, has focused on both theoretical and applied atmospheric science. He has explored the scale of cyclones and anticyclones, landscape effects on atmospheric circulation, factors controlling the temperature gradient between the poles and the equator, and overall mechanisms and impacts of global warming.

Held is best known for modeling Hadley cells, which describe the properties of atmospheric circulation in Earth's equatorial zone. His three decades of research have garnered him numerous awards, and in 2003, Held was elected to the National Academy of Sciences. His Inaugural Article, published in a recent issue of PNAS (1), deals specifically with projected climate change in Africa's Sahel region, the transition zone between the Sahara desert and the rainforests of Central Africa and the Guinean Coast.



Isaac M. Held

Coming to America

Held was born in 1948 in a refugee camp in Ulm, Germany. While living in the camp, his father, Israel Held, met his mother, Bertha Blum, who was a survivor of the concentration camp at Auschwitz, Poland, during the Holocaust. In 1952, the family received long-awaited passage to the United States and settled in St. Paul, MN, where Held's father worked at a meatpacking plant. In 1956, Israel Held passed away, leaving Bertha to raise Isaac and his older brother, Herman, while she worked full-time as a seamstress. Although not scientifically inclined, Held's mother strongly encouraged the boys to excel in their schoolwork, which for young Isaac meant focusing on mathematics in grade school. Initially, praise and recognition fueled Held's interest in mathematics, but by high school, he began to appreciate the aesthetic and inherently logical nature of the field. At the University of Minnesota (Minneapolis), Held gradually transferred this enthusiasm to theoretical physics, impressed by the ability of mathematics to explain the real world. In 1969, he graduated with a bachelor's degree in physics.

Held left the Midwest to pursue a Ph.D. in physics at the State University of New York at Stony Brook (now called Stony Brook University; Stony Brook, NY). But his plans went astray. Says Held, "It was kind of a complicated period. This was during Vietnam protests and Cambodia, and so there was a lot of unrest on campus, especially this particular campus. It wasn't that easy to focus on one's studies. There was just a lot going on." Held became disillusioned with traditional physics and began longing to study something "a little more relevant," as he puts it, something he felt he could share with friends and colleagues. "I was working on some very theoretical things in physics," he says, "which weren't easy to explain to people, or even to myself, frankly, why they were important."

While browsing in the library, he came upon the report *Man's Impact on the Climate* (2), considered one of the first significant assessments of anthropogenic-triggered climate change. As part of the Study of Critical Environmental Problems prepared for the 1972 United Nations Conference on the Human Environment, the report showed that the majority of climate scientists believed greenhouse gases produced by human activities were warming the Earth. In the report, climate scientists projected that doubling atmospheric carbon dioxide levels could raise average global temperatures by between 1.5°C and 4.5°C and melt the Arctic ice cap within 100 years. "I thought it was a challenging problem," says Held, "and understanding it *really* had importance to society."

One study in the report, by Syukuro Manabe, a researcher at GFDL/National Oceanic and Atmospheric Administration (NOAA), intrigued Held. Titled "Estimates of Future Change of Climate Due to the Increase of Carbon Dioxide," Manabe's study presented computer models of climate, arguing that these models were the essential tools needed to predict how the Earth's atmosphere would respond to rising carbon dioxide levels. After visiting GFDL and finishing his master's degree in physics in 1971 at Stony Brook, Held shifted his graduate studies to Princeton University (Princeton, NJ) to study climate modeling in the school's Atmospheric and Oceanic Sciences Program.

A New Direction

Held's work has focused primarily on climate mechanisms and atmospheric properties and not specifically on responses to rising greenhouse gases. He has studied temperature gradients between the equator and the poles, location of the jet stream and why multiple streams do not exist, and characteristic scales of cyclones and anticyclones (3, 4). An anticyclone is a system of winds that rotates around a center of high atmospheric pressure (as opposed to low atmospheric pressure found in a cyclone), generally creating fair weather and clear skies.

The first subject to truly captivate Held was the mechanism dictating the direction of the Earth's wind belts. In the tropics, trade winds blow primarily east to west. In the middle latitudes, from 30° to 60°, the winds gust west to east. In polar regions, the winds once again flow from east to west. "That pattern is pretty important," says Held, "and of fundamental importance to oceanography." Many deserts, like the Sahara, are located in the subtropics, at ≈30° latitude. This location is intimately related to the wind transition from easterlies to westerlies. "If you understand the wind fields, you understand why the deserts are where they are. . . . The wind fields also control the ocean circulation," says Held.

Exactly what causes the wind belts to blow in a particular direction was the

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subject of one of Held's earliest publications (5). Spontaneous instabilities in the atmosphere and irregularities in the landscape generate Rossby waves, an inherent property of which is to transport angular momentum in a direction opposite to their propagation. Therefore, in middle latitudes, where most of these waves are produced, the convergence of angular momentum carried by Rossby waves causes the surface winds to flow from west to east. Although these ideas were "in the air" at the time, according to Held, his approach caught the attention of Edward Lorenz, a famous applied mathematician and professor of meteorology at the Massachusetts Institute of Technology (MIT; Cambridge, MA). Lorenz contacted Held, a graduate student at the time, to discuss the work. "He told me in person that he really enjoyed it and that was pretty encouraging to me. After that, I felt that I really could do something important in this field. I could make a contribution," says Held.

Although Lorenz gave Held the confidence to embark on a career in climate modeling, Held credits Manabe, the leading climate modeler for the last two decades, as his most influential mentor and ultimately the reason he joined GFDL. Joseph Smagorinsky, who passed away in 2005, also played an important role in shaping Held's tenure at GFDL. Smagorinsky founded the laboratory and was largely responsible for coupling it with Princeton University, where Held later became a lecturer with rank of professor in 1986. The union yielded a rich supply of talented graduate students and postdoctoral researchers, many of whom have become close colleagues and friends of Held's over the years.

Secrets of the Hadley Cell

In the 1980s, Held studied Hadley circulation, research that has been generally cited as his most important to date. The Hadley cell is named for the 16th-century meteorologist George Hadley, who observed trade winds and inferred the presence of atmospheric overturning in the tropics. In a Hadley cell, warm air rises near the equator, reaches the top of the troposphere, travels to the subtropics, and descends back to the tropics. Asks Held, "One of the big questions is why does it go to the subtropics? Why doesn't it just keep on going? It sort of stops at about 30° latitude and subsides and then returns. What determines that latitude, or why doesn't it stop sooner?"

Held took a crack at these questions during a postdoctoral fellowship at Harvard University (Cambridge, MA), together with graduate student Arthur Hou. Using a model incorporating principles of angular momentum conservation and energy conservation, and building on the work of fellow postdoctoral researcher Ed Schneider, Held and Hou produced a simple theory for the width of the Hadley cell (6). They showed that the Hadley cell's stop in the subtropics had nothing to do with the atmospheric instability in this region, which was the conventional view, but rather that this action was controlled by the planet's rotation. The model predicted that if Earth's rotation increased, the Hadley cell would shrink, whereas if the rate of spin decreased, the cell would expand. The model also predicted that the cell would expand if the height of the tropopause increased, which is relevant to global warming. Held's and Hou's model has become the generally accepted explanation for the width of the Hadley cell, which dominates the atmospheric circulation between 30°S and 30°N and has a dramatic influence on tropical and subtropical weather.

Ideal Versus Real World

Much of Held's work has attempted to bridge the gap between simple idealized models of the climate with complex models that simulate actual meteorological phenomena. If the Earth's surface were smooth and perfectly symmetrical, says Held, with no mountains and no land-sea contrasts, then the climate would just be a function of latitude. But these topographical features cause strong longitudinal climate variations. Over the years, atmospheric scientists have shown how land surfaces, such as the Rocky Mountains in North America or the Tibetan Plateau in Asia, affect atmospheric flow and create stationary waves in the atmosphere, which then create local climates. Held wrote a series of papers in the 1980s that "helped put this theory of stationary waves on a more solid foundation," he says. This research led to an improved understanding of the relative importance of the Tibetan Plateau versus the Rockies, and the distribution of the continents, for shaping this stationary wave pattern (7–9).

"Can we explain the changes in rainfall over Africa in the 20th century?"

During the early 1990s, Held delved into studying storm tracks, paths that cyclones and anticyclones follow as they propagate eastward. Using a theoretical model, Held and his colleague Sukyoung Lee found that these storms organized into clusters, and these "storm packets" moved faster than the individual storms did (10). This finding may have implications for weather forecasting, as Held and Lee have found that these results hold true in real-world observations. "Typically in our field, it goes the other way," says Held about researchers' attempts to explain observations, "but here we found something in one of our theoretical models that surprised us, and then we went to the observations, and we found it there as well. . . . I use this work to justify these idealized models to skeptics who see such theoretical research as removed from the real world."

During the mid-to-late 1990s, as Held's interest in global warming resurfaced, he turned his attention to the distinctive weather patterns of the tropics, one of the most problematic regions with respect to climate modeling. Unlike middle latitudes, tropical weather is dictated in large part by small-scale turbulence. Held was interested in the factors controlling these tiny convection cells that were on the scale of kilometers rather than the thousand-kilometer scale of the Hadley cells with which they coexist.

In some of these studies, Held used a nonrotating "flat-Earth" model to create an idealized simulation of the tropics. His intent was to pinpoint what determines the distribution of water, evaporation, precipitation, and cloud cover (11, 12). Held does not believe his exploration of the tropical atmosphere was as successful as his midlatitude studies. "It's more complicated. In the tropics you have a lot more small-scale circulation patterns, like thunderstorms, on the order of 1 to 10 km, playing important roles," he says. Still, Held's growing interest in global warming kept his sights on the region.

Global Warming and the Sahel

Although much of Held's research has been rooted in the theoretical realm, approximately 5 years ago, he began devoting more time to the problem of climate change. "The main objective of our laboratory is to simulate the climate on a computer as best we can, so that we can then perturb it and do global warming simulations, or try to understand the ice ages [for example]," says Held.

Held's PNAS Inaugural Article offers a climate simulation of Africa's Sahel region during the 20th and 21st centuries (1). The study was inspired by Held's participation in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, in which he focuses on regional climate change in Africa. The report is scheduled for release in 2007.

During the 20th century, climate changes in the Sahel, the band of countries lying on the southern boundary of the Sahara desert in Africa, were the largest of any observed worldwide. Between the 1950s and 1980s, a 30% reduction in rainfall was observed in this region, with the most severe period of drought spanning the late 1970s and early 1980s. The region never recovered, and the dry weather continues today. "It is one of the biggest changes we have observed in the 20th century, and we don't understand it very well," says Held, "so when we build a climate model, that is one of the things we look for. Can we explain the changes in rainfall over Africa in the 20th century?" Answering this question has been particularly difficult, according to Held, and, until recently, success has been limited.

Using the CM2 model developed by researchers at GFDL over the last 6 years, Held and his colleagues have predicted that the Sahel will become drier over the next century (1). CM2 is one of approximately 20 models that have been contributed for the 2007 IPCC report. Together, the models offer a range of different predictions for Africa's future climate, with some models actually projecting a wetter climate for the Sahel.

The prevailing popular perception is that the low rainfall of the Sahel is a product of desertification: overgrazing and overpopulation. Much of the current literature suggests that the changes result from what people have done to the land surface. "Our understanding right now is pretty much the opposite. These changes in climate result from what happened over the oceans," says Held. The South Atlantic, Indian, and Pacific Oceans warmed much more than the North Atlantic Ocean during the second half of the 20th century. "It is that gradient that we think is important for rainfall over Africa," he says.

Held's confidence in his latest model stems from the observation that CM2 simulates the 20th-century African climate more accurately than any other model. This assumption suggests that CM2's prediction of 21st-century weather may also be more accurate. "Some of the drying in the 20th century was actually greenhouse-gas-induced, according to our model. So, based on this model, you [could] say that the industrial countries, like the U.S., produced a part of this drought in Africa," says Held. But, he adds, researchers need a better understanding of why the models differ before solidifying such a claim.

Also, one of the biggest challenges facing climate scientists is simulating the water cycle and not just temperature changes. "Most of us have switched over to thinking about changes in the rainfall patterns rather than the temperature itself. Temperature is pretty robust. I don't think there will be as many surprises there," says Held.

Expanding the Tool Kit

For the past 5 years, Held has slowly transitioned from theoretical to applied studies by constructing high-end models of global climate and integrating contributions from ocean, sea ice, and the ozone layer. He has been frustrated, however, by the chasm that exists between the simple theoretical systems he spent a career developing and the comprehensive models of the Earth's climate. In fact, the latter models are so complicated that it is difficult to determine exactly why they project different outcomes for the Sahel, for example.

To rectify the problem, Held hopes to help coordinate the systematic development of a hierarchy of models to straddle the divide between these simple theories and the comprehensive models (13). "I think the gap is affecting the sociology of our science because there are different groups of people doing the theory and the comprehensive models, and they don't talk to each other much, which is unhealthy," says Held.

Although biologists possess a rich hierarchy of simple organismal models with which to work, climate researchers only have one: the Earth. Because climatologists do not have a variety of planets with simple atmospheres to study, they must build a theoretical hierarchy of models instead. The more complex, high-end models influence global warming projections, storm predictions, and daily weather forecasting. "So you can be doing theory in a little corner of your office," says Held, "but if you are not having an impact on these simulation models, you are not having an impact on the application of your science. So if a gap develops between the theoretical work and the high-end simulations, then that really concerns me because I feel like I'm not influencing applications. I want to help fill that gap for the rest of my career."

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