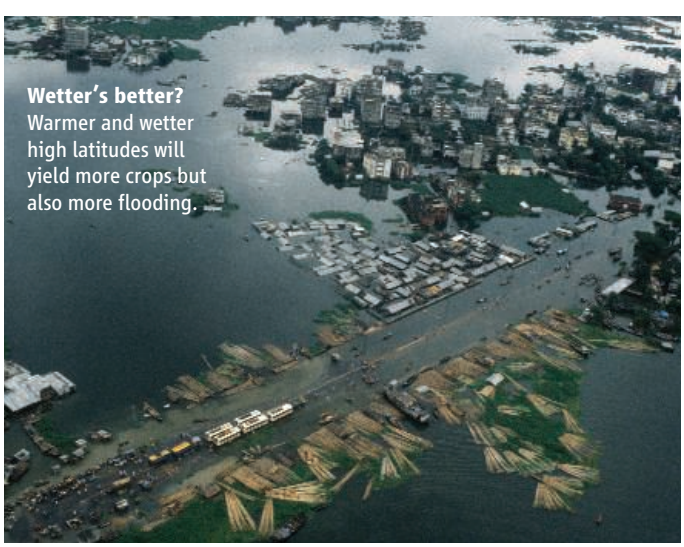
Global Warming Is Changing the World

An international climate assessment finds for the first time that humans are altering their world and the life in it by altering climate; looking ahead, global warming's impacts will only worsen

IN EARLY FEBRUARY, THE UNITED NATIONS–sponsored Intergovernmental Panel on Climate Change (IPCC) declared in no uncertain terms that the world is warming and that humans are mostly to blame. Last week, another IPCC working group reported for the first time that humans—through the greenhouse gases we spew into the atmosphere and the resulting climate change—are behind many of the physical and biological changes that media accounts have already associated with global warming. Receding glaciers, early-blooming trees, bleached corals, acidifying oceans, killer heat waves, and butterflies retreating up mountainsides are likely all ultimately responses to the atmosphere's growing burden of greenhouse gases. "Climate change is being felt where people live and by many species," says geoscientist Michael Oppenheimer of Princeton University, a lead author of the report. "Some changes are making life harder to cope with for people and other species."

The latest IPCC report (www.ipcc.ch/SPM6avr07.pdf) sees a bleak future if we humans persist in our ways. The climate impacts, mostly negative, would fall hardest on the poor, developing countries, and flora and fauna—that is, on those least capable of adapting to change. Even the modest climate changes expected in the next few decades will begin to decrease crop productivity at low latitudes, where drying will be concentrated. At the same time, disease and death from heat waves, floods, and drought would increase. Toward midcentury, up to 30% of species would be at increasing risk of extinction.

"This stark and succinct assessment of the future … is certainly troubling," wrote economist and coordinating lead author Gary Yohe of Wesleyan University in Middletown, Connecticut, in an e-mail message from the final meeting of the IPCC working group in Brussels, Belgium. It is now obvious, he says, that even if greenhouse gas emissions are immediately reduced, changes are inevitable. Humans will have to adapt, if we can.



Wetter's better? Warmer and wetter high latitudes will yield more crops but also more flooding.

Toning down the message

The working group's report had a difficult coming-out party on 6 April. Like the reports from the two other IPCC working groups (WGI—see *Science*, 9 February, p. 754—and WGIII, due out on 4 May), Working Group II's involved a couple of hundred scientist authors from all six continents analyzing and synthesizing the literature over several years. Reviews by hundreds of experts and governments generated thousands of comments. Twenty chapters totaling 700 printed pages led to a Technical Summary of 80 to 100 pages and a Summary for Policymakers (SPM) of 23 pages. Then came the hard part: the 4-day plenary session in Brussels, which brought together scientists and representatives of 120 governments. There, unanimity among governments is required on every word in the SPM, ostensibly to ensure that the phrasing clearly and faithfully reflects the reviewed science of the chapters.

This time, there were "bigger bumps than normal," says climate scientist Stephen Schneider of Stanford University in Palo Alto, California, a coordinating lead author. "It was longer and more painful than usual," Oppenheimer agrees. Especially as the deadline approached early Friday morning, a few countries—attendees mention coal-rich China and oil-rich Saudi Arabia most often—insisted on substantial changes. Sometimes, the softening of the summary could be taken as a technical adjustment. For example, the SPM draft's "20 to 30% [of] species at increasingly high risk of extinction" as the world warms 1° or 2°C became "Up to 30% of species at increasing risk of extinction."

Perhaps the most substantial loss from the draft SPM was in the tables. The plenary session eliminated parts of a table that would

Drought will return to southwest North America.

"For the first time, we concluded **anthropogenic warming has had an influence on many physical and biological systems.**"

—Cynthia Rosenzweig, Goddard Institute for Space Studies

CREDIT: KAPOOR BALDEV/SYGMA/CORBIS

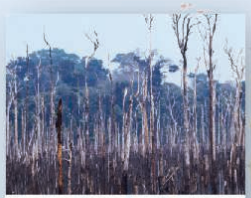
Published by AAAS

Winters in Northern Europe will be less severe.

Arctic permafrost will thaw.

The Mediterranean region will dry out.

Rising sea level will increase coastal flooding.



Savanna will replace tropical forests.

IPCC's Projected Impacts

Mountain glaciers will disappear.

Most corals will suffer major declines.

MAP PHOTO CREDITS (LEFT TO RIGHT): GEORGE E. MARSH/AP/NOAA; KAREL NAVARRO/AP; JOHN MAIER JR./LPI; STEVE PARKIN/AFP/GETTY IMAGES; JUAN MANUEL SERRANO/AP; ROGER TIDMAN/CORBIS; FARJANA K. GODHULY/AFP/GETTY IMAGES; OVE HOEGH-GULDBERG/AP

have allowed a reader to estimate when in this century the various projected impacts might arrive. Also dropped was an entire table that laid out quantified impacts—such as annual bleaching of the Great Barrier Reef in the relatively near term—in an easily accessible, region-by-region format.

Toning-down aside, "it's still a decent report," says Schneider. "There are no key science points that didn't come through in the SPM," says ecologist Christopher Field of Stanford, a coordinating lead author. And all of the losses from the draft SPM are still available in the Technical Summary and the underlying chapters for the determined reader. However, anyone reading the SPM "should understand that the findings are stated very conservatively," says Field.

Impacts, present and future

Conservative though it may be, the report holds one major first. "For the first time, we concluded anthropogenic warming has had an influence on many physical and biological systems," says impacts analyst and coordinating lead author Cynthia Rosenzweig of NASA's Goddard Institute for Space Studies in New York City. Media coverage of weird weather and its effects had come to imply that global warming was affecting things both living and inanimate, and individual studies pointed that way too, but no official body had given the link its imprimatur.

To make it official, IPCC authors considered 29,000 series of observations from 75 studies. Of those series, 89% showed changes—glaciers receding or plants blooming earlier, for example—consistent with a response to warming. Those responses so often fell where greenhouse warming has been greatest that it's "very unlikely" the changes were due to natural variability of climate or of the physical or biological system involved. "It's clear it's not all about future impacts," says Field. As an example, he cites the decline of more than 20% in snowmelt since 1950 as the U.S. Pacific Northwest has warmed. That puts a squeeze on everything from hydroelectric dams to salmon.

Like the ongoing effects of global warming, future impacts will vary greatly from region to region. Perhaps the most striking example is shifting precipitation. WGII authors started with WGI's model-based prediction of increasing dryness at low latitudes (the U.S. Southwest and northern Mexico; the Caribbean region, including northeast Brazil; and all around the Mediterranean) and increasing wetness at high latitudes (northern North America and northern Eurasia). They then drew on published studies of the effects of climate change on crops.

The results of a meta-analysis of 70 modeling studies "are compelling," says geographer William Easterling of Pennsylvania State University in State College, a coordinating lead author. "It's become very clear that in high latitudes, a warming of 1° to 3°C is beneficial for the major cereals—wheat, corn, and rice. At

Published by AAAS

the same time, in low latitudes, even a little warming—1°C—results in an almost immediate decrease in yield." In the north, the added water accompanying warming boosts yields, but toward the equator, the added heat is too much for the plants. But "you can't warm the mid-latitudes forever without getting some negative response," says Easterling. "After a 3°C warming, you get this consistent downturn in cereal yield" even at higher latitudes. A 3°C warming is possible globally late in the century if nothing is done about emissions.

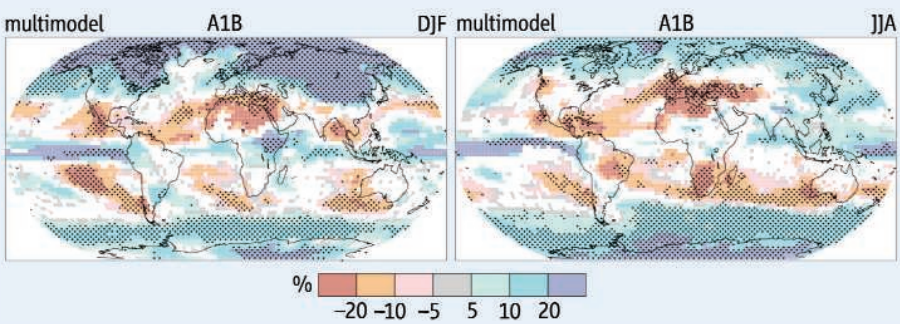
Other global warming impacts are even more localized. As glaciers melt in the next few decades in places such as the Andes and Himalayas, flooding and rock avalanches will increase at first. Then, as the glaciers continue to recede toward oblivion, water supplies will decrease. Sea-level rise from melting glaciers and ice sheets would flood low-lying coastal areas, threatening tens of millions of people living on the megadeltas of Africa and Asia, such as the Nile and Brahmaputra. Coral lives near its upper limits of temperature, so even modest warming is projected to lead to more frequent bleaching events and widespread mortality. Extreme heat waves would become more frequent and more deadly for people. Warming and drying would encourage forest pests, diseases, and fire, hitting forests harder as larger areas are burned. The IPCC list goes on and on.

The report also briefly considers potentially catastrophic climate events. WGI had already found that in this century, the great "conveyor belt" of currents carrying warm water into the chilly far North Atlantic will only slow, not collapse. So Western Europe isn't about to freeze over. In fact, it would warm under the strengthening greenhouse. But WGII still sees likely North Atlantic–wide effects including lower seawater oxygen and changes in fisheries.

More ominous is the report's discussion of potentially large sea-level rise. The main statement is low-key: "There is medium confidence that at least partial deglaciation of the Greenland ice sheet, and possibly the West Antarctic ice sheet, would occur over a period of time ranging from centuries to millennia for a global average temperature increase of 1–4°C (relative to 1990–2000), causing a contribution to sea level rise of 4–6 m or more."

Four to 6 meters of sea-level rise would be globally catastrophic. New Orleans, south Florida, much of Bangladesh, and many major coastal cities would be inundated. Centuries to millennia might seem like plenty of time to deal with this still-uncertain prospect, but the "1–4°C" is a tip-off. Combine that with the table of greenhouse gas–emission scenarios dropped from the SPM, and it is evident that a 1°C warming would in all likelihood arrive by mid-century, assuming no action to cut emissions. A 3°C warming could be here by the end of the century. Although the sluggish ice sheets might not respond completely to that warming for centuries or millennia, before the century is up, the world could be committed to inundation of its low-lying coastal regions.

Projected Patterns of Precipitation Changes



Some of both. Global warming will bring more precipitation (bluish) to high latitudes in both winter (*left*) and summer (*right*) and less precipitation (reddish) to low latitudes.

The world loses

So what's the bottom line? WGII did that calculation too. According to the SPM, "Global mean losses could be 1–5% [of] Gross Domestic Product (GDP) for 4°C of warming." That's a range from significant but bearable to truly burdensome. "There's too much uncertainty in that calculation" to take it too seriously, Yohe says. That's because it is a messy computation involving assumptions about all sorts of factors: how sensitive the climate really is to added greenhouse gases; what people alive today owe to future generations; how to balance the needs of greenhouse gas emitters and climate victims. And the calculation doesn't even include many nonquantifiable impacts, such as ecosystem losses and the conflicts resulting from climate refugees, that could double damage costs. The SPM's bottom line: "The net damage costs of climate change are likely to be significant."

Economists are "virtually certain," however, that whatever the global climate costs prove to be, not everyone will bear them equally. Some people will be exposed to more climate change than others. Some will be more sensitive to it. Some will be less able to adapt to it. And some will suffer on all three accounts. These people might live in countries that lie in low latitudes where drying will predominate. Their economies are likely based largely on agriculture that is susceptible to drought. And they are more likely to be developing countries without the wealth needed to adapt to climate change, say, by building irrigation systems.

Because such happenstances of geography, climate, and economics make some groups particularly vulnerable, Yohe says, "climate change will impede progress toward meeting Millennium Development Goals"—eight U.N.–sponsored goals, which include eradicating extreme poverty and hunger and ensuring environmental sustainability. "If you don't do something about climate, you're swimming upstream" trying to meet these goals across the world. Fortunately, says Yohe, many of the steps that would help communities adapt to climate change would also help meet the U.N. goals.

Although the report emphasizes the vulnerability of poorer, developing countries, it foresees no real winners. Every population has vulnerable segments, Oppenheimer points out. In the European heat wave of 2003 that killed perhaps 30,000, it was the elderly. When Hurricane Katrina hit New Orleans, Louisiana, killing 700, it was the poor. Adaptation—building levees in the case of New Orleans—has not worked out all that well so far.

And no one region seems exempt. In a paper published online by *Science* on 5 April (www.sciencemag.org/cgi/content/abstract/1139601), climate modeler Richard Seager of Lamont-Doherty Earth Observatory in Palisades, New York, and his colleagues look at 19 global climate models run for the IPCC. They expect the dryness of the 1930s Dust Bowl to return to the American Southwest by midcentury, for good. If the models are right, the western drought of the past decade is only the beginning. If the world's biggest emitter of greenhouse gases needed some prodding to take action on global warming, this could be it.

–RICHARD A. KERR

CREDIT: IPCC SUMMARY FOR POLICYMAKERS, WORKING GROUP I

Global Warming Is Changing the World

Richard A. Kerr

Science **316** (5822), 188-190.
DOI: 10.1126/science.316.5822.188