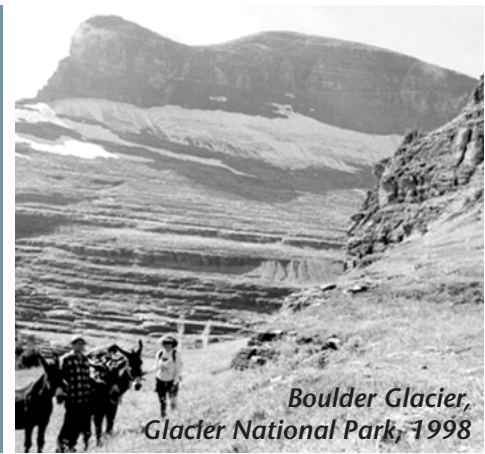


Boulder Glacier,
Glacier National Park, 1932

Global Climate Change



Boulder Glacier,
Glacier National Park, 1998

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Everyone seems to have an opinion on climate change, and most of us have heard numerous contradictory statements. With so many scientists, politicians, industry representatives, and bloggers weighing in, what and who should we believe? And where can we find the most reliable sources of information about this issue?

What we know

In spite of the arguments over climate change, much knowledge is not controversial. In terms of the Earth's climate and atmosphere, we know that:

- Solar energy penetrates the atmosphere and warms the Earth.
- The Earth then radiates some of the energy back into space as low-energy infrared waves.
- Carbon dioxide (CO₂), water vapor, nitrous oxide (N₂O), methane (CH₄), and certain other gases trap some of the infrared energy, which then warms the planet.
- These compounds are called greenhouse gases.
- Normal levels of greenhouse gases are needed to keep the Earth warm enough to support life as we know it.
- At times in the past, the Earth has been warmer or colder than it is now.
- During the 20th century, the Earth's temperature increased.
- The amount of CO₂ in the atmosphere began increasing around the year 1750.
- Since that time, CO₂ production from burning wood, coal, oil, and gasoline has outpaced CO₂ removal by plants and oceans.

We also know that climate affects life on Earth:

- When the Earth is relatively cool, ice sheets and glaciers enlarge in the polar and temperate zones. As this ice forms, it removes large amounts of water from oceans, exposing more land in the warmer zones.

- Conversely, when the Earth is warmer, melted ice adds large amounts of water to the oceans.
- Air and water temperatures influence the timing of many biological processes and cycles, such as migration and breeding.
- Climate strongly influences where plants and animals can live. If conditions change, species must either move to climates they can tolerate, evolve new adaptations, or die out.

In addition to these verifiable facts, we also know that there is widespread agreement that most people value the Earth and its resources and want to be responsible stewards.

There are, however, diverse opinions on how to go about this.

The debate

If there is so much agreement, then what are people arguing about? Some people believe that the current warming is part of a long-term trend, while others suggest it is part of a natural fluctuation between warm and cool periods. Still others suggest that global warming ended about 10 years ago. Some people argue over just how quickly the Earth responds to higher CO₂ levels. Some challenge the idea that future climate change will cause significant problems, or they disagree on whether the rise of CO₂ in the atmosphere is caused by human activity. Finally, some worry that they will be blamed or will be asked to make unacceptable sacrifices.

What science tells us

Science provides us with information on how climate has changed in the past, and how it is likely to change in the future.

Observations and experiments

Scientists make observations and test possible explanations (hypotheses) for what they observe. Since reliable temperature measurements go back only to the late 19th century, scientists use recorded observations of natural

phenomena, such as yearly dates of first lilac bloom (Schwartz and Reiter 2000) and natural records, such as fossils, ice cores, and tree rings, to study historical climates.

The most reliable way to test a hypothesis and develop projections is to conduct a controlled experiment in which one group of research subjects (people, animals, plants, etc.) is treated using an established procedure, while another group (called the control group) does not receive that treatment. Scientists then compare the results from these two groups and draw conclusions.

Obviously, doing this on a planet-wide scale is not possible.

Models

Scientists cannot conduct controlled whole-planet experiments, but they can use models. Climate models are representations or simulations that mimic certain natural processes or systems. These models predict the way climate will behave under particular conditions.

Most of us use models in our daily lives. For example, when driving between two cities, we might develop a simple model to estimate our driving time. Our model could use the distance between the cities, the time of departure, and the normal travel speed. If our data and assumptions are accurate, this model will do a good job of predicting arrival time.

However, if the model fails to consider important factors, such as weather, road construction, or traffic patterns, it

will do a poor job of predicting arrival time. Models can be continually updated with new information, which increases the accuracy of their projections.

Climate scientists use complex models that link together simpler models of the atmosphere, ocean, land, and ice. These models include equations to describe physical laws and processes. Each aspect of a model can be revised, tested, and updated with new information. This process of model revision and refinement is a crucial part of the scientific method.

Climate scientists compare projected (modeled) and measured (observable) changes in temperatures, sea level, rates of ice melt, animal migrations, and flowering dates (Tables 1 and 2). These comparisons provide tests of model accuracy and show whether the models are doing a good job of describing past and present changes (Tables 1 and 2).

The methods, results, and interpretations of scientific research are reviewed and critiqued by other experts. Research that passes this stringent review process is then published, so it is available for further evaluation. Thus, as science progresses, errors are corrected and our understanding of the natural world increases.

Model projections and supporting evidence

Current climate models project that future global warming will have many worrisome consequences that will worsen if levels of greenhouse gases continue to increase (Porter, Parry,

Table 1. Some physical consequences projected by climate change modeling (left column) and evidence that supports those projections (right column).

Projected physical consequences	Evidence that projected physical changes are already taking place
<ul style="list-style-type: none"> The average surface temperature of the Earth will rise by at least 1.1°C and possibly as much as 6.4°C by the end of the 21st century (IPCC 2007a). Sea surface temperatures will rise (IPCC 2007a). Sea water will absorb more CO₂, forming more carbonic acid, which will make the oceans more acidic (IPCC 2007a). Glaciers, ice sheets, and sea ice will shrink (IPCC 2007a). Sea level will rise (IPCC 2007a). The timing of peak stream flow will change, along with a change in irrigation water availability (Climate Impacts Group 2009). Permafrost, the layer of arctic soil that has been frozen for many centuries, will become thinner (IPCC 2007a). 	<ul style="list-style-type: none"> The decade 2000–2009 was the warmest decade since record keeping began in 1880 (Cole and McCarthy 2009). The upper ocean’s average temperature increased by 0.10°C between 1961 and 2003 (IPCC 2007b). Ocean water has become more acidic since the 1750s (IPCC 2007b). Glaciers are getting smaller, arctic sea ice is getting thinner, and ice sheets in Greenland and Antarctica are shrinking faster (Dyurgerov and Meier 2000; Kwok et al. 2009; Velicogna 2009). From 1880 to 2009, sea level rose about 21 cm and the rate of increase is accelerating (Church and White 2011). Lake ice has been melting earlier in New England ever since the 1800s (Hodgkins, James, and Huntington 2002). Peak spring stream flow is occurring earlier across western North America (Stewart, Cayan, and Dettinger 2005). Permafrost on the Tibetan Plateau is thinning (Cheng and Wu 2007).

and Carter 1991; Peters 1992; IPCC 2002, 2007a; Climate Impacts Group 2009).

Hundreds of independent studies of every continent and ocean provide evidence that warming is already taking place. Tables 1 and 2 list some projected physical and biological consequences of warming (left column) and documented supporting evidence (right column).

The human factor

Projections that include both human and natural influences on climate change fit observed data better than simulations that include only natural sources. Models that consider only natural sources indicate that global temperatures should have cooled during the last 50 years. However, this projection does not fit the observed data. Natural factors, such as solar storms, that caused previous global warming events are no longer occurring (IPCC 2007a).

Table 2. Some biological consequences projected by climate change modeling (left column) and evidence that supports those projections (right column).

Projected biological consequences	Evidence that projected biological changes are already taking place
<ul style="list-style-type: none"> • Many animal species will not survive in the warmer parts of their geographic ranges, so they will shift their ranges or become extinct (Peters 1992). 	<ul style="list-style-type: none"> • The geographic ranges of hundreds of species have shifted northward or upslope (Parmesan 1996; Parmesan et al. 1999; Parmesan and Yohe 2003; Hickling et al. 2006; La Sorte and Jetz 2010).
<ul style="list-style-type: none"> • Many corals will die, and species that depend on coral reefs will decline (IPCC 2007a). 	<ul style="list-style-type: none"> • Corals, along with many organisms associated with coral reefs, are dying (Reaser, Pomerance, and Thomas 2000).
<ul style="list-style-type: none"> • Spring migrations, breeding seasons, and other events that occur in spring will begin earlier (IPCC 2002). 	<ul style="list-style-type: none"> • Some birds and frogs have begun breeding earlier in the spring (Sanz 2002; Parmesan and Yohe 2003). Many plants have begun to leaf out, flower, or fruit earlier than they had previously (Schwartz and Reiter 2000; Peñuelas, Filella, and Comas 2002; Badeck et al. 2004; Wolfe et al. 2005).
<ul style="list-style-type: none"> • Some species of insects will be more likely to survive winter (Porter, Parry, and Carter 1991). 	<ul style="list-style-type: none"> • Warmer winters allow greater overwintering survival for many crop pests, such as the European corn borer, potato leafhopper, and disease-carrying aphids (Iglesias and Rosenzweig 2007).
<ul style="list-style-type: none"> • Some insects and other organisms that reproduce several times per year will have more breeding cycles (Porter, Parry, and Carter 1991). 	<ul style="list-style-type: none"> • In 44 European moth and butterfly species, the number of generations per year has increased since 1980 (Altermatt 2010).
<ul style="list-style-type: none"> • Some disease-causing organisms will expand or otherwise change their geographic ranges (Peñuelas, Filella, and Comas 2002). 	<ul style="list-style-type: none"> • Ticks that carry encephalitis are appearing at higher elevations in the Czech Republic (Daniel et al. 2009). Warming has allowed a fungal disease to spread among Central American frogs, causing many species to become extinct (Kannan and James 2009).
<ul style="list-style-type: none"> • Initially, forests will burn more often and with greater intensity (IPCC 2007a). 	<ul style="list-style-type: none"> • Wildfires in mid-elevation forests of the northern Rockies are more frequent and last longer than they used to (Westerling et al. 2006).
<ul style="list-style-type: none"> • Many of the effects listed here will interact in ways that disrupt current food chains (Loeb et al. 1997). 	<ul style="list-style-type: none"> • Numbers of krill (small crustaceans that provide food for whales, penguins, and many fish) decline near Antarctica in years with reduced sea ice (Loeb et al. 1997). Populations of Adélie and chinstrap penguins have decreased because of this drop in their main source of food (Trivelpiece et al. 2011).

The road ahead

What we can do

Fortunately, there are things we can do to address the problem of climate change. We can reduce the level of greenhouse gases that we release into the atmosphere, and we can remove some of the greenhouse gases that are already there.

Consumers

We can reduce fossil fuel use (the primary source of greenhouse gases) substantially by:

- reducing fossil fuels used for transportation by switching to mass transit, telecommuting, and using fuel-efficient vehicles;
- using energy sources that do not produce greenhouse gases, such as wind, solar, and hydroelectric energy;

- increasing home and office energy efficiency by replacing older appliances, windows, insulation, and light bulbs with highly efficient models; and
- including a higher proportion of vegetables, grains, beans, and dairy products in our diets.

Agriculture

Because farming practices strongly affect carbon and nitrogen cycles, those who work in agriculture can make a major contribution to society's efforts in reducing greenhouse gases (Kruger et al. 2010) by, for example:

- increasing nitrogen use efficiency in order to reduce N₂O production and the amount of fossil fuel used for fertilizer production;
- reducing tillage in order to reduce fossil fuel use and minimize oxidation of organic matter and CO₂ release;
- increasing the efficiency of farm inputs, such as fuel, fertilizers, and pesticides;
- decreasing methane emissions by increasing the efficiency of dietary protein production and by improving manure management;
- conserving forested areas and reforesting marginal land where appropriate; and
- increasing production of plant biomass and its incorporation into the soil.

The risks of inaction

Even if future global warming and its impacts turn out to be less dramatic than current models project, changes that have already taken place create sobering challenges.

Conclusions

The scientific method has led to many advances in technology and medicine. The same scientific method is being used to assess current trends in global climate change and to project future changes and their impacts. Scientists from around the world are working to refine climate models. Although some puzzles remain, the consensus of thousands of climate scientists in hundreds of countries worldwide is that the Earth is getting warmer, that human activity is the principal cause of this warming, and that this warming will have serious ecological, health, and economic consequences for the 21st century.

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