Uncertainty

Scientists are constantly improving their models by comparing them with actual conditions. For example, they found that ice was melting more rapidly than had been predicted a couple of decades ago because the models did not take into account the fact that, when ice melts, cracks appear and water flows down the cracks, speeding up the collapse of ice shelves; they created newer models that include the physics of how ice changes when it melts and that make more accurate predictions.

Despite all we have learned, there are still some uncertainties in the models, which mean that warming could be less destructive or more destructive than forecasted.

Sensitivity and Risk

The models that the IPCC uses differ about how sensitive temperature is to greenhouse gas emissions. The IPPC's most probable estimate is that doubling carbon dioxide in the atmosphere will increase temperature by 3°C; but according to various climate models that it uses, doubling carbon dioxide could increase temperature by 1.5°C to 4.5°C. The source of this uncertainty is the effect of warming on cloud formation. It is a tricky issue: some clouds, such as high, wispy cirrus clouds, let sunlight reach the surface but block some heat from escaping, increasing warming; others, such as low, thick stratus clouds, reflect sunlight into space before it reaches the surface, reducing warming.[104]

This uncertainty is why the IPPC shows a range of projections for future temperatures, with sensitivity of 3°C as the line in the center and with a band around it wide enough to include sensitivity of 1.5°C to 4.5°C. This is also why the IPPC projections involve probabilities, saying that a given scenario of emission reductions gives us a 50% probability or a two-thirds probability of holding warming down to 1.5°C.

But what about the smaller probabilities, the results that have only 1% or 2% chance of happening?

The late Harvard economist Martin Weitzman looked at these smaller probabilities. Using sophisticated mathematical analysis based on the uncertainty of the climate's sensitivity to carbon

dioxide emissions and on the possibility of melting permafrost releasing methane, he found that there is a 1% chance of 20°C (36°F) warming by 2200. The effect clearly would be catastrophic, and Weitzman said it could destroy 99% or more of the world's economy.[105] With this much temperature gain, the tropics would be too hot all year for people to spend time outdoors or for crops to grow. In the temperate zones, it would be too hot go outdoors during much of the year, and the summers too hot for crops to grow. Billions of people would die from the heat or flee toward the poles to escape the heat. The amount of food the Earth could produce would plummet. Massive displacement and hunger would undoubtedly cause war throughout the world.

So, Weitzman concluded, we should control climate change as a sort of insurance. We spend money on fire insurance for our homes, even though there is not much chance that a given house will burn down, because we want to avoid even that small chance of being devastated financially by losing our homes. Likewise, spending money to control global warming is justified to avoid the 1% chance that warming will devastate the world economy and the Earth's ability to support life.

Tipping points

Most impacts of global warming, such as temperature increases, get steadily worse as greenhouse-gas concentrations increase and can be reversed by reducing greenhouse gas concentrations. But there are also some impacts that become inevitable when warming reaches some point and that cannot be reversed for thousands of years. The points where massive changes occur are called tipping points.

These tipping points involve a different sort of uncertainty. We know that are bound to reach them if warming continues, but because they are unique events, we do not have past experience to let us predict precisely when we will reach some of them. Here are examples of tipping points:

- **Polar Ice:** As polar ice melts, the remaining ice becomes less structurally sound and less sunlight is reflected back into space, so warming happens more rapidly. Eventually, we will reach a series of tipping points where it will become impossible to stop loss of virtually all the ice in the West Antarctic, other parts of the Antarctic and Greenland, which would raise ocean levels

dramatically.[106] As we have seen we are already near a tipping point where West Antarctica will inevitably lose most of its ice. (There is little evidence of an irreversible tipping point in the Arctic,[107] where the ice floats on the ocean; in the Antarctic and Greenland, ice rests on land and will inevitably flow into the ocean and be lost if it becomes structurally weak.)

- **Monsoons:** The summer monsoons in India and nearby countries depend on air circulation patterns that are sensitive to warming. At some point, these circulation patterns could shut down completely, eliminating the major source of water for hundreds of millions of people.[108]
- **Amazon Rain Forest:** Warming could change the Amazon rain forest abruptly to a grassy savannah[109] because there will be less rain and a longer dry season as temperature increases.[110] The Amazon is also in danger of reaching another human caused tipping point: the trees there pull water out of the ground and release it into the atmosphere, forming clouds that bring rain to the region, so there is less rain as trees are removed. About 17% of this rainforests' trees have already been removed to open up land for agriculture and grazing; if 25% are removed, there would no longer be enough rain to support the rain forest, so it would change to savannah.[111] This would release 90 gigatons of carbon dioxide into the atmosphere as the trees die and decay.[112]
- **Boreal Forests:** These are the vast northern forests that extend through Canada, Scandinavia, and Russia. Warming makes them vulnerable to insect infestation and other diseases that cannot tolerate lower temperatures and to forest fires.[113] As a result, warming could change them from forest to a type of savannah, with groves of trees in open grassland.[114] This could release 110 billion tons of carbon dioxide into the atmosphere,[115] more than the Amazon rainforest.
- **Permafrost:** Ecosystems on lands in the far north change as permafrost thaws, allowing shrubs to spread northward into the tundra, which also increases warming by reducing the amount of sunlight the permafrost reflects. At some point, this change could make it inevitable that all the permafrost will melt,[116] causing catastrophic warming, as the methane stored in the permafrost is released. Permafrost contains more carbon to the atmosphere than the total that is in the atmosphere now, and it would release methane, which causes much more warming than carbon dioxide.

- **Other Ecosystems:** Many other ecosystems could reach tipping points similar to those of the Amazon and boreal forests. For example, we have seen that this sort of tipping point is very close for coral reefs and the ecosystems they support. Without a sharp reduction of global warming, many terrestrial, marine and fresh-water ecosystems will collapse in the 21st century[117]—and, of course, it will be impossible to restore them because many of their species will be extinct.

Some of these changes would happen quickly when the tipping point is reached. Others could take centuries to happen. But once we reach the tipping point, the change becomes inevitable and will persist even if we bring greenhouse gas concentrations down to the preindustrial level.

We do not know with any precision where these tipping points are, but we do know that the danger of reaching them increases as warming continues.

For example, the IPCC has said that, for some level of warming between 1.5°C and 4.5°C, it would become inevitable that all the ice of Greenland would melt.[118]

Overall, the IPCC says that there is a relatively low risk of reaching most tipping points at 1.5°C to 2.0°C of warming, but substantial risk as warming increases to 3°C.[119] This implies that it is probably impossible to limit warming to 3°C or 4°C: with that much temperature increase, we are very likely to reach one of the tipping points that increases warming, making it likely that we will reach more tipping points.

It obviously makes sense to limit warming strictly to avoid the risk of reaching these tipping points.

Deniers use uncertainty to argue against action, but uncertainty means that effects could be worse than expected as well as better than expected, and it means that tipping points could come sooner as well as later. Those who say that we should not try to stop climate change because of uncertainty could use the same reasoning to say that we should go ahead and play a few rounds of Russian roulette because it is not certain that we would kill ourselves.