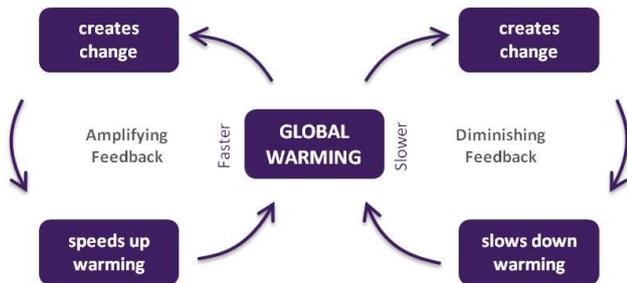


Risks from Climate Feedbacks



The Fifth Assessment Report of the IPCC concluded that human activities are causing the climate to warm, but there is uncertainty in how the climate will continue to change. Climate feedbacks could both increase and decrease global warming. This POSTnote discusses what climate feedbacks are, as well as the challenges they present for climate change mitigation policies.

What is a Climate Feedback?

The climate is a system of interacting components that includes the atmosphere, land and oceans. Feedbacks between components of the climate system can either increase the rate of global warming, or decrease the rate of global warming. A climate feedback is a change to a component of the climate system that causes a knock-on effect which further alters the original change.

- An **amplifying feedback** (also referred to as a 'positive feedback') increases the rate of global warming. For example, as the climate warms it will cause snow to melt exposing the land underneath. The darker land absorbs more sunlight than the highly reflective white snow so the Earth heats up quicker. This causes more snow melt, exposing more land which results in even more warming.
- A **diminishing feedback** (also referred to as a 'negative feedback') decreases the rate of global warming. For example, an increase in CO₂ in the atmosphere will allow plant growth rates to increase. This will reduce the rate at which CO₂ accumulates in the atmosphere thereby decreasing the rate of global warming.

To avoid the worst effects of climate change, many nations agree global warming should be limited to 2°C above pre-industrial levels.¹ Climate feedbacks may cause difficulties when trying to stay within this target, although it remains uncertain to what extent.

Overview

- Feedbacks in the climate system can either increase or decrease the rate of global warming.
- Although knowledge of climate feedbacks is increasing, there remains uncertainty about the scale of many of their impacts.
- In aggregate, climate feedbacks will likely cause additional carbon to be released into the atmosphere, increasing the risk of exceeding a 2°C rise in global temperatures.
- If human carbon emissions are reduced beyond existing commitments, it may reduce the impacts of additional atmospheric carbon from climate feedbacks.
- A better understanding of climate feedbacks could reduce uncertainty of how the climate will respond to future warming.

Feedbacks in the Climate System

Climate feedbacks may be divided into those involving physical components of the climate system and those involving the Earth's carbon cycle.

Physical Climate Feedbacks

Physical feedbacks involve physical components of the climate system such as glaciers and the Earth's surface. Of the many physical feedbacks, two well known examples are discussed below:

Water Vapour Feedback

As the climate warms the atmosphere is able to hold more water. Water vapour is a greenhouse gas which causes the climate to warm in a manner similar to CO₂. Consequently, a warmer climate leads to more atmospheric water vapour and more warming.² The water vapour feedback is significant as it causes the climate to warm twice as much as it would if the feedback were not to occur.³ Because this feedback is relatively well understood, it is considered well represented in all climate models (Box 1).²

Albedo (Reflectivity) Feedback

This amplifying feedback occurs due to the different abilities of light and dark surfaces to absorb sunlight. Ice and snow are highly reflective and consequently absorb little sunlight; while the darker surfaces of the land and ocean absorb

Box 1. Models and Climate Feedbacks

By emitting greenhouse gases into the atmosphere, humans are changing a component of the climate system. As the climate is a global system, scientists are limited in the experiments they can conduct. Therefore, in order to understand how the climate may respond, scientists use mathematical models, based upon the laws of physics, to simulate the processes of the climate system. Components of the model are then experimented on to understand their response.

For the models to be useful, climate processes must be well characterised within the models. The underlying physics of physical climate feedbacks are relatively well understood so they are comparatively well represented in models. However, some carbon cycle feedbacks are either poorly represented or omitted from climate models because of uncertainties in their underlying biological and geological processes. Some commentators have suggested that the under-representation or omission of feedbacks in climate models may result in inaccurate projections. This does not alter the fundamental model prediction that increased greenhouse gas concentrations in the atmosphere will cause the climate to warm, but it does increase uncertainty about the magnitude and speed of the warming.

more sunlight. As the climate warms, snow and ice melts, exposing the darker land and ocean surfaces. This reduces the Earth's reflectivity (albedo) causing more sunlight to be absorbed, further warming and further ice and snow melt.

Carbon Cycle Climate Feedbacks

Feedbacks involving components of the carbon cycle are termed carbon cycle feedbacks. How carbon is moved between the atmosphere, land and oceans by a variety of chemical and biological processes, such as conversion into rocks and photosynthesis, is referred to as the carbon cycle. CO₂ and methane are carbon-based greenhouse gases that contribute significantly to global warming. Consequently, the movement of carbon around the global carbon cycle has a critical role in determining the impacts of carbon-based greenhouse gases on the climate.⁴

Carbon Stores

Within the carbon cycle, accumulations of carbon are called carbon stores. These are either active or inactive:

- Inactive carbon stores, such as oil and gas fields, are so described because the carbon within them will not move between other parts of the carbon system for millions of years, unless accessed by humans.
- Active carbon stores, such as vegetation, are so described because the carbon within them is available to the wider carbon cycle within a relatively short time period, such as when a tree dies or is damaged.

Carbon cycle feedbacks affect the movement of carbon around the carbon cycle, as well as the size and stability of carbon stores. There are many different carbon cycle feedbacks, two are outlined below:

Soil Carbon Feedback

Dead plants and animals are partly comprised of carbon. Soils are a significant store of active carbon as they can contain large amounts of dead plants and animals. Micro-organisms in the soil break down the dead plant and animal matter and release carbon into the atmosphere. Warmer temperatures increase the rate at which micro-organisms

break down plant and animal matter, which causes more carbon to be released into the atmosphere, warming the climate further leading to further carbon release. The soil carbon feedback is an amplifying feedback.

CO₂ Fertilisation Feedback

Changes in the climate system can cause carbon stores to increase.⁴ Plants require CO₂ for photosynthesis, so they increase their growth rates with increasing levels of atmospheric CO₂. This reduces the rate at which carbon accumulates in the atmosphere by increasing the amount of carbon stored in the vegetation and soil carbon stores. The CO₂ fertilisation feedback is therefore a diminishing feedback as it reduces the rate of global warming.⁵

Uncertainties in Climate Feedbacks

The Fifth Report of the Intergovernmental Panel on Climate Change, released in September 2013, stated that "warming of the climate system is unequivocal" and that "human influence on the climate system is clear".⁴ However, there is uncertainty about the future magnitude and speed of this warming.⁴ The uncertainty in future predictions occurs partly because of uncertainties in how climate processes, including climate feedbacks operate (Box 1).⁴

Uncertainties in Physical Feedbacks

Although comparatively well understood compared to carbon cycle feedbacks, uncertainty remains for some physical feedbacks including the cloud feedback⁶ and the Pacific Decadal Oscillation (PDO) feedback⁷. The PDO feedback refers to the circulation of cold and warm waters around the Pacific. The latest research suggests that the diminishing PDO feedback may explain the recent period of lower than expected warming by increasing the length of the La Niña cooling period (See POSTnote 400).⁷

Cloud Feedback

Clouds can both warm and cool the climate and the sum of these effects determines whether clouds result in a net cooling or warming effect.⁸ Both high and low clouds reflect the sun's radiation back into space, causing the Earth to cool, and trap heat, preventing it from being lost into space. Low clouds trap less heat than they reflect so they have a cooling effect on the climate, while high clouds trap more heat than they reflect so they have a warming effect.⁸

Although the cooling and warming properties of different clouds are well understood, there is uncertainty about how climate change will influence the height of clouds.⁶ Most models suggest the feedback will be amplifying as the height of clouds will increase in a warmer world.⁸ However, some models predict the feedback will have little overall amplifying effect. No models predict the cloud feedback to be net diminishing.

Uncertainties in Carbon Cycle Feedbacks

Uncertainties exist about how carbon cycle feedbacks will influence the movement of carbon to and from carbon stores. This uncertainty is greater than that for physical feedbacks as the biological and chemical processes of the

carbon cycle are less well understood than the physical processes of the physical feedbacks.⁹ Uncertainties for some carbon cycle feedbacks are discussed below:

Permafrost Feedback

Changes in the climate system can result in carbon cycle feedbacks that cause inactive carbon stores to become active.¹⁰ Frozen soils at high latitudes (permafrost) are carbon rich as they contain large amounts of dead, but only partially decomposed plants. It is too cold for the micro-organisms that normally break down the plants to grow so it is an inactive store of carbon. However, as the Earth warms the frozen soils will melt, allowing micro-organisms to grow. These micro-organisms will break down the plants and emit carbon into the atmosphere, causing the carbon store to become active. The additional carbon in the atmosphere will cause more warming, further melting and further carbon release. This is an amplifying feedback.¹⁰

Estimates of the strength of the permafrost feedback vary because of uncertainties in how much permafrost will thaw, and in what form and quantity the carbon will be released.¹⁰ The more thawing occurs, the more carbon will be active and available for release into the atmosphere. However, it remains unclear over what area, to what depth, and how quickly the permafrost will thaw.

Once thawed, the previously solid ice will turn to liquid water. The amount and type of carbon released from the soil depends on how much of this water remains as the micro-organisms that break down plants work differently in wet and dry conditions.¹⁰ If the newly liquid water drains away, it will allow oxygen into the soils and the micro-organisms will break down the plants aerobically. Aerobic decomposition is rapid and results in CO₂ emissions. If water remains and the soils are water logged, it will prevent oxygen entering the soils and the micro-organisms will break down the plants anaerobically. Anaerobic decomposition is slower but results in methane emissions. Methane is a considerably stronger greenhouse gas,¹¹ so lower levels of methane emissions can have a greater impact than higher levels of CO₂ emissions. Permafrost covers over 16% of the Earth's total land surface¹⁰ and the landscape is highly variable, so it is difficult to predict how the water of the thawing soils will respond. Consequently, there is high degree of uncertainty over the actual and relative amounts of CO₂ and methane that will be released from the permafrost feedback (Box 2).

Wetland Methane Feedback

As the Earth warms, average global rainfall is predicted to increase, although locally it may reduce. Since wet soils result in anaerobic decomposition and methane release, a warmer world could lead to increased methane emissions and the amplifying wetland methane feedback. There is medium confidence that wetland methane emissions will increase in a warmer world.⁴ But there is low confidence in the predictions of the size of this increase because of uncertainty in the estimates of wetland expansion⁴.

CO₂ Fertilisation Feedback

Increased plant growth rates from CO₂ fertilisation increases the vegetation and soil carbon stores. However, there is uncertainty over how much the stores will grow. This is because the ability of plants to increase their growth rates is not only determined by CO₂, but also other nutrients such as nitrogen. As plants are often limited by the natural availability of nutrients it is very likely that nutrient shortages will limit the CO₂ fertilisation feedback. However, data on vegetation growth rates and the natural abundance of nutrients are lacking for many regions.

Ocean Carbon Feedback

CO₂ dissolves in water, and the oceans currently absorb about 25% of human CO₂ emissions.⁴ Increasing levels of CO₂ in the atmosphere causes the oceans to absorb more CO₂ and increases the size of the ocean carbon store. This is the diminishing ocean carbon feedback. However, surface layers of the ocean can become saturated and unable to absorb more CO₂.⁴ Currently this does not occur as surface waters naturally circulate into the deep oceans to be replaced by unsaturated waters. However, there remains uncertainty over how global warming will influence circulation patterns and how this may affect the ocean carbon feedback.⁴

Methane Hydrates (Methane Clathrates) Feedback

Methane hydrates are deposits of ice that contain methane. Found in the ocean floor, they are currently stable due to the high pressures and low temperatures of this environment¹². Warming could destabilise the methane hydrates, causing methane to be released into the atmosphere, but there is much debate over the likelihood of this (Box 2).

Feedbacks and Global Carbon Stores

Overall, carbon stores either absorb or emit carbon:

- a carbon sink is a carbon store that absorbs more carbon from the atmosphere than it emits.
- a carbon source is a carbon store that emits more carbon into the atmosphere than it absorbs.

Globally, the land carbon store (that is the combined vegetation and soil carbon stores) and the ocean carbon store are both carbon sinks. Presently, they absorb around 50% of all human carbon emissions.⁴ Carbon cycle feedbacks effect whether a carbon store will remain a sink or a source, as well as the size of that sink or source. Climate feedbacks will influence how the land and ocean carbon stores respond to climate change. This may affect the size and speed of future warming by influencing the levels of carbon in the atmosphere.

Climate models (Box 1) predict with high confidence that the ocean carbon store will remain a significant carbon sink.⁴ Although, the effectiveness of the sink is likely (medium confidence) to reduce over time.⁴ Uncertainties in our understanding of the ocean carbon cycle feedback means that there is uncertainty in the estimates of how the ocean carbon sink will weaken. As increased oceanic carbon causes ocean acidification, an increase in the ocean carbon store creates further policy challenges¹³.

Box 2. Omitted Carbon Cycle Feedbacks**Permafrost Feedback**

There is low confidence in estimates of potential permafrost carbon release, hence its omission from most models. The best estimate is 50-250 gigatonnes (1 gigatonne = 1 billion tonnes) of carbon (taking account of both CO₂ and methane) in a high-warming scenario.⁴ For comparison, human activities have emitted about 550 gigatonnes of CO₂ since 1750 and current emissions are about 10 gigatonnes a year.⁴ To avoid warming greater than 2°C, it is estimated that total CO₂ emissions from human activities would need to be capped at about 1,000 gigatonnes.¹⁴ An additional release of carbon from permafrost would require significant downward revision of emissions targets.

Methane Hydrates Feedback

The ocean floor is estimated to hold 2,000-9,300 gigatonnes of methane within methane hydrates.⁴ The East Siberian Arctic Shelf (ESAS) may contain about 50 gigatonnes of methane.¹⁵ ESAS deposits are at greatest risk of warming as the ESAS is shallow so hydrates occur relatively close to the ocean's surface.¹⁶ It is uncertain how much methane could be released from the ESAS as it is not known how the hydrates are structured within the seabed or how the seabed will warm.¹⁷ Once released, it is also unknown how much methane will reach the atmosphere as some methane may dissolve in the seawater. It is highly uncertain whether a release from ESAS will occur, although the probability increases with warming.⁴ The significant uncertainty surrounding all methane hydrates leads to their omission from all models.

The majority of models predict the land carbon store will remain a sink, although its ability to absorb carbon will weaken.⁴ But when the effect of nutrient limitation on the CO₂ fertilisation feedback is taken into account, the rate of carbon uptake is reduced further. In some models, the land carbon store even becomes a carbon source.⁴ Estimates of the future of the land carbon sink are further complicated by the omission of the permafrost feedback from most models (Box 2). Uncertainties in the land carbon cycle feedbacks means that there is low confidence in predictions of the future of the land carbon sink.

Climate Feedbacks and Emissions Targets

Many nations have agreed that global warming should be limited to no more than 2°C above pre-industrial levels in order to avoid the worst affects of climate change.¹ To reach this limit, model estimates suggest that global CO₂ emissions from human activities should be capped at about 1,000 gigatonnes.¹⁴ Estimates for this cap do consider model predictions of additional carbon release resulting from carbon cycle feedbacks. However, as described above, there remain uncertainties in the underlying processes of many carbon cycle feedbacks, leading to their under-representation or omission (Box 2) from climate models.

Policy Responses to Climate Feedbacks

As part of global efforts to avoid a greater than 2°C rise in global temperatures, the UK has a legal national carbon emissions reduction target of 80% by 2050.¹⁸ As a statutory body, the Committee on Climate Change uses estimates of how carbon stores will respond to climate change to advise the Government on emission reduction targets.¹⁹ There is uncertainty about the size and direction of many climate

Box 3. Feedbacks and Changes to the Climate System

When interactions between different components of the climate system are balanced the climate is stable. If a component of the climate is altered, the climate can become unstable and undergo a major shift as the system rebalances. Shifts between different climate states can occur relatively quickly. For example, past shifts between warm and cool phases of ice ages (Dansgaard-Oeschger events) have occurred over only a few decades.

The threshold at which the climate may change from one stable state to another can be small and is known as a tipping point.²⁰ A large change to the system, such as strong amplifying feedback can cause a tipping point to be crossed.

It is not yet possible to predict where tipping points are within the climate system, and when they might be crossed. However, the following have been hypothesised as potential tipping points²⁰:

- Greenland Ice Sheet (GIS): As the GIS thaws the height of the ice sheet is lowered. Temperatures increase with decreasing altitude causing further warming and loss of the GIS. The elevation-temperature feedback could cause a tipping point to be crossed where the GIS irreversibly shrinks. Complete melt would cause a 7m rise in sea level, although it may take over 1,000 years.
- Arctic Sea Ice (ASI): The albedo feedback may change ASI state, causing ice-free summers to become normal. This may cause changes in weather, including colder European winters. Warming could initiate or amplify both the hydrate and permafrost feedback.

feedbacks and this results in uncertainty about the estimates of additional release from carbon stores.

Compared to existing model estimates, it is likely that climate feedbacks will result in additional carbon in the atmosphere and additional warming. This is because the majority of poorly represented climate feedbacks are likely to be amplifying feedbacks. This additional atmospheric carbon from climate feedbacks could make it more difficult to avoid a greater than 2°C rise in global temperatures without additional reductions in greenhouse gas emissions. The strength of many amplifying feedbacks is likely to increase with warming, which could increase the risk of the climate changing state (Box 3). Some commentators suggest the uncertainties in our knowledge of carbon cycle and physical feedbacks may mean the Earth will warm faster than models currently estimate.

Endnotes

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