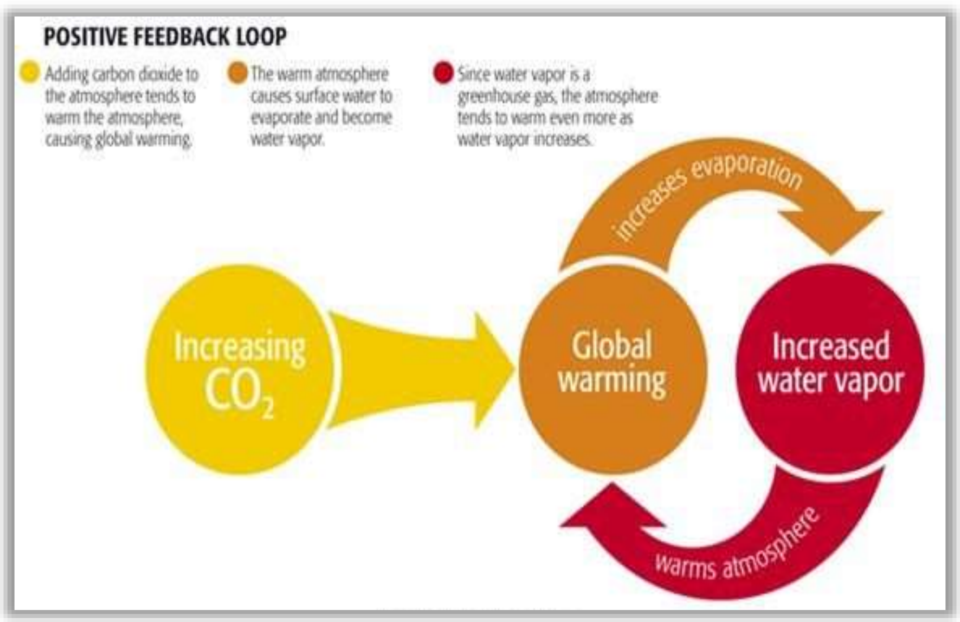
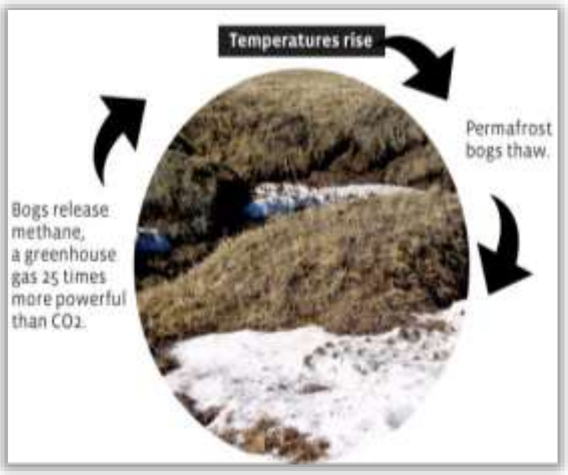
TEACHER BACKGROUND:
UNDERSTANDING FEEDBACK LOOPS

The sensitivity of Earth's climate system is determined mostly by *feedback loops* or *mechanisms.* Feedbacks occur within the system that can either dampen or amplify the response to external factors affecting the climate. In other words, the effect of an initial process causes changes in a second process, which then influences the initial one. *Negative feedbacks* decrease the direct effects of the original process, and *positive feedbacks* increase it. When thinking about the concentrations of greenhouse gases in the atmosphere and their *direct* effects on Earth's climate, it is absolutely necessary to consider what their *indirect* effects might be as well.

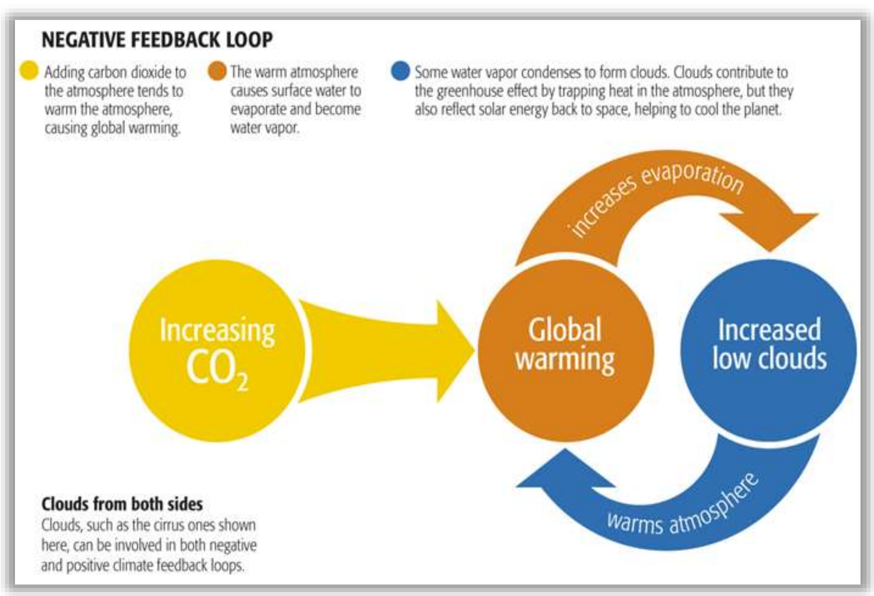


As mentioned, positive feedback loops will accelerate a response, making the climate much warmer or colder. An important example is the *water vapor feedback loop*. Although water vapor is a greenhouse gas, it has very little effect on the external factors controlling the climate, unless "pushed" from within. If the atmosphere starts to warm, the amount of water vapor in the atmosphere will increase. This will then slowly increase the greenhouse effect, reducing the amount of heat able to escape from Earth. The atmosphere warms further, enabling more water vapor to be held in the atmosphere, and so on in an accelerating positive feedback loop.



Another positive feedback includes the greenhouse gas *methane.* Methane is a gas trapped in frozen *peat bogs, permafrost* and as "water ice" (*hydrates*) under sediment on the sea floor. If the atmospheric temperature and ocean temperature increases, the peat bogs and hydrates will thaw and release methane. This will cause greater warming and the release of more methane.

Often a system can be 'self-regulating' as negative feedbacks reduce processes enough to create stability within the system. This is called a *negative feedback loop.* There are a few of these negative feedbacks within the climate system. One is the *solubility pump* of the ocean. Carbon dioxide (CO_2) in the atmosphere can be regulated by the oceans as it dissolves in water. Currently, about 33% of CO_2 emitted to the atmosphere is "absorbed" by the oceans. But this regulating process has a limit; absorption can take centuries and the efficiency is dependent on ocean circulation.

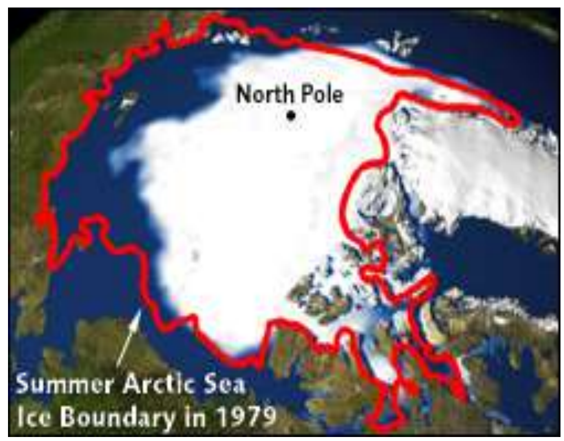


Water vapor that remains in the atmosphere will eventually condense and form clouds. Clouds can add to the greenhouse effect by trapping heat in the atmosphere, or they can reduce the warming by reflecting solar energy back to space. Depending where the clouds form, they can either warm or cool the atmosphere complicating things even more. High-level clouds tend to keep heat in, therefore increasing the warming. If the clouds form at low altitudes they have a cooling effect, off setting some of the warming.

The accelerating effects of positive feedback loops can be at risk to irreversible *tipping points* which are changes to the climate that are not steady and predictable. Basically tipping points are small changes within the climate system that can change a fairly stable system to a very different state. Similar to a wine glass tipping over, wine is spilt from the glass as the tipping event occurs and standing up the glass will not put the wine back; the state of a full wine glass becomes a new state of an empty glass.

Identifying what phenomena are capable of passing tipping points can be tricky. "*Tipping elements*" is used to describe large-scale components of the Earth system that may be subject to tipping points:

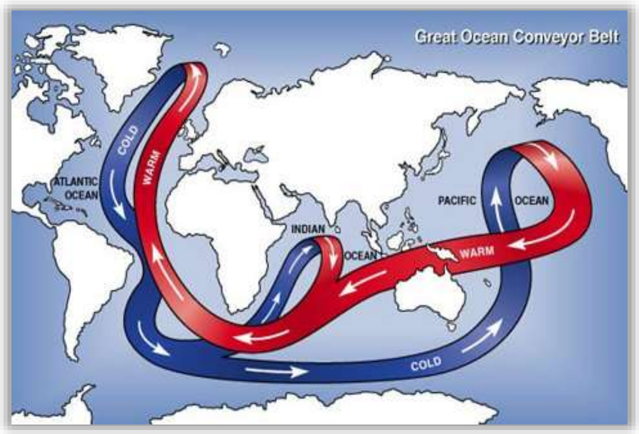
- ***Arctic sea-ice*** – Sea-ice provides a large white surface, reflecting solar radiation away from Earth, known as "*albedo*". As sea-ice melts it exposes the much darker ocean surface, which absorbs radiation rather than reflects it. This, in turn, amplifies warming. Large Arctic sea-ice loss in the summer may reach a critical, irreversible threshold.



- *Greenland and West Antarctic Ice Sheets* – Ice sheets produce a similar albedo effect as sea-ice. They are much thicker than sea-ice though, and can be up to several miles thick and penetrating into the colder, higher altitude atmosphere. Ice sheets thin as they melt at their edges and their albedo is reduced. The Greenland Ice Sheet is thinning and as it thins its surface lowers, subjecting it to warmer temperatures at lower altitudes.

In West Antarctica, the ice sheet is largely resting on rock below sea level. Ocean water is able to melt floating ice but also undercut ice sheets, forcing more ice to float and therefore melt. *Palaeo-records* have shown that both Greenland and West Antarctic Ice Sheets have melted and collapsed in the past, suggesting they are probably vulnerable to tipping points

- ***Atlantic Deep Water formation***- Cold, deep water is produced in the North Atlantic as part of the *thermohaline* ocean circulation. To maintain the ocean "*conveyor belt*" which transports warm ocean water towards Great Britain, heavy salty water must sink in the north. However, when ice sheets in the north melt, they release freshwater into the Atlantic. An input of freshwater makes the ocean less salty and less heavy, reducing the amount of Deep Water produced and slowing down the ocean conveyor belt. As ice sheets are susceptible to rapid melt, it means Deep Water formation and ocean circulation are probably vulnerable to a critical tipping point as well.



Feedback loops such as these are complex on their own and even more complex when part of an integrated global climate system. Some are already at work, while others have not kicked in yet. Others – both positive and negative – may be discovered in the future. But one thing that scientists have learned is that a little atmospheric temperature rise can unlock vicious feedback loops that speed up global warming. Some of these feedbacks are already taking effect; others may be triggered by continued warming. If global temperatures continue to rise, some of these feedbacks could spiral beyond our ability to reverse the warming.