The water and carbon cycles do not act completely independently within the atmosphere. One of the key connections involves the absorption of carbon in rainwater, which facilitates key processes and affects the magnitude of both stores and transfers.

The acidity of a solution is measured by its pH value. Pure water has a pH of 7.0 (neutral). However, natural unpolluted rainwater is mildly acidic, with a pH of about 5.6. This acidity comes from the natural presence of three substances, carbon dioxide, nitric acid and sulphur dioxide, found in the troposphere (lowest level of the atmosphere). Carbon dioxide is present in the greatest concentration and is therefore the primary source of acidity in unpolluted rainwater. If air is polluted, say with high concentrations of sulphur dioxide from the combustion of fossil fuels, rainwater can become very acidic with a pH of 4 or even lower. In 1982, the pH of a fog on the west coast of the United States was measured at 1.8!

Acidic rainwater affects weathering. On contact with carbonate rocks, such as limestone and chalk, the acidic rainwater (a mild carbonic acid) converts calcium carbonate into calcium bicarbonate, which is soluble. This process is called *carbonation*. The dissolved carbon is then carried away by rivers to the oceans where it is used for shell growth and ultimately buried to form new limestone deposits. Some carbon is transferred directly back to the atmosphere.

Feedback links to climate change

A **feedback** is a return or 'knock-on' effect that usually leads to a change in the effectiveness of one or more processes. We have seen that positive feedback enhances the outcome driving a system in one direction and leads to instability, whereas a **negative feedback** works against the outcome, leading to stability and a state of equilibrium. It is possible to identify a number of ways in which water and carbon feedbacks are linked to climate change.

Water cycle feedback loop

Ice reflects radiation from the Sun so less heat is absorbed by the surface. The extent of the Arctic ice has been shrinking alarmingly in recent years exposing more water (Figure **2** and 4.13), with subsequently less reflection and more absorption of heat from the Sun. This warms the water and further melts and reduces the ice coverage. This affects the type and magnitude of water transfers between land, ocean and atmosphere. The local and regional impacts of these changes could have profound effects on life on Earth by affecting patterns of precipitation and the availability of freshwater. Political and economic implications are also considerable – for example, no Arctic sea ice will affect trading routes, the exploitation of resources and the development of settlements.

Figure 2 *Melting Arctic sea ice, Greenland*

Carbon cycle feedback loop

Warmer temperatures in the Arctic are having two opposite effects on the carbon cycle.

- Higher temperatures have increased the growing season for plants and this has increased the absorption of carbon from the atmosphere.
- Higher temperatures have, however, started to melt the permafrost, particularly in parts of Siberia. Organic matter (plant roots and animals) trapped in the frozen ground act as an important carbon store. It is estimated that there is more carbon currently stored in the permafrost than exists in the atmosphere. On melting, the organic matter in the permafrost starts to decompose as oxygen is introduced. The bacteria involved in decomposition produce carbon dioxide and methane as a waste product. These gases bubble to the surface and escape to the atmosphere (Figure **3**).

Currently, the Arctic acts as a net carbon store. However, scientists are concerned that if the scale of permafrost melting increases, the balance might tip such that the Arctic becomes a net carbon source. In this scenario, the higher temperatures and melting permafrost will become part of a highly destructive positive feedback.

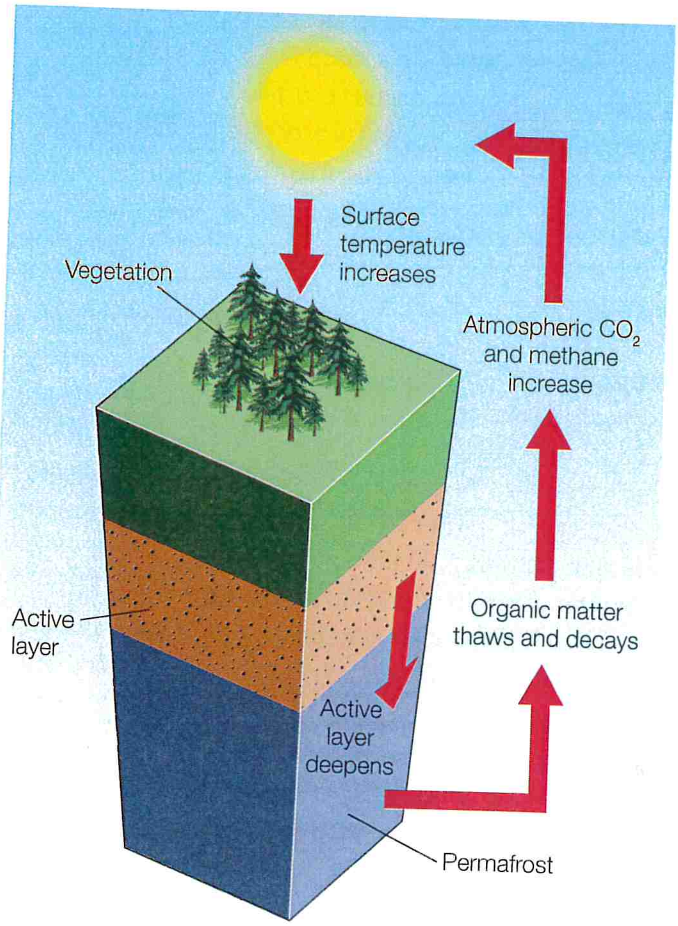


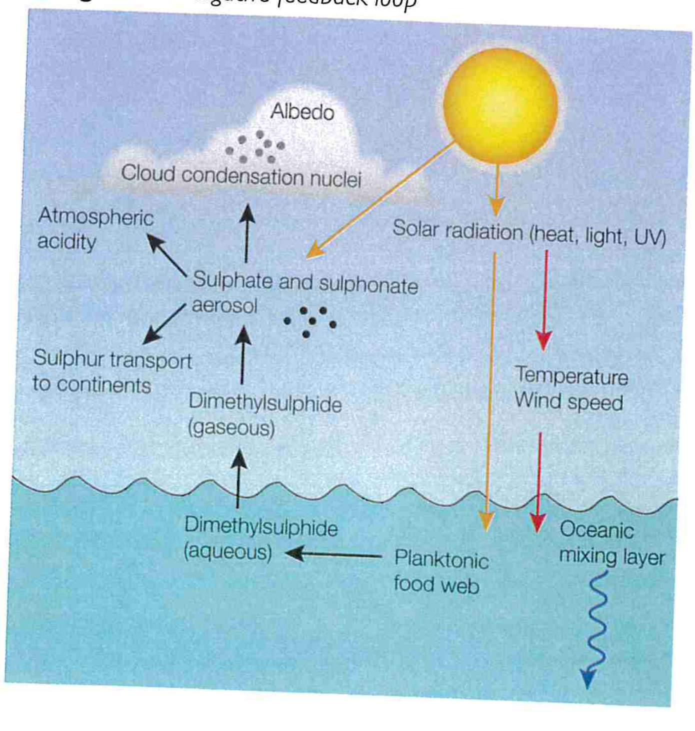
Figure 3 *Melting permafrost: a carbon cycle positive feedback*

Water cycle/carbon cycle feedback loop

Phytoplankton are microscopic plant-like organisms that live in water. In common with terrestrial plants they use the energy of the Sun, together with carbon dioxide (dissolved in the water), to photosynthesise, live and grow. They are the primary producers in aquatic ecosystems sustaining the food web. They are also important stores of carbon.

Marine phytoplankton releases a chemical substance called dimethylsulphide (DMS) that may promote the formation of clouds (condensation) over the oceans. Increases in phytoplankton populations associated with warmer temperatures and more sunshine could therefore lead to an increase in cloudiness and global cooling. This is because clouds reduce the amount of solar radiation reaching the Earth's surface. Of course, less sunshine might lead to a reduction in the amount of phytoplankton, thereby reducing this cooling effect. This complex feedback loop (though not all phytoplankton species react in the same way) is an example of a negative feedback (Figure **4**).

Figure 4 *A negative feedback loop*



EXTENSION

Mountain thermostats – how mountain vegetation controls global temperatures

Research carried out in the Peruvian Andes by scientists from the Universities of Oxford and Sheffield has found that, through an important negative feedback loop, the rates of weathering in mountains caused by vegetation growth play a major part in controlling global temperatures; in effect, acting as a thermostat.

Figure 5 *The valley in the Southern Peruvian Andes where fine root growth and organic layer thickness were measured over several years.*

In warmer climates, tree roots grow faster and deeper aided by the decomposition of leaf litter (decomposers are more effective in warm, moist conditions). This enables acidic water to react with carbonates, increasing the rate of weathering.

By sequestrating carbon dioxide from the atmosphere to facilitate weathering, there is a subsequent lowering of global temperatures, decreasing the rate of vegetation growth. This self-regulating process maintains the global temperature balance, keeping the climate relatively stable and maintaining life on Earth despite repeated global climatic events.

To what extent this regulatory process will be able to mitigate recent man-made global warming is an interesting question.

ACTIVITIES

1 Work in pairs to produce a summary table describing, for each of water and carbon, how stores and cycles are vital in supporting life on Earth.

S 2 Draw a flow diagram in the form of a cycle to show the links between the water cycle and the carbon cycle in the context of carbonation weathering.

3 Study Figure **3**.

a How does this feedback loop operate and why is it a positive feedback?

b Assess the regional and global impacts of the Arctic becoming a net carbon source in the future.

4 Study Figure **4**. Consider how global warming may impact on the negative feedback loop. Use a simple diagram to illustrate some of these possible effects.

S 5 Attempt to draw a diagram similar to Figure **4**, to show the mountain thermostat negative feedback loop.

STRETCH YOURSELF

Find out more about why permafrost is melting and how it results in the release of carbon dioxide and methane.

- Are the causes entirely natural or are human activities to blame?
- What evidence is there that this is affecting the climate?
- Can anything be done to reverse the process?