BBC

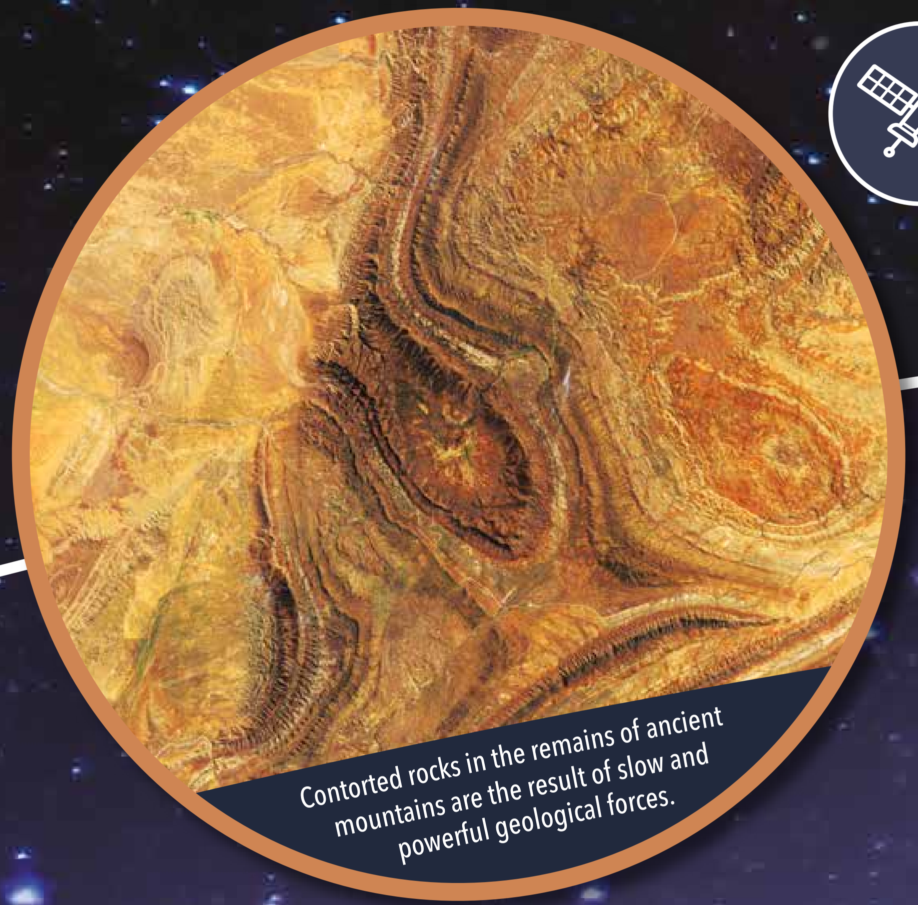
EARTH FROM SPACE

A MAGNIFICENT SIGHT FILLED WITH CHANGING COLOURS, PATTERNS AND SHAPES

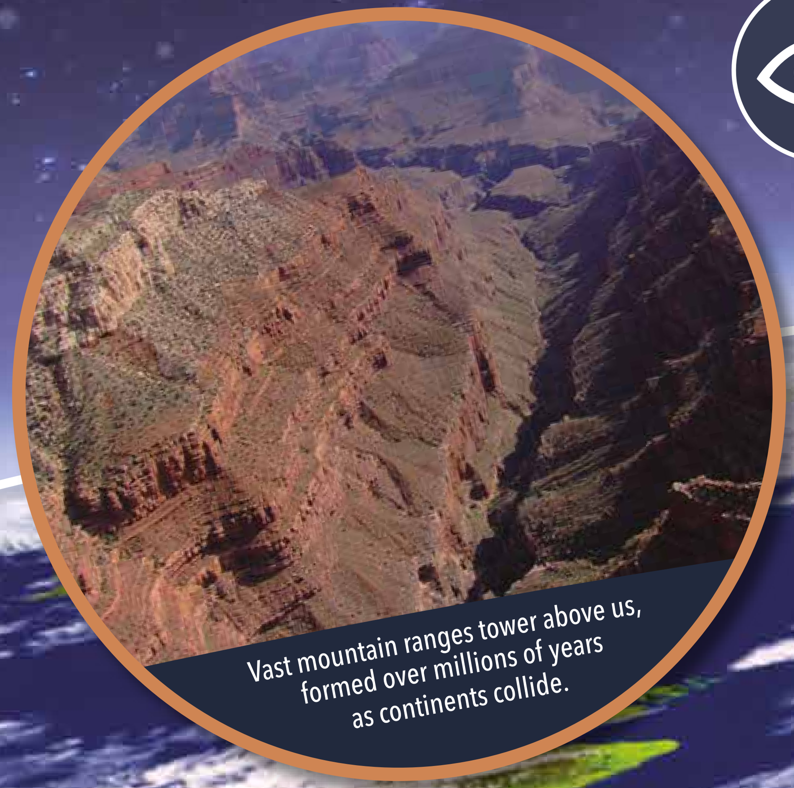
The Open University 50 YEARS

ROCKS

Huge forces operating over millions of years have shaped the surface of our rocky planet. The landscapes that we see, from the highest mountains to the deepest valleys, are the scars left by these forces.



Contorted rocks in the remains of ancient mountains are the result of slow and powerful geological forces.



Vast mountain ranges tower above us, formed over millions of years as continents collide.

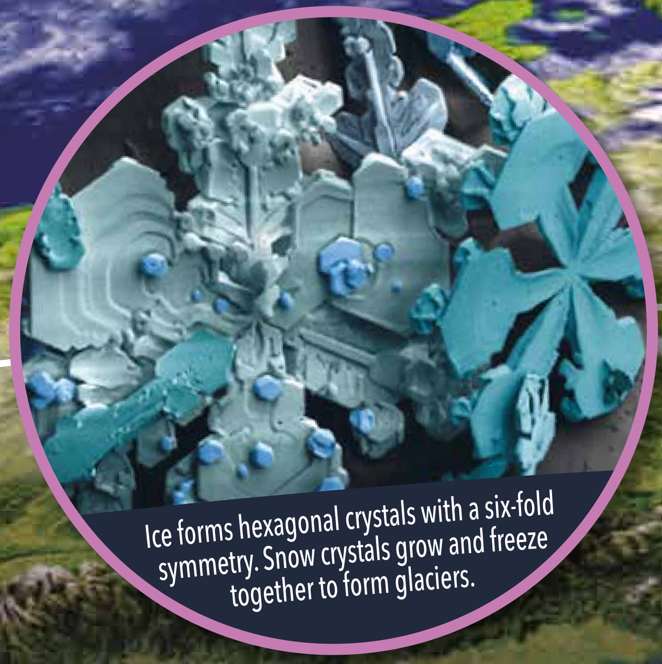
Slices of rocks as thin as a hair tell the hidden history of how they formed.

ICE

The presence and movement of ice has shaped the topography of our planet over millennia. It has worn away mountains, changed our coastlines and is a key component affecting the climate of our planet.

Glaciers flow down valleys to lower altitudes transporting rock and shaping the landscape as they move.

When glaciers reach and fracture directly into the ocean, the ice face can be dramatic and dangerous.

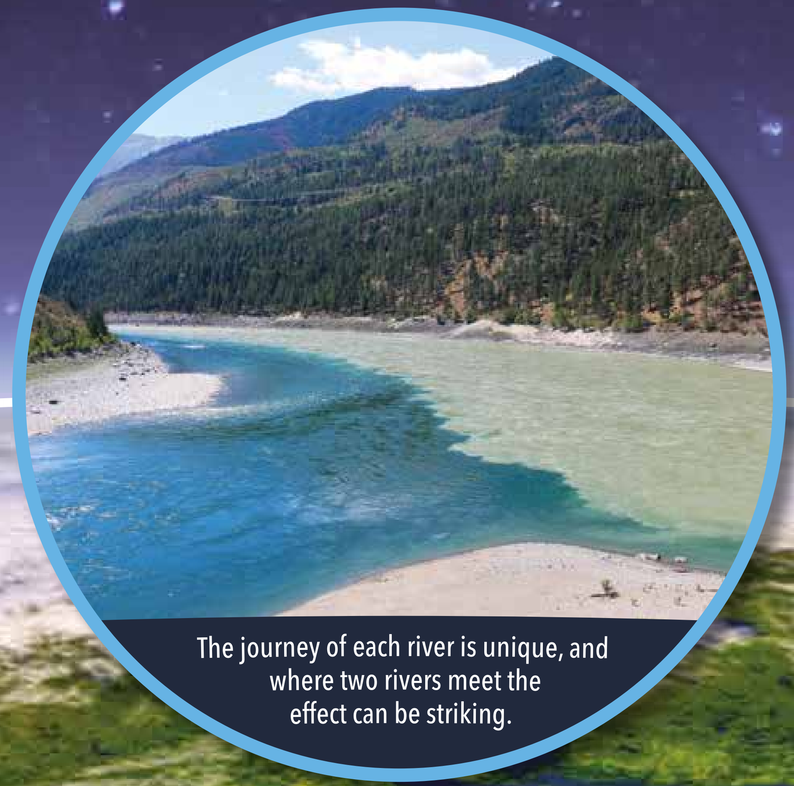


Ice forms hexagonal crystals with a six-fold symmetry. Snow crystals grow and freeze together to form glaciers.

WATER

Essential for life, water makes our planet unique. A powerful force of nature, it creates impressive patterns across the landscape as it continually moves around the Earth.

Rivers connect the land to the sea, and river deltas are shaped by the forces of both water bodies.

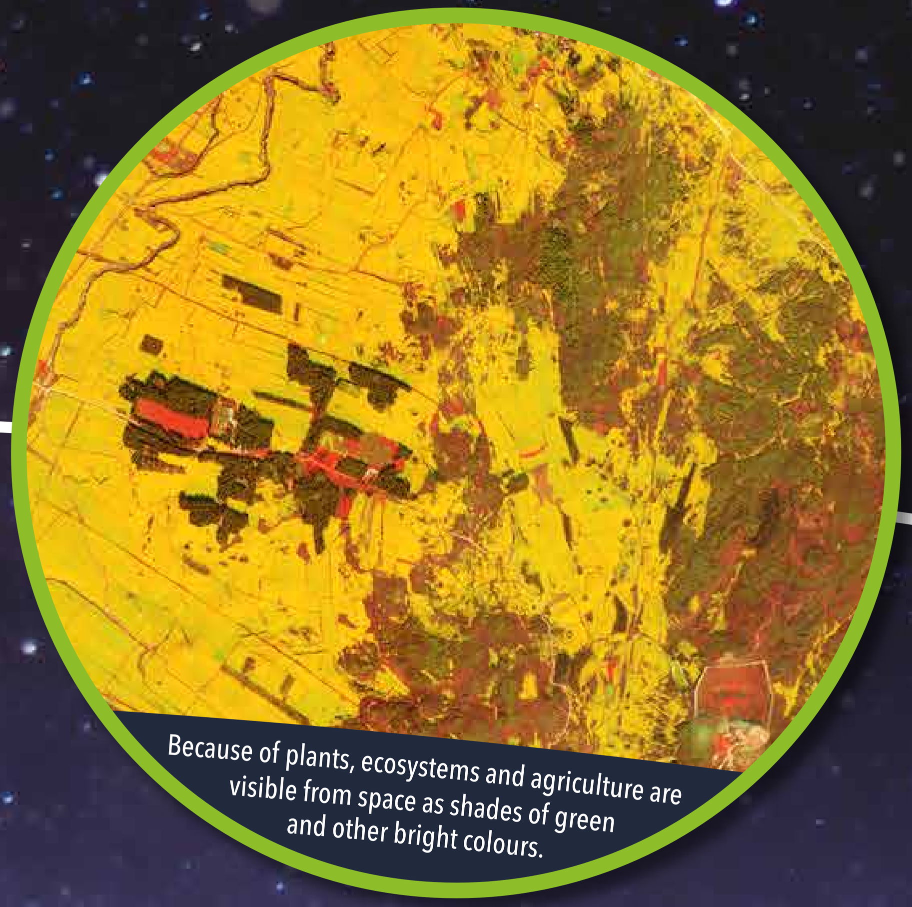


The journey of each river is unique, and where two rivers meet the effect can be striking.

Every drop of water is coloured by the microscopic life and sediment particles it carries.

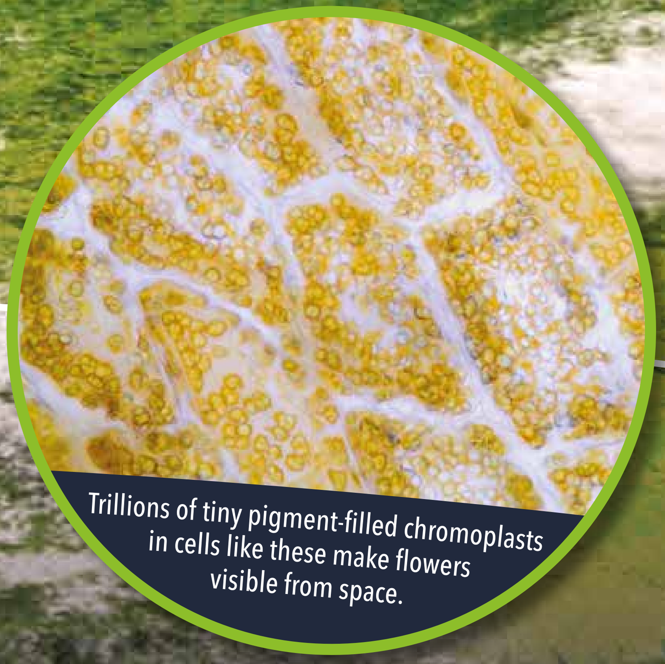
PLANTS

Plants changed the Earth's atmosphere. Ancient plants became fossil fuels. We rely on plants for oxygen, food and many materials. Plants dominate ecosystems on land making patterns across landscapes.



Because of plants, ecosystems and agriculture are visible from space as shades of green and other bright colours.

Plants constantly change around us as they grow, flower, lose leaves, set seed and are harvested.



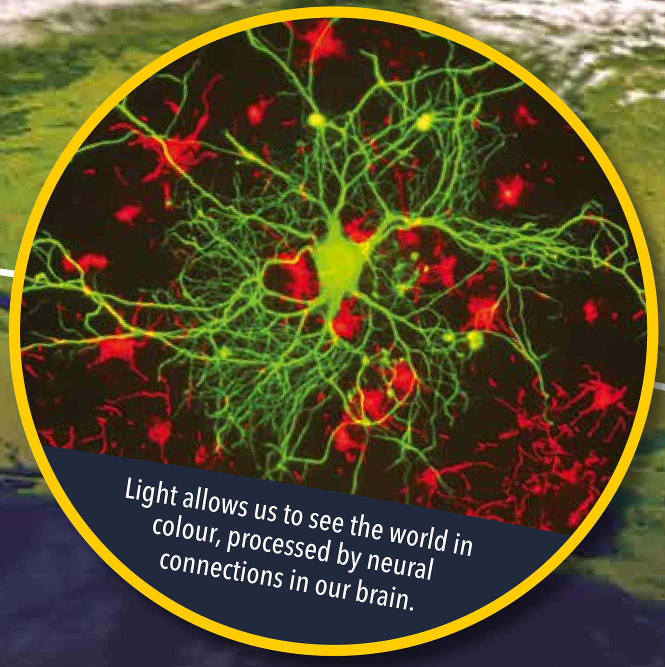
Trillions of tiny pigment-filled chromoplasts in cells like these make flowers visible from space.

PEOPLE

In the last 40 years, the number of people on Earth has more than doubled, and there is now no part of the planet unaffected by our behaviour. We are a force for global change.

The presence of people on Earth is never more visible from space than at night, when our lights shine brightly.

People are increasingly urban and connected globally, with satellites critical for communication and transport.



Light allows us to see the world in colour, processed by neural connections in our brain.

VIEW FROM SPACE | VIEW AT EYE LEVEL | VIEW UNDER A MICROSCOPE

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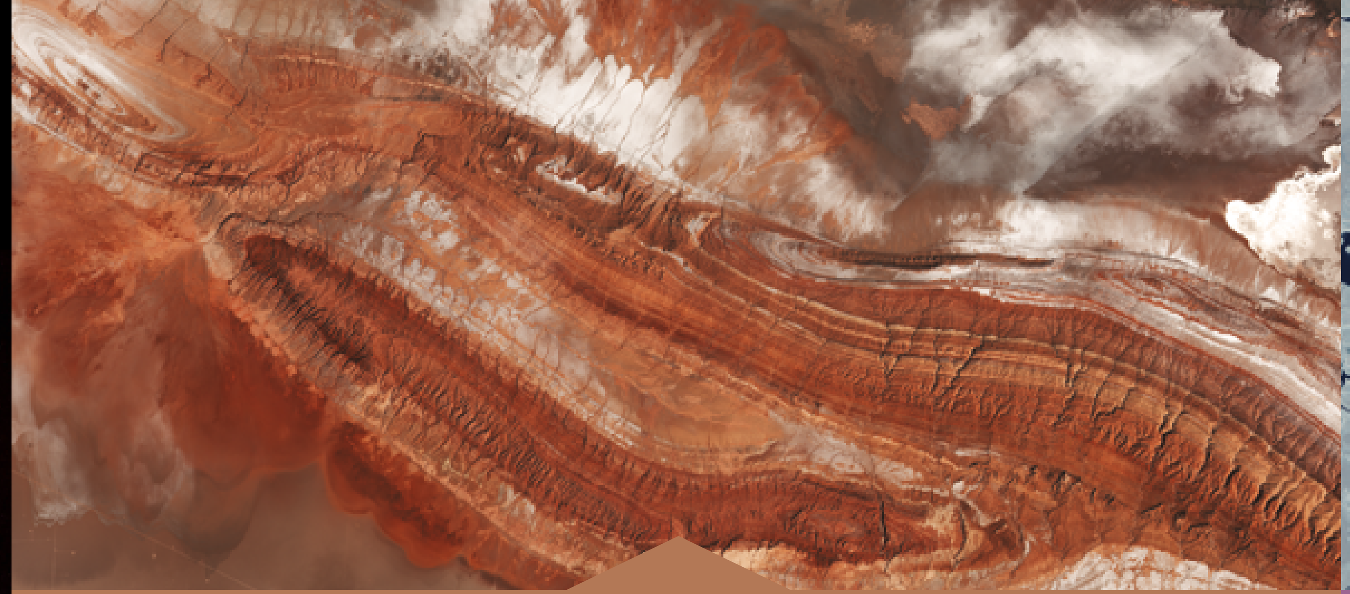


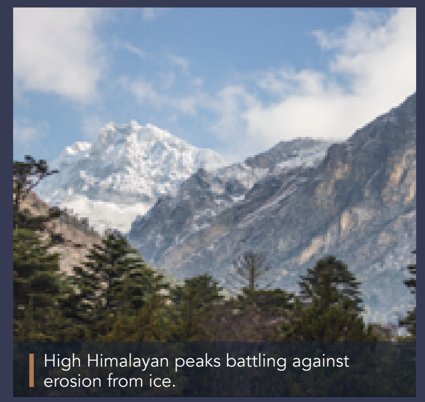
ROCKS

Huge forces operating over millions of years have shaped the surface of our rocky planet.

Although the rocky surface of Earth appears solid, stable and unchanging, it is actually continuously on the move. The surface of the Earth is made up of individual sections known as tectonic plates, like the panels on a football. These plates constantly move around the surface of the Earth at the speed your hair grows: about 40–50 mm every year. This may not seem much but over geological timescales that means 40–50 km every million years.

The various ways these plates move in relation to each other produces different landforms, shaping the face of our planet. One of the most striking landforms on Earth, mountains, form in a number of different ways. Hidden under the oceans, vast mountain ranges can form where plates are moving apart and magma wells up to form new sea-floor crust. On land, when plates collide with each other, massive mountain ranges form like the Alps, Andes and Himalayas. The huge tectonic forces that push plates together cause the Earth's crust to buckle and bend, squeezing and distorting the rocks, and creating intricate patterns that are visible from space.

Mountains themselves aren't permanent structures of our Earth, however. The immense forces that push rocks upwards to form mountains are balanced over time by the destructive force of erosion, wearing down the



High Himalayan peaks battling against erosion from ice.

surface of the Earth. When mountains first start to form, they are uplifted faster than they are eroded. The Himalayas are going through this process now, and are still rising. Mount Everest is still rising by about 4 mm a year, and is now thought to be about 2.5 cm higher than when it was first climbed in 1953! Erosion acts faster when slopes are steep, and slopes are steepest when uplift is fastest. Eventually, as the plates grind to a halt and movement is transferred elsewhere in the crust, erosion takes over and slowly wears the mountains away. But even when mountains are worn down towards sea level and their original towering topography is removed, billions of years after they formed, their scarred remnants are still visible from space.

By monitoring Earth from space, geologists can observe how the rocky plates of the Earth's crust move, and how fast. Rapid geological events such as earthquakes and volcanic eruptions are the end product of very slow underground movements that can be tracked and measured by satellites. Satellite images taken before and after these events can show geologists where and by how much the crust has moved, and potentially help predict future seismic events. Understanding large-scale patterns in the rocks also enables geologists to look for new resources that power our modern world, such as fossil fuels or the precious metals required by renewable energy sources and modern technologies.

DID YOU KNOW?

Rocks are dated using radioactivity. Radioactive elements decay into new, stable elements with a fixed decay rate.

Radioactive decay is generally very slow, but over geological time (millions of years) these newly stable elements become concentrated enough for geologists to measure them with a mass spectrometer and calculate how much time has elapsed. The science of dating rocks is called *geochronology* from the Greek words *geo* meaning Earth and *chronos* meaning time.

ICE

The presence and movement of ice has shaped the topography of our planet over millennia.

Ice is the solid-state form of water, and it is unique. You may not have thought about it before but the fact that it floats is amazing: it means the solid form of water is less dense than that of the liquid below. That's important for life on our planet – for example, can you imagine what would happen to the animals in a pond in winter if the ice sank?

In winter at the higher latitudes of Earth, such as mountains, rain can freeze and turn to snow. When it first settles it's usually light and fluffy, with a lot of air trapped between the snowflakes. As more snow falls, the gaps between the flakes become smaller and smaller and they are soon completely closed off from contact with the atmosphere. At this point they are solid ice containing isolated trapped bubbles of air. Once a large amount of ice has formed, it becomes a glacier or ice sheet and is a solid that is close to its melting point. The glacial ice can flow downhill, just like liquid water – although much, much slower!

As glaciers advance, they push loose rubble and sediment, called *moraine*, that is in the way. This sediment, which consists of very large boulders as well as small fragments of rock, gets trapped in the ice, turning into something similar to a giant abrasive file grinding down the rocks beneath to leave scars and gouges. On a larger scale, the once-angular valleys of young mountain ranges become rounded and

Ice blocks piled up at the edge of the frozen Arctic landscape.

eroded into a wide U shape.

As well as eroding mountains by grinding them down, the effect of ice can be more subtle but just as devastating. Water expands as it freezes, and in mountains the freezing of water in small cracks both widens the cracks and shatters the rock to generate huge quantities of the sharp-edged rubble called *scree* that is often found on the flanks of mountains.

The amount of ice on our planet has not stayed constant, and over the last 50 million years great ice sheets have grown as the Earth has cooled. First, in Antarctica, the ice started to grow about 35 million years ago, then in the last 5 million years or so in Greenland. In about the last 3 million years, as our climate has changed the glacial ice has expanded and retreated several times. Just 20,000 years ago, more than half of the UK, northern Europe, Canada and most of the United States were covered with vast ice sheets. Since then, as our climate has warmed, the ice sheets have been melting and water trapped in them is raising our sea level. Plant life, animals and people moved into the regions where the ice was.

Today we are seeing the effect of global warming. In the Arctic, almost all ice sheets are in retreat, and glacial retreat will affect the lifestyle of those in many places, such as the Indian subcontinent, where the retreat of the Himalayan glaciers will make a huge impact on water supplies.

DID YOU KNOW?

The largest ice sheet, in Antarctica, covers around 14 million km^2, with an average thickness of 2.16 km.

It holds around 61% of all the fresh water on our planet. One section – the West Antarctic Ice Sheet – is particularly vulnerable to climate change and its glacial ice is being melted by warm oceans. The Pine Island and Thwaites glaciers are melting the fastest, which is expected to be one of the major causes of sea-level rise in this century.

WATER

Essential for life, water makes our planet unique as it continually moves around the Earth.

We live on a wet planet. Most of the Earth's surface is below water: the world's oceans cover more than 70% of the Earth's surface area, and the deep ocean trenches are further below sea level than the highest mountains are above it. Water is very special: it is the only compound that naturally exists in solid, liquid and gas form on Earth. It is essential for life, which started in the seas of early Earth over 3 billion years ago.

Most of the water on Earth is salty, and only two per cent of Earth's water is the fresh water that is essential for sustaining life on land. We also rely heavily on this fresh water for industry, food production and recreation, and the rate at which we use water is increasing faster than our population is growing. Therefore, our increasing demand for these finite freshwater resources will have major implications for life and society, and managing our demands for this precious resource is one of the biggest challenges we face in the coming decades.

We can see both the direct and indirect effects of these changes to our water resources from space. For example, we can see the reduction in lakes due to the removal of river water for crop irrigation, and the greening of irrigated fields. Specific satellites are used to measure the amount of water that is in soil and vegetation. Weather satellites are constantly monitoring

The clearest fresh water on Earth. Rotomairewhenua, South Island, New Zealand

clouds and rainfall, and with changes to the climate system we can expect changes to where, when and how much rain will fall in the future. How all these changes will affect our lives are questions of major importance, and Earth observation satellites play a crucial part in monitoring these impacts and developing solutions for a more sustainable future.

Water can also be an immense force. Flooding and storm surges cause significant damage and are the main cause of loss of life in hurricanes and large storms. However, we can also use the power of water for our benefit. In the past we used to use flowing rivers to turn waterwheels in mills, and we now accumulate the power of water in large dams and convert this to electricity. In the future we will increasingly harness the energy in the movement of tides and currents for a more sustainable form of energy production.

Water is continually moving around the planet in what is known as the *hydrological cycle*, whereby water evaporates from the oceans and soil and plants pump it into the atmosphere through their leaves. This water vapour condenses into clouds and then falls as rain. Rain that falls on land returns to the atmosphere or flows to the oceans, completing the cycle. Over millions of years, the movement of water around the planet has shaped the landscape and formed some of the amazing patterns we see on Earth's surface today.

DID YOU KNOW?

Water on Earth may be more than 4.5 billion years old, or older than the Earth itself.

Water is made of oxygen and hydrogen. By measuring the amount of deuterium (which is hydrogen with an extra neutron) in very old rocks and asteroids, and using computer models of deuterium formation in the early solar system, scientists have determined that some water has been here since Earth was formed, and may have origins that are even older.

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PLANTS

Plants are visible from space as shades of green and other bright colours.

Plants are vital to humans. Our food is mainly plants or animals that eat plants. The oxygen we breathe comes from plants or their relatives. We wear clothes of plant material, live in houses of wood and burn long-dead plants as fuel.

The colours and patterns in vegetation we see from space hold information. Changes in these colours show deciduous trees and the spread of invasive weeds. Patterns show how closely vegetation types mirror soils and climate. The amount of light and other radiation reflected or released from plants, collected by sensors on satellites, can be used to estimate the amount of foliage in ecosystems and how much carbon is stored.

Plants lose water through tiny pores on their leaves, which cools when it evaporates. Heat maps show how this *transpiration* cools ecosystems and urban landscapes, as shown in the false-colour image on the right, showing warmer yellow buildings and cooler bluish plants. This phenomenon is particularly useful in cities, where plants help keep urban areas cool as well as mitigate pollution and flooding.

Plants use sunlight to convert water and carbon dioxide into sugars. In this process they release a tiny glow, known as *fluorescence*. Different amounts of fluorescence are released at specific wavelengths depending on how well a plant's power systems are

Thermal image of a tree against a building.

working. Hand-held devices measure fluorescence to detect plant stress (e.g. from drought or disease) before it is obvious to the eye. New satellites are providing dynamic global maps of vegetation fluorescence to record productivity and identify stressed plants. Global measures of plant health are important for mitigating climate change and managing food security.

Plant size and vigour can be estimated by comparing the amount of near-infrared radiation and red light recorded by satellites. Changes in these values show forest clearing and land-use changes, while other light and radiation combinations can show burned areas.

Scientists also use data about plant traits, recorded from space, to monitor biodiversity. Plant traits are characteristics specific to a species or group, such as plant height and the ratio of leaf area to ground area. Traits are a powerful way of understanding how an ecosystem is functioning, such as how quickly nutrients are recycled or how much growth occurs per year. New sensors are being developed to measure more plant traits.

To interpret satellite observations accurately, their data must be matched with what we measure in plants on the ground. Then we can use satellites to collect information about plants from more places and more quickly than ever before. Earth observation has enormous potential to help manage the natural resources provided by plants for the future.

DID YOU KNOW?

A new global vegetation map is compiled from satellite data every two days.

These maps chart deforestation, predict crop production, measure plant health and improve models of climate change and ecosystem distribution. As technology develops, the satellites that observe plants are becoming smaller, and provide higher resolution scans. Current versions have a field of view over 2000 km wide and a resolution of 100–300 m.

PEOPLE

There is now no part of the planet unaffected by our behaviour. We are a force for global change.

We can see ourselves in great detail from space – not just large human-made objects like the Great Wall of China, but buildings and even gatherings such as the Shaolin students performing.

Since the evolution of humans, there has been a huge change in our relationship with the environment, from the environment shaping human population size and behaviour to people shaping the environment.

Ice ages and environmental conditions once limited the number of people and determined where they lived. For the last 12,000 years, however, the climate on Earth has been reasonably stable, and the human population has grown from under 15 million people to more than 7 billion today. Key to this population increase was the development of agriculture and the Industrial Revolution (when people learned to mechanise agriculture and manufacturing, and developed new methods of generating power and transport). Our population is now increasing exponentially, and where we live is changing. In the last 50 years, our numbers have doubled and today 55% of people live in urban environments. Today we are the ones changing the climate and the way the Earth looks from space.

But the technologies that have enabled our population to grow have also left their mark on the planet in many ways we can see from space. Vast

Shaolin students perform.

agricultural belts show intricate patterns of single types of plants, mines change the texture of landscapes, dams hold up massive amounts of water and cities are expanding at rates visible from space over very short timescales. Large areas of land change colour as forests are cleared. We can also track changes in climate and their impacts, from shifting weather patterns to sea-level rise.

Information from space has also changed how we perceive our planet. The 1960s Apollo 8 mission crew invoked a new appreciation of Earth with the striking images they captured; the public saw Earth from a distance as a beautiful but finite planet, isolated in space. Such images from space illustrated our reliance on this planet and so have affected human culture as well as scientific understanding.

We rely on satellite data every day for communication, navigation and weather predictions. Our planet is surveyed more often and more comprehensively than ever before. New types of sensors are giving novel insights into how we interact with our planet. Views from space remind us that we share a unique planet with an extraordinary diversity of life, and revealing it shows the brilliance of our capabilities but also the costs of our innovations. However, the dynamic, global perspectives provided by looking at Earth from space give us the opportunity to make better decisions about how we live and what planet Earth will look like in the future.

DID YOU KNOW?

Humans are very visible from space at night, when cities blaze light and transport networks glow.

Light pollution is a damaging waste of resources. Night lights have caused a loss of biodiversity in some areas. Many animals, including mammals, birds, insects and spiders, are nocturnal and light pollution confuses their ability to navigate. The loss of darkness means one in five people can't see the Milky Way at night.

SATELLITES

The visually striking images from satellites, with their wealth of colours, patterns and textures, contain huge amounts of information about our changing planet.

EARTH OBSERVATIONS

Since the early days of space exploration, it has been an ambition and mission priority to look back at Earth and make observations. As technology has progressed and satellites have become ever more complicated, today there are almost 1500 of them orbiting Earth. Some of them take images, some are for communications, some measure the extent of ice, some make weather observations that are vital to modern weather forecasting, and some are used to track animals and measure human impact.

Because satellites are far above the atmosphere, they don't need engines to remain above Earth. The amount of time one satellite takes to make a single orbit is called its *orbital period* and the further away a satellite is from the surface of Earth, the slower its orbit. Satellites that orbit over the North and South Poles at about 700 km above the Earth have an orbit that would take about 100 minutes, and to cover Earth's entire surface with their sensors would take just over 14 orbits. That means they would be able to capture the entire globe in about a day.

Some satellites occupy geostationary orbits 35,786 km above Earth's surface. These satellites stay directly over one location on the equator and in combination can map the entire surface of the planet. They are therefore vital tools for weather forecasting, and it would be hard to function as a society without the information they give us.

While humans can see in what we call visible light, the sensors carried on satellites can take measurements across the entire electromagnetic spectrum as well as the visual images we would recognise. Such satellites can measure the temperature of the planet, the carbon dioxide and sulphur dioxide in the atmosphere, and the moisture in soil, as well as spotting forest fires and erupting volcanoes. With lasers and radar, they can take incredibly precise measurements of, for example, the thickness of the ice in Antarctica, and more importantly over a period of years they can map how this thickness changes.

In just 60 years the satellite age has allowed us to see our planet as we could previously only imagine.