climate change initiative

tertiary education resources

ESSENTIAL CLIMATE VARIABLES

climate change initiative– ESSENTIAL CLIMATE VARIABLES
https://climate.esa.int/educate/

Compiled from ESA websites by University of Twente (NL)

The ESA Climate Office welcomes feedback and comments
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ESSENTIAL CLIMATE VARIABLES

Fast facts

Subjects: supplementary materials for the introduction lecture

Type: reading

Complexity: medium

Lesson time required: 2 hours

Cost: none

Location: indoors

Includes the use of: internet

Keywords: climate change, essential climate variables, satellite

Brief description

An overview of essential climate variables produced under the Climate Change Initiative programme of the European Space Agency

The information presented in this document is compiled from ESA websites

Intended learning outcomes

Reading this document, students will be able to:

Have an overview of all essential climate variables produced from the scientific projects of the Climate Change Initiative.

Summary of activities

	Title	Description	Outcome	Requirements	Time
1	Essential Climate Variables	An overview document that supports the introductory lecture on climate change and essential climate variables	have an overview of all essential climate variables produced from the scientific projects of the Climate Change Initiative	Reader, or any device that can read files in PDF, Word and PowerPoint format	2 hours

Times given are for the main reading activity. They include time for searching the web, but not experimenting with the Climate from Space application or the Cate toolbox.

Aerosol

https://www.esa.int/ESA_Multimedia/Images/2003/07/Volcano_-_grey_with_smoke2#.X0jSSlDwvjQ.link

65 million years ago an asteroid 10 kilometres wide generated a huge explosion. This explosion spread a layer of dust and debris (aerosols!) into the atmosphere, which resulted in these aerosols blocking incoming sunlight. The temperature of the earth dropped and this started the extinction of the dinosaurs.

These days, however, most people know aerosols as products from human activities such as fossil-fuel burning and agricultural activities that generate dust and aerosolised nitrogen products. But though most 'know' about aerosols, not many know exactly what they are or what they do, because most aerosols we can hardly see with the human eye. In fact, all these tiny particles in the atmosphere interact with incoming radiation from the sun. Depending on the type of aerosol, a certain portion of the solar radiation is reflected back into outer space. But water vapour may also attach to these particles, altering cloud properties, and their radiative effect (see clouds). Based on their type, aerosol particles could either cool or warm the atmosphere.

The cooling effect of aerosol has masked the accelerated global warming. Besides, these fine aerosol particles are a major concern for public health, causing cancer and cardiopulmonary mortality. Human activities have increased the total amount of aerosol particles in the atmosphere by a factor of two in comparison to the pre-industrial era.

Biomass

https://www.esa.int/ESA_Multimedia/Images/2015/07/Ground_work_in_Gabon#.X0jRZpnIYNU.link

Have you ever thought about what you could do with information on the total mass of all vegetation on earth? This combined mass of trees, plants and other types of vegetation is known as biomass and is extremely valuable knowledge for climate science. As vegetation captures and stores carbon dioxide from the atmosphere, knowing about their biomass allows for translation to carbon storage and exchange. Rain forests, especially, play a major role, because of their dense vegetation; they can store a lot of carbon dioxide and they act as a sink as they take up CO_2 as the forests grow. But logging activities, forest fires or natural degradation can lead to the forests releasing CO_2, making them then act as a source (Read the CfS's story on Carbon Cycle). The animals living in those forests also encounter the effects of changing biomass. As trees are cut down, some species may lose their homes and either die or migrate – their biomass in that area decreases. If this happens, another animal's source of food may be gone. Therefore, a change of biomass of one animal can affect the whole biodiversity in the forest. (Read the CfS's story on Biodiversity and Habitat loss).

Cloud

Image source:

https://www.esa.int/ESA_Multimedia/Images/2010/06/Swirling_cloud_art_in_the_Atlantic_Ocean#.X0jS76j6PmQ.link

Have you ever taken a hot shower with the door closed? Didn't it get misty at some point? You probably had to wipe down the water vapour from the mirror before you could use it. Clouds start similarly, except that water vapour does not attach to a mirror, but to the surfaces of aerosol particles: warm moist air rises, cools down, and the water vapour condenses, forming clouds (Read the CfS's story on The Water Cycle)

Clouds largely control the amount of energy reaching and leaving the earth, and different cloud types do so in different ways. The type of cloud is determined by many factors: like the land cover (water, forest, urban area), topography, movement of weather systems (fronts), and the type of aerosol water vapour is attached to. A recent discovery has shown that urban areas enhance the persistence of cloud cover in the afternoon and evening which may lead to an increase in the urban heat island effect (Read the CfS's story on Urban Hotspot).

Fire

Image source: Climate Change Initiative_ ESA, Provided by Planetary Vision

Fire – orange and red flames that are fed by oxygen which, luckily, most of us associate with cosy controlled campfires. Unfortunately, this image may be rapidly changing as wildfires have been making headlines more frequently lately. Wildfires run uncontrolled through the natural landscape – consuming all they come across; from forest to grassland and savannah.

Satellite data from the European Space Agency shows that globally there were almost five times as many wildfires in August 2019 compared to August 2018. However, a detailed analysis reveals precisely where these fires have been occurring – most have been blazing across Asia, though Australia, California, the Arctic, France, Greece and Indonesia, as well as many other areas in the world, did not remain unaffected. These large-scale fires not only destroy the natural landscape and cause habitat loss (Read the CfS's story on Biodiversity and Habitat loss), they also contribute about 25%-35% to the total carbon dioxide (CO_2) net emissions. Next to CO_2, they also contribute largely to other greenhouse gas emissions, such as carbon monoxide (CO), methane and aerosols. Wildfires and the resulting deforestation are not only releasing extra CO_2, but also reducing the Earth's capacity to absorb and store carbon (Read the CfS's story on The Carbon Cycle).

Looking to the future, when climate change will raise global temperatures, increase the frequency of heatwaves, and cause changes in rainfall and droughts, conditions will raise the prospect of any even greater number of wildfires.

Greenhouse Gases

Image source: Climate Change Initiative_ ESA, Provided by Planetary Vision

Do you know that feeling; the first warm day of the year. You sit in the classroom looking forward to going outside and finally enjoy the warm weather. The sun shining through the window is almost burning your skin, but when you can finally go outside, the sun no longer seems that strong. Inside the classroom, it is almost as if you are in a greenhouse; all the heat that enters through the window gets trapped, and once in, even at night, merely escapes. Greenhouses make sure that even in geographical areas that are generally too cold to grow certain crops, they can be grown. They also help generate high enough temperatures for crops during winter.

In greenhouses, it seems like the only way for heat is in. Once in, there's no way out. The atmosphere around the earth acts similarly, but on a bigger scale. Instead of glass ceilings trapping the heat, it is certain gases in the atmosphere that do so. Any idea what the overarching name is for those gases? Do you see the link yet? They have been called greenhouse gases!

(Link to http://esamultimedia.esa.int/docs/edu/G03_the_greenhouse_effect.pdf)

The result is that the Earth's atmosphere is warmer than it would be without the greenhouse effect. On the other hand, if greenhouse gases were not present in Earth's atmosphere at all, life as we know it would be almost impossible because the average surface temperature would be several degrees Celsius below zero.

Although natural greenhouse gases exist in the atmosphere, it is the human-emitted greenhouse gases that are of concern, e.g. CO_2 (Read the CfS's story on to the Carbon Cycle) and methane (CH_4). The concentrations of these gases have been increasing in the atmosphere since the beginning of the industrial revolution.

Glaciers

Image source: Climate Change Initiative_ ESA, Provided by Planetary Vision

One of the most dramatic ways to be faced with climate change is to visit a glacier. Seeing the seemingly indestructible, monstrous ice walls cry rivers and retreat as they give into the warming of our planet, is spine-tingling.

Glaciers are giant masses of land ice that have formed due to compression of snow. At high altitudes, snow is compressed to add ice to the glacier, pushing ice down to lower altitudes where it may either melt or end up in the ocean. For a long time, this formation-breaking-down process was in balance, but research has shown that since 1961, glaciers have lost well over 9,000 gigatonnes of ice due to the warming of our planet caused by the greenhouse gases that we are pumping into the atmosphere. To give you an idea of how much weight that is; if the entire world population would step on a scale, that would be just 0.035 percent of what has been lost to ice. All that ice eventually ends up as meltwater in the ocean, which has led to a 27mm global sea-level rise since 1961 (Read the CfS's story on The Water Cycle). We know this because satellite images allow us to see how the elevation of different places on Earth has changed over time.

If the warming of our planet and the melting of our ice were to continue at the rate it has over the past decades, sea levels might rise perhaps several metres by the end of this century. Such a rise would cause widespread flooding of low-lying coastal areas and threaten many large cities (Read the CfS's story on Country under Threat).

Satellite data not only helps us monitor how the melting of our ice leads to sea-level rise, but also identifies icebergs that may potentially be a threat to ships crossing the arctic (Read the CfS's story on A Passage Opens). In August 2010, for example, ESA's Envisat orbiter observed that the 70km 'ice tongue' of Greenland's Petermann glacier had broken off, which has been hovering over the ocean waters ever since.

Antarctic Ice Sheet

Image source: Climate Change Initiative_ ESA, Provided by Planetary Vision

Can you imagine where your house stands today might once have been covered with a ice pack several kilometres thick? Well, this might have been reality about 20,000 years ago, when much of Europe, Asia, North and South America was covered by huge chilly, sheets of ice, each many kilometres in depth. Today, the only ice sheets on Earth's land masses are found in Antarctica and Greenland. Some ice also occurs as glaciers in mountainous regions and as floating ice drifts in the Arctic Ocean and around Antarctica.

As global temperatures increase, the magical images that we have of polar bears wandering the ice turn to be a rarity. Massive ice sheets that once lay over Antarctica like a thick blanket, have started to melt with increasing rates. If our planet continues to warm, and ice continues to melt, then polar bears on ice sheets will make space for ships on new shipping routes (Read the CfS's story on A Passage Opens).

Observations from space suggest that parts of the major ice sheets are beginning to melt more rapidly. This could partially be explained by the fact that ice sheets act as a mirror, reflecting sunlight and cooling the earth. If the ice disappears, sunlight will not be reflected – and will be trapped to heat the oceans instead, causing left-over ice to melt even more rapidly. It would cause sea-level rise of perhaps several metres by the end of this century. Such a rise would cause widespread flooding of low-lying coastal areas and threaten many large cities (Read the CfS's story on Country under Threat). Can you imagine that where your house stands today, could eventually be covered by oceans?

Greenland Ice Sheets

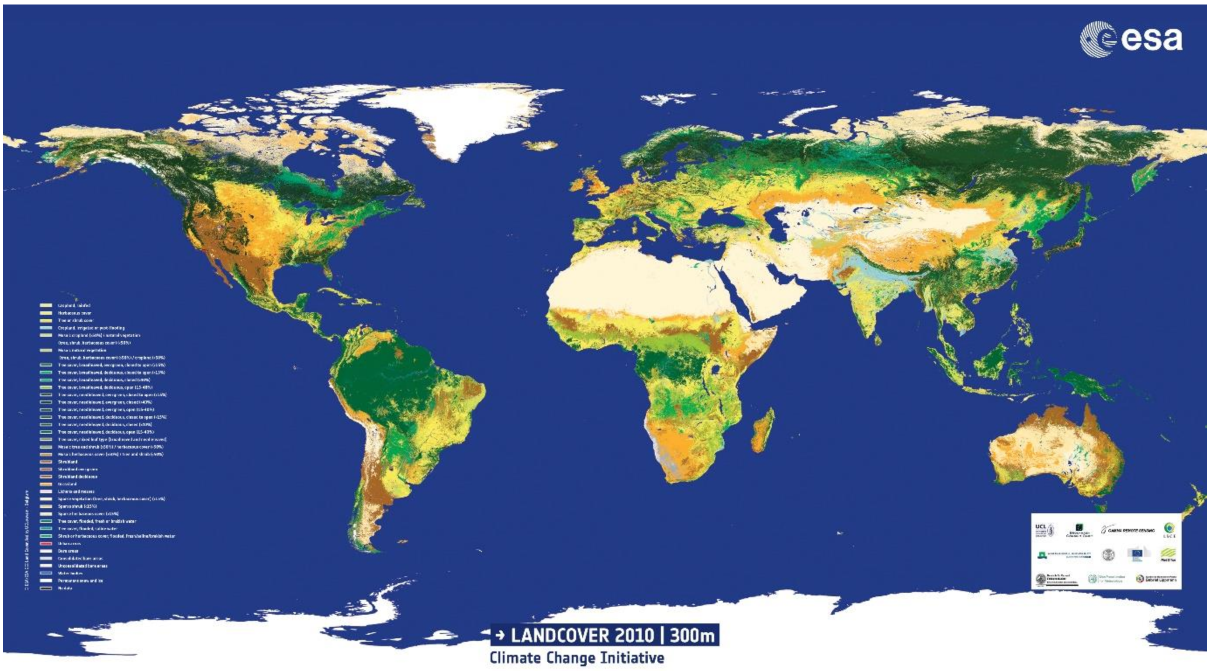
https://www.esa.int/ESA_Multimedia/Images/2018/11/Losing_ice#.X0jUkMTK4mM.link

Greenland is icy and Iceland is green – an interesting paradox that many people use to remind themselves of the difference between the two lands. Unfortunately, future generations will probably have to come up with a different mnemonic – data from several satellites suggest that Greenland is slowly turning into an actual green land.

An ESA satellite called CryoSat has been measuring the amount of ice in Greenland, discovering that much ice has been melting over the last decade; water flows away more rapidly from glacier outlets, ice sheets get thinner and ice mass loss increases. The solid ice is turning into liquid water flowing into Earth's seas, making them rise (Read the CfS's story on The Water Cycle). Greenland's cumulative ice loss from 1992-2017 was 3,900 billion tonnes, which contributed approximately 11 mm of the global sea-level rise. This has many people worried because rising sea levels cause major problems like flooding coastal towns and cities all over the world (Read the CfS's story on Passage Opens, Country under Threat).

If we do not know there is a problem, then we cannot do anything to solve it! That is why the *Greenland Ice Sheet CCI project* focuses on getting good monitoring of how Greenland's melting ice is raising sea levels, so we can be better prepared to tackle potential problems. CryoSat, for example, measures the height of Greenland's vast glaciers of ice very accurately. It does this by using a high-tech instrument called a radar altimeter, which measures how high the ice is. CryoSat is a good example of how satellites in orbit around Earth help monitor our planet (Read the CfS's story on Taking the Pulse of the Planet).

Land Cover



https://www.esa.int/ESA_Multimedia/Images/2014/10/Land_cover_2010#.X00CDTXvjEQ.link

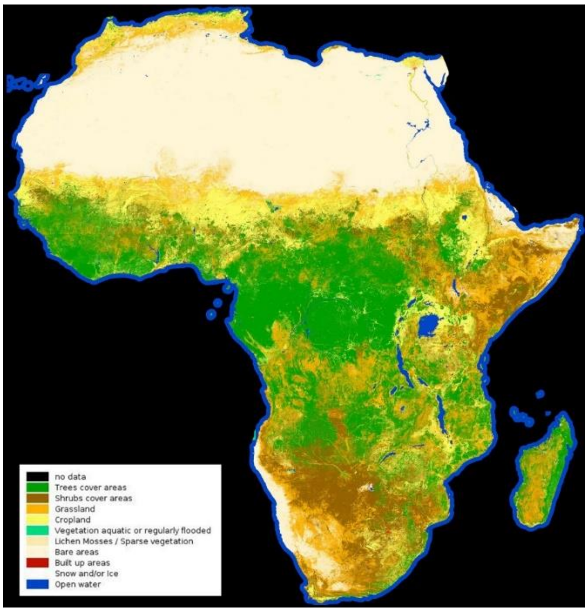
We know that trees capture and store carbon dioxide via photosynthesis, as do plants, but to smaller extents. If we replace them with factories, cities, or infrastructure – which are sources of CO_2 – then the land in that spot will contribute much differently to the exchange of energy, water and aerosols (Read the CfS's story on The Carbon Cycle). Even local temperatures will change! (Read the CfS's story on Urban Hotspot)

Of course, land cover changing from vegetation to built-up areas is about the most extreme change you may find. But even small changes – such as a new type of trees in an area – may disrupt existing ecosystems or cause habitat loss for the species that originally lived there (Read the CfS's story on Biodiversity and Habitat Loss).

But land cover may also affect other processes on Earth. The degree to which a certain type of land cover allows for infiltration of water to the ground, for example, will determine whether water can also be released for evaporation to keep the water cycle running (Read the CfS's story on The Water Cycle).

Monitoring land-use change and the status of land cover from space provides a global view and helps understand the interaction between land cover, weather extremes and climate change (Read the CfS's story on Taking the Pulse of the Planet). The more we understand the impact of land cover change on the health of our planet, the better we can develop sustainable land management projects, which contribute to reducing the negative impacts on climate change, ecosystems and societies.

High-resolution Land Cover



https://www.esa.int/ESA_Multimedia/Images/2017/10/African_land_cover#.X0jVMQwH9p8.link

When you are standing on a high tower and looking at the view, what do you see? You may see some buildings, parks, roads, perhaps a river. But when you are looking even further away, it becomes harder to distinguish the different land cover types. This is also what satellite sensors have to deal with. They take photos of the Earth, with which we can see where new buildings are constructed, but also where forests are cut. Every camera has a certain resolution; the higher the resolution, the more pixels it has and the sharper the image gets.

For the satellites orbiting high above the Earth's surface, for them to produce sharp pictures, the cameras must have an extremely high resolution. Some cameras have a pixel size of 300m, which means that one pixel is the size of 300m by 300m. Such an image contains enough information to know what crops are being harvested in farmland areas, though the resolution is too low to distinguish individual buildings. High-resolution cameras can have a resolution of 10m, allowing for more detailed information on things like small built-up areas or roads. This increased detail helps our understanding of how human activities impact the climate.

High-resolution images can help make more efficient use of natural resources for food production (Read the CfS's story on Feeding a Growing World). The sensors on the satellites capture frequent images of the Earth, enabling land cover changes to be tracked.

The CCI High-Resolution Land Cover project will produce Land Cover and Land Cover Change maps with high spatial resolution, investigating their impact and the crucial role of spatial resolution on climate models at regional scale. Monitoring those changes gives us insights about the health of our planet (Read the CfS's story on Taking the Pulse of the Planet).

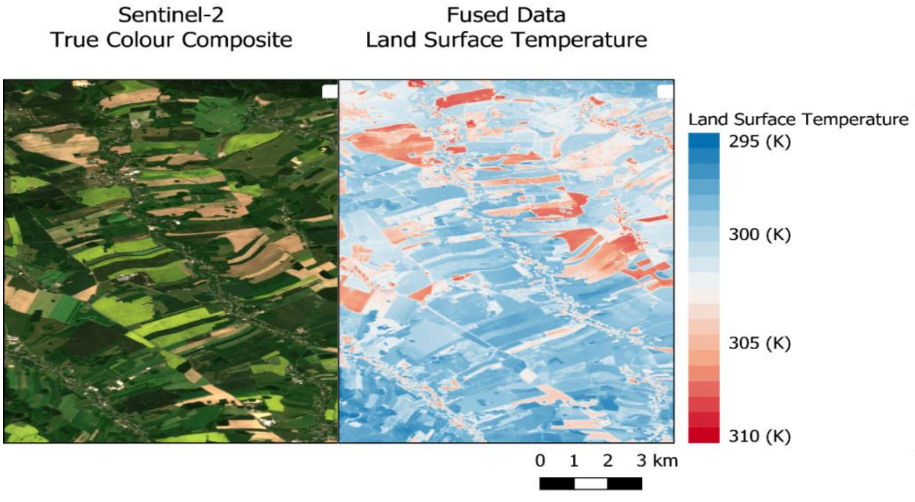
Lakes

https://www.esa.int/ESA_Multimedia/Images/2014/03/Great_Lakes_North_America#.X0jVevASSeI.link

On a hot summer day, you may go to the nearby lake to cool off. Even when not jumping into the cool water, you may enjoy the cool ambient of the lake. City dwellers too, gather around the small ponds in their urban parks, waiting for the sun to set (Read the CfS's story on Urban Hotspot). Lakes – and water bodies in general – play an important role in the local and global climate regulation. Lakes with great depth can take absorb significant amounts of energy from the sun, with the energy spread to the deepest water levels. As summer proceeds, these lakes warm up slowly. In winter, they slowly cool down again, releasing the energy back into the atmosphere. Monitoring lake temperature can teach us something about the energy balance on our planet.

But there are more interesting things that our satellites can help us with. By looking at factors like the lake water level, we can analyse the balance of water input (like rain, streams) and the water output (like streams, evaporation) (Read the CfS's story on The Water Cycle). Lakes can act as a rainwater catchment area in hilly areas, or catch melting snow from the mountains in spring and summer.

Land Surface Temperature



Updated from: https://www.esa.int/ESA_Multimedia/Images/2020/04/High-resolution_land-surface_temperature#.X0jV24IlpVs.link

The atmosphere and land are constantly exchanging energy and water. Energy can be in the form of heat. Lay your hand on a surface that has been in the sun all day. Does it feel warm? That is the sun's energy! When the sun sets, the object that you just touched will give back the heat to the atmosphere. The more heat the object can absorb, the more heat it will give back at night. Buildings and road tarmac, for example, store much more heat than vegetation – it is for this reason that cities are much warmer during the day and stay much warmer for a long time after the sun sets (Read the CfS's story on Urban Hotspot).

Land surface temperatures (LST) impact natural processes in their local environment. An increase in LST will cause water to evaporate faster, contributing to the water cycle process (Read the CfS's story on The Water Cycle). In regions near the equator, this leads to rainstorms or thunderstorms. Interestingly, people living there know from experience at what time of day they can expect these storms, and their daily routines are shaped around them.

But there are more examples of natural events that are triggered by LST, and therefore occur with certain timing. The blossoming of flowers when the first warmer days of spring occur, for example. How about seasonal crops? Your typical summer fruits or winter vegetables? Food production is largely driven by temperature too. Information about LST can help us secure the effective production of crops when combined with other physical properties, such as information about vegetation and soil moisture (Read the CfS's story on Feeding a Growing Planet). Another example is understanding how habitats are changing and how we might preserve vulnerable biomes and biodiversity (Read the CfS's story on Biodiversity and Habitat Loss). But there are also applications in urban environments; ESA is developing sensors for satellites that will allow for adequate analysis of LST, specifically in the metropolitan areas of European cities.

Ocean Colour

https://www.esa.int/ESA_Multimedia/Images/2011/02/Red_tides_in_Benguela_upwelling#.X0jWejD9KCU.link

What is the colour of the ocean? You would probably answer that it is blue, and you are mostly right! But that is only the colour we can see with our eyes. Sensors that are mounted on satellites can see more 'colours' than we can. They can assist us in seeing the unseen, like infrared or microwave wavelengths, as well as seeing a greenish colour that microscopic phytoplankton collectively reflects. While these marine plants are so tiny that you cannot see them with the bare eye, ESA's sensors can detect them!

You may wonder why we care about such minuscule organisms. In addition to their role as the basis of the food chain, every second breath you take comes from phytoplankton in the oceans. Just like on-land vegetation, they use carbon dioxide for growth (Read the CfS's story on The Carbon Cycle). Especially in places where cold water wells up, this plankton is in abundance. The upwelling water brings with it nutrients from the seafloor on which the plankton thrive. Mapping the Sea Surface Temperature shows where cold water is upwelling, providing a good indication where the plankton is (Read the CfS's story on Planetary Heat Pumps). But we can also see the phytoplankton from space. While phytoplankton themselves are individually microscopic, the chlorophyll they collectively contain colours the ocean's waters, providing a means of detecting these tiny organisms from space with dedicated ocean colour sensors. The colour of the ocean can also be used to get information on where the fish can be found, to make effective use of the resources of the sea (Read the CfS's story on Feeding a Growing Planet).

Ozone

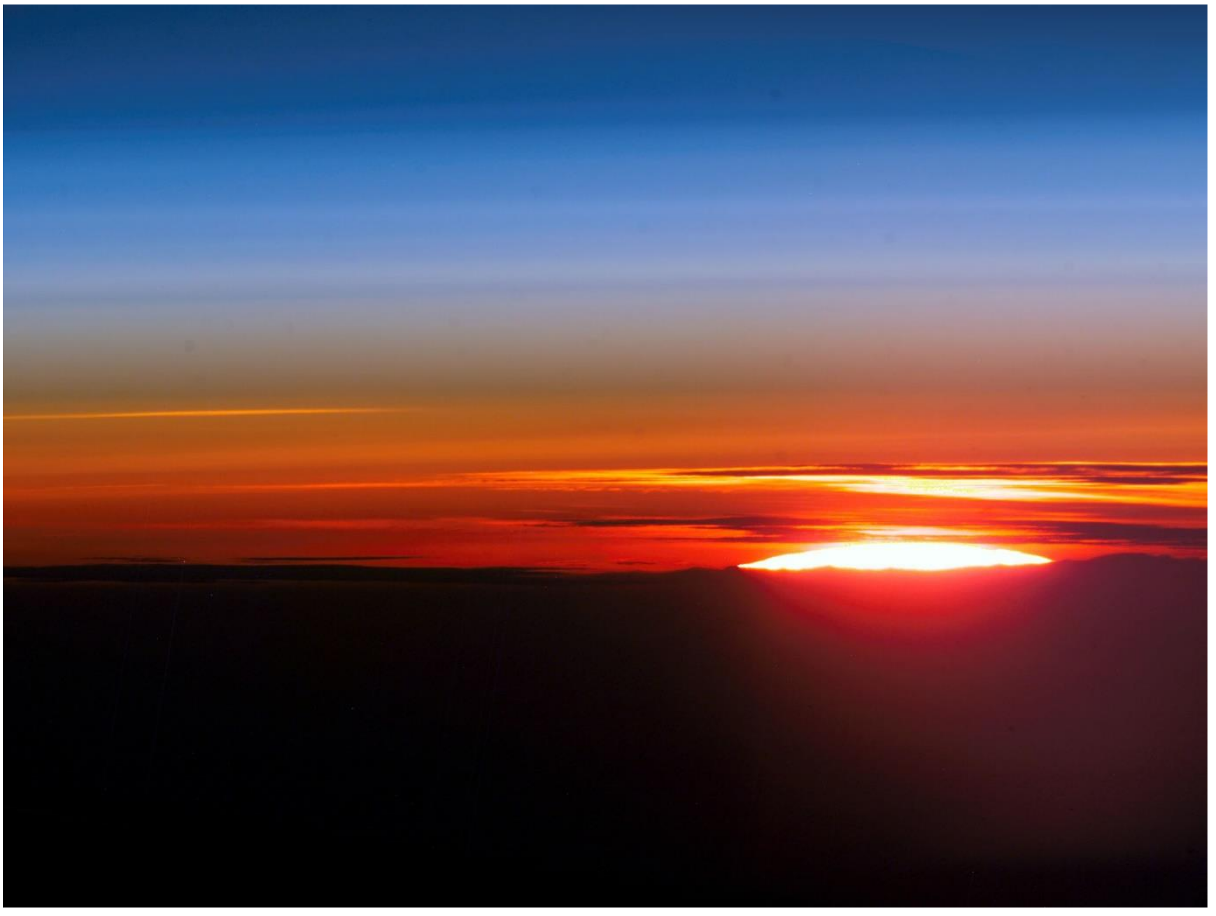


Image source: Climate Change Initiative_ ESA, Provided by Planetary Vision

Who has not been confused about ozone; if the hole in the ozone layer is bad because it allows harmful UV to burn our skins, then we need ozone right? But then it is also bad because it pollutes our air? (Read the CfS's story on is ozone good or bad?) Let's have a closer look at that. The chlorine and bromine-containing gases that come from our deodorant are responsible for major ozone losses in the upper atmosphere, which results in a cooling effect in the Earth's surface. In contrast, pollution from car exhaust and fossil-fuel burning will increase the level of ozone lower down near the surface which is harmful and has a warming effect on the Earth's surface. Due to these dual processes, the climate impact of changes in ozone concentrations varies with the altitude.

Satellites have aided the discovery of the hole in the ozone layer and now help us monitor the changes in total ozone as well as its vertical distribution.

Permafrost

https://www.esa.int/ESA_Multimedia/Images/2019/05/Permafrost_thaw#.X0jXdS6G0Ko.link

If you are familiar with the water cycle (Read the CfS's story on The Water Cycle), you will probably think that each and every water droplet on Earth has a very dynamic life; travelling the oceans, flying through the air and falling back down in the mountains. But not all water droplets have such a dynamic life. Some are stuck between rocks, soil and sediment in the ground near the poles or in mountainous areas, where they live as permafrost.

Permafrost is ground that remains frozen for at least two years. The top layer of the permafrost can melt, but the layers underneath stay at or below the freezing point of water in all seasons and therefore remain frozen. About a quarter of the ground in the Northern Hemisphere has layers of permafrost underneath. From measurements on the permafrost, we know that during the past three decades permafrost has been warming and it continues to warm.

This changing permafrost interacts with ecosystems and the loss of permafrost can make areas uninhabitable for animals (Read the CfS's story on Biodiversity and Habitat Loss).

Monitoring the changes of permafrost gives valuable information, though it cannot be directly detected from space. How does the CCI Permafrost project then monitor the depth or temperature of the permafrost?

This is done by first getting information we can see from space; the effects of the permafrost on the surface – like Land Surface Temperature, Snow Water Equivalent and land cover – can be measured using satellites. Combining this with on the ground measurements means a smart algorithm can be constructed. This algorithm then produces maps with the permafrost temperature. Scientists then measure whether the algorithm is correct and adjust it so that its values are as accurate as possible.

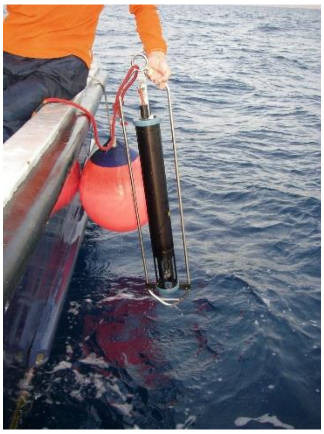
REgional Carbon Cycle Assessment and Processes

If we were to give you and your friends a 100 euro note and said you could buy anything you want, you would still have to make decisions; who is going to get how much? What are you going to spend it on? Maybe, if you all take some side-jobs, you could make some more money to spend! But what if one of you gets a higher hourly-wage; are you still going to distribute the money you collectively make equally?

This is something policy-makers worldwide also have to deal with. Except that they have to share and allocate greenhouse gas emissions. To fight global warming, it is now globally decided that we cannot just keep going the way we have done before. We need to cut down on our fossil-fuel burning so that emissions are limited. For this reason, there's a Global Carbon Budget – a total maximum amount of greenhouse gases emitted by humans redistributed among the ocean, atmosphere and biosphere. This budget is divided between countries so that they all know how much they can 'spend'. But what if a country takes on a side-job of creating more carbon sinks? Then practically, they have more to spend (Read the CfS's story on The Carbon Cycle). They can decide to emit more themselves or sell their emissions to other countries.

How can you quantify regional emissions and sinks? To monitor whether the carbon budgets are reached, ESA's REgional Carbon Cycle Assessment and Processes (RECCAP) project collaborates with the Global Carbon Project. They support and accelerate the analysis of regional carbon budgets, closing the gap between the emissions measured and finding the source (and sinks) to reduce the uncertainty in the budget. The data-driven models allow for monitoring of regional CO_2 budgets. This enables policy-makers worldwide to collaborate on finding solutions to keep our planet healthy (Read the CfS's story on Taking the Pulse of the Planet).

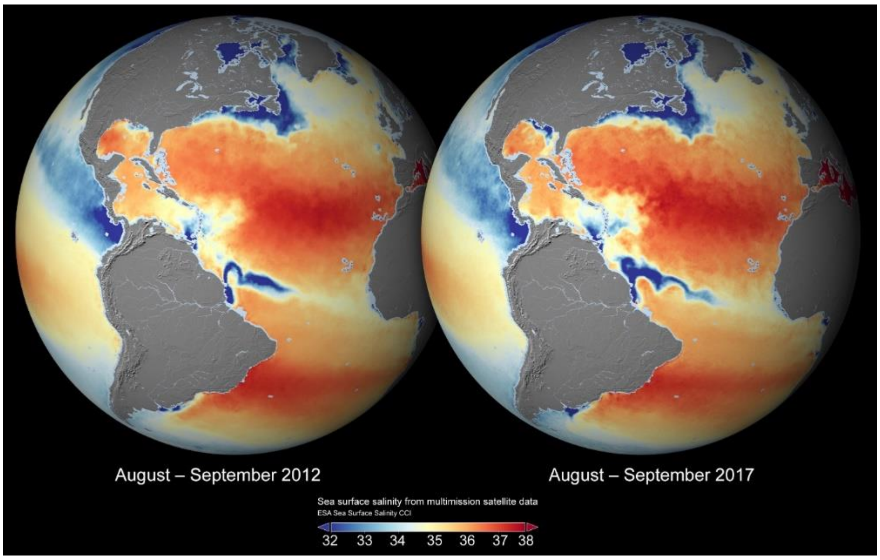
Sea Surface Salinity



https://www.esa.int/ESA_Multimedia/Images/2008/06/Sea-surface_salinity_calibration#.X0jX7glQTtQ.link

Whales travel around the world throughout the year, going with the flow of what is known as the global ocean conveyor belt – great global ocean circulation. This circulation is driven by temperature and salinity. The water that warms up at the equator travels poleward, where it cools down. The cold, salty water is dense and sinks to the bottom of the ocean, where it moves southward again, making space for warmer surface water to be transported north and undergo a similar process.

The concentration of salt in the water, together with winds and the rotation of the earth affects the ocean circulation. Ocean circulation plays a crucial role in moderating the climate by transporting heat from the Equator to the poles (Read the CfS's story on Planetary Heat Pumps). Ocean salinity is also linked to the oceanic carbon cycle, as it plays a part in how much CO_2 can be stored and hence the ocean's uptake and release of CO_2. Some animals and plants prefer to live in the water with a certain salinity level, so the salinity also gives information about changing habitats (Read the CfS's story on Biodiversity and Habitat Loss). If you are a keen sea-swimmer, you may have noticed that the water can be saltier in some places than others. This is because the saltiness of the water depends on nearby additions of freshwater from rivers, rain, glaciers or ice sheets, or on the removal of water by evaporation. ESA's Soil Moisture and Ocean Salinity (SMOS) mission observes soil moisture over the Earth's land masses and salinity over the oceans. Combined, these measurements are a powerful aid to the understanding of the water cycle (Read the CfS's story on The Water Cycle). The data on ocean salinity is vital for improving our understanding of ocean circulation patterns.



https://www.esa.int/ESA_Multimedia/Images/2019/11/Global_sea-surface_salinity_2012_and_2017#.X0jYTQIQTxI.link

Sea Ice

Image source: Climate Change Initiative_ ESA, Provided by Planetary Vision

What different types of ice exist? There is ice cream, ice cubes, ice that you can skate on and many other types of ice. But do you have any idea what kind of ice made up the iceberg that the Titanic hit right before it sank? What was that floating iceberg doing in the middle of the ocean? It was not just seawater that had frozen. In fact, this was a broken-off piece of a glacier that drifted off to more southern waters before it collided with the Titanic. Whereas sea ice is frozen sea water, icebergs are chunks of ice that have broken off the edges of ice-shelves or fronts of glaciers where they reach the sea.

But even sea ice has numerous different distinctions; when formed along the coasts or seafloor it is called fast sea ice, as it is attached to the shoreline. When floating on the surface, carried on sea currents and winds, it is drift ice. When these free floating chunks of ice encounter another chunk, they may melt a bit and freeze into a larger chunk of ice – this is what we call pack ice.

Polar sea ice both shows that climate change is occurring globally, but it is also driving climate change. We now have over 40 years of satellite data to directly monitor its evolution in concentration, area and extent, and almost 30 years for its depth.

In the Arctic, sea-ice extent and volume have decayed in all seasons, with the strongest reduction in late summer. This leads to a younger and more mobile sea-ice cover in the Arctic Ocean. In the Southern Hemisphere, sea-ice extent increased rather steadily until 2015, with much smaller coverage since 2016. With this reduction of sea ice comes the opportunity of new shipping routes (Read the CfS's story on A Passage Opens).

Sea Level

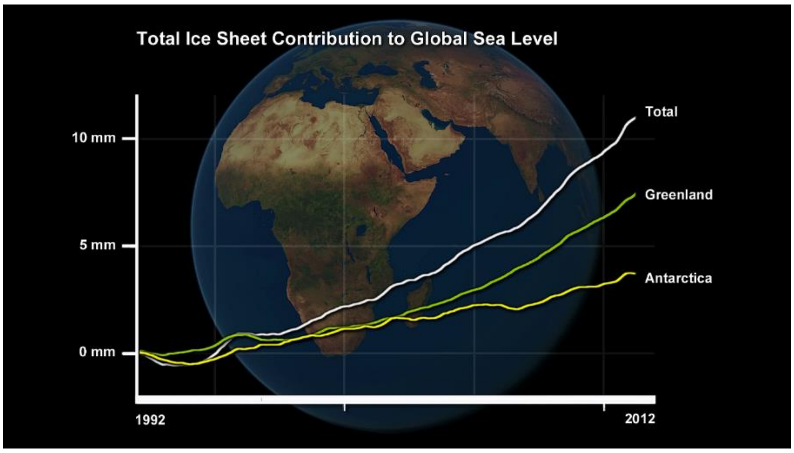
Image source: Climate Change Initiative_ ESA, Provided by Planetary Vision

How many causes of sea-level rise can you mention? Climate Change is an overarching factor, but what kind of processes does it spark that contribute to the rising sea level? Firstly,
as the ocean warms in response to global warming, sea waters expand. This is because warmer water needs a larger volume and, as a result, the sea level rises. Secondly, when mountain glaciers melt in response to increasing air temperature, the sea level rises because more glacial freshwater discharges into the oceans. Similarly, ice mass loss from the ice sheets will provide additional input to sea-level rise.

Did you know that ice never contains saltwater? When ice forms from saltwater the salt gets left out and makes the surrounding water denser, driving ocean circulation (Read the CfS's story on Planetary Heat Pumps). When the ice melts again this freshwater mixes with saltwater in the oceans, reducing its salinity, decreasing its density and affecting ocean circulation patterns that in turn affect sea level. Many small islands are expected to be drowned, due to sea-level rise, in the next century (Read the CfS's story on Country under Threat).

The global mean level of the oceans is an indicator of climate change. It incorporates the reactions from several different components of the climate system. Precise monitoring of changes in the mean level of the oceans is vitally important for understanding not just the climate but also the socioeconomic consequences of any rise in sea level (Read the CfS's story on Taking the Pulse of the Planet).

Sea Level budget closure



https://www.esa.int/ESA_Multimedia/Images/2014/03/Sea-level_rise_from_ice_sheets#.X0jaQsE1xRM.link

Water from melting glaciers and ice sheets, along with the thermal expansion of ocean water due to rising temperatures, is causing global sea-level rise. This is then the 'income' of the sea level budget. Scientists are exploiting satellite data to better understand how much each component contributes to this devastating consequence of climate change. Understanding where and how the water gets added to the ocean and where and how water gets out of the ocean is the ocean budget, similar to the money budget. Here we deal with closing budget, exploring what the yet unknown 'income and costs' of this budget are.

Identifying the individual contributors to sea-level rise is one of the most complicated challenges in climate science. This involves tracking water as it moves in all its forms – solid, liquid or gas – around the Earth.

While Earth observation satellites continuously map global and regional sea-level change, they can also be used to quantify the amount of water coming from various sources.

Under ESA's Climate Change Initiative (CCI), experts in the domains of oceans, land, atmosphere and the cryosphere (all about water in solid-state, think of ice) are working together to quantify the various sources of sea-level change – known as balancing the sea-level budget.

Quantifying contributions to sea-level rise from melting ice, as well as from ocean warming, will lead to better predictions of sea-level changes. These are imperative to the development of mitigation strategies, especially for low-lying coastal areas (Read the CfS's story on Country under Threat).

To make these predictions, satellite data is used to validate climate models developed to estimate future changes of climate parameters, including sea level. To gain confidence in the projected changes, it must first be checked that the climate models can reproduce present and recent past variations correctly.

Sea State

https://www.esa.int/ESA_Multimedia/Images/2018/02/AutoNaut_-_autonomous_boat_wave_propelled_and_with_solar_powered_ocean_sensors#.X0jZ1LOgIUg.link

Have you ever stood on the beach watching the waves come rolling in and listening to them break on the shoreline? Wondering how and where on Earth – if it is not a windy day – these waves were created? They may have started from a remote storm in the sea and may have been altered by wind and swells along the way.

Those studying the sea state climate try to understand the effect of the wind, sea surface temperature and internal dynamics of the ocean on the state of the sea. This knowledge is useful to understand air-sea interactions and large-scale climate patterns, such as El Nino, but also provides valuable engineering services. What extremes should we design coastal defences, ship routings and ocean platforms for? It also helps us understand how sea ice develops and how extreme sea levels at the coastlines occur. Moreover, knowledge of sea state is extremely valuable in improving the accuracy of satellite measurements of sea level (Read the CfS's story on Country under Threat).

Snow

https://www.esa.int/ESA_Multimedia/Images/2020/05/Snow_mass#.X0jZlqms9Cs.link

One of the most uncomfortable things to do on a hot summer day is get into a car. The feeling of your skin touching the hot seat. And the seat-belt – that is even worse. Did you know that if your car's interior was white – you wouldn't have that much of a problem during hot days? Whereas darker colours tend to absorb heat, lighter colours reflect heat into the air, cooling the local climate. It is for this reason that snow plays an essential role in cooling our planet. Especially the seasonal snow which covers 50% of the northern hemisphere's land surface during mid-winter and is an important component of the climate system.

Seasonal snow cover is a crucial and challenging research issue in climate analysis and modelling. Apart from snow shielding our planet from trapping incoming heat from our sun, it also influences energy, moisture and gas fluxes between the land surface and atmosphere. Its sensitivity to precipitation and temperature regimes makes it widely recognised as a fundamental indicator of climate variability and change.

Snow plays a key role in our water cycle. When a snowflake gently drifts down from the clouds to the ground, chances are high that they have a long bumpy journey ahead, down the alpine streams, into rivers and back to the ocean. But this is not for all. Some argue that there's nothing better than drinking the ice-cold meltwater from the streams in alpine regions, making snow a major, if not dominant, freshwater source in many alpine, high- and mid-latitude regions (Read the CfS's story on The Water Cycle).

Soil Moisture

Close your eyes and think about nothing but the sound of crickets and your own breath to control your body's response to a hot, 40 degree breeze touching your skin. What setting do you imagine? Do you already see tumbleweeds rolling by? What kind of soil do you imagine standing on? Chances are big you were thinking about standing in the middle of the desert or on dry cracked soil.

Image source: Climate Change Initiative_ ESA, Provided by Planetary Vision

With our Earth warming, contexts like these will occur much more often due to more intense and frequent droughts – and that is a problem, because the important role of water in the soil (or soil moisture) for the environment and climate system is well known(Read the CfS's story on The Water Cycle).

Soil moisture influences hydrological and agricultural processes, run-off generation, drought development and many other processes. Lands like the one you imagined can no longer be used for growing crops on, consequently threatening food production and our ability to feed the ever-growing global population (Read the CfS's story on Feeding a Growing World). Also, if soil moisture levels drop and droughts occur, trees may die, animals lose their habitats, and there will be fight over the limited available water resources (Read the CfS's story on Biodiversity and Habitat Loss).

Sea Surface Temperature

Image source: Climate Change Initiative_ ESA, Provided by Planetary Vision

Depending on where you live, you might consider the ocean to be a source of comfort to cool down after a hot day, or you will think of it as something cold that you rather stay away from. Covering two-thirds of the Earth's surface, the oceans have absorbed most of the heat of global warming caused by human activities, like burning fossil fuel and industry. The water in oceans and seas retains heat for much longer periods than either the land or the atmosphere. This feature of heat retention means that it takes a much time and energy to shift sea temperature. Because oceans and seas retain temperature and work like vast reservoirs of heat, oceans are regarded as the 'memory' of the Earth's climate system (Read the CfS's story on Planetary Heat Pumps). In this respect, scientists regard tracking sea surface temperature (SST) over a long period as the most reliable way of measuring the exact rate at which global temperatures are increasing.

Over 150 years of data on sea surface temperatures have shown that oceans have been getting warmer over the decades. In the early years, scientists used ships and buoys to collect on-site measurements. But today's scientists use satellite data. Since ships/buoys only measure the temperature of the sea around them, satellites provide additional coverage to complement the measurements. They can provide sea surface temperature for the whole earth every few days (Read the CfS's story on Taking the Pulse of the Planet). From more than 35-years of satellite observation of sea surface temperature, we know that the rate of ocean warming has more than doubled since 1993.

The warmer the water gets, the more it expands – and the more it expands, the higher our sea levels. Sea-ice sheets in Polar Regions will melt with a faster rate when surrounded with warmer water, adding thereby more water. If you are living up a mountain, on the fourth floor of an apartment complex or a two-story house in the middle of a continent, you may not directly be affected by warmer oceans and the corresponding sea-level rise. But the tropical islands you see in travel magazines will certainly face the impacts – which will be disastrous. (Read the CfS's story on Country under Threat).

Water Vapour

https://www.esa.int/ESA_Multimedia/Images/2002/02/Water_vapour_real#.X0jZP_KYg5Y.link

If you have ever been in a sauna, you have seen that to keep the sauna hot and humid, you must put water on glowing stones. The water evaporates and becomes water vapour. The higher humidity makes it feel hotter and therefore you sweat more, the sauna steam has a Finnish name: löyly. Interesting enough, water does not need to boil to evaporate. Water can evaporate at any temperature, this is because evaporation depends on the energy of individual water molecules. When a water molecule gains enough energy, it can escape the water surface as vapour.

Water vapour in the atmosphere is a key component of the Earth's hydrological cycle. Many physical processes help redistribute water from the oceans to the land involving the formation of clouds, precipitation, and extreme weather events (Read the CfS's story on The Water Cycle). Water vapour also has a key role in constraining the Earth's energy balance. It is the single most important natural greenhouse gas in the atmosphere and constitutes a strong positive feedback to anthropogenic climate forcing from carbon dioxide (CO_2). The water vapour feedback is critically important in understanding the past and determining future climate change, along with its global and regional impacts. Because of its importance in these different processes, water vapour is an Essential Climate Variable (ECV).

The properties of the Earth's atmospheric water vapour distribution challenge not only climate research, but also Earth observation science, from instrument development to retrieval of science.