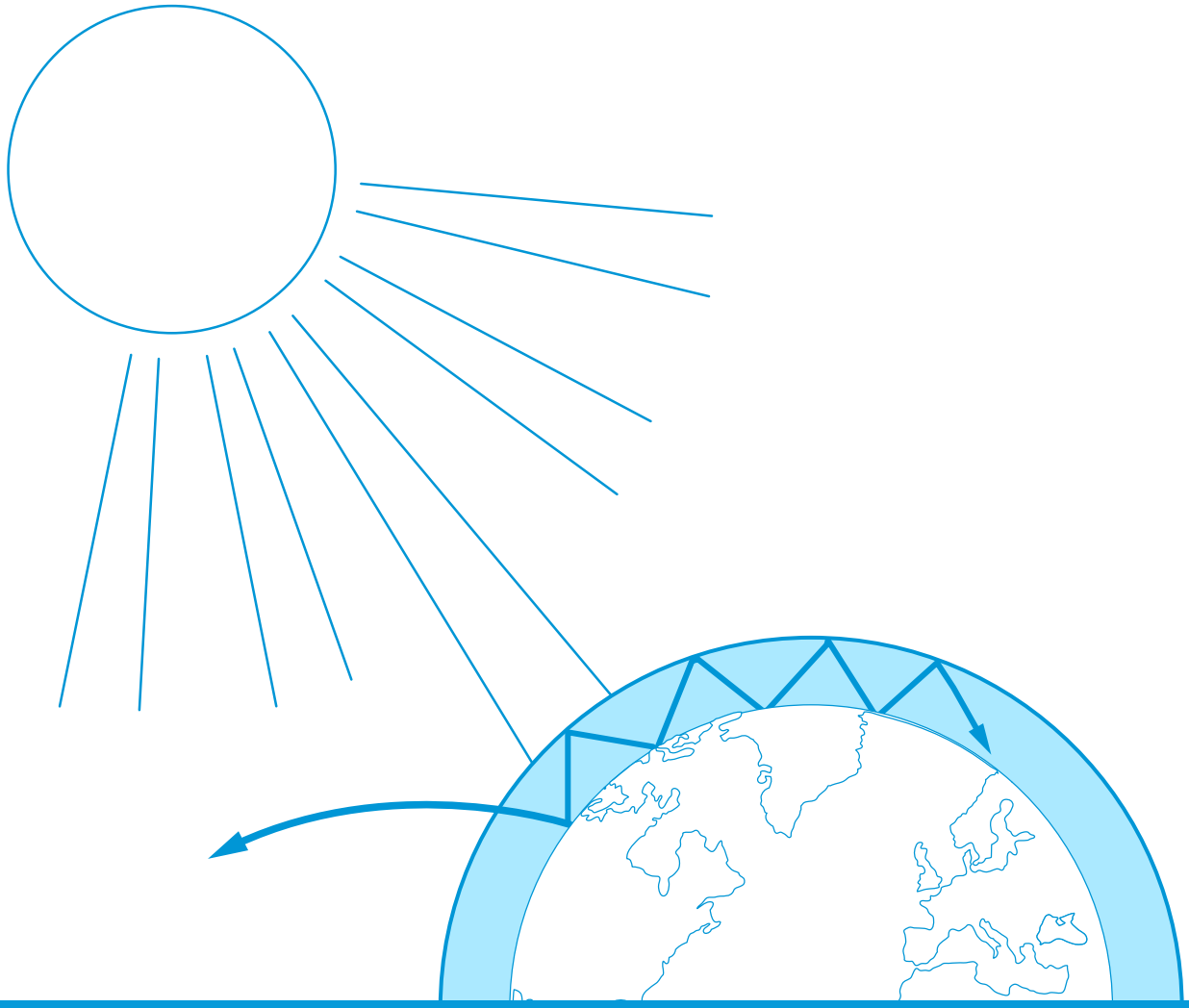
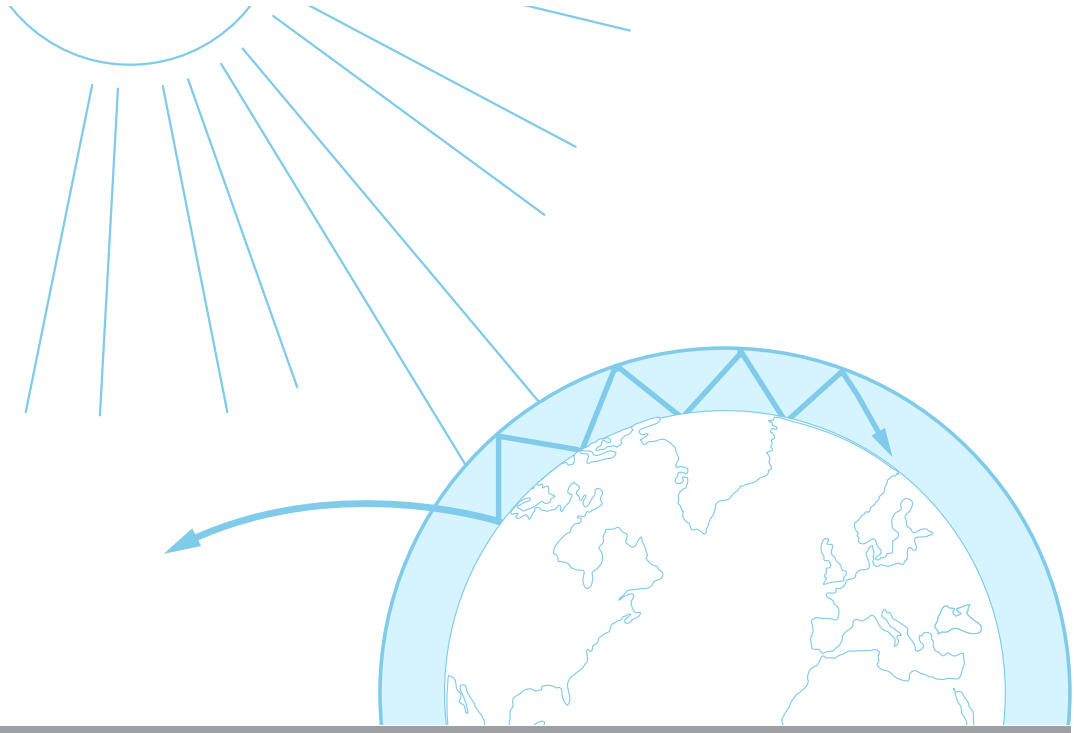
teach with space

→ THE GREENHOUSE EFFECT AND ITS CONSEQUENCES

Investigating global warming





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→ THE GREENHOUSE EFFECT AND ITS CONSEQUENCES

Investigating global warming

Fast facts

Subject: Geography, Physics, Science
Age range: 12-15 years old
Type: hands-on student's activity
Complexity: easy
Lesson time required: 45 minutes per activity
Cost: low (0 – 10 euros)
Location: indoors and outdoor
Includes the use of: computer, internet, infrared thermometer
Keywords: Greenhouse effect, Carbon dioxide, Global warming, Sea level, Albedo, Climate, Geography, Physics, Science

Brief description

This set of activities includes hands-on experiments and the interpretation of satellite images for better understanding the overall effects of global warming.
In activity 1 students will make a model to demonstrate the greenhouse effect by showing that a higher level of carbon dioxide (CO_2) means a higher temperature. The experiment will be complemented by the interpretation of satellite images showing the Earth's CO_2 levels at different time periods.
Students will then learn about some of the consequences of an increased greenhouse effect – ice melting and changing albedo values. Students will explore these topics in activities 2 and 3.

Learning objectives

- What the greenhouse effect is and how human activity changes the energy balance in Earth's atmosphere.
- The potential effects of increased levels of carbon dioxide on the Earth's climate.
- Possible consequences of the increased greenhouse effect.
- The different consequences of flooding and rising sea water level due to melting sea-ice and melting ice sheets and glaciers.
- What albedo is and how the reflectivity of different surfaces affect temperature.
- How Earth observation can be used to monitor Earth's climate.

→ Summary of activities

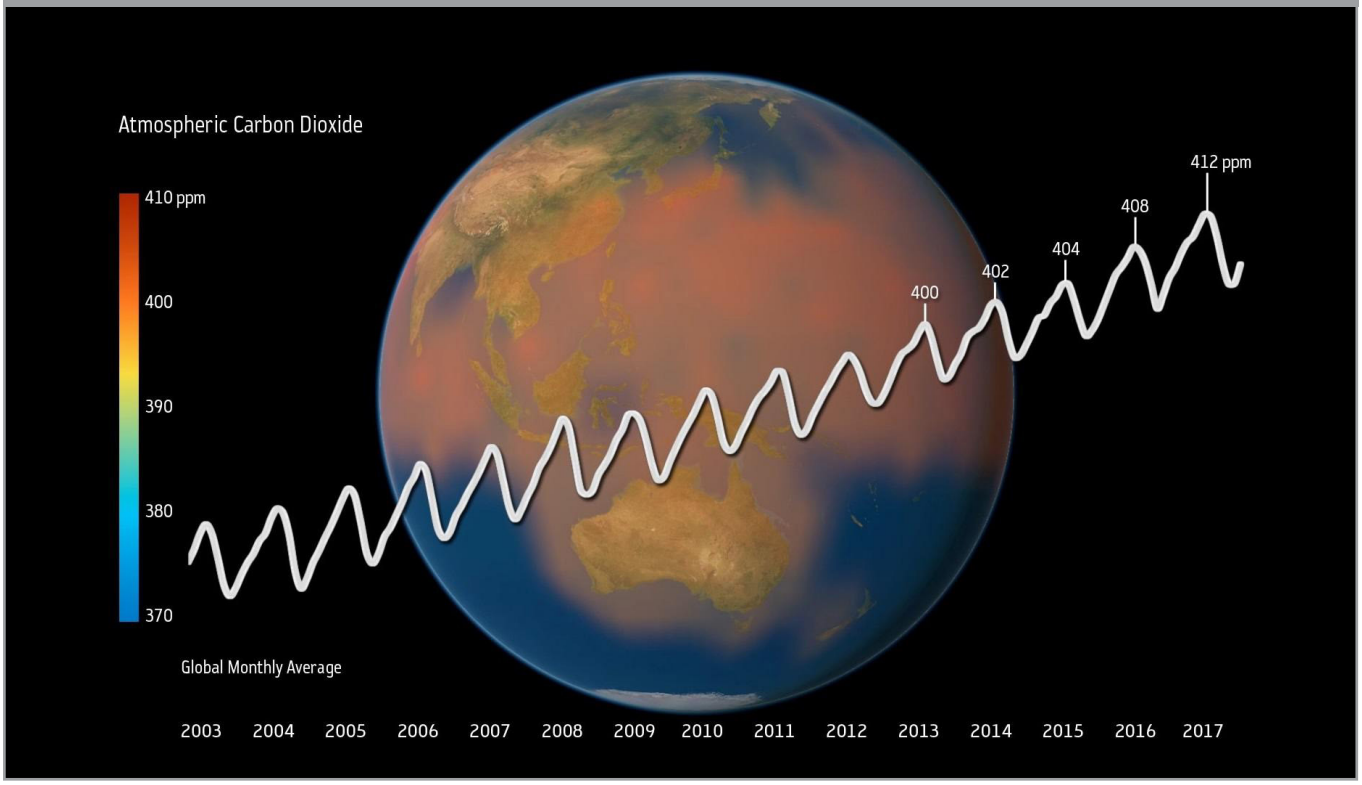
Summary of activities					
	Title	**Description**	**Outcome**	**Requirements**	**Time**
1	Greenhouse effect – what is that?	Students produce the greenhouse gas CO_2 through a simple chemical reaction, measure the effect of the gas on air temperature, and relate their conclusions to the greenhouse effect in our atmosphere.	Understanding CO_2's role as a greenhouse gas and what the greenhouse effect is.	None	45 minutes
2	Sea level as an indicator of global warming	Students explore by means of hands-on activities the effects of the melting of land ice and sea ice.	Understanding the effect on flooding from melting sea ice versus melting glaciers and ice sheets.	None	45 minutes
3	How changes in albedo can affect the climate	Students measure the reflectivity of different surfaces and investigate how the reflection from surfaces of different colour affects their temperature.	Better understanding of albedo and its role in the Earth's energy budget.	None	45 minutes

→ Introduction

The understanding of global warming can be rather complex. To understand these concepts it is essential to investigate some of the 'invisible' but important processes that have an effect on Earth's climate. For example, global warming is related to the greenhouse effect, and the melting of Earth's ice sheets is linked to the planet's albedo.

Satellite images are key tools for monitoring changes in Earth's atmosphere, oceans and surface. Different types of satellite images like radar images, visible light images or infrared-images give us important information about atmospheric carbon dioxide, the amount of clouds or water vapour in the atmosphere, the sea level, the sea ice concentration, and much more. ESA's Climate Change Initiative involves a community of over 350 climate scientists that analyse long-term observations from Earth Observation satellites in order to understand and inform the international response to changes in the Earth's climate.

Figure A1



↑ Levels of carbon dioxide in the atmosphere measured by Earth Observation satellites. The annual ups and downs of the curves are due to seasonal changes in vegetation and therefore more/less photosynthesis.

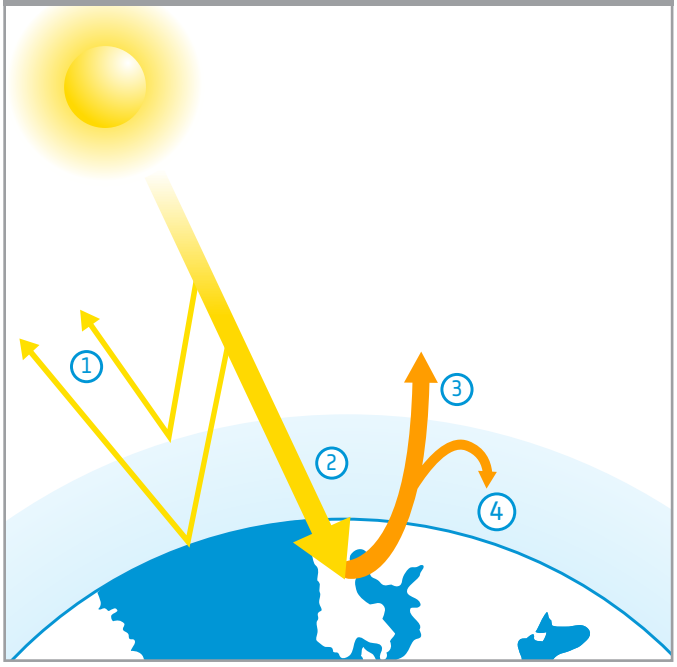
The increase in carbon dioxide (CO_2) is the most important contributor to human-induced global warming. The higher levels of CO_2 make the greenhouse effect too powerful and lead to increasing temperatures on Earth.

In this resource, students will do hands-on experiments, and analyse satellite data to investigate the greenhouse effect is and some of the consequences of global warming.

→ Background

Most of the energy the Sun radiates is visible and near infrared light that consists of short wavelength radiation. This radiation easily passes the particles found in the atmosphere. When this short-wave radiation hits the Earth a large proportion of it is converted into heat. Earth's temperature does not infinitely rise because the surface and the atmosphere are also radiating heat back to space. This net flow of radiation into and out of the Earth system is called Earth's radiation budget (Figure A2). Heat is long-wave radiation that individually contains less energy than the short-wave radiation. This means it interacts with the atmosphere in a different way. The Earth radiates heat back into the atmosphere during the day and night, which helps to cool the surface. However, not all of this heat escapes to space, some remains trapped by the greenhouse gases in the atmosphere. The result is that the Earth's atmosphere is warmer than it would be without this 'greenhouse effect'.

Figure A2



↑ Earth's radiation budget.
1 - Some radiation is reflected by the atmosphere, clouds and Earth's surface.
2 - Some radiation is absorbed by the atmosphere, clouds and most of it is absorbed by the land and oceans, heating the Earth.
3 - Infrared radiation is emitted by Earth's surface. Some of this radiation escapes to space.
4 - Some is trapped by the greenhouse gases in the atmosphere.

If greenhouse gases were not present in Earth's atmosphere, life as we know it would be almost impossible because the average surface temperature would be several degrees Celsius below zero. The primary greenhouse gas in Earth's atmosphere is water vapour. It traps the largest amount of heat coming from the ground. However, the greenhouse gases that climate scientists are more concerned about are CO_2 and methane (CH_4) because these are the major greenhouse gases emitted by human activities and have been increasing in the atmosphere since the beginning of the industrial revolution.

→ Activity 1: GREENHOUSE EFFECT – WHAT IS THAT?

In this activity, students will test a hypothesis about how the atmospheric carbon dioxide can affect the temperature on Earth to understand the greenhouse effect. Students will answer the question: How does the atmospheric carbon dioxide affect the Earth's temperature? Students will also analyse satellite images to understand how it is possible to monitor greenhouse gases from space.

Equipment (per group)

- 2 1L flasks
- Corks with hole for holding the thermometer
- 1 lamp with a heating bulb (more than 100W)
- 2 thermometers (0.1°C precision)
- Acetic acid 32%
- Baking powder
- Ice cubes (optional)

Health & safety

The flasks and the lamp must be handled carefully. Students should avoid touching the heat lamp. The teacher should help adding the acetic acid into the flasks.

Exercise

For detailed instructions about the experiment setup, see the student worksheet. The experiment can be extended by placing an ice cube in the bottom of each jar. Students can then investigate how long it takes for the ice cubes to melt.

Please note that this experiment is very sensitive and should be tested in advance. The experiment can also be done with a CO_2 dispenser (used to create soda water to drink) instead of acetic acid 32% and baking powder.

This exercise can be run as a hands-on student activity or as a demonstration.

Results

In the flask with CO_2, the temperature will rise faster than in the flask without. After 10 minutes, usually there will be 1-3°C difference. It should be stressed that an average increase of just 2 degrees across the planet could have catastrophic effects. For example, this could cause sea levels to increase significantly resulting in major flooding.

Discussion

The composition of the air in the flasks affects the amount of scattered and absorbed heat. The students compare differences in the heat absorption (changes in temperature) in a control sample and in an increased CO_2 environment. Students should conclude that the temperature in the flask with CO_2 will increase faster than the temperature in the "control flask".

Discuss with the students how the atmospheric CO_2 affects the Earth's temperature. They should conclude that CO_2 traps the heat emitted from Earth. Because of this, the temperature on Earth is higher than if there was no CO_2 in the atmosphere. Students should understand that our atmosphere and the greenhouse gases that make it up are what makes our planet habitable.

However, the increase in human-produced greenhouse gases is altering the 'normal' quantity of these gases in our atmosphere, causing global warming.

As an extension, students can analyse satellite data to investigate and discuss seasonal and long term changes of CO_2 in the atmosphere (see the links section for video suggestions).Students should conclude that CO_2 in our atmosphere is continuing to increase globally over the last years. They should also observe a seasonal fluctuation. This fluctuation is due to vegetation growing (specially in the northern hemisphere where most of the world's vegetation is found) . During summer the vegetation absorbs carbon dioxide through photosynthesis and some of this carbon dioxide is released in the winter.

The "Climate from Space" app from ESA's Climate Change Initiative (CCI) gives an overview of greenhouse gases and the data viewer shows global satellite derived distributions of atmospheric CO_2. Screenshots of the data viewer are available as an annex in case students don't have access to internet. Teachers can print these pictures in order for students to discuss long term changes of CO_2 in the atmosphere.

→ Activity 2: Sea level as an indicator to global warming

The change in sea level is one of the main impacts of anthropogenic – or human-induced – climate change. In this activity students will investigate the impact that global warming could have on sea levels by doing a hands on activity.

Health & safety

No special precautions are necessary. Students should take care to wet their hands before picking up the ice cubes, to stop the ice sticking to their fingers.

Exercise

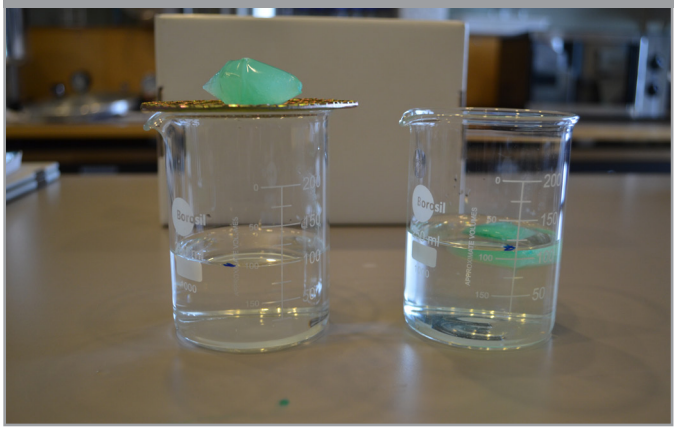
Before starting the practical experiment, students should discuss in small groups their expectations/ predictions. If necessary explain the difference between sea ice and land ice.

For instructions to carry out the activity, please see the student's worksheet.

The average salinity of sea water is 3.3%. To prepare the sea water students should add one teaspoon (approximately 5g) of salt to the water. To prepare a solution for the all class, see the instruction below:

- Weigh 33 g of salt.
- Add the salt to a beaker and add fresh water until the total mass is 1,000 g.
- Stir with a stirring rod until all the salt is dissolved.

Figure A3



↑ The set- up of the experiment.

Results

Table 1 - Experimental results				
	Amount of water (ml)	Grid net added	NaCl %	Observations
Beaker 1	150	Yes	0	The level of the water is higher than in the beginning.
Beaker 2	150	No	0	Water stays at the same level as ”starting level”.
Beaker 3	150	Yes	3.3	The level of the water is higher than in the beginning.
Beaker 4	150	No	3.3	Water stays at the same level as ”starting level”.

The students should also observe that the ice cube in the fresh water melts faster than the one in the salty water. This is because the salt is changing the melting point of the ice.

Depending on the students' level of knowledge, the differences in heat capacity can be discussed giving the students a better understanding of why the ice cubes in water melt faster than the one on 'land'.

The students observe that when the fresh water ice cube is melting in the salty water the ice cube's fresh water (which is coloured) stays as a coloured layer on top of the surface due to the differences in density of fresh water and salty water (Figure A4).

Figure A4

↑ The melting water in salty water will stay on top (left beaker). The melting cold water in fresh water will sink (right beaker).

Discussion

Water is one of the few substances that is less dense in its solid form than its liquid form. This is why ice floats. It means also that the same amount of water when in the solid form takes up a greater volume than in the liquid form. Teachers can use the Archimedes principle to explain why there's no change in water level when ice that is floating in the water melts. For that students could also weigh the ice cubes.

It is melting land ice that mostly leads to rising sea levels. Note that indirectly, melting sea ice can lead to rising sea levels, through changing properties such as the salinity, and density.
The melting of land ice and sea ice changes the Earth's radiation budget (this is going to be explored in activity 3).

As an extension students can watch the video "Contributors to sea-level rise" (see links section) about what influences the sea-level rise and compare their findings to the information in the video.

→ Activity 3: How changes in albedo can affect the climate

By a hands-on experiment, students will develop and test a hypothesis about how the reflectivity from surfaces of different colours affects temperature. Students will understand that the reflectivity of different surfaces, their albedo, plays an important role in the Earth's climate. They will investigate the following questions:

1) How does colour influence the temperature of the surfaces?

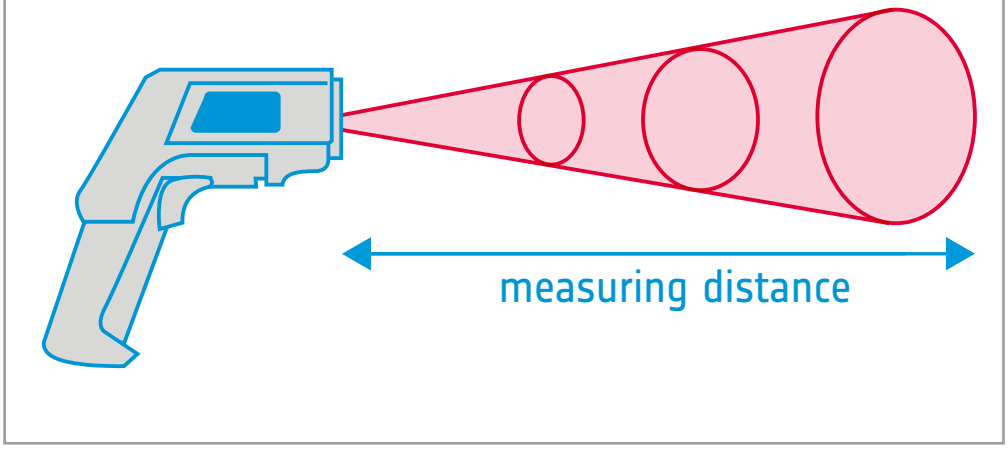
2) How does the wind and humidity affect the albedo and thus the temperature of the surface measured?

Equipment

- IR-thermometer
- Pieces of paper or cardboard with different grey tones and different colours (see annex II)
- Lamp with heat bulb (if not sunny)

Note: An infrared thermometer is a thermometer which infers temperature from a portion of the thermal radiation emitted by the object being measured. The amount of IR radiation emitted from an object or a surface is proportional to its temperature. Large amounts of IR radiation mean a high temperature and small amounts of IR radiation mean a low temperature.

Figure A5



↑ Schematic representation of how an IR-thermometer measures the average IR radiation.

The IR thermometer should be pointed at a surface from a distance of a few centimetres. The thermal radiation detected is converted into an accurate temperature of the surface. Be sure to use the same distance in every measuring. An infrared thermometer only measures the surface temperature of an object.

Exercise

For instructions to carry out the activity, please see the student worksheet. Before carrying out the exercise students should become familiar with the use of the IR-thermometer.

If there is no IR-thermometer available, the experiment from annex III can be conducted.

Results

In Exercise 1, within a rather short interval the students will typically observe a temperature raise of 0.3-0.5°C per grey tone.

In Exercise 2, students should observe that there are many factors that influence the surface temperature reading including the humidity, cloudiness and time of the day, in addition to the colour and texture of the surface.

Discussion

The surface colour of a material has an impact on the heat absorbed from radiation. Students should observe that the darker the surface colour the higher the temperature (this is because darker materials absorb more heat than lighter materials). In the discussion, students should relate this to Earth. What surfaces are likely to reflect the most radiation? Which ones are likely to absorb the most radiation? Students should conclude that:

- bright surfaces(ice, snow) have a high albedo, meaning they reflect most of the solar radiation;
- dark surfaces (water, oceans, grass) have a low albedo, meaning they absorb most of the radiation from the Sun;
- melting ice will increase the temperature of the Earth further, because it will become water, which results in a smaller light area (ice) and a larger dark area (water);
- as the ice-covered area shrinks, more heat is absorbed by the ocean in summer; the ocean therefore takes longer to cool in autumn, so the formation of new ice starts later.

→ THE GREENHOUSE EFFECT AND ITS CONSEQUENCES

Investigating global warming

→ Activity 1: Greenhouse effect – what is that?

In this first activity, you will study how carbon dioxide (CO_2), a "greenhouse gas", can affect the air temperature in a closed environment. You will investigate the following question:
How does atmospheric carbon dioxide affect the Earth's temperature?

As an extension you will also analyse satellite data about the concentration of carbon dioxide in the atmosphere to investigate seasonal changes and identify long-term trends.

Equipment

- 2 1L flasks
- Corks with hole for holding the thermometer
- 1 lamp with a heating bulb (more than 100W)
- 2 thermometers (0.1°C precision)
- Acetic acid 32%
- Baking powder
- Ice cubes (optional)

Health & safety

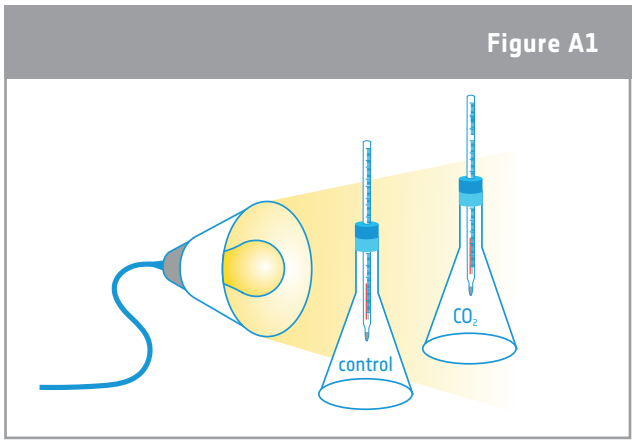
The flasks and the lamp must be handled carefully. Avoid touching the heat lamp.

Exercise

In this exercise you will investigate the temperature inside two flasks; one contains CO2 (flask 1) and the other serves as control (flask 2).Before starting your experiment, make a prediction about which flask will retain the most heat.

1. Place the two flasks next to each other under the lamp. Be sure that the two flasks receive the same amount of light. The flasks and the lamp should NOT be moved while the experiment is running.
2. Place the two thermometers in the two corks.
3. Mix 5 grams of baking powder and 20 mLs of acetic acid in one of the flasks (ask your teacher to help add the acetic acid to the flask).
4. Close the two flasks with the corks holding the thermometers.
5. Record the initial temperature of each thermometer.
6. Turn the lamp on.
7. Wait for 2 minutes and read the temperature.
8. Wait another 2 minutes and read the temperature. Continue until you have 8 sets of temperature readings.
9. Record your data in Table 1 and construct a line graph in the Results section below. Include a title and label the axes of your graph.

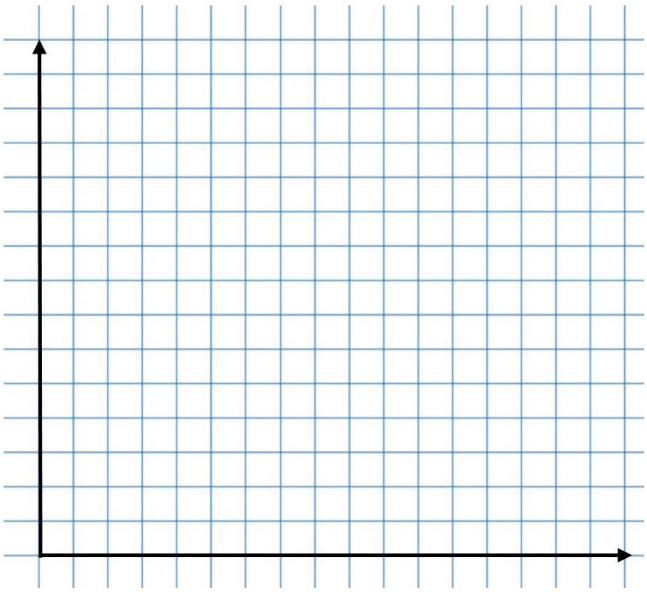
Figure A1



↑ The set up of the experiment: one flask contains CO2 and the other serves as a control.

Results

Table 1 - Experimental results		
Time	Temp. Flask 1	Temp. Flask 2
0 min		
2 min		
4 min		
6 min		
8 min		
10 min		
12 min		
14 min		
16 min		



Discussion

1. Compare the results of the two flasks. Do the results agree with your predictions ?

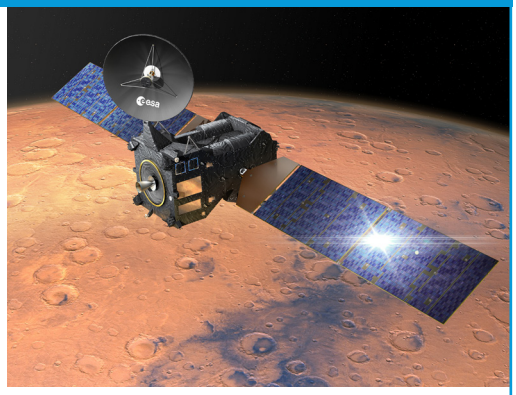
2. Explain your results.

3. Based on your results try to answer the introductory question:

   How does the atmospheric carbon dioxide affect the Earth's temperature?

4. Carbon dioxide is a greenhouse gas released through natural processes and through human activities. Explain in your own words what the greenhouse effect is.

Did you know?



Studying other planets' atmospheres, can help us understand climate change on Earth. Mars' atmosphere, for example, is primarily carbon dioxide but the existing atmosphere is so thin that it cannot retain much of the Sun's energy. As a consequence, there are extreme temperature contrasts between day and night, or sun and shade. However, most scientists agree that Mars was much warmer in the past, which means that the atmosphere was probably different to how it is now. The ExoMars Trace Gas Orbiter, part of the ESA–Roscosmos ExoMars mission, will investigate the composition of the planet's trace gases, which make up less than 1% of the volume of the planet's atmosphere. In particular, the orbiter will seek evidence of methane and other gases that could be signatures of active biological or geological activity.

Extension – Monitoring CO_2 from space

1. You will now analyse satellite data about the global carbon dioxide concentration. Before you start doing that, discuss in small groups your expectations:

   a) Seasonal changes - Do you expect changes in the concentration of atmospheric CO_2 in different months of the same year? Explain why or why not.

   b) Do you expect significant changes in the concentration of atmospheric CO_2 when comparing the same month in different years? Explain why or why not.

   c) Local and global changes – Do you expect the distribution of CO_2 in the atmosphere to be similar when comparing different places on Earth? Explain why or why not.

2. Compare your expectations with real satellite data. Is your analysis from real satellite data similar to your expectations in question 1? Try to explain any differences.

3. Identify possible consequences to the Earth's climate due to changes in the atmospheric CO_2 concentration.

→ Activity 2: Sea level as an indicator of global warming

Sea level rise is a primary indicator of global climate changes. In this activity, you will investigate the following question:

What will be the effect on sea levels if sea ice and land ice (for example, glaciers) melts?

Equipment

- 4 glass beakers 250 ml
- Metal net with a diameter slightly bigger than the beakers
- Coloured ice cubes
- Table salt (NaCl)
- Tea-spoon or spatula to stir with
- Marker pen
- Timer

Figure A2

↑ The set-up of the experiment.

Exercise

1. Add 150 ml of cold tap water to beaker 1 and beaker 2. Put a metal net on top of one of the beakers(beaker 1). Mark the water level on the beakers.

2. Take two identical coloured ice cubes.

3. Place one ice cube on the metal net above the beaker and carefully drop the other ice cube into the water in the other beaker (beaker 2). Identify the kind of ice that you think is represented in beaker 1 and in beaker 2.

Beaker 1:_____ Beaker 2:_____

4. Once again, mark the water levels on each beaker. This is the 'starting' level.

5. Start a timer.

6. Carefully observe what happens as the ice cubes melt. How does the melting water behave in the water?

_____

7. In table 2, below register how long it takes for each ice cube to melt completely.

8. While you wait, answer the following question:

What do you expect to happen to the water level in the different beakers?

_____

_____

9. Repeat the experiment but this time with “Sea water” in beaker 3 and beaker 4. Sea water has an average salt content of 3.3 % NaCl. Again, it is very important to mark the water levels and to carefully observe what happens in the water during the melting of the ice cubes.

Results

Table 2 - Experimental results

	Amount of water (ml)	Grid net added	NaCl %	Start time	Melting time	Observations
Beaker 1	150	Yes	0			
Beaker 2	150	No	0			
Beaker 3	150	Yes	3.3			
Beaker 4	150	No	3.3			

Discussion

1. Do the ice cubes in beaker 1 and 2 melt in the same time as one another? Explain your results.

2. What happened to the water levels in beaker 1 and 2? Are the results similar to your predictions?

3. Compare your observations of beaker 1 and beaker 2 with your observations of beaker 3 and 4. Explain any differences.

4. Based on your results try to answer to the introductory question:
   What will be the effect on sea levels when sea ice and land ice (for example, glaciers) melts?

Did you know?

The first measurements of sea level were made by monitoring tides in the 18th century. For more than 100 years, sea level records have been maintained by tidal gauges. Today, measurements by satellite radar altimetry provide near global coverage of the Earth's oceans. Tidal gauges continue to provide important in–situ observations, but since the early 1990s, satellite altimetry has become the main tool for continuously measuring global sea levels. Satellite altimetry precisely measures the time taken by a radar pulse to travel from the satellite antenna to the surface and back to the satellite receiver. Combined with precise satellite location data, altimetry measurements are able to produce sea-surface heights. The ESA Sentinel-3A satellite with its radar altimeter can measure sea level in locations of the globe that were previously poorly sampled.

→ Activity 3: How changes in albedo can affect the climate

The reflectivity of different surfaces is known as their albedo. It plays an important role in the Earth's climate. In this experiment, you will investigate the following questions:

1. How does colour influence the temperature of the surfaces? (Exercise 1)

2. How will the wind and humidity affect the albedo and thus the temperature of a surface? (Exercise 2)

Equipment

- IR-thermometer
- Pieces of paper or cardboard with different grey tones and different colours

Exercise 1

1. Place the paper with the different grey tones in the Sun (or under a lamp that radiates heat).

2. Wait for 4-5 minutes.

3. Measure the temperatures with the IR thermometer for each grey tone and register your results in table 3. Take care to hold the thermometer at the same distance of the surface for each grey tone.

4. Wait another five minutes and repeat the measurements. Be aware not to cast a shadow on the paper when taking the measurements.

Table 3 – Temperature of the different grey tones

Percentage of grey	0%	10%	20%	30%	40%	50%	60%	70%
Measurement 1 (°C)								
Measurement 2 (°C)								

Exercise 2

You will now measure the temperature of different surfaces, such as grass, wood, the pavement, leaves, etc. To investigate the influence of wind and humidity the experiment has to be done outside.

1. Measure the temperature of the different surfaces with the IR thermometer.

2. Register your results in table 4. Do not forget to register the time of the day, the air temperature and if it's a windy place or not.

Table 4 – Temperature of different surfaces					
Surface	Temperature	Colour	Shade	Humid	Other observations
Grass (levelled)					
Grass (On a tiny hill)					
Wood					
Pavement					
Leaves					
Water					
Other					

Note: In the column 'Shade' write yes or no. In the column 'Humid', write yes or no due to how wet the surface feels while touching it. If available, you can use a humidity sensor.

Discussion

1. Based on your results from Exercise 1, what can you conclude between the colour of a material, the temperature and its albedo?

2. Which surfaces have the higher albedo (Table 4)? Explain by using all the information you collected about the surfaces.

3. If an increase of 1°C in global temperatures causes the Arctic Ocean to remain ice-free for two additional weeks each year, how will it affect the ocean's albedo? Why?

4. If the ocean's albedo changes, how will this affect ocean temperatures and ice formation in the winter? Explain.

5. Discuss what effect the melting of sea ice, glaciers and ice sheets will have on albedo and thus on global warming.

Did you know?

EarthCARE is an ESA mission that will improve our understanding of the role that clouds and aerosols play in both reflecting solar radiation back into space and trapping infrared radiation emitted from Earth's surface. EarthCARE - the Earth Cloud Aerosol and Radiation Explorer – is being developed in collaboration with ESA and the Japan Aerospace Exploration Agency, JAXA. EarthCARE will collect global observations of cloud and aerosol profiles together with solar and thermal radiation to include these parameters in numerical weather and climate models. In addition, EarthCARE aerosol data will be valuable for monitoring air-quality.

→ Links

ESA resources

ESA classroom resources
esa.int/Education/Classroom_resources

ESA space projects

ESA Climate Change Initiative (CCI)
http://cci.esa.int

ESA CCI greenhouse gases
www.esa-ghg-cci.org

Sentinel-3
esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-3

EarthCARE
esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/EarthCARE/ESA_s_cloud_aerosol_and_radiation_mission

Extra information

ESA app “Climate from Space”
esa.int/Our_Activities/Observing_the_Earth/Space_for_our_climate/Climate_at_your_fingertips

Video "Contributors to sea-level rise"
esa.int/spaceinvideos/Videos/2017/06/Contributors_to_sea-level_rise

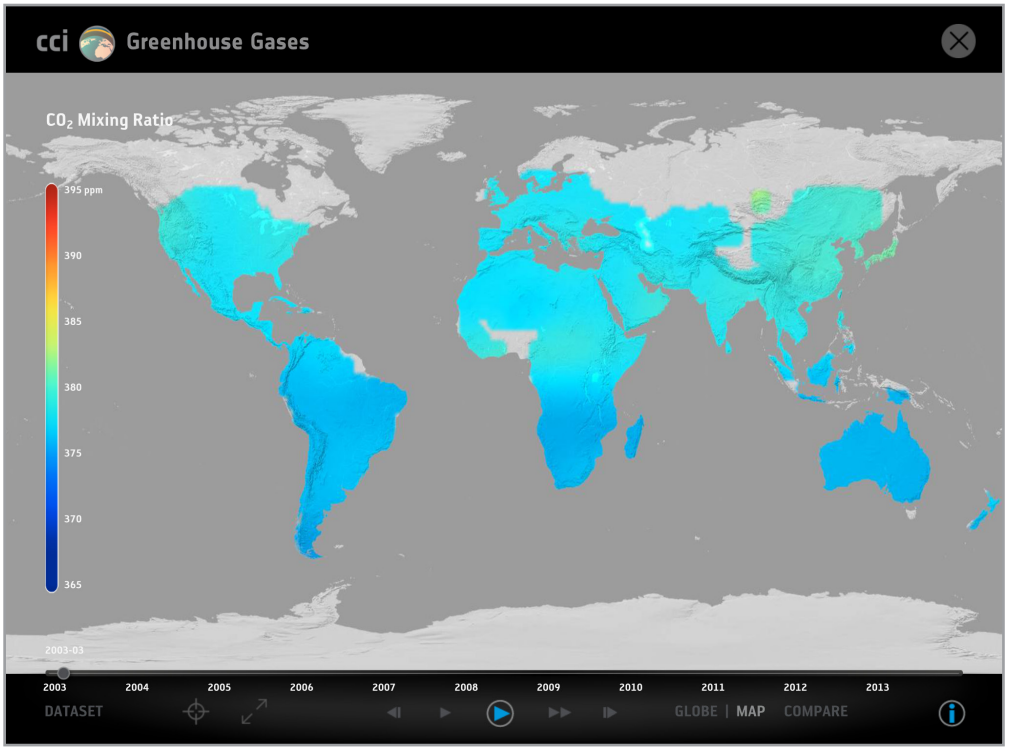
Video about the carbon cycle and its role in climate change
esa.int/spaceinvideos/Videos/2018/02/Carbon_Cycle

Video about how atmospheric constituents are changing and how these changes are affecting our climate
esa.int/spaceinvideos/Videos/2018/01/Change_in_atmosphere

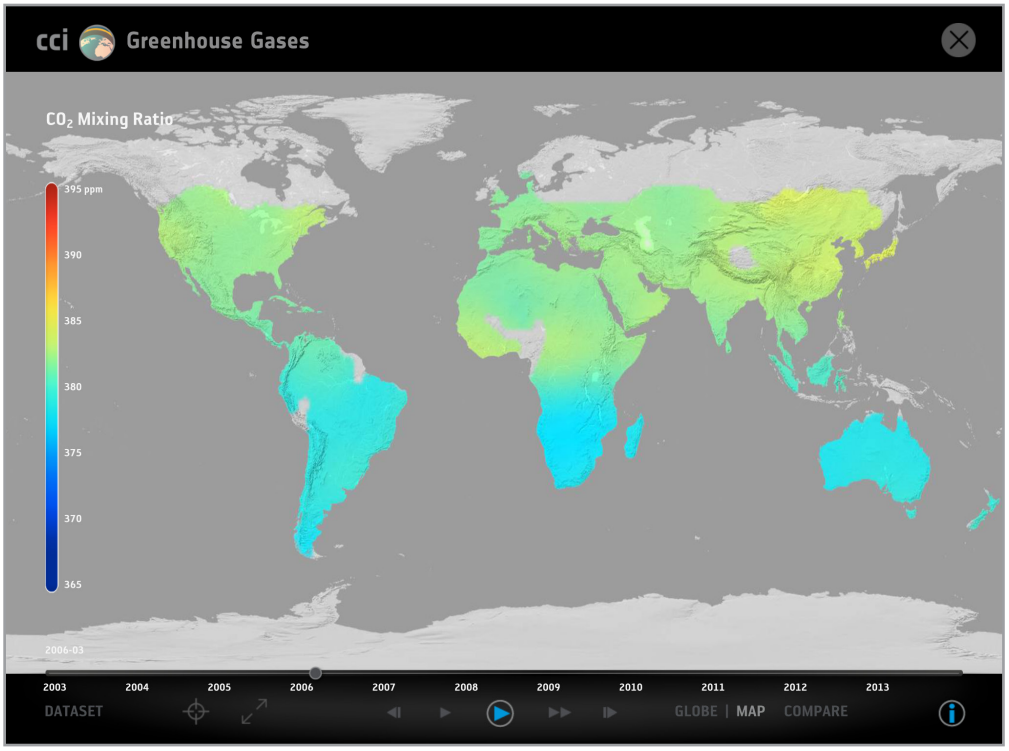
Information about the sea level and how it is measured
www.esa-sealevel-cci.org/Sea%20Level%20information

→ Annex - I

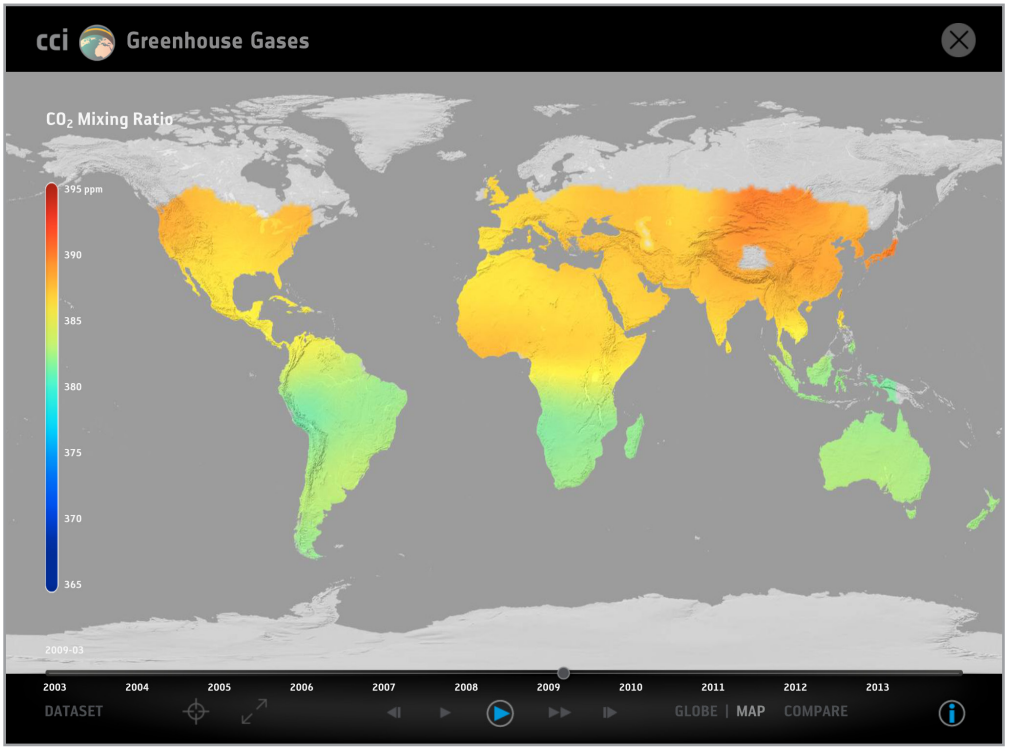
The maps below show satellite-derived distributions of CO_2 in parts per million (CO_2 mixing ratio) for different years. All the data has been produced by the ESA CCI greenhouse gases team.



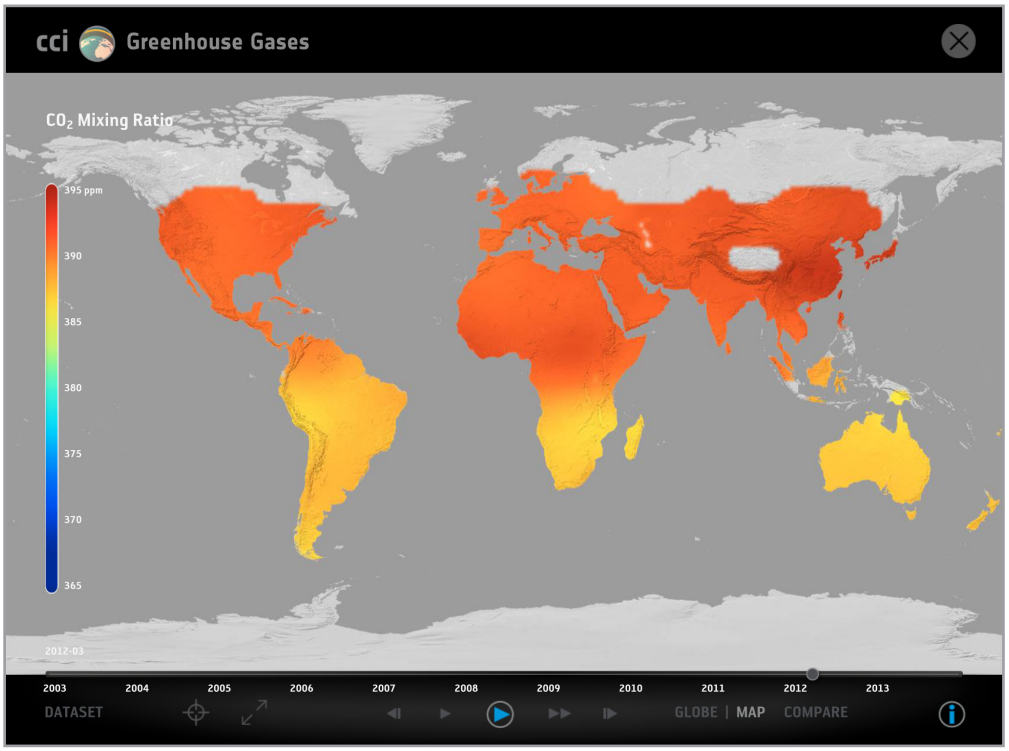
↑ March 2003



↑ March 2006

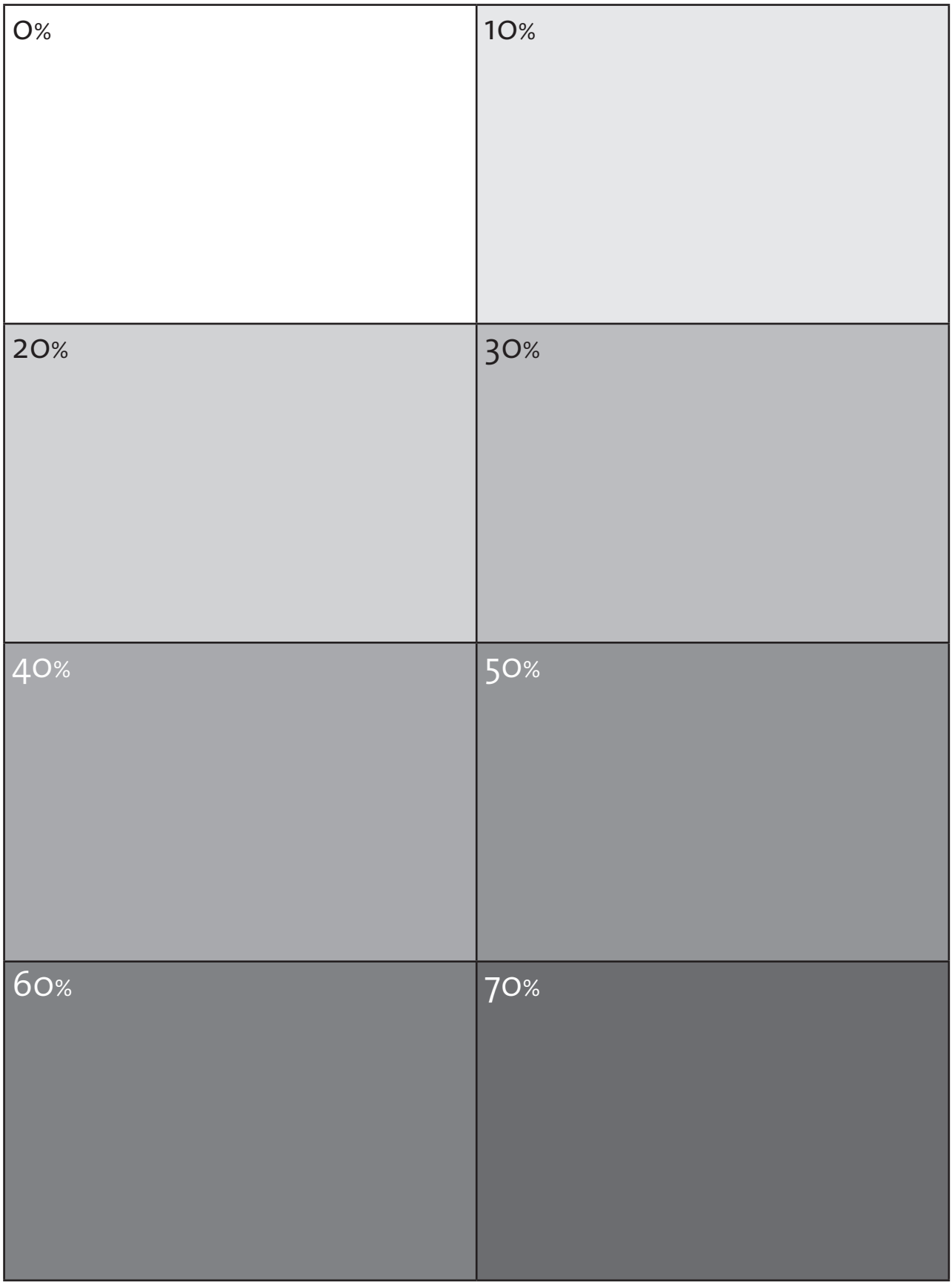


↑ March 2009



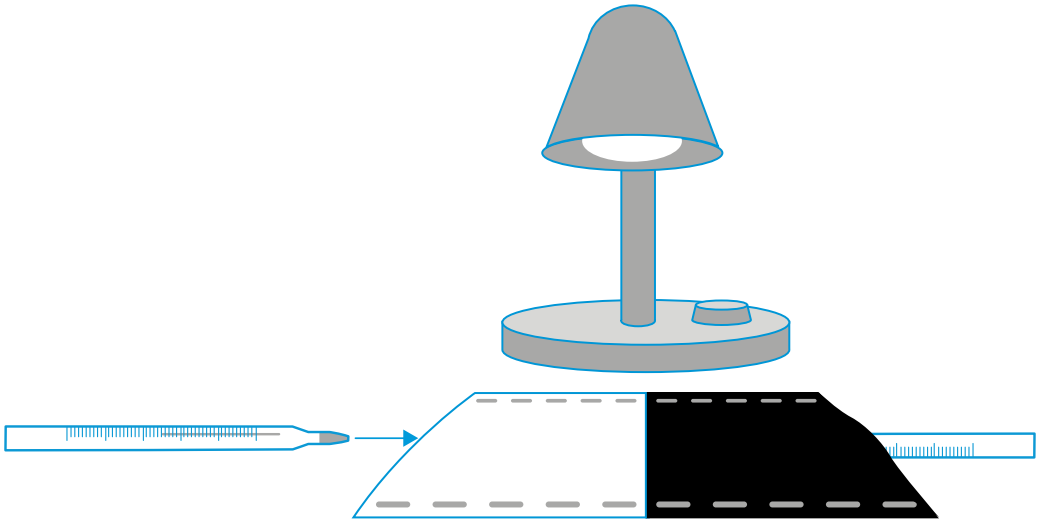
↑ March 2012

→ Annex - II



→ Annex - III

How does colour influence the temperature of the surfaces?



1. Cut two 15 x 15 cm squares, one from black construction paper, one from white construction paper.
2. Fold each square in half twice.
3. Staple two edges of each square to form pockets.
4. Place the bulb end of a thermometer into each pocket.
5. Place the thermometers directly under the lamp (or outside in the sun) so that they receive equal amounts of light. The lamp should be pointed straight down (See figure above).
6. Allow two minutes for the thermometers to reach the temperature of the surrounding air. This will be the initial temperature. Make sure that the thermometers are not exposed to sunlight for this.
7. Turn on the lamp. Record the temperature of each thermometer every two minutes for the next 20 minutes.

The difference in temperature between the white and black sheets will typically be 2-3 °C when measuring under a lamp, but maybe 5-6 °C when measuring outside in sunshine.