Teachers Teaching with Technology™

T³ EUROPE

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Estimating the Earth's Albedo

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1. Sustainable Development Goals and STEM

This activity addresses UN/EU sustainable development goal 13, Climate Action and 11, Sustainable Cities and Communities. In particular *raise awareness and educate people about the climate challenge and actions to take.*

The activity is rooted in Earth Science, Physics and Mathematics.

2. Learning Outcomes.

a. Lesson activity

The Earth's albedo determines the amount of solar radiation reflected by the Earth's surface, it is about 30%. Students carry out a laboratory exercise to measure the Earth's albedo using a light probe and coloured paper to resemble different surfaces. They calculate the percentage of light reflected and consider why this is important when constructing models for climate change.

b. Learning outcomes.

Students

- Are able to use a light sensor to measure the amount of illumination.
- Are able to determine the percentage reflectance for different colours.
- Are able to estimate the Earth's *albedo* from the results obtained.
- Know that albedo affects global warming.
- Are able to estimate, in what dimension different surfaces in urban areas are affecting the Albedo effect.
- Are able to make a direct relation of use up / consumption of soil and change of Albedo.

3. Overview of the science: (Earth Science, physics and mathematics)

The fact that the Earth is visible from 6 billion km is due to its albedo and the position of the Sun. The albedo is the percentage of solar radiation reflected back into space, and for the Earth this is about 30%.

When solar radiation reaches the Earth's atmosphere, three processes occur: **reflection, absorption and transmission.**

The solar radiation incident perpendicular to the top of the atmosphere at a point where the Sun is directly overhead, at all wavelengths is about **1370** J per square meter per second, ie, **1370** W/m^2. This value is called the **solar constant** and its measurement is made by satellites placed above the atmosphere. It is an average value adopted by the World Meteorological Organization. It is roughly 2 calories/minute/square centimeter!

a. Let's see what happens to this energy:

- About 30% of incident radiation is reflected into space by clouds and the Earth's surface. This is the albedo of the planet.
- The rest of the incident radiation, 70%, is distributed approximately as follows:
- 19% is absorbed by the atmosphere and clouds; ultraviolet radiation of high energy is absorbed in the thermosphere and other radiation with lower energy in the stratosphere, most of the infrared radiation is absorbed in the lower troposphere and stratosphere;
- 51% is transmitted to the surface, but only 25% of that radiation is direct sunlight, the remaining 26% is from reflection and scattering to the Earth's surface by clouds and atmosphere. The radiation that arrives at a point on the Earth's surface will depend on factors such as the latitude, time of day, season and atmospheric transparency.
- Earth's average surface temperature due to its albedo and the greenhouse effect is currently about 15°C. Knowledge of the albedo is important for generating climate change models.

b. Change in the albedo is caused by

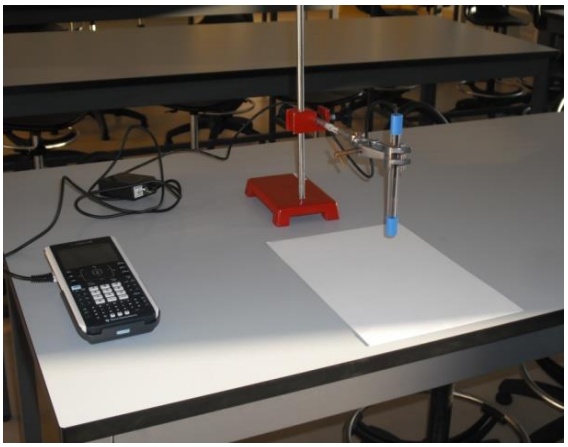
- Changing weather patterns which result in change in cloud cover.
- Increased urbanization resulting in continuous and worldwide sealing and compaction of our soils, deforestation and mining. The loss of the natural function of our soils is very worrying! Therefore, it is essential, that we conserve our soils and that the students are made aware of the importance of our soil. (>>> see material in the appendix)
- Agriculture itself which involves changes in forestry and the creation of bodies of water for irrigation. At the same time many inland seas such as the Aral Sea are shrinking.

- Desertification and the shrinking of glaciers resulting in the exposure of dark rock also contribute to a changing albedo.
- See question 5 for estimates of the percentage coverage of different surfaces. ***water**-70%, **deserts** - 9%, **forests and plantations** - 14%, **ice and snow** - 7% and **Asphalt** - 0.05%.*

4. Experimental work

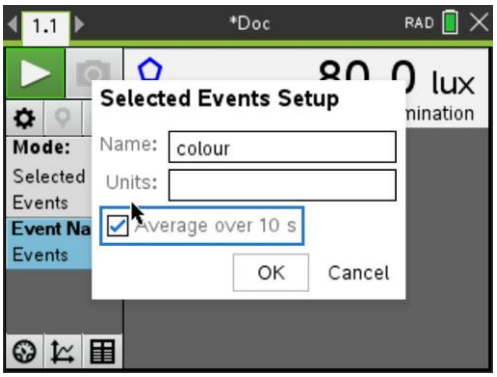
a. Apparatus needed

- TI-Nspire Handheld
- Lab Cradle or Innovator-Hub + Sensor link
- Light Sensor (Vernier)
- Aluminum foil
- Stand and utility clamp
- Five sheets of colored paper: white, black, blue, green and sand color



b. Experiment set-up and collection mode:

- Position the light sensor 5 cm above the sheet (see photo). The existing light in a classroom will be sufficient for this activity
- Data collection mode: Selected Events, averaging over 10 seconds.
- Calculations in a Lists & Spreadsheet application



5. Experiment activity and tips

- Lesson starter: Teachers may want to use the Pale Blue Dot image as a lesson starter. Show the image and ask what the relative positions of Voyager Sun and Earth were for the image to be possible. Students may not realise that Voyager I had to have moved well above the ecliptic plane (containing the Sun and the planets) otherwise the glare of the Sun would have blotted out the inner planets. The Earth has to be on the far side of the Sun from Voyager otherwise albedo or not there would have been no reflected light to make the Earth visible.

- Use sheets of A4 paper of different colours. It is possible to find colours as below which provide reflectances similar to different surface features such as desert and ocean.

- Although undetectable to your eyes, artificial lights flicker. The light sensor picks up this flicker, and variation in light intensity can be seen when you view the values displayed in meter view. The selected events mode average provides a single illumination value for each run.

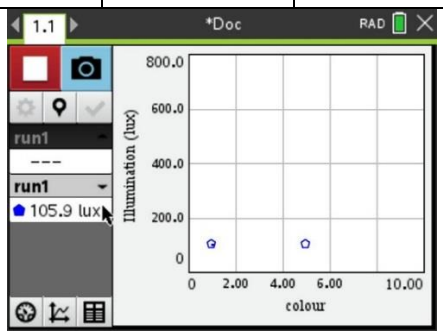
Exemplar results

1. *Since the earth is roughly a sphere, determine the average value of the incoming solar radiation over the entire Earth at the upper surface of the atmosphere.*

The surface area of a sphere is $A = 4 \times \pi \times R_{earth}^2 \quad \Rightarrow \quad I = \frac{1370}{4} = 342 \ W/m^2$

2.

Color	Aluminum	White	Green	Blue	Sand color	Black
Reflection value (Lux)	575.14	394.72	131.40	143.39	184.13	35.42
% of reflectivity	**100 %**	**68.63 %**	**22.85 %**	**24.93 %**	**32.01 %**	**6.16 %**



3. *What type of surface will give a planet a high reflectivity? Explain.*

Surfaces such as snow, ice and water would be expected to give a planet high reflectivity. The results of this activity suggest that light-colored and shiny surfaces reflect light best.

4. *Does planet Earth have a high reflectivity? Explain.*

Planet Earth has some reflectivity because much of it is covered by snow, ice, sand and water. The dark-colored parts of the earth, such as forests and green-crop land, would have lower reflectivity.

5. *The distribution of surface area of earth is approximately:* ***water****-70%,* ***deserts*** *- 9%,* ***forests and plantations*** *- 14%,* ***ice and snow*** *- 7% and* ***Asphalt*** *- 0.05%. Based on this information and with the results obtained, make an estimate of the* ***albedo*** *of the Earth.*

$$Earth_{albedo} = \frac{(6{,}16 \times 5 \times 10^{-4}) + (68{,}63 \times 0{,}07) + (22{,}85 \times 0{,}14) + (24{,}93 \times 0{,}7) + (32{,}01 \times 0{,}09)}{1} = 28{,}34\%$$

6. *Find out what the current value for the Earth's* ***albedo*** *is and compare with the value obtained in this activity (suggestion - determine the relative error)*

$$\%\ \text{error},\ E_r = \frac{|30 - 28{,}34|}{30} \times 100 = 5{,}5\%$$

7. *Based on the results, determine the energy absorbed (in W/m^2) by the earth's surface.*

$$I_{absorbed} = 342{,}5 \times (1 - 0{,}283) = 245{,}6\ \ W/m^2$$

8. *How is the so-called "global warming" affected by the* ***albedo*** *of our planet?*

If the Earth's average temperature increases due to the "enhanced greenhouse effect" the surface covered by snow and ice will fall and the earth's surface will reflect less radiation. As a result, its albedo will decrease and the earth will absorb more energy. The temperature of the Earth's atmosphere and oceans will rise even more.

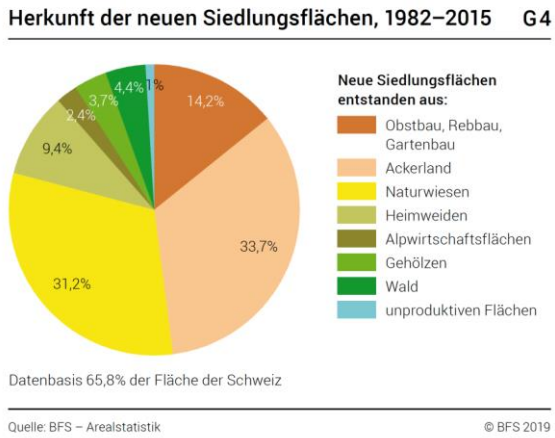
When a change results in processes which themselves increase the change, such as increased climate temperature resulting in melting glaciers and lower albedo, the change is known as positive feedback. It is generally an undesirable effect, for example the chips in your laptop are cooled by a fan. Should the fan break the chips will warm up and their resistance will fall thereby allowing them to draw a greater current and become even hotter. In a short time the chips will melt, an undesirable effect! Positive feedback may result in catastrophic changes to the Earth's atmospheric systems and is known as the "runaway greenhouse effect".

6. Extension work

Students can be directed to studies on urbanization and changing albedo. Urbanization is a complicated progress that greatly affects urban albedo via land cover change, human heat, aerosol, and other human activities.

https://esdac.jrc.ec.europa.eu/themes/global-soil-erosion for work on soil erosion worldwide.

7. Appendix



As an example: Switzerland:

Switzerland is losing about 1.5m² of natural land area per second. These have the following origin:

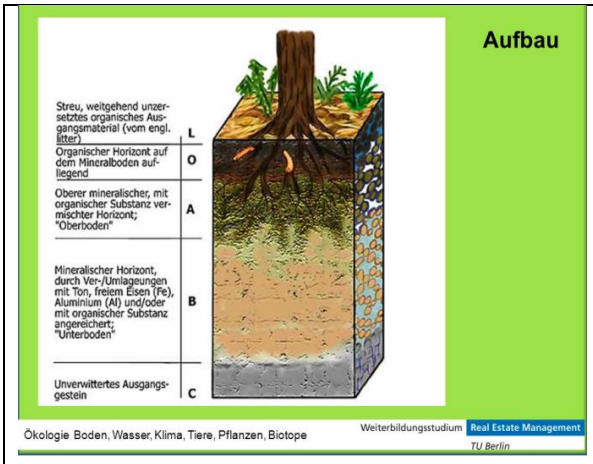
Why soils matter:

Of the importance of the soil for us probably only few people are really aware of. Many ignore its value; they don't give the needed appreciation to it. Through its sealing, compaction and intensive use, the soil often loses its central and important functions irreversibly:

Those are:

- CO2 storage (98% of the existing carbon is stored in the soil !)
- Heat storage
- Water filter, water storage
- Habitat (per m² there are millions of organisms, especially in forest soils, which are important to us!)
- Mineral storage
- Archive

Soil structure:



Consequences:

The worldwide change of natural surfaces also changes the energy radiation and thus the amount of thermal energy that remains in the environment.

In the cities it is significantly warmer than in rural areas, a fact that probably also fits into the learners' wealth of experience. If not, it is desirable to make them aware of it: to observe, to perceive.

The feedback effect of these facts follows immediately:

- Due to warmer average temperatures, glaciers in the Alpine region are melting fast; much faster than in earlier times. Dark rock / dark scree masses are emerging.
- As can also be shown in the classroom experiment, there is hardly any reflection on black (dark) surfaces. The absorption is very strong; heat penetrates the rock and is stored.
- This heat is then released much more slowly: this means in reverse: reflected radiation travels much faster away from the earth's surface.

Conclusion:

There is an urgent need to rethink the way we design our cities; how to reduce the highly absorbent surfaces. In addition we have to decide how the remaining natural land resources can be protected. Any change in natural land areas → Deforestation, mining, urban development, intensive agriculture changes the Albedo.

Activity:

Discuss with the students how appropriate actions can be taken to protect the soil and what can be done /contributed to improve the local situation.

