



Analysis of the Impact of Radiation and Albedo on Variations in Earth's Surface Temperature

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Abstract

Solar radiation reaching the Earth is partially absorbed by the surface and partially reflected back into the atmosphere as shortwave and longwave radiation. This study aims to analyze the impact of radiation and albedo on variations in Earth's surface temperature. The experimental procedure involved exposing different surface types—soil, water, and rock—to light for 20 minutes and then observing their behavior without light for another 20 minutes. The results indicate that low-albedo surfaces absorb more radiation, leading to a temperature increase of 3°C, from 26°C to 29°C. Medium-albedo surfaces, such as rock, experienced a similar temperature rise of 3°C (from 28°C to 31°C), whereas high-albedo surfaces, such as water, showed only a 1°C increase (from 27°C to 28°C). These findings highlight the significant role of albedo in regulating surface temperature fluctuations. Surfaces in high-albedo areas tend to cool more rapidly than those in low-albedo regions. This demonstrates that albedo directly influences radiation absorption and temperature change, making it an effective instructional example for understanding physical concepts such as heat transfer and energy balance at the Earth's surface.

Keywords: Albedo, Earth's surface, Radiation Solar Radiation, Heat Transfer, Energy Balance

INTRODUCTION

The energy reaching Earth from the Sun is partially absorbed by the atmosphere, while a significant portion approximately 30% is reflected back into space by clouds and the Earth's surface. The majority of the incoming solar energy, however, is absorbed by the planet's surface and subsequently re-emitted as heat (Cory, 2009; Oduor et al, 2023). Energy is transferred between the Earth's surface and the atmosphere through various mechanisms, including radiation, conduction, and convection. A fundamental principle of meteorology is that the Sun heats the ground, and the ground in turn heats the air. This activity focuses on radiation the primary process by which the Sun warms the Earth's surface. Solar energy serves as the

driving force behind weather and climate systems (Khan & Ali, 2025).

Radiation is the transfer of energy through the propagation of electromagnetic waves (Dance & Carlsson, 2007; Kamal & Haider, 2023; Mauri, 2023). The transfer of energy from the Sun across the vacuum of space occurs primarily through radiation. Radiation takes place without the involvement of any physical medium. The Sun emits various forms of electromagnetic radiation in differing amounts (Xia & Gao, 2022). Approximately 43% of the total radiant energy emitted by the Sun lies within the visible spectrum. The majority of the remaining energy is distributed across the near-infrared region (49%) and the ultraviolet region (7%). Less than 1% of solar radiation is emitted as X-rays,

gamma rays, and radio waves (Sanchez et al, 2020).

An ideal radiator emits energy across all possible wavelengths; however, the energy is not distributed uniformly across those wavelengths (Tulandi, 2022). The temperature of a radiating object determines the intensity of its spectrum at specific wavelengths, with maximum radiation occurring at progressively shorter wavelengths as the object's temperature increases. The hotter the radiating body, the greater the amount of energy it emits. Thus, a perfect radiator emits energy efficiently across a broad range of wavelengths, with the peak shifting toward shorter wavelengths as temperature rises.

The amount of energy absorbed by an object depends on its absorptivity, which, within the visible wavelength range, is a function of the object's color, as well as the intensity of the incoming radiation. Each surface on Earth absorbs and reflects energy at different rates, depending on its color and texture (Laksmiyanti & Hendra, 2020). Dark-colored objects absorb more visible radiation, while light-colored objects reflect a greater portion of visible radiation. (Sirojiddi & Muhayo, 2024).

Albedo refers to the amount of energy reflected by a surface without being absorbed. In this context, Earth's albedo is measured on a scale from 0 to 1 (Wu & Ding, 2023). Simply put, albedo represents the ratio between the sunlight received by the Earth and the portion reflected back by its surface. The Earth's average albedo is approximately 0.3, which is sufficient to maintain the planet's temperature balance and support life (Sledd & L'Ecuyer, 2019). However, Earth's albedo can fluctuate depending on the presence of ice or snow cover (Stephens et al., 2022). High-albedo objects reflect most of the incoming radiation, whereas low-albedo objects

reflect only a small portion and absorb the majority of the radiation.

White surfaces, such as white paint, reflect most of the incoming radiation and therefore have an albedo value close to 1 (Lei et al., 2024). Dark-colored surfaces, such as gravel and asphalt, absorb a large portion of incoming radiation and have low albedo values, approaching zero. This explains why dark surfaces tend to have higher temperatures. For example, during summer, black asphalt roads can become extremely hot. Albedo is critically important in the context of climate, as it affects how much solar energy is absorbed by the Earth. This experiment will explore the relationship between radiation and albedo using surfaces with different characteristics, with the aim of analyzing the impact of radiation and albedo on variations in Earth's surface temperature.

MATERIALS AND METHODS

This research was conducted at Yogyakarta State University (UNY). The research method applied in the radiation and albedo experiment involved a systematic series of experimental stages, beginning with the preparation of tools and materials, the identification of experimental variables, and the execution of the radiation and albedo testing. The variables used in the experiment included independent variables such as the duration of exposure (with the light on and off) and the types of Earth surface materials (soil, rock, and water). The dependent variable was the surface temperature.

The tools and materials used in this experiment included three 500 mL beakers, dark-colored soil, water, small stones, three thermometers, a 100-watt incandescent lamp, and a stopwatch. The experimental setup is shown in Figure 1.



Figure 1. Experimental setup for radiation and albedo

The experimental procedure consisted of the following steps: First, three beakers were filled to the same height with different materials one with dark-colored soil, one with rocks, and one with water. Second, the beakers were placed on a table, and an incandescent lamp was positioned approximately 12 inches above them (the lamp remained off at this stage). Third, a thermometer was inserted into each beaker, with the tip positioned just below the surface of the respective material (soil, rocks, or water). Fourth, all equipment and materials were placed in an enclosed room to maintain a controlled ambient temperature. Fifth, the initial temperature of each material was recorded immediately before the lamp was turned on (time = 0), and these values were entered into a data table. Sixth, the lamp was switched on, and temperature readings were recorded at five-minute intervals over a 20-minute period. Finally, after 20 minutes, the lamp was turned off, and temperature measurements continued every five minutes for an additional 20 minutes.

Data were collected through direct observation of the temperature scale indicated on the thermometer, measured in degrees Celsius. This observation aimed to monitor

temperature changes and to understand how the physical characteristics of Earth's surface influence the absorption and release of heat from solar radiation. In this experiment, the incandescent lamp served as a substitute light source for the Sun.

Data analysis in the radiation and albedo experiment was conducted by processing and evaluating the observed temperature changes of different surface materials as they absorbed and released heat from radiant energy. The data collected included several experimental variables such as time, temperature, and type of surface material. These data were organized into a results table and further visualized through graphs illustrating the relationship between temperature and time for each surface type. Subsequently, the data were qualitatively analyzed to identify patterns or correlations among the variables and to interpret the overall outcomes of the experiment.

RESULTS AND DISCUSSION

Radiation received by a surface depends on the time of measurement. Typically, during the daytime, the intensity of radiation is higher, whereas at night, radiation is significantly reduced

or even absent. Furthermore, radiation refers to the energy received from the Sun or other radiant sources, while albedo is the fraction of radiation that is reflected back by a surface. Different types of surfaces possess varying albedo values, which influence how they absorb or reflect incoming radiation.

Surfaces with high albedo reflect most of the incoming radiation and tend to absorb less solar energy. As a result, these surfaces maintain lower temperatures despite exposure to radiation. In contrast, surfaces with low albedo absorb a greater portion of

incoming radiation and convert it into heat, leading to significantly higher surface temperatures compared to other types of surfaces. Surfaces with moderate albedo exhibit intermediate levels of reflection and absorption, resulting in temperatures that are higher than those of high-albedo surfaces but lower than those of low-albedo surfaces. Temperature measurements resulting from radiation exposure, and their correlation with surface albedo, can be observed in the results of Experiments 1 and 2 presented below.

Results of the First Experiment (Light On Condition)

Table 1. First Experiment under Light-On Condition

Substance/Material	Initial Temperature (°C)	Temperature (°C) at Minute				Average Temperature (°C)
		5	10	15	20	
Dark-colored Soil	26	28	28	28	29	28,25
Rock	28	28	29	30	31	29,5
Water	27	27	28	28	28	27,75

The experiment was also conducted without the application of light. The

results of this trial can be seen in Table 2 below.

Results of the Second Experiment (Light-Off Condition)

Table 2. Second Experiment under Light-Off Condition

Substance/Material	Temperature (°C) at Minute				Average Temperature (°C)
	25	30	35	40	
Dark-colored Soil	29	28	28	28	28,25
Rock	31	30	29	29	29,75
Water	28	28	28	28	28

Based on the results in Table 1, the experiment demonstrated temperature changes across the three types of surface materials during the initial 20-minute period. The initial temperature refers to the temperature measured before any

treatment was applied that is, prior to exposure to the incandescent lamp light.

By comparing the initial temperatures and the average temperatures after treatment, an increase in temperature is observed. The order of

temperature increase from highest to lowest occurred on the rock surface, followed by dark-colored soil, and then water. This phenomenon can be scientifically explained using the heat transfer equation:

$$Q = mc\Delta T$$

Where Q is the amount of heat energy absorbed, m is the mass of the substance, c is the specific heat capacity, and ΔT is the change in temperature. Thus, a surface with a lower specific heat capacity, such as rock, will experience a greater temperature increase compared to water, which has a much higher specific heat capacity. As a result, even if the same amount of energy is absorbed, the temperature increase in water will be

smaller. Subsequently, the results from Table 2 show temperature changes across the three types of surface materials during the final 20 minutes, after the incandescent lamp was turned off. A decrease in temperature was observed over time beyond the 20-minute mark for all three surface types. This temperature decrease can also be analyzed using the same heat transfer equation; however, in this case, the direction of temperature change (ΔT) becomes negative.

The relationship of temperature changes over time for the three types of surface materials can be observed in the graphs presented in Figure 2 and Figure 3 below.

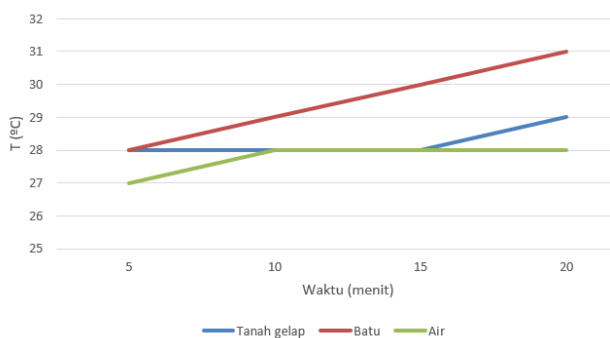


Figure 2. Temperature Changes on Various Surfaces under Active Illumination

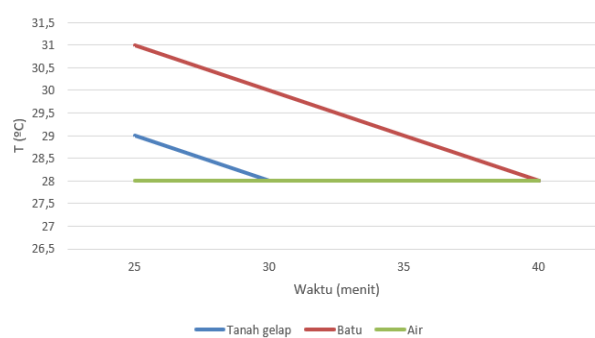


Figure 3. Temperature Changes on Various Surfaces under Inactive Illumination

A temperature increase was observed on the dark-colored soil surface, rising from an initial temperature of 26 °C to 29 °C after 20 minutes of exposure to the incandescent lamp. Similarly, the temperature of the rock surface increased steadily at five-minute intervals, rising from 28 °C to 31 °C. For water, the temperature rose more gradually, from 27 °C to 28 °C. Although temperature increases occurred on all three surfaces, the changes were relatively modest. This is attributed to the absorption of radiation from the incandescent lamp, which served as a substitute for solar radiation and simulated daytime conditions on Earth,

when radiation intensity is typically higher.

Among the three surfaces, each exhibited a different temperature change. Rocks and soil showed greater temperature increases compared to water. This indicates that rocks and soil absorb a larger amount of radiant energy and reflect only a small portion of it back into the atmosphere. This is consistent with the findings of Dwivedi, (2017) who stated that soil absorbs the majority of shortwave solar radiation, with only a small fraction being reflected or transmitted. In addition, rock also exhibits a high level of absorption when exposed to radiant energy. (Gasoyan & Tyutneva, 1976). Although both have

low albedo, in this experiment the rock exhibited a greater temperature increase compared to soil. This may be attributed to several factors that influence heat absorption and release. Compared to soil, rock has higher thermal conductivity, lower heat capacity, and distinct mineral structure and composition, which can contribute to differences in how rock and soil absorb and release heat (Garrido et al, 2020; Hall & Jackson, 2005; Zhukov, 2021).

Furthermore, in the case of the liquid substance water there was only a 1 °C increase in temperature, indicating that water requires more energy to raise its temperature per unit mass compared to soil. In other words, when sunlight (or its substitute in the experiment) shines on water, much of the absorbed energy is used to increase the internal energy of water molecules (such as through phase change into vapor) rather than directly raising the temperature. (Saidal & Mar, 2020). In relation to albedo, dark-colored soil surfaces tend to have low albedo, meaning that a greater portion of solar energy is absorbed while only a small amount is reflected back into the atmosphere (Xu et al., 2018). Conversely, water has a higher albedo, meaning that a significant portion of the solar energy striking its surface is reflected back particularly at certain angles thereby reducing the amount of energy absorbed and resulting in a lower temperature increase compared to dark-colored soil and rock.

A decrease in temperature was observed up to the 40th minute across all three surface types. On the rock surface, the temperature dropped every 5 minutes, starting from 31 °C immediately after the lamp was turned off and decreasing to 29 °C, indicating a total temperature reduction of 2 °C. For soil, the temperature declined from 29 °C to 28 °C over the final 20 minutes, representing a emits. This equilibrium is influenced by several factors, including the object's

smaller change of 1 °C. This shows that although the soil experienced a temperature decrease, it was less significant. In contrast, the temperature of the water remained at 28 °C during the same period. Water has a high specific heat capacity, approximately 4.186 J/g°C, which means that when it absorbs energy, the resulting temperature increase is relatively small. (Halliday & Walker, 2014). The absorbed energy is predominantly used to increase the internal energy rather than directly raising the temperature.

This is consistent with the theory that albedo is important not only in determining how much energy is absorbed or reflected by surfaces such as soil, rock, and water, but also in influencing how quickly these materials heat up or cool down (Lei et al., 2024). The baseline albedo generally depends on wavelength and varies with surface type. Soil typically has a relatively low albedo, ranging from 0.03 to 0.05 (Seidlitz & Mayer, 2001). Furthermore, rock surfaces particularly for crushed rock layers have an albedo value ranging approximately from 0.1 to 0.2 (Qin et al., 2016). The albedo value of water surfaces in specific regions can range from 0 to 0.45, with an average value of approximately 0.14 (Du et al, 2023). Surfaces with low albedo (such as dark-colored soil or rock) absorb more solar energy, heat up more quickly, and release heat more slowly. In contrast, surfaces with high albedo (such as water) reflect a larger portion of incoming energy, resulting in slower heating. Higher surface albedo can also lead to reduced heat release due to the lower amount of solar energy absorbed.

These results support the fundamental concept that an object will continue to increase in temperature until it reaches thermal equilibrium a state in which the amount of energy absorbed by the object equals the amount of energy it temperature, albedo and color, and emissivity (Swift, 2018). Object

temperature, the higher the temperature of an object, the more energy it emits, in accordance with the Stefan–Boltzmann law. However, if the absorbed energy is insufficient to raise the temperature further, the object's temperature will stabilize at a certain value. Albedo and object color, objects with low albedo (dark-colored surfaces) absorb more solar energy, resulting in higher temperatures. Conversely, objects with high albedo (light-colored surfaces) reflect most of the incoming solar radiation, absorb less energy, and therefore tend to have lower temperatures. Emissivity, objects with high emissivity (e.g., rough or dark surfaces) are more efficient at emitting thermal radiation. In contrast, smooth and bright surfaces (with low emissivity) emit less thermal energy compared to high-emissivity objects (Swift, 2018).

The experiment conducted on water can also be observed in natural environmental phenomena, such as the absorption of solar radiation by oceans. Ocean albedo, which measures how much solar energy is reflected by the sea surface, plays a significant role in influencing the warming of the ocean surface (Dai, 2021). Because the ocean has a low albedo, most of the incoming solar energy is absorbed, warming the ocean and creating temperature differences between the sea and the land (Hogikyan et al., 2020). This temperature difference creates a pressure gradient that drives the sea breeze winds that move from the ocean toward the land. If the ocean's albedo increases, less solar energy is absorbed, which may reduce the temperature difference and weaken the sea breeze. Therefore, ocean albedo is directly related to the intensity of sea breeze circulation (Xu et al., 2015).

CONCLUSION

Based on the results, this study provides direct evidence that variations in Earth's surface albedo significantly impact the absorption of solar radiation and surface temperature changes. Surfaces with low albedo, such as dark-colored soil, experienced a greater temperature increase (by 3 °C) due to higher absorption of radiation. In contrast, high-albedo surfaces, such as water, absorbed less radiation and showed only a minimal temperature increase (by 1 °C). These findings reinforce the critical role of radiation and albedo in influencing Earth's surface temperatures.

Practically, this study can serve as a foundation for environmental management decisions, such as the selection of surface materials in urban areas to help mitigate the urban heat island effect. Educationally, the concepts of albedo and radiation are highly valuable for teaching in secondary schools or university-level environmental physics courses. Through simple experiments demonstrating the effects of albedo on temperature, students can gain conceptual and scientific skills, making lessons more relevant and hands-on.

Therefore, this study not only enriches scientific understanding by contributing to the environmental physics framework but also supports a shift in science education strategies toward addressing local environmental phenomena. These findings can further be utilized in future research to evaluate the effectiveness of high-albedo materials on various tropical land surfaces, contributing to the development of locally based climate mitigation and adaptation strategies.

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