



Final Explanation Examples

The goal is to have students produce evidence-based explanations for the unit driving question, “Why is the Arctic warming twice as fast as the rest of the world?” The “evidence” students should reference includes any activities, videos, visuals, datasets, etc. they interacted with during the unit. Text underlined in the examples below represents evidence.

Example 1:

The Arctic is warming twice as fast as the rest of the world. We know this because of the NASA global temperature anomalies video (Lesson 1). This phenomenon, known as Arctic amplification, is the result of Earth’s energy budget being imbalanced.

The Earth receives almost all of its energy from the Sun in the form of shortwave energy. Shortwave energy that is not reflected back to the atmosphere is absorbed by Earth and transformed into heat. The Earth radiates heat in the form of longwave energy that either passes through the atmosphere or is absorbed and reradiated by atmospheric greenhouse gases causing some of the longwave energy to remain in the atmosphere. We know this because of the Earth energy budget model we constructed (Lesson 2). Earth’s atmosphere and the effective trapping of heat (longwave energy) by greenhouse gases is what maintains the perfect balance of energy that allows humans to live on Earth. However, it is possible to have too much of a good thing. We know this because of the “Molecules and Light” PhET simulation and class discussion (Lesson 3). Human activities and the subsequent increase in greenhouse gas emissions have contributed to a dramatic rise in the concentration of atmospheric greenhouse gases. As a result, more and more outgoing longwave radiation is absorbed and reradiated back into Earth’s atmosphere causing global temperatures to increase. Rising global temperature in response to an enhanced greenhouse effect has contributed to a decline in Arctic sea ice.

Satellite observations of Arctic sea ice from 1979-present show a decline in September sea ice extent from ~7 million km² to ~4.3 million km², a decrease of about 13% each decade. We know this because of the NASA sea ice visualization. Sea ice plays a major role in keeping the Arctic climate system cool because it has a high albedo (reflectance), on average ~0.6. This means that when shortwave radiation interacts with sea ice, about 60% of incoming shortwave radiation is reflected and only 40% is absorbed as heat. In contrast, darker surfaces have a low albedo. We know this because we measured the albedo of light and dark surfaces using an albedo app (Lesson 6). For example, the ocean has an albedo of ~0.06. This means that when shortwave radiation comes into contact with the ocean, only 6% is reflected and 94% is absorbed as heat.

The rise in global temperatures and subsequent decline in Arctic sea ice has reduced the albedo of the Arctic. We know this because of the Arctic albedo and sea ice extent datasets that showed a direct relationship (Lesson 8). With more ocean exposed, more shortwave radiation is absorbed causing the ocean and atmosphere to heat up. This temperature increase causes more sea ice to melt, and the cycle continues. This cycle is called the ice-albedo feedback and is an example of a positive feedback, a cycle in which the end product (more heat absorbed) of an action (melting sea ice), causes more of that action to occur (more sea ice melts). We know this because we calculated the albedo of two Arctic maps, one with lots of sea ice and one with diminished sea ice (Lesson 7).

In conclusion, global temperatures are rising in response to an enhanced greenhouse effect; however, the warming in the Arctic is amplified by the ice-albedo feedback. This additional



warming, the result of a decrease in albedo and increase in the absorption of heat by the ocean, is contributing to the Arctic warming twice as fast as the rest of the world.

Example 2:

The Arctic is a polar region located over the North Pole. It is made of sea ice over water (no continent.) The average global surface temperature has risen since the 1880s and is now more than 2°F above that of the late 19th century. We know this from surface temperature measurements of weather stations and ship and buoy-based measurements of ocean temperatures. However, by looking more closely at this data, we see that the Arctic area is warming twice as much as the global average.

What is causing this warming? The sun emits energy mainly in the short wave region. We know this due to the temperature of the sun and what wavelengths of energy are emitted by blackbodies of that temperature. The short wave solar radiation can either be reflected by the Earth or absorbed by the Earth. The Earth emits longer wave radiation, due to the cooler temperature compared to the sun. Some gases in the atmosphere, called greenhouse gases, let the short wave energy from the sun pass through the atmosphere but absorb the longer wave radiation emitted from the Earth and re-emitting it. We explored this information with the pHet Greenhouse Gas simulator. We see from the Global Monitoring Laboratory data that the concentration of atmospheric CO₂ has been rising from the early 1900s and specifically in the Arctic the rise is even greater. Carbon dioxide, as well as some other gases such as water vapor, methane and N₂O, is a greenhouse gas. So with the increased greenhouse gas concentration in the Arctic, more long wave radiation is being absorbed, thus increasing the temperature over the Arctic. We can confirm from radiometer and satellite data that the incoming shortwave radiation to the Arctic has stayed about the same over the past 20 years while outgoing longwave radiation has increased. The Arctic temperature follows the increasing trend of the outgoing longwave radiation.

One major outcome from this warming is that the expanse of the sea ice in the Arctic has been declining since 1979, as seen by satellite data. The size of the polar ice sheet normally waxes and wanes over the year, with a minimum extent occurring around September. When the sea ice melts, it leaves ocean behind. Surfaces with high albedo reflect more shortwave solar radiation. Ice has a high albedo, closer to 1, than ocean water. This means that ice reflects more solar radiation than ocean water. We learned this with our albedo app experiment. So as sea ice melts and leaves ocean water, the albedo of the Arctic decreases. A decrease in albedo means more energy is absorbed, leading to an increase in ocean and air temperature. This increase in temperature causes more ice to melt. This is considered a positive feedback loop.

In summary, the Arctic is warming in response to an enhanced greenhouse effect. That warming is amplified by the ice-albedo feedback.



Example 3:

The Arctic is warming as a result of the energy balance of the Earth becoming imbalanced. The sun emits shortwave radiation which passes through the atmosphere to the land, water, and ice below. The land and water absorb heat, with darker surfaces absorbing more (lower albedo reflects more). Ice reflects more of the shortwave radiation/heat, as it has a higher albedo. In addition to some shortwave radiation being reflected, the Earth emits longwave radiation. This longwave radiation normally passes through the atmosphere, and into space. However there has been an increased buildup of greenhouse gases in the atmosphere, as a result of fossil fuel combustion. Fossil fuels absorb some of the longwave radiation, and release it in different directions, often sending it back towards Earth. As a result, the temperature of the Earth is increasing. The increased temperatures cause ice in the Arctic to start melting. When ice melts, it either reveals more land or water, which has a lower albedo. As a result, the Earth absorbs more shortwave radiation from the Sun, causing the Earth's temperature to continue to increase. This is a positive feedback loop, as the system is shifting to a new normal/state. As a result, more ice melts, the albedo decreases, temperature increases, and more ice melts.