Antarctic Life & Albedo - Teacher Guide

Setting the Stage

In Lesson 2, we left off asking how penguins are impacted by a changing environment. This lesson explores the importance of albedo (or reflectivity) to penguins and the surfaces they inhabit—and more broadly to snow and ice surfaces—and how penguin colonies may be mapped using satellites.

Photo Credit: Closeup of Emperor penguin colony in winter mtp@mtpa.org.uk via Wikipedia

Lesson Overview

- *Part 1 – (5 min) Brainstorm*
  Students brainstorm ways in which penguins might impact their physical environment.
- *Part 2 – (10 minutes) Physical Basis*
  Students learn what albedo is and why it is important.
- *Part 3 – (5 minutes) Science of mapping penguins from space*
  Students learn the relationship between guano-stained areas and penguin colony size.
- *Part 4 – (25 minutes) Satellite Imagery Exercise*
  Using satellite imagery, students measure the area of penguin colonies (and also explore their albedo).
- *Part 5 - (15 minutes) Group reporting and plotting penguin colony size versus time*
  Students/groups will report back colony areas and penguin counts will be estimated and plotted versus time, along with uncertainty in the estimates.

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Instructional Overview	
Grade Level	Middle/High School
Instructional Time	60 minutes
Standards Alignment	**NGSS:** ● **ESS2.A: Earth Materials and Systems:** Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. ● **Analyzing and Interpreting Data** ● **Stability & Change** ● **Patterns**
Anchoring Phenomenon	● Climate change and environmental feedback loops are causing Antarctic ice to melt, which is causing dramatic local and global impacts.
Driving Questions	● How do penguins impact their environment? ● What is albedo and why is it important? How can we use it to track penguin populations? ● What is happening to penguin colonies in the Antarctic?

Learning Goals	● Students will be able to:
	    ● Describe and demonstrate how satellite observations, field observations, and simple linear models can be used to track Antarctic penguin populations.
	    ● Explain the concept of albedo and how this impacts energy absorption and reflection.

Materials	❏ Internet-connected laptops ❏ Calculators ❏ Google accounts (for using Google Sheets) or Excel software ❏ Student handout ❏ Lesson slide deck
Material Preparation	❏ Print out student handouts (1 per student)
Vocabulary	<u>Albedo</u>: The proportion of incident light that is reflected by a surface. This typically refers to solar (i.e., shortwave) radiation that is centered in the visible part of the electromagnetic spectrum. <u>Remote sensing</u>: The continuous or repetitive collection of information about a target from a distance. In this case, we're using satellites to remotely sense Earth's surface.
Instructional Strategies	● Full-class or group brainstorming ● Breakout groups

	Web Links for Lesson Resources
Part 1	None
Part 2	• Youtube video explaining albedo. Only first minute necessary. https://www.youtube.com/watch?v=uWZEvZ118DM
Part 3	All links in section
Part 4	• Google Earth Engine mapping application https://sleuthyruthie.users.earthengine.app/view/penguinpolygons • Google sheets https://sheets.google.com
Part 5	None

Part 1
Brainstorm (5 minutes)
Driving Question: How do penguins impact their environment?

1. Ask students to engage in a short, 5-minute brainstorming session (think/pair/share, for example) using the following prompt:
   - How do you think penguins might impact their environments?
     There are a large range of possible answers (predator/prey relationships, for example), but the one that we want to make sure to emphasize is that penguin guano darkens the snow surface, leaving a visible signature.

Fundamentally, the penguins are altering the color of the surface (i.e., it's reflectance in different areas of the visible portion of the electromagnetic spectrum), as well as the surface albedo, or the proportion of incident sunlight that is reflected.

Part 2
Physical Basis (10 minutes)
Driving Question: What is albedo and how is it important?

This part of the lesson is mostly instructor-led, but the students are provided with several images and short questions introducing the concepts.

1. Introduce the following: Now that we know that penguins leave an imprint on their surroundings by darkening the surface, let's explore the physical basis (i.e., what is the scientific term for this, and why is it important when both mapping penguins and thinking about how snow and ice melt?).

When penguins poop, they darken the snow, causing albedo to drop. Albedo is simply how reflective something is. Surfaces that reflect a higher proportion of incoming light have a higher albedo, which also means they absorb less of the sun's light.

2. To help introduce this to students, show this excellent YouTube video (only the first 1 minute are necessary for this lesson): https://www.youtube.com/watch?v=uWZEvZ118DM

3. Project the lesson slide deck for your students to see. Use the remaining time to provide the definition of albedo and show some examples of surfaces with different albedos using photos and figures provided (slides 1-7). You can use the questions on the slides to prompt discussion. Here are answers to the discussion questions provided in the slide deck:

- (Slide 2) Why do school busses often have white-painted roofs? *Because white is reflective - it has a high albedo.*
- (Slide 3) Why would it be better to wear light colored clothing in a desert, but dark colored clothing in a cold environment? *To stay cooler and warmer, respectively.*
- (Slide 4) Which planet has a higher albedo? *Answer is Venus.*
- (Slide 4) Why would this be important?*: Despite being closer to the Sun (think of this like being closer to a flashlight shining light in your eyes), the surface of Venus actually absorbs LESS sunlight than Earth. As a result, if it weren't for the composition of its atmosphere containing gases that trap heat, Venus would actually be much colder than Earth despite receiving much more of the Sun's energy at the top of its atmosphere! In reality though, Venus is much hotter because its atmosphere is almost entirely carbon dioxide (CO_2), meaning it has an intense greenhouse effect!*
- (Slide 5) Which has a lower albedo: fresh snow or dirty snow? *Dirty snow has a lower albedo.*

- (Slide 5) Which would absorb more sunlight? *The dirty snow absorbs more sunlight because of its lower albedo.*
- (Slide 6) What happens to the temperature of something that absorbs more sunlight? (Can remind students of the light vs dark clothing, or relate it to something like blacktop vs asphalt). Which of these two surfaces, fresh snow or dirty snow, will melt more quickly? *The dirty snow has a lower albedo, thus it absorbs more sunlight and will warm up faster than fresh snow (causing it to melt more quickly).*
- (Slide 7) *And if it melts more quickly, that can help it expose more dark snow (or bare ground, dark ice, etc.), and thus keep albedo low, keep absorbing a high proportion of sunlight, and sustain melting. This underscores a melt-albedo positive "feedback" that will be explored further in Lesson 4, but for now we will turn to penguins and how they can modify albedo, and how that's advantageous for observing them from satellites.*

Part 3
Science of mapping penguins from space (5 minutes)

In part 1, we identified that penguin waste would create dark stains on snow and ice surfaces, and in part 2 we identified that this would result in a lower surface albedo. And in lesson 2, we mapped penguins from space. In part 3 here, we will link parts 1 and 2 of this lesson, with lesson 2, to show that mapping low-albedo, stained snow is one way in which scientists estimate penguin colony sizes from space!

There are many excellent resources on the web related to mapping penguins based on their waste:

- Vox: How do you count penguins from space? From their poop smears, of course

- NASA: Peeking at Penguins: Poop from Space (oriented for kids)- https://earthobservatory.nasa.gov/blogs/eokids/peeking-at-penguins-poop-from-space/
    - Activity: https://earthobservatory.nasa.gov/blogs/eokids/wp-content/uploads/sites/6/2020/01/24_Penguin-Poop_Jan-2020.pdf

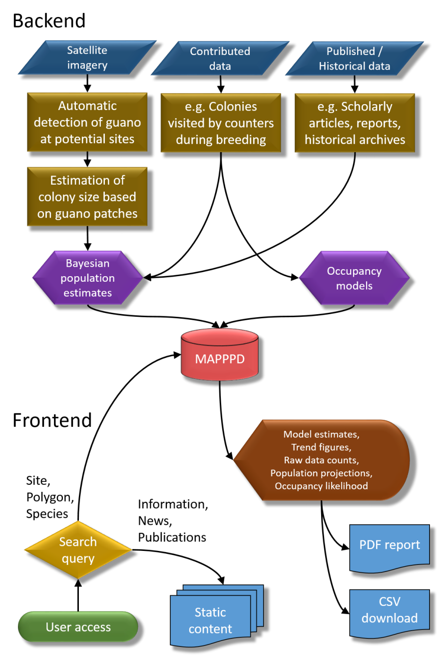
- NASA: Scientists Locate Penguins by What They Leave Behind: https://earthobservatory.nasa.gov/images/38868/scientists-locate-penguins-by-what-they-leave-behind

- NASA: Penguin Droppings Are Fertile Ground for Science: https://earthobservatory.nasa.gov/images/90372/penguin-droppings-are-fertile-ground-for-science

And here's a good scientific journal article that we'll show a figure from relating penguin colony area (measured by satellite) and penguin counts (measured on the ground).

- An Emperor Penguin Population Estimate: The First Global, Synoptic Survey of a Species from Space by Fretwell et al., (2012), PLOS ONE https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0033751

1. To begin this part of the lesson, it might be good to quickly show the framework for how the penguin colony size tool used in Lesson 2 worked. This can be accessed by going to the MAPPPD website (http://www.penguinmap.com/mapppd), clicking About Us, then expanding the section under "How does MAPPD work?" This will reveal this figure (also on Slide 9 in the lesson slide deck):



The upper "Backend" part of the figure is most relevant here. Point out that the basis for this is observations from satellites, ground data, and published records. The satellite data is key, and MAPPD relies on detecting guano stains and using that to estimate penguin colony sizes. From there, they use statistical methods to combine the various data types to estimate colony size over time. We will essentially be doing the same thing first-hand in this lesson!

3. (Optional) If you're showing the MAPPD website in class, it might also be a good time to quickly expand the "Meet the MAPPD team" (Slide 10 in slide deck) to some show some faces behind the science. Note that the project is led by Dr. Heather Lynch at Stony Brook University, with a group of experts in different areas of science and information technology.

4. Now that we know that Lesson 2 relied on mapping penguin poo from space, you can show a quick [satellite imagery](#) example of of an emperor penguin colony (Slide 11). The bigger the stain, the more penguins! Scientists have [quantified this relationship](#) (from the journal article linked earlier in this section) by counting the number of penguins on the ground at eleven ground-truthing sites. The relationship is linear, and allows for estimating the number of penguins in a colony based on the area of stained snow and ice. The graph showing this linear relationship is shown on Slide 12.

5. Demonstrate how to derive an equation from the graph on Slide 12 to solve for the number of penguins based on a given area:

The equation of linear best fit line is y = mx + b. And in this case:

*Penguin colony area (in m^2) = 1.072 * Penguin count + 0*

So, there's roughly 1 penguin for every square meter of the ground (~3 feet by ~3 feet).

We could rearrange this equation to solve for number of penguins based on a given area:

*Penguin count = 0.933 * Penguin colony area (in m^2)*

For certain groups, you may wish to have them rearrange the equation to solve for penguin counts on their own.
This will be the basis for the rest of the assignment.

Part 4
Satellite-based mapping exercise (25 minutes)

Now that we know how to estimate penguins from space, we can do this ourselves!

Students will use a Google Earth Engine application that loads satellite data across an area that a penguin colony has existed for many years. The application will allow students to calculate the area of the colony from different images representing different dates. Image dates can be selected by clicking 'Layers' and only selecting the date of interest. Currently there are 13 dates, allowing students to track areas and estimate penguin population size over time.

If you like, you can run your students through a brief tutorial on how to use the Google Earth Engine app for estimating penguin colony sizes using Slides 15-16 in the slide deck. You can also print the slides out and provide copies to each group.

1. Have students break into small groups, each with their own computer and tasked with analyzing a specific image. Assigning small groups of students to calculate the area of a specific image will allow for students to compare areas and provide an estimate of uncertainty with measuring the area of the colony. Once students have individually calculated areas, have them compare numbers within their group - if wildly different, have them recalculate. Students may wish to discuss among their groups what criteria they used to select the area of penguins vs. no-penguins, as this determination is subjective!

2. Once students within the groups narrow their results, have each group calculate an average area based on their individual numbers (using Google Sheets or Excel), and consider it a "best

estimate” of penguin area size for that image from that group (Slide 17). Then have them complete this exercise using all available images, keeping track of their “best estimate” of penguin colony area for each image/date.

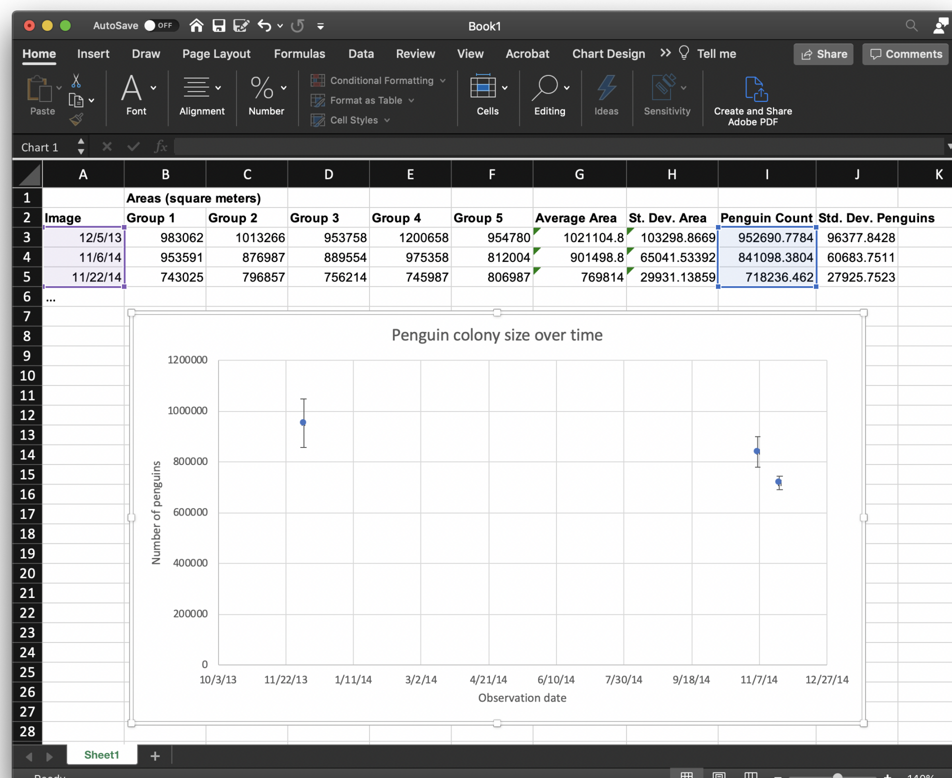
Part 5

Calculating change in penguin colony size over time (10 minutes)

Driving Question: What is happening to penguin colonies in the Antarctic?

1. As a class, have the groups report back their “best estimates” for penguin area for each image. Tabulate these responses for each image/date using Google Sheets or Excel. Then calculate the mean and standard deviation of area for each image/date.

2. Using the linear regression from the PLOS ONE paper, convert areas into population sizes in a new column. Make a scatter plot of colony size vs time. (Optional) If you use Microsoft Excel for this step, you can also add error bars based on standard deviation of measurements from the groups *(Note: these are just example data. Actual values will be different!)*:



	Areas (square meters)								
Image	Group 1	Group 2	Group 3	Group 4	Group 5	Average Area	St. Dev. Area	Penguin Count	Std. Dev. Penguins
12/5/13	983062	1013266	953758	1200658	954780	1021104.8	103298.8669	952690.7784	96377.8428
11/6/14	953591	876987	889554	975358	812004	901498.8	65041.53392	841098.3804	60683.7511
11/22/14	743025	796857	756214	745987	806987	769814	29931.13859	718236.462	27925.7523
...									

3. (Optional) If you want students to add custom error bars showing plus and minus one standard deviation (or range, or some other metric of spread/variance), they will need to use

Microsoft Excel as Google Sheets does not have this functionality. See here for adding “Custom” error bars:
https://support.microsoft.com/en-us/office/add-change-or-remove-error-bars-in-a-chart-e6d12c87-8533-4cd6-a3f5-864049a145f0

If you don’t have access to Excel, you can simply calculate and plot penguin counts in Google Sheets without error bars.

4. Ask students to analyze what the plotted results show. Any trends over time? What might this signify? Are there images with particularly large standard deviations? Why might this be?

5. Also ask students to consider how they might improve the methods. Some ideas students may have:

- Train a computer algorithm to calculate the sizes automatically based on albedo or other multispectral reflectance characteristics.
- Consider how dark (or how low of an albedo) an area is as a metric for how densely populated certain areas are. So rather than just measuring area, could also measure how intense abedo is reduced to determine whether more penguins are living in a certain area of the penguin colony. This would of course also require fieldwork to verify!
- Use data with higher spatial or temporal resolution that could measure penguin colony size more precisely (or count individual penguins even!) and more frequently.

6. At the conclusion of the lesson, frame the issue of penguin colony size and change with environmental conditions. Since penguins need the sea ice, how could climate change impact penguin colony size? And if the ocean is changing, what is happening to the food sources that penguins rely on and that we learned in Lesson 2? How are climate changes leading to ecosystem change?

Thinking even more broadly, how would a change in sea or land ice affect albedo of the polar regions? These broad ideas about the changing physical characteristics of polar regions under the stress of climate change will form the basis of the next lesson (Lesson 4).