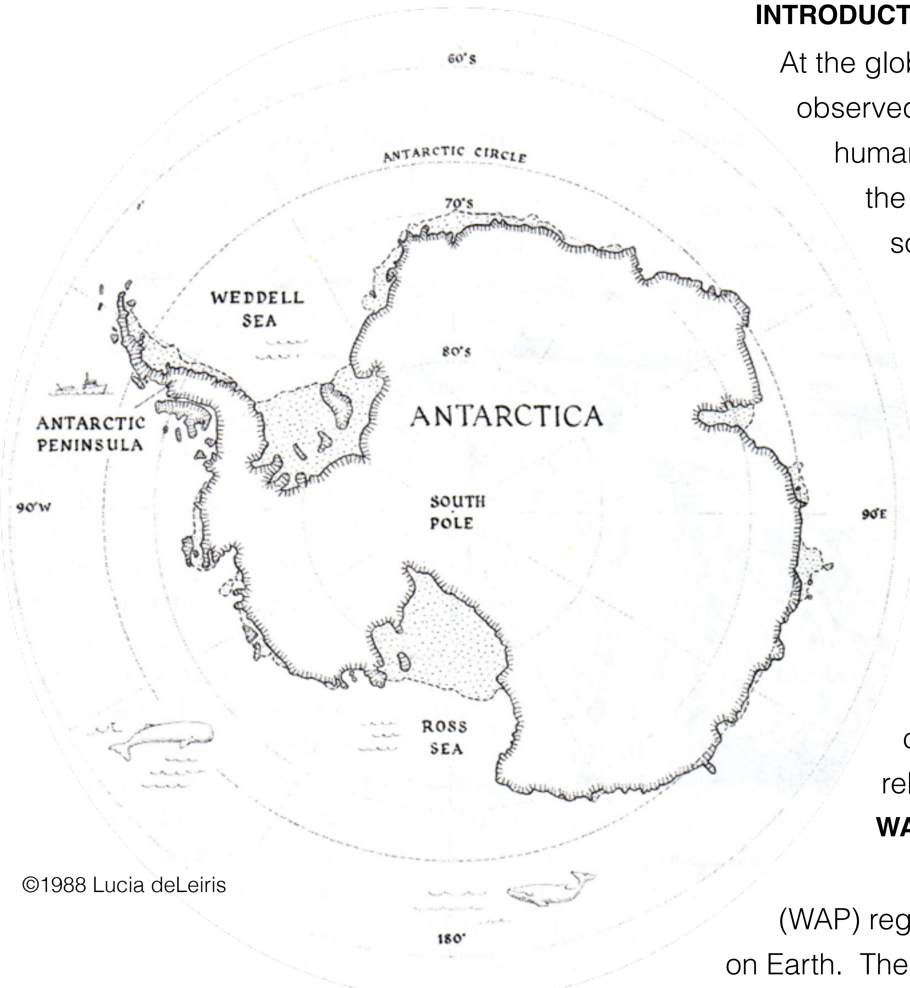
Now You “Sea” Ice, Now You Don’t:

Penguin communities shift on the Antarctic Peninsula

Based on a lesson called Climate Change From Pole to Pole, intended for high school science educators published by the National Science TeachersAssociation (www.nsta.org). Revised and updated with permission March, 2013.
besimmons@oceaningenuity.org / Palmer LTER Education & Outreach http://pal.lternet.edu

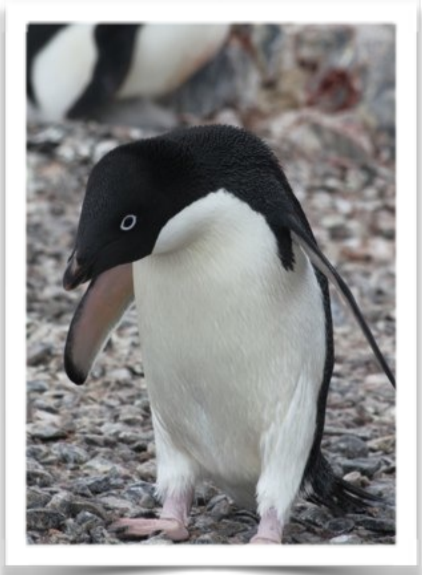


INTRODUCTION

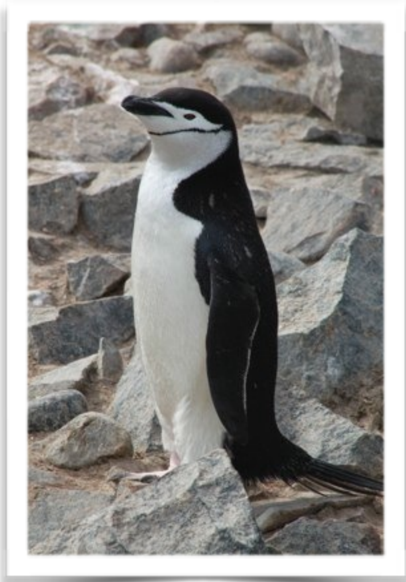
At the global level, strong evidence suggests that observed changes in Earth’s climate are largely due to human activities (IPCC, 2007). At the regional level, the evidence for human - dominated change is sometimes less clear. Trends or patterns may be seen but vary from place to place. It is documented that climate change is transforming ecosystems on an extraordinary scale and at an extraordinary pace. Scientists have a particularly difficult time explaining warming trends in Antarctica - a region with a relatively short history of scientific observation yet a climate that is highly variable (Ducklow et al. 2007). A compelling way to study ecosystem change is to identify interdisciplinary relationships across multiple levels.

WARMING CLIMATE, WANING SEA ICE

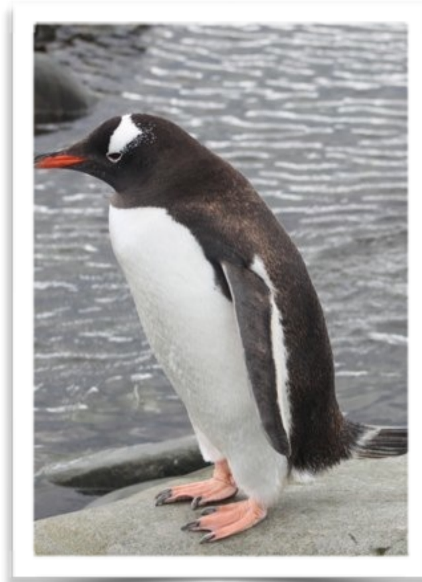
Presently, the Western Antarctic Peninsula (WAP) region is one of the most rapidly warming places on Earth. The mean average temperature is -3 °C, more than 2° warmer than it was 50 years ago. That leaves mid-winter temperatures showing a 6 °C increase which is five times the global average. Dubbed the “linchpin” in the Antarctic ecosystem, sea ice affects ocean productivity in organisms as small as bacteria to larger seabirds like penguins with atmospheric changes causing noticeably warmer and windier conditions. These conditions are particularly affecting a region of the Antarctic Peninsula over the entire West Antarctic Ice Sheet. Since the 1970s satellites have complimented Palmer LTER research, helping scientists track sea ice changes from space in great detail. While sea ice defines the Antarctic marine environment, its magnitude, duration and trends are dependent on the region studied and the time of year (or season). Recent data suggests, that while the Southern Ocean as a whole has shown a 2% increase in sea ice over 26 years, the greater western Antarctic peninsula (WAP) has shown a 40% decrease - a sea ice season shortened by almost three months. These rapid changes in sea ice are triggering pronounced shifts and a reorganization in the ecosystem, with the Antarctic *pygoscelid* penguins showing the most dramatic change.



Adélie penguin
(*Pygoscelis adeliae*)



Chinstrap penguin
(Pygoscelis Antarctica)



Gentoo penguin
(Pygoscelis Papua)

THE IMPACTS - PENGUIN COMMUNITIES

External forces imposed on ecological systems cause ecosystems to respond with results cascading throughout the food web. Near the WAP, scientists have most clearly seen these climate forces shift the population and distribution of several penguin species, particularly the Adélie penguin (*Pygoscelis adeliae*). A warm blooded, flightless bird, the Adélie is approximately 28 - 30 inches tall, weighing up to 12 lbs. It has occupied territory along the WAP near Palmer Station for at least the last 600 years (Smith et al.1999). The Adélie is considered to be a true Antarctic seabird, serving as an indicator species exhibiting a lifestyle that is closely linked with environmental changes and sea ice. Scientists from the Palmer Long Term Ecological research (LTER) project have been studying the Adélie penguin colonies for approximately thirty years.

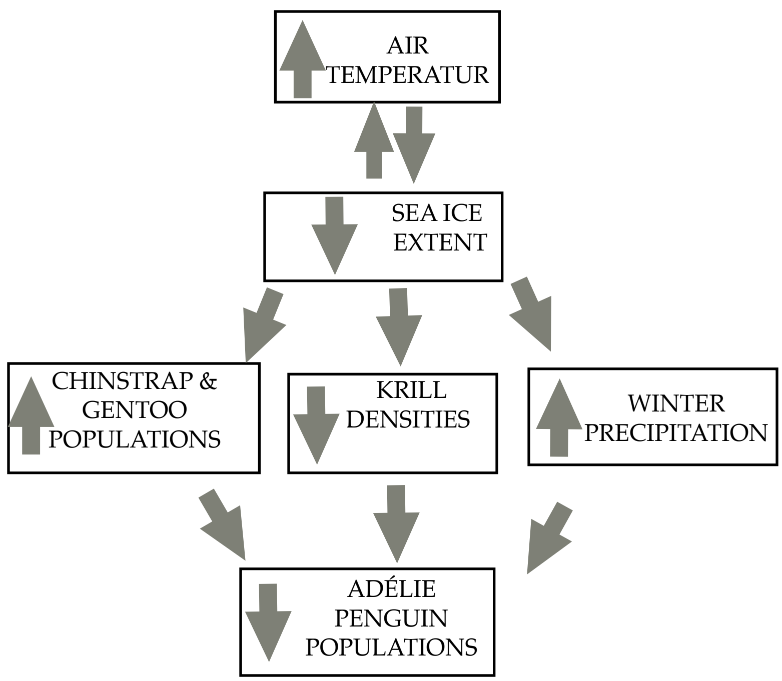


Figure 1: A flow chart (feedback cycle) demonstrating the impact of climate change on air temperature, sea ice extent, penguin and krill population densities and winter snow.

The Adélie community composition near Palmer station and on nearby Litchfield and Torgersen Islands has shifted over the last 30 years. The sea ice season has shortened, access to prey has decreased and winter survival is more challenging. Long term research is showing two sub Antarctic species, the Chinstraps (*Pygoscelis antarctica*) and the Gentoo (*Pygoscelis papua*) replacing the Adélies, living and breeding successfully on islands in close proximity to the few remaining Adélie colonies (Ducklow et al. 2007). The new maritime, subpolar regime with warmer mid winter temperatures is displacing the existing polar climate along the WAP, allowing new species to immigrate. Bill Fraser, the Palmer LTER seabird ecologist has studied these seabirds for the past 35 years, and now must include the Gentoo and Chinstrap species in his studies as the Adélies react to these changing conditions.

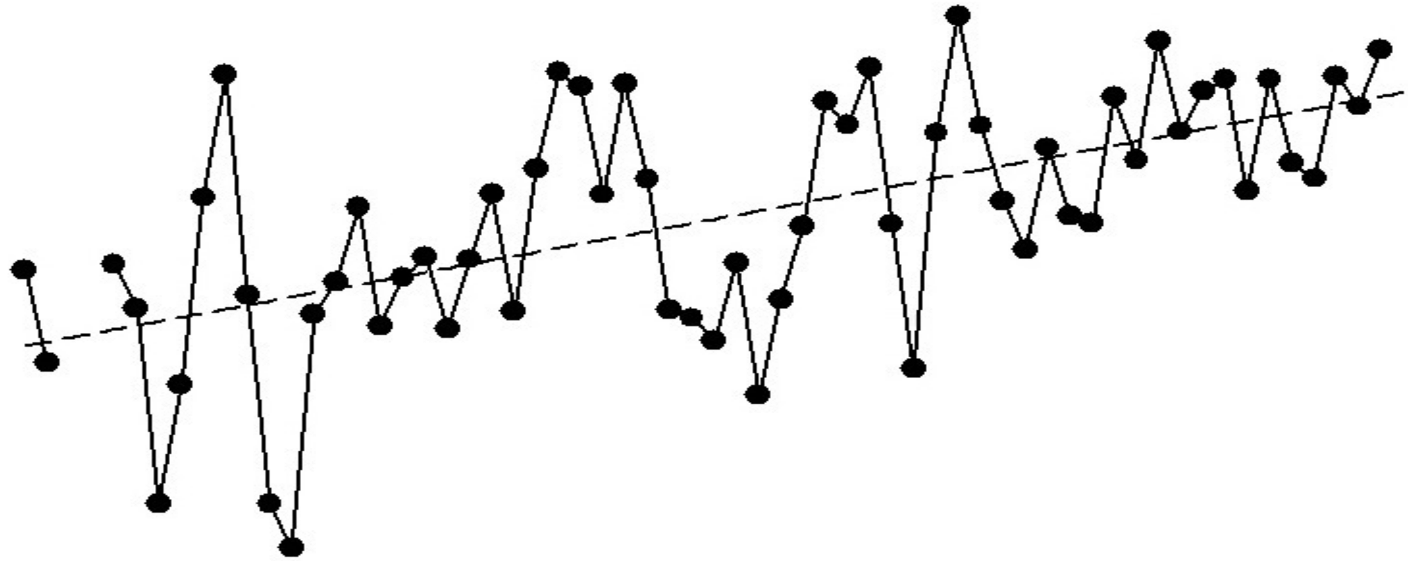


Figure 2: A snapshot Annual average air temperature recorded at Faraday/Vernadsky Station (65°15'S, 64°16'W) from 1951 to 2008. The linear regression fit (solid) and ± standards deviation (dotted) (http://www.antarctica.ac.uk/met/gjma/temps.html).

WHY IS SEA ICE IMPORTANT TO ADÉLIES?

Research on Adélies closely links their life histories to sea ice. It serves as a feeding platform for Adélies once they reach their feeding grounds. It aids in reducing their metabolism, helping them store energy and cope with long migration paths back to breeding colonies. Krill, the primary prey and food source of Adélies, graze on microorganisms growing underneath the sea ice (Fraser, 1997). For Adélie penguins, it is more energy efficient to find food under the sea ice than in large stretches of open water (Ainley, 2002). Foraging trips by Adélies for krill often occur near the ice pack and can result in excursions can last a few hours up to a few days. They rely on the sea ice to rest, to find food to fill their stomachs and even to huddle with others for warmth during their long journeys. Additionally, sea ice helps control the local climate. It keeps the peninsula cool by reflecting solar radiation back to space. Areas in the south that were previously covered with ice now have open water, causing ocean productivity rates to shift. However, this is not uniform across the peninsula. Overall, net productivity of the WAP appears to have decreased, reflecting a shift in plankton biomass and size which has direct consequences for grazers like krill. As air temperatures increase and sea ice melts, there is more open water converting radiation into heat which amplifies the upward trend in local air temperatures (Wadhams, 2000). Finally, sea ice acts as a giant cap on the ocean limiting evaporation. As sea ice declines, condensation along with moisture are released back into the atmosphere. This atmospheric disturbance causes a change which results in more precipitation. This extra precipitation often times impacts the Adélie penguins who start nesting during the December months along the WAP. The extra precipitation and the warmer surface air temperatures are causing more rain events and creating ice and snow to melt. This meltwater can potentially drown their newly hatched eggs (Fraser and Patterson,1997).

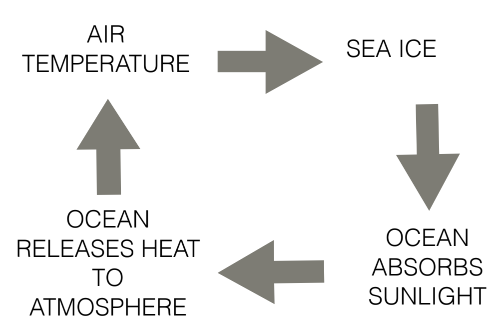


Figure 3: Melting sea ice amplifies the effects of climate change.

ACTIVITY OVERVIEW:

This directed inquiry uses the jigsaw method, a cooperative learning technique that encourages every student to be an active and equal participant (Aronson, 2011). To begin, students are categorized into "base groups" investigating the topic from five specialized perspectives. Individuals from each base group reorganize into five "specialist groups" that each contain one type of scientist. For example *specialist group one* would include all of the Bird Ecologist and *specialist group 2* all of the Oceanographers etc. Each specialist group receives a data sheet which entices them with only a few facts to guide their research. This data is analyzed by the students who create data tables, brainstorm explanations for patterns in their data and report results back to their "base groups". Utilizing the expertise of each "specialist", the base groups now have several scientists' perspectives who work collaboratively to organize all the data and reconstruct the story. They share their understanding by building a flow chart supported by explanations of their findings.

TEACHING NOTES:

This inquiry is interdisciplinary. You will use a cooperative approach to investigate how the biotic (living) and abiotic (nonliving) components of the western Antarctic Peninsula (WAP) are influencing the dynamic Antarctic ecosystem. This activity encourages the importance of gathering evidence in the formulation of scientific explanations. Data for the activity last updated in June, 2013.

TIME: 1 - 3 1/2 HOURS

TARGET AUDIENCE: 8 - 16

PRIOR KNOWLEDGE

Before starting this activity, students should have at best a rudimentary knowledge of Antarctica and penguins. You can find a collection of links to our favorite Antarctic online resources on page ten**.**

OBJECTIVES:

✓ Graphically represent data.

✓ Integrate evidence to generate scientific explanations of ecosystem-level changes on the western Antarctic Peninsula.

✓ Describe how climate change has led to ecosystem-level changes.

✓ Participate in interdisciplinary scientific investigations.

✓ Understand the nature of science.

NATIONAL SCIENCE EDUCATION STANDARDS:

✓ Unifying concepts and processes in science

✓ Systems,order and organization
Evidence, models and explanation

✓ Science as inquiry
Abilities necessary to do scientific inquiry and understand scientific inquiry

CLIMATE LITERACY STANDARDS:

✓ Essential Principle 3A: Climate's role in habitats ranges and adaptation of species to climate change.

✓ Essential Principle 7E: Ecosystems on land and in the ocean have been and will continue to be disturbed by climate change.

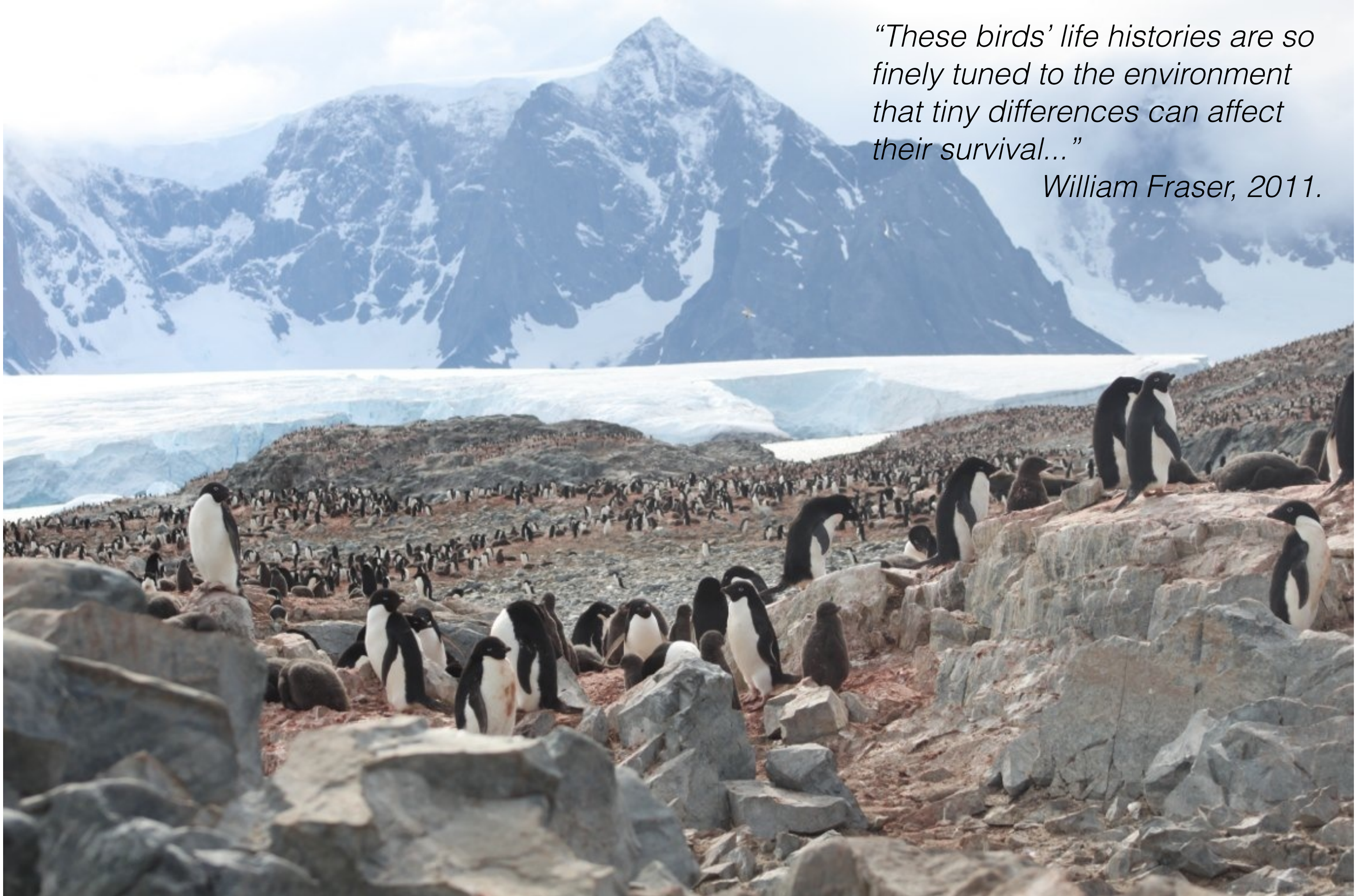
MATERIALS:

- ✓ Specialist fact sheet (one for each student, or one overhead for the entire class)
- ✓ Data sets for each specialist group
  1.) Ornathologist/Bird Ecologist: *Adélie*,*Chinstrap* & *Gentoo* penguins, 2.) Physical Oceanographer: Sea ice, 3.) Meteorologist: Winter snow/precipitation, 4.) Biologist: Krill, 5.) Climatologist: Temperature
- ✓ Specialist group report sheets (one for each student)
- ✓ Sheets of graph paper (one for each student), or computers connected to a printer (one for each specialist group)
- ✓ Sets of six flowchart cards (one complete set for each base group)
- ✓ Paper, markers, and tape for constructing flow charts

PREPARATION:

1. Split the class into <u>base groups</u> containing at least five students per group. Give each student in the base group a researcher title (Bird Ecologist, Oceanographer, Meteorologist, Biologist, Climatologist).
2. Direct the specialists to reorganize themselves separated from their base groups and meet within their respective specialities. Note: *Specialist groups should not interact with other specialist groups.*
3. Within these groups, instruct the student specialists to read the fact sheet, assuming the identity of the researcher from the list.
4. Instruct students to analyze the data sets, graph their data and interpret their graphs by recording everything on their report sheets.
5. After they have completed their data analysis, have students return to their base groups and introduce themselves and their specialty to the entire group. At this point students should be able to glean this description from their fact sheets. For example: *"Welcome! I'm a X climatologist. I study long-term patterns in climate. My colleagues and I have tracked changes in air temperatures on the Antarctic Peninsula since 1947. We have observed that although temperature cycles up and down, it has increased overall. We think this might be occurring because of an increase of greenhouse gases, but we are unsure of the impacts on the Antarctic ecosystem. Your team's job is to describe the interconnected effects of warming on Antarctica's living and nonliving systems."*

Palmer Station / Marr Ice Piedmont Glacier © Simmons



"These birds' life histories are so finely tuned to the environment that tiny differences can affect their survival..."
William Fraser, 2011.

Avian Island, Antarctica © B. Simmons, 2011

PROCEDURE: FLOWCHART AND CLASS DISCUSSION

After base groups have finished briefly summarizing their data they should be instructed to work collaboratively in their base groups to build the flow charts.

1. Hand out one complete set of flowchart cards to each base group. Groups begin with specialists revisiting their findings and cooperatively construcing a flowchart using all of the flowchart cards and arrows. Remind the students throughout this process that they should use the weight of evidence to construct the flowcharts. In other words, as the flowchart is built, the base teams need to take into account all evidence presented from each specialist and each idea should be accepted or rejected by the group based on the amount of support it has.
2. Have students consider these discussion questions during the flowchart process or as a class, by base group, or as homework for each student.

Q: How has the ecosystem of the Antarctic Peninsula changed in the last 50 years? What are the most likely explanations for these changes?

Q: Is there sufficient evidence to support these explanations? Why or why not? What further questions are left unanswered?

Q: Did your group come up with any explanations that you think are not very likely or not even possible, based on the complete story presented?

ASSESSMENT:

To assess student learning, you can use a simple performance rubric that focuses on group work and the nature of science. Depending on the unit of study in which this inquiry is used, a variety of specific content standards may also be assessed.

PERFORMANCE RUBRIC

Criteria	Points	Self	Teacher	Comments
Active participation in the group process	5			
Appropriate graph is used to display data. All required elements are present. Data graphed accurately	5			
Data and interpretations from Specialist Groups are clearly communicated to Base Groups by individual specialists	10			
Alternative explanations are weighed based on available evidence and prior scientific knowledge.	10			
Conclusions are clearly and logically communicated.	10			
Report Sheet is complete	5			
TOTAL	45			

MODIFICATIONS:

Some students may have initial difficulties with the construction and interpretation of flowcharts. Once students have connected their flowchart cards with arrows, it may be useful to have them label each flowchart arrow with a verb. For instance: (Decrease) SEA ICE EXTENT -----> CAUSES (Increase) WINTER SNOWFALL

You can also construct a worksheet with a model of the flowchart (e.g., the general shape of the flowchart and some of the text within the boxes and students can fill in the arrows).

You can shorten this lesson by starting immediately with specialist groups, rather than with base groups. Another option is to provide pre-made graphs of the data rather than having specialist groups create their own graphs.

To make this lesson more open-ended, students may do additional research on the connections between sea ice, krill, and penguins and climate. Some of the publications and multimedia resources can be found at http://pallter.net.edu. If you have access to a university library, you might wish to make a classroom file of related journal articles. A more engaging extension would be for students to generate ideas for new research studies that would address questions left unanswered by the current inquiry. This type of activity could range from asking students to formulate new hypotheses to asking students to write short proposals that include specific research questions and plans on how they propose to answer those hypotheses.

BROADER CONNECTIONS:

Many students have trouble comprehending how just a few degrees of atmospheric warming (in this case, 6°C) could make a difference in their lives. This lesson demonstrates that a decline of such a charismatic species like the Adélie penguin is an example of how a seemingly minor change in climate can pose a major threat to the breeding success of a species. Additionally, students should understand that studying ecosystem change involves identifying what mechanisms underly the correlations. This involves an interdisciplinary approach. In an environment like Antarctica which is highly variable, long term data sets that demonstrate these patterns are critical to showing change over time. Encouraging students to visualize these connections through graphing, data analysis, building flow charts and engaging in discussions is how science is done - everything is intimately connected.

Beyond the study of climate change, however, the activity emphasizes the multi-disciplinary, international, and cooperative nature of science and that science goes beyond lab work involving some extraordinary field work experiences in some extraordinary places.

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OTHER RECOMMENDED RESOURCES: These additional resources were used to create the Student Pages, but are not cited in the text:

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ONLINE RESOURCES:

1. Palmer Long Term Ecological Research (LTER) program: http://pal.lternet.edu
2. Palmer LTER Multimedia (video, audio, photographs): http://pal.lternet.edu/outreach/multimedia/videos/
3. Children's book, Sea Secrets: Tiny Clues to a Big Mystery, Moonlight Publishing, Layfayette, Colorado. ISBN 10:0-9779603-9-0 pp.32. http://cce.lternet.edu/outreach/seasecrets/ .
4. Science Education and Outreach Miami University Laboratory for Ecophysiological Cryobiology http://www.units.muohio.edu/cryolab/education/index.htm
5. Miami University Laboratory for Ecophysiloigcal Cryobiology Antarctic Bestiary http://www.units.muohio.edu/cryolab/education/antarcticbestiary.htm
6. National Snow and Ice Data Center http://nsidc.org

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Juanita Constible — science educator/writer
Luke Sandro — biology teacher Springboro High School, Ohio
Robert E. Lee — distinguished professor Miami University in Oxford, Ohio.

PALMER LTER

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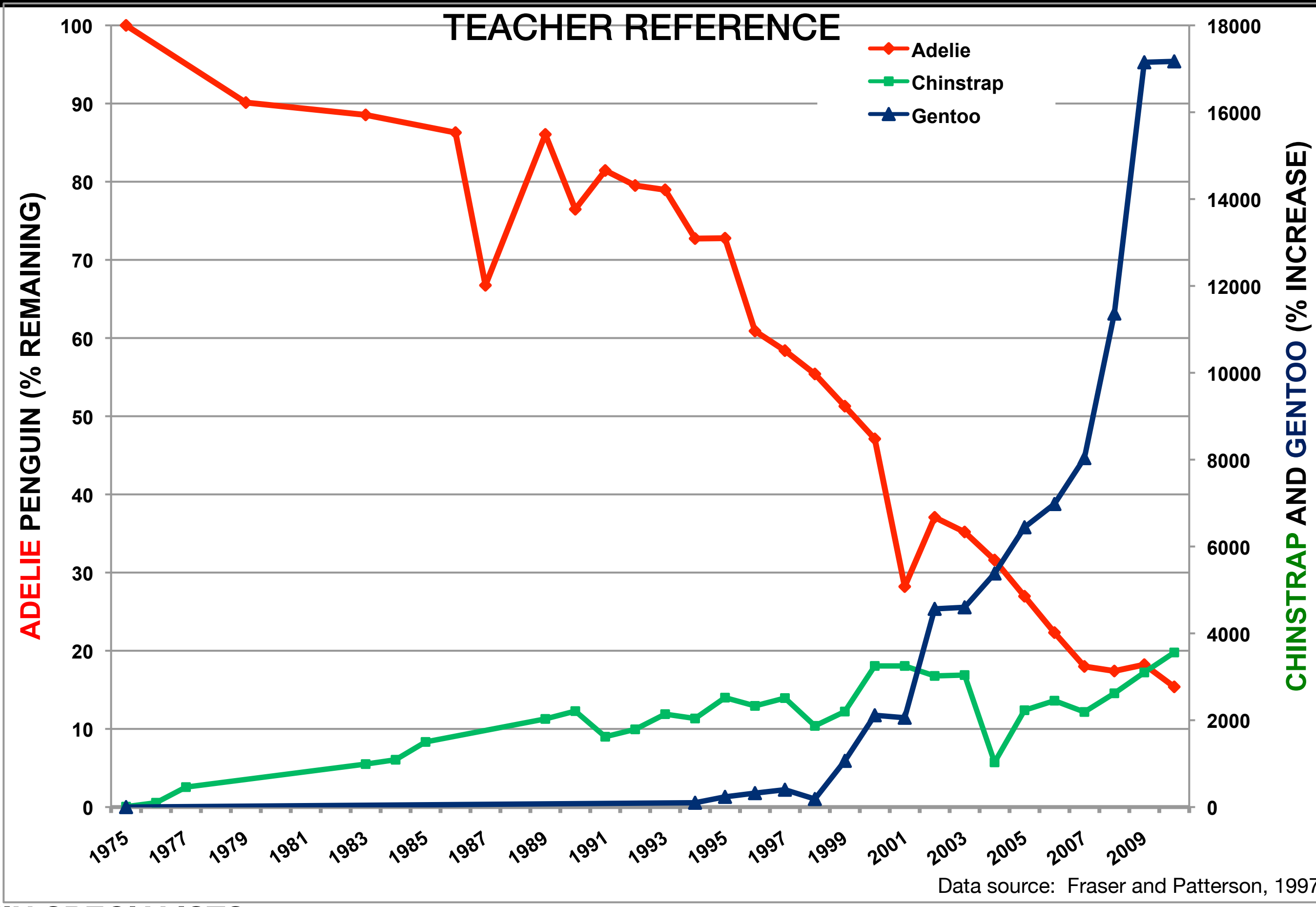


PENGUIN SPECIALISTS:

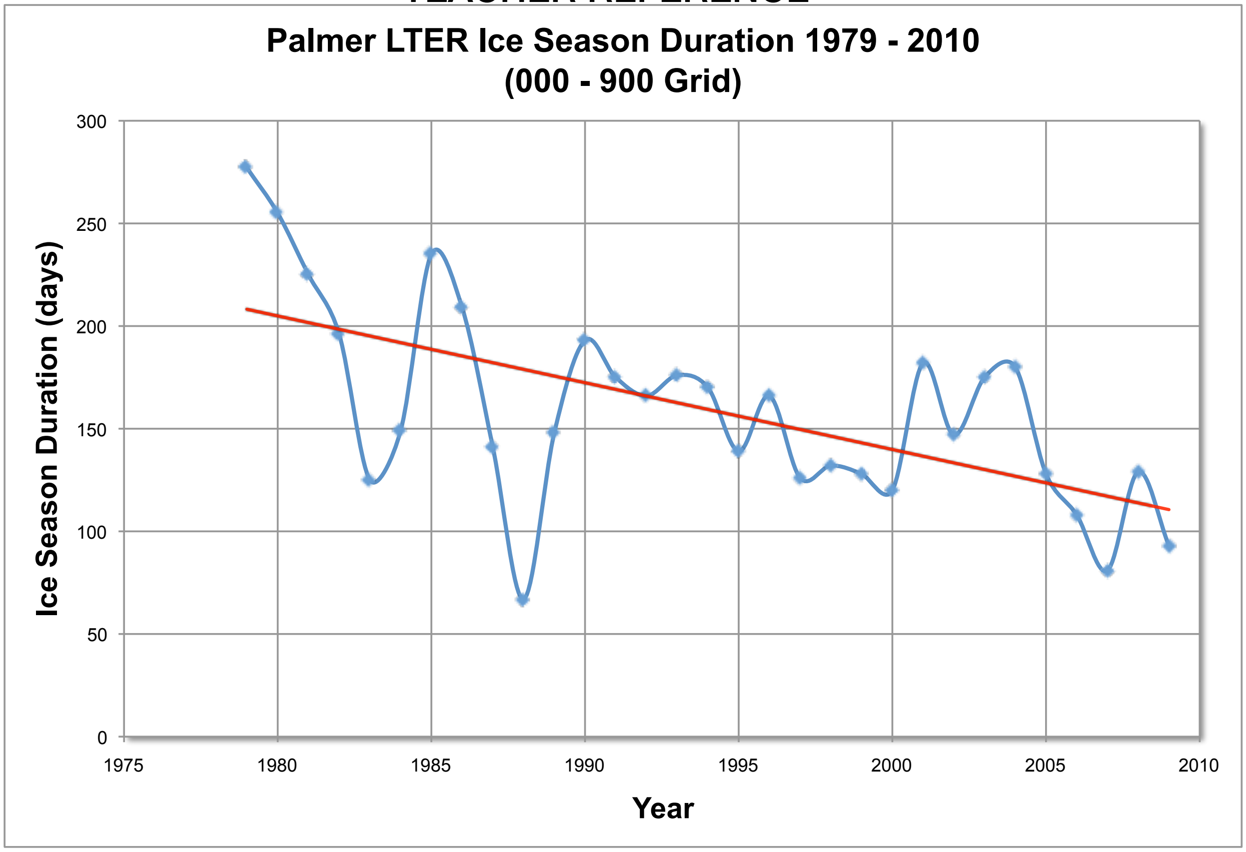
Shifts in penguin populations along the western Antarctic Peninsula are linked to changes in precipitation patterns, sea ice and plankton community structure. These changes are most dramatically documented in the Adélie penguins, a true native Antarctic species. The ice-dependent Adélie populations have dropped by 90% in the northern WAP region, whereas the ice - intolerant Chinstrap (*P. Antarctica*) and Gentoo (*P. Papua*) penguin populations have risen in the north and mid-Peninsula regions (Schofield et al., 2010).

What causes such significant change? The changes are related in part to decreasing sea ice cover and its link to prey availability. Penguins typically breed in locations where they have access to abundant prey. These locations afford them opportunities to forage during the day and then return to their colonies to feed their chicks. The underside of sea ice serves as a major habitat for microorganisms like algae which are critical for young krill to feed and grow. Krill are a central link to the Antarctic food web acting as prey to a variety of upper trophic level organisms, like penguins. Therefore, a shorter winter sea ice season leads to more open water. With a 40% decrease in sea ice, the season is shortened by almost three months, and the Adélies platform to reach rich feeding grounds in winter is gone. Adélies are expending more energy in search of food - roughly eight to thirteen hours per trip (Montaigne, 2009) unable to successfully raise and feed their chicks. Meanwhile, the sub-Antarctic Chinstrap and Gentoo penguins prefer these open ocean conditions and have arrived in large numbers.

As climate changes the ecosystem around them, the Adélies not only have to cope with the changes in sea ice but the added impact of a warmer climate. Precipitation has increased with more frequent rain and snow events. Adélies have little success nesting on snow and dealing with snowmelt. Their rock nests collapse and they often lose eggs in meltwater ponds.

While northern colonies near the Western Antarctic Peninsula face insurmountable challenges, 250 miles south, two and half million pairs of Adélie penguins are still breeding successfully, some even experiencing the optimal mixture of ice and open water to help them breed and thrive.

TEACHER REFERENCE

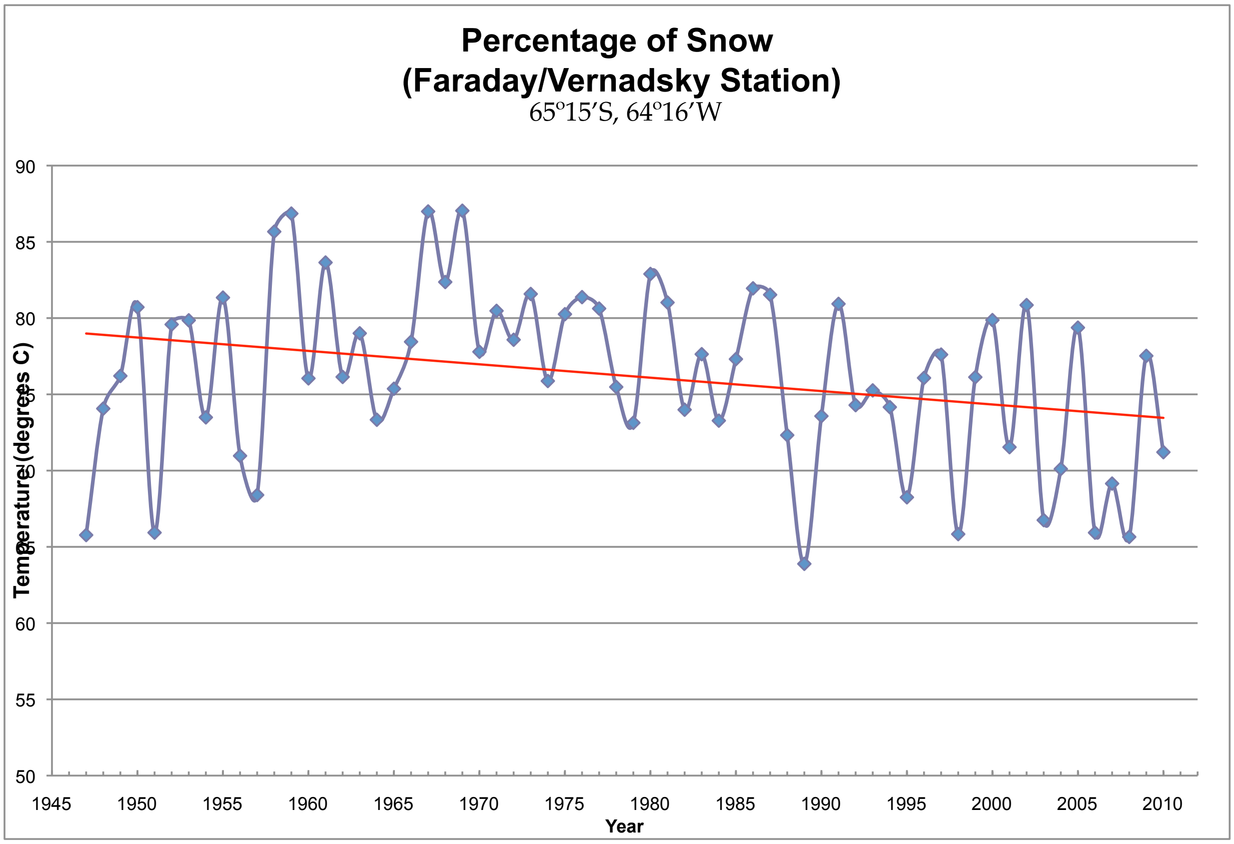


NOTE: Ice season duration (days) for Palmer Station Grid (000 - 900 lines), number of day between the first appearance of sea ice and the last based on the "ice year" (which goes from mid-Feb. to mid-Feb.) The new version of data based on improved GSFC Bootstrap time series data version 2.0 for 1979 - 2010. Data source: http://nsidc.org/data/docs/daac/nsidc0079_bootstrap_seaice.gd.html

ICE SPECIALISTS: Sea Ice Duration 1979 - 2010

One ecosystem response to the regional warming along the western Antarctic peninsula includes increased heat transport, and decreased sea ice extent (cover) and duration (time). The dynamics of the Antarctic ecosystem are dominated by these seasonal changes and their interannual variations. Various trends have been detected in Antarctic sea ice, showing that the size and direction are strongly dependent on the region and when they are studied. Here we analyze trends from 1979 - 2010 (N=32), in ice season duration (http://nsidc.org/data/docs/daac/nsidc0079_bootstrap_seaice.gd.html). Ice season duration is the difference between when the sea ice first arrives and the last day it departs. Scientists have documented sea ice decreasing fastest along the western Antarctic Peninsula region. The maximum winter sea ice extent which is the location of the winter ice edge, is highly variable, with no detectable trend. However, its duration at winter maximum has become shorter with time. In other words, it is extending as far to the equator as before but does not remain there as long. Overall, the western Antarctic Peninsula is showing a decreasing trend in ice season duration with a regional decrease of ~ 100 days/year. What causes such significant change? This decreasing trend is due to sea ice arriving later in autumn and departing earlier in spring (Stammerjohn, 2012). Two other critical factors influencing this change are stronger winds over the Southern Ocean and rising surface air temperatures during winter. With less sea ice, the exchange between the ocean and the atmosphere (called flux) is amplified by the winds. This changes the regional marine climate, the ice dynamics and the ecology in the area as there is opportunity for increased solar ocean warming. The implications of a shorter ice season impact the life histories of marine species that are synchronized with the sea ice season. The Antarctic ecosystem is changing faster than species can adapt (Ross et al. 1966a; Smith et al. 1995). Scientists are now embracing a suite of ocean observing systems like remote sensing techniques (satellites), underwater gliders, and moorings that provide a slew of measurements across multiple platforms to help characterize and document the ecosystem shifts.

TEACHER REFERENCE



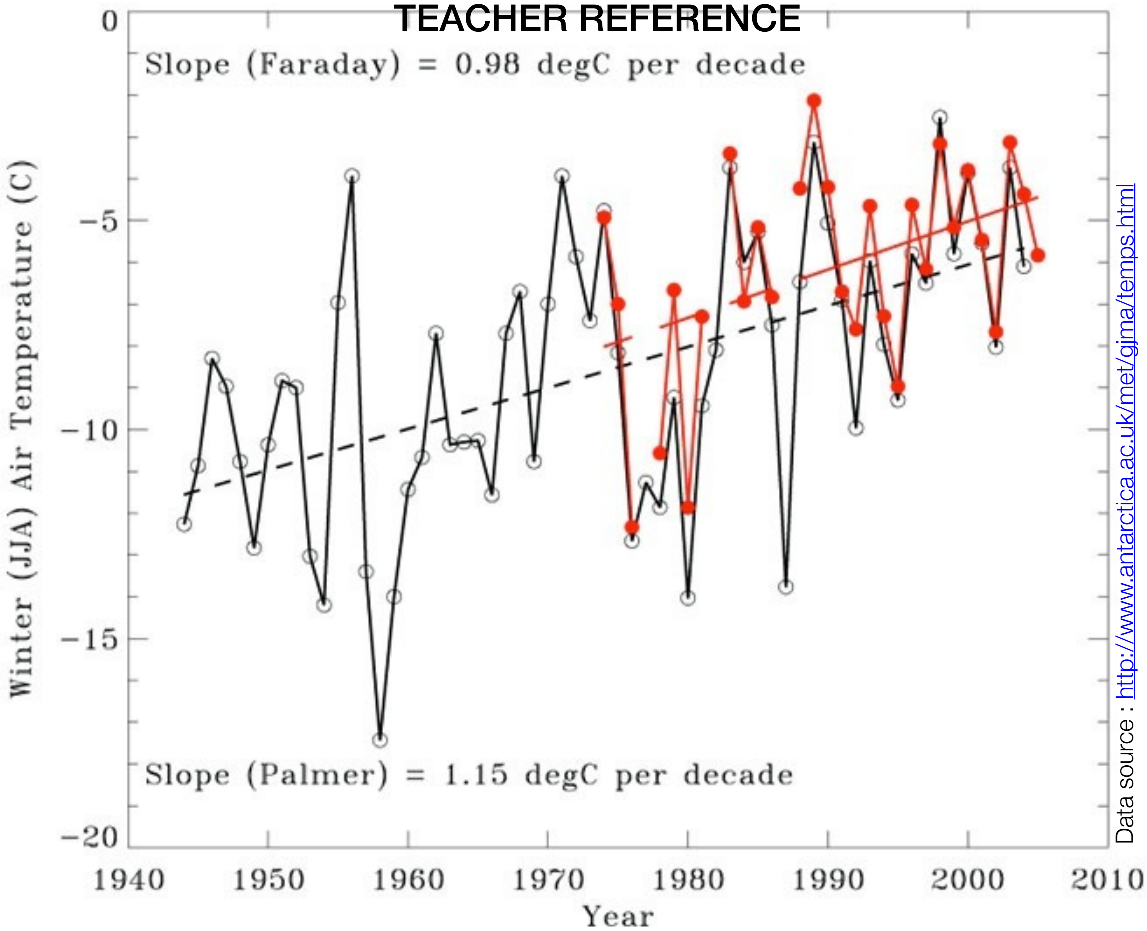
Note: The Vernadsky Station is located at at 65.4S 64.4W and the data goes from 1947 to 2010. This data was collected by taking the total number of reports recorded as precipitation events from the station and extracting those that were specifically reported as snow. *Data source: British Antarctic Survey from the Faraday/Vernadsky station http://www.antarctica.ac.uk/cgi-bin/metdb-form-2.pl?http://www.antarctica.ac.uk/cgi-bin/metdb-form-2.pl?*

METEOROLOGIST SPECIALISTS: Percent of Precipitation Events that are Snow 1945 - 2010

Precipitation is extremely difficult to measure because of blowing-snow effects, which can cause snow to be added to or removed from the snow gauges in the absence of precipitation when wind speeds exceed 10 ms^{-1} (Turner,1997). Meteorologists often define precipitation as any day when there is at least one report of snow, rain, drizzle, hail or a shower. Observations of precipitation events for the WAP region are recorded at the Vernadsky Station (65.4° S,64.4° W) (subsequently F/V). For this lesson they were compiled to investigate how precipitation changes over space and time along the western side of the Antarctic Peninsula. This long term record shows the largest recorded warming in history, with meteorological records dating back to the late 1940s.

The greatest increase in air temperature occurs during winter (King, 1994; King et al., 2003; Turner et al., 2005) where the records indicate a statistically significant increase in the number of seasonal precipitation events. On average, almost 50% more reports of precipitation occur at this time of year than during the 1950s. It is argued that the systematic increase in the number of precipitation events at Faraday is associated with changes in the depression tracks or areas of low atmospheric pressure jetting across the Bellingshausen Sea. A great number of them are approaching from outside the Antarctic Circle rather than from the west. Atmospheric depressions develop when warm air from the Tropics collide with cold air from the Polar regions. As a front passes by a region, there are often sudden changes in wind patterns. These stronger winds pass over the surface of the Southern Ocean where there is more exposed open water due to decrease ice cover. This pulls the warmer air into the atmosphere which leads to increased evaporation. With that moisture in the air there is greater cause for more precipitation to fall along the WAP. Precipitation mostly falls as snow, although rain does occur during the summer months (December - February) at many coastal locations at low elevation (like Palmer Station). These coastal research sites continue to document the changes and study the impacts of these changing climate conditions as they cause the ecosystem to respond.

TEACHER REFERENCE



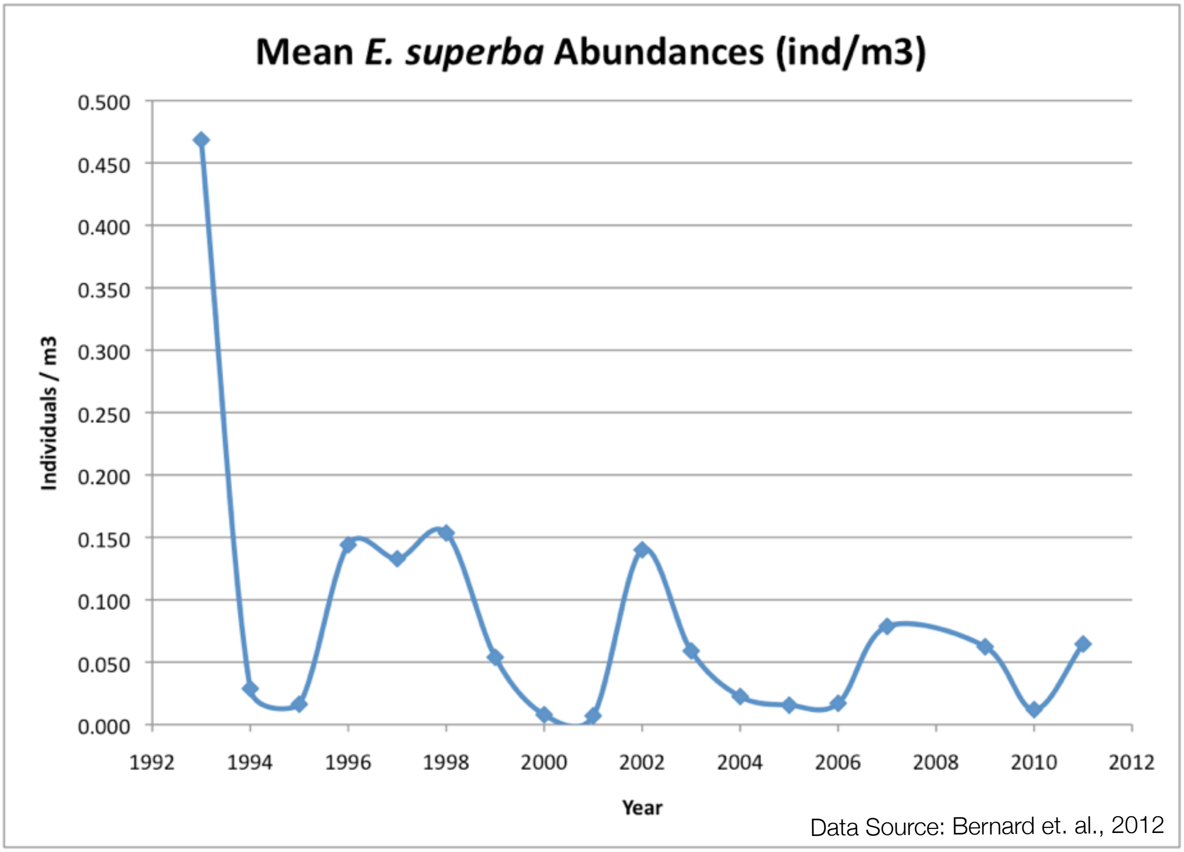
CLIMATOLOGIST SPECIALISTS: Winter Surface Air Temperature

Significant changes have occurred over the last half-century in the Antarctic Peninsula (AP) region, including the northwestern Weddell and southern Bellingshausen Seas. Instrument records, station observations, satellite data, and paleoenvironmental records (Domack et al. 2003) all reveal that surface air temperatures are warming in winter at a rate of 5-6 °C over the last 50 years, a warming rate that exceeds any other observed on Earth (Vaughan et al. 2003).

On the graph above, the British Antarctic Survey (BAS) meteorological observations (http://www.antarctica.ac.uk/met/gjma/temps.html) at Faraday/Vernadsky station (65°15'S, 64°16'W) is represented in black with the United States Palmer Station represented in red. The changes in the annual progression of temperature and the amount of variability with those temperatures suggests a rising climate shift along the WAP. Continental influences from the south (like longer ice duration and colder air) are giving way to increasing maritime influences from the north (Smith et al. 1999).

There is a strong correlation between the monthly changes in air temperatures and the high interannual variability of sea ice coverage during the fall and winter seasons. The source of heat to warm the air and water and even melt glaciers is in part due to the increased upwelling from the Antarctic Circumpolar Current (ACC). This current hugs the edge of the western continental shelf along the Peninsula. And, because sea water has a great ability to retain heat, even small increases in ocean temperatures can reflect large changes in the regional heat balance. Contributing to this is a 90 day decline in sea ice cover per year, resulting in more open water. A thinning Antarctic Ozone layer is also altering these atmospheric heating rates, changing atmospheric pressure and wind patterns over the continent. The winds sweep over the water surface pulling up the heat off the surface of the relatively warmer water due to increased upwelling from the ACC. The ocean - atmosphere exchange (flux) contributes to the region nearing a tipping point and producing profound effects on sea life.

TEACHER REFERENCE



Biological Oceanographer: Zooplankton Ecologist

Antarctica harbors one of the most extreme yet abundant ecosystems on Earth, supporting vast populations of penguins, seals, whales, and fish that flourish in its frigid waters. These and dozens of other species are sustained by changing macrozooplankton species. Antarctic krill (*Euphausia superba)*, a small, shrimp-like macrozooplankton swims in dense swarms extending over many kilometers in the ocean. Krill are central to the Antarctica food web and feed on algae on the underside of sea ice. In the northern region of the western Antarctic Peninsula, shifts in sea ice cover are accompanied by changes in plankton communities (Bernard et. al., 2012) as krill recruitment and the winter survival of larval krill need the sea ice to feed and grow. When sea ice retreats it typically leaves the water stratified resulting in more light entering the ocean surface, promoting greater plankton blooms. However, increased wind forcing and cloud cover in the northern region of the WAP have resulted in a dramatic decline in the biomass of phytoplankton (measured as chlorophyll-a derived from satellites) during the austral summer months over the last thirty years (Montes Hugo et al., 2009). By comparison however, further south along the WAP an increase in open water associated with changes in sea ice have caused an increase in phytoplankton biomass (Montes-Hugo et al., 2009).

One contributing factor relates to phytoplankton cell size. Large phytoplankton cells are shifting to small cells although there is great inter-annual variability. These shifts in cell size seem to have direct consequences for macroplankton grazers like krill (*E. Superba*) who eat the phytoplankton. Krill are not as efficient at eating these small-sized algae cells. When phytoplankton biomass changes, scientists often document equal shifts in zooplankton (Ross et al., 2008). Therefore, it has become evident that a new grazer called Salp (*Salpa thompsoni*) a gelatinous organism who favors these phytoplankton cell sizes are increasing in abundance in the northern WAP shelf region. They have high ingestions rates and may completely change the grazing impact in the ecosystem. Typically *S. thompsoni (salps)* and *E.superba (krill)* tend not to overlap in the same areas, but with changing conditions and the mixing of the Upper Circumpolar Deep Water (UCDW) the Palmer LTER researchers are finding they co-occurred at some sampling stations along the Palmer LTER grid (Bernard et. al., 2012). As climate changes the ecosystem around them the result may have negative implications for krill in the area as they compete for food. It may also have a dramatic domino effect on higher trophic level organisms like fish, seals, whales and penguins who feed on krill.

SPECIALIST REPORT SHEET

Name: ________________________________**Specialist Group:**________________________________

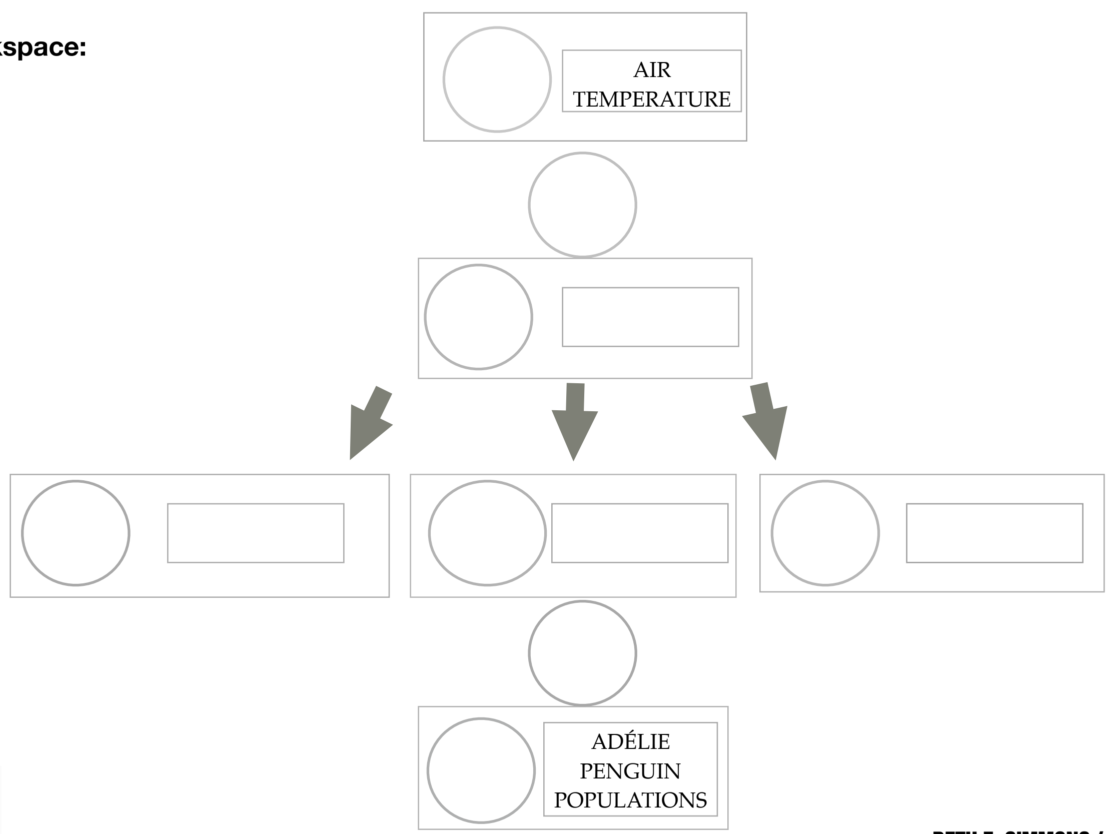
- [ ] Analyze the data sets. Graph your data.
- [ ] Interpret your graphs by describing possible explanations for your findings. Summarize the general trends or patterns in your data. Attach a graph of your data to the back of this sheet. Support your explanations.
- [ ] Write out how you will introduce yourself when you return back to your base group. For example: *"Welcome! I'm a X climatologist. I study long-term patterns in climate. My colleagues and I have tracked changes in air temperatures on the Antarctic Peninsula since 1947. We have observed that although temperature cycles up and down, it has increased overall. We think this might be occurring because of an increase of greenhouse gases, but we are unsure of the impacts on the Antarctic ecosystem. Your team's job is to describe the interconnected effects of warming on Antarctica's living and nonliving systems."*
- [ ] Consider the following questions with your Specialists group and record your answers:

  Q: How has the ecosystem of the Antarctic Peninsula changed in the last 50 years? What are the most likely mechanisms for these changes?

  Q: Is there sufficient evidence to support these explanations? Why or why not? What further questions are left unanswered?

  Q: Did your specialist group come up with any explanations that you think are not very likely (or not even possible!), based on the complete story presented by your base group?
- [ ] **Broader Connections:** How can ecosystems changes pose such a threat to the breeding success of a charismatic species like the Adélie penguin? Demonstrate the connections you have learned by first filling in the variable boxes □ adding words like sea ice, Chinstraps/Gentoos, krill densities, and precipitation from you unique specialist perspective. Then, add up ↑and down ↓ arrows in the flow chart circles ◯. See how your chart compares to the others in your base group when you return.
- [ ] As a base group build a flow chart that your entire group agrees upon taking into account all the various perspectives. Raise your hand and check with your instructor when your base group is ready to have their flow chart checked.
- [ ] Participate in class discussions when instructed by your teacher and when everyone is finished.

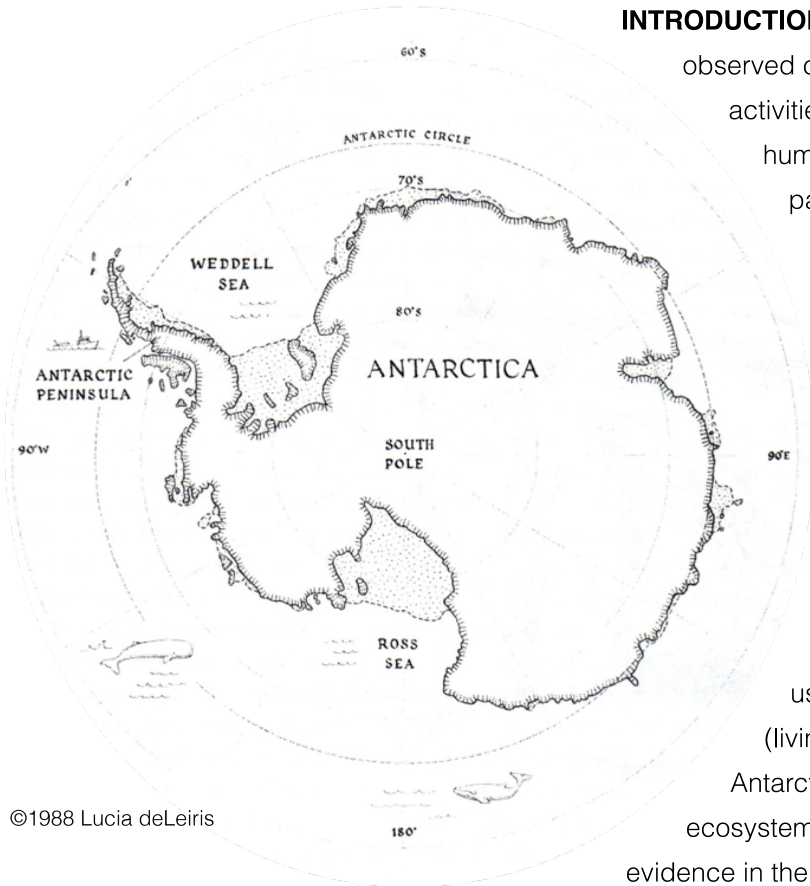
Workspace:



Now You “Sea” Ice, Now You Don’t:

Penguin communities shift on the Antarctic Peninsula

Based on a lesson called Climate Change From Pole to Pole, intended for high school science educators published by the National Science Teachers Association (www.nsta.org). Revised and updated with permission March, 2013.
besimmons@oceaningenuity.com / Palmer LTER Education & Outreach



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INTRODUCTION : At the global level, strong evidence suggests that observed changes in Earth’s climate are largely due to human activities (IPCC 2007). At the regional level, the evidence for human - dominated change is sometimes less clear. Trends or patterns may be seen but vary from place to place. It is documented that climate change is transforming ecosystems on an extraordinary scale and at an extraordinary pace. Scientists have a particularly difficult time explaining warming trends in Antarctica - a region with a relatively short history of scientific observation yet a climate that is highly variable (Ducklow et al. 2007). A compelling way to study ecosystem change is to identify interdisciplinary relationships across multiple levels.

AT A GLANCE: This inquiry is interdisciplinary. You will use a cooperative approach to investigate how the biotic (living) and abiotic (nonliving) components of the western Antarctic Peninsula (WAP) are influencing the dynamic Antarctic ecosystem. This activity encourages the importance of gathering evidence in the formulation of scientific explanations.

TIME: 1 -3 1/2 HOURS

TARGET AUDIENCE: 8 - 16

OBJECTIVES:

✓ Graphically represent data.
✓ Integrate evidence to generate scientific explanations of ecosystem-level changes on the western Antarctic Peninsula.
✓ Describe how climate change has led to ecosystem-level changes.
✓ Participate in interdisciplinary scientific investigations.
✓ Understand the nature of science.

NATIONAL SCIENCE EDUCATION STANDARDS:

✓ Unifying concepts and processes in science

✓ Systems,order and organization
Evidence, models and explanation

✓ Science as inquiry
Abilities necessary to do scientific inquiry and understand scientific inquiry

CLIMATE LITERACY STANDARDS:

✓ Essential Principle 3A: Climate’s role in habitats ranges and adaptation of species to climate change.

✓ Essential Principle 7E: Ecosystems on land and in the ocean have been and will continue to be disturbed by climate change.

Avian Island, Antarctica © B. Simmons, 2011

SPECIALIST FACT SHEET:

1. **Ornithologist (Bird Ecologist)**: A scientist who studies birds. Uses visual surveys (from ship or on land), diet analysis, bird banding, and satellite tracking to collect data on birds of the Antarctic.
2. **Physical Oceanographer (Sea Ice Specialist):** A scientist who studies the conditions and physical properties within the ocean including currents and properties of the water. This scientist may use satellite imagery, underwater sensors, and manual measurements of sea ice thickness to collect data on sea ice conditions and ocean temperature.
3. **Meteorologist (Snow):** A scientist who studies the weather over a short period of time (minutes to months). This scientist uses automatic weather stations and visual observations of the skies to collect data on precipitation, temperature, and cloud cover.
4. **Biologist (Krill Densities):** A scientist who studies relationships between living organisms like plankton and their community structure. This may involve investigating plankton abundance, migration and grazing rates, food webs and biogeochemical cycling.
5. **Climatologist (Temperature):** A scientist who studies average atmospheric changes or patterns in temperature, humidity atmospheric pressure, wind, precipitation over long periods of time across large scales. They may work with satellites, and or computer models to simulate and predict the Earth's global conditions.

ORNATHOLOGIST

Beth E. Simmons

Adélie penguin
(*Pygoscelis adeliae*)

PERCENT (%) CHANGE IN ADELIE PENGUINS

Year	Adélies
1974	
1975	100
1976	
1977	
1978	
1979	90.12629917
1980	
1981	

Year	Adélies
1982	
1983	88.54755953
1984	
1985	
1986	86.28469938
1987	66.74779634
1988	
1989	86.05446652
1990	76.47677937
1991	81.43665307
1992	79.51585318
1993	78.9632943
1994	72.72727273
1995	72.7733193

Year	Adélies
1996	60.89988159
1997	58.39363242
1998	55.40718327
1999	51.28272596
2000	47.10564399
2001	28.20681489
2002	37.06749112
2003	35.1927378
2004	31.6076832
2005	26.97013551
2006	22.31943165
2007	17.99105381
2008	17.40560453
2009	18.22128667

Data source: Fraser and Patterson, 1997

QUICK FACTS:

- ✓ A true Antarctic species.
- ✓ Adélie penguins spend their summers (December - February) on shore, where they breed. They spend winters on the outer extent of the sea ice surrounding Antarctica, where they molt their feathers and fatten up.
- ✓ Adélies are visual predators, meaning they need enough light to see their prey. Near the outer part of the pack ice, there are only a few hours of daylight in the middle of the winter. There is less sunlight as you go further south (closer to land).
- ✓ On the western Antarctic Peninsula, Adélie penguins mostly eat schooling krill, a shrimp-like crustacean but will also feed on small schools of fish and other zooplankton.
- ✓ Adélies look for food under sea ice. It is more energy efficient to find food there than in stretches of open ocean.
- ✓ Rely on sea ice during foraging trips.
- ✓ Several countries have been heavily harvesting krill since the mid-1960s.
- ✓ Adélie penguins need dry, snow-free places to lay their eggs. They use the same nest sites each year and during about the same time every year.
- ✓ Heavy snowfalls during the nesting season increases meltwater, drowns adult nests and Adélies lose eggs.
- ✓ Female Adélies lay a clutch of two eggs typically three days apart. Males taking the first incubation shift.
- ✓ The two most common causes of death of eggs and chicks are abandonment by the parents (if they cannot find enough food) and predation by skuas (hawk-like birds).
- ✓ In the water, Adélies are eaten mostly by leopard seals and killer whales.
- ✓ Adélie penguins have lived in the western Antarctic Peninsula for at least 644 years.

ORNATHOLOGIST

Beth E. Simmons

Gentoo penguin
(Phygoscelis Papua)

PERCENT (%) CHANGE IN GENTOO PENGUINS

Year	Gentoo
1974	
1975	0
1976	
1977	
1978	
1979	
1980	
1981	

Year	Gentoo
1982	
1983	
1984	
1985	
1986	
1987	
1988	
1989	
1990	
1991	
1992	
1993	
1994	100
1995	235.7142857

Year	Gentoo
1996	321.4285714
1997	400
1998	185.7142857
1999	1064.285714
2000	2114.285714
2001	2057.142857
2002	4564.285714
2003	4600
2004	5378.571429
2005	6442.857143
2006	6978.571429
2007	8035.714286
2008	11364.28571
2009	17150

Data source: Fraser and Patterson, 1997

QUICK FACTS:

- ✓ Mainly a sub-Antarctic species or most northern penguin of this genus. It is now extending its geographic boundaries to the Antarctic Peninsula.
- ✓ Can be found around their breeding colonies all year round unless ice prevents access.
- ✓ Forage much closer inshore than the Adélie and Chinstrap.
- ✓ Characterized by a white patch around and behind the eye that joins on the crown with a distinct orange-red lower mandible.
- ✓ Colonies are usually smaller and less densely packed with nests found in ice-free areas and beaches. Birds sometimes present all year round.
- ✓ Birds go to sea daily before laying with females fasting for five days prior to laying the first egg.
- ✓ Normally two eggs are laid with a 3.4 day interval in between with females going to sea for 1 -2 days in between laying the eggs.
- ✓ Parents alternate sitting on egg for about 35 - 37 days with crèching beginning at 25 -30 days and fledging occurring at 80 - 105 days.
- ✓ Fledged chicks return to parents to be fed for an additional 5 - 10 days.
- ✓ Diet varies but mostly consists of fish and krill.

ORNATHOLOGIST

Beth E. Simmons

Chinstrap penguin
(Phygoscelis Antarctica)

PERCENT (%) CHANGE IN CHINSTRAP PENGUINS

Year	Chinstrap
1974	
1975	10
1976	100
1977	460
1978	
1979	
1980	
1981	
1982	
1983	990
1984	1090
1985	1500
1986	
1987	
1988	
1989	2030
1990	2210
1991	1620
1992	1790
1993	2140
1994	2040
1995	2520
1996	2330
1997	2510
1998	1870
1999	2200
2000	3250
2001	3250
2002	3020
2003	3040
2004	1030
2005	2230
2006	2450
2007	2190
2008	2620
2009	3100

Data source: Fraser and Patterson, 1997

QUICK FACTS:

- ✓ Delicately colored bird with white face and a thick dark line running under the lower chin - "chin strap".
- ✓ Chinstrap penguins breed on land near rocky outcrops with steep slopes in the spring and summer. They may spend the rest of the year in open water north of the sea ice.
- ✓ The number of chinstraps that successfully breed is much lower in years when the sea ice does not melt until late in the spring.
- ✓ Chinstraps feed almost exclusively on krill, a shrimp-like crustacean.
- ✓ Arrive in colonies October/November with egg laying November/December with males arriving to the breeding site first. Both partners will fast until egg laying which can vary from 2 -3 weeks.
- ✓ Clutch size is usually two eggs with a laying interval of 3.2 days and females take the first shift of incubation averaging 5 - 10 days at a time.
- ✓ Chicks crèche at 23 - 29 days and fledge at 52 - 60 days.
- ✓ Chinstraps primarily hunt in open water, because they cannot hold their breath for very long. They leave their breeding colonies during winter migrate north of the pack-ice and stay at sea until the next spring.
- ✓ The main predators of chinstraps are skuas (hawk-like birds), leopard seals, and killer whales.
- ✓ Chinstraps will aggressively displace Adélie penguins from nest sites in order to start their own nests, and may compete with Adélies for feeding areas.
- ✓ Although Chinstrap penguins have occupied the western Antarctic Peninsula for over 600 years, they have become numerous near Palmer Station only in the last 35 years.

PHYSICAL OCEANOGRAPHER (SEA ICE DATASET)

Beth E. Simmons

AREA OF SEA ICE EXTENDING FROM THE ANTARCTIC PENINSULA (km²)

Year	Sea Ice Extent
1978	-999
1979	132357.94
1980	146885.23
1981	128420.85
1982	114700
1983	74066.45
1984	82076.36
1985	74938.16
1986	122947.22
1987	129518.7
1988	81074.41

Year	Sea Ice Extent
1989	35243.2
1990	84244.43
1991	104094.71
1992	104279.24
1993	93329.05
1994	100652.6
1995	94145.4
1996	80612.66
1997	96598.32
1998	72051.26
1999	77972.52

Year	Sea Ice Extent
2000	74287.41
2001	67177.42
2002	105466.23
2003	80407.88
2004	93440.1
2005	103673.78
2006	78743.56
2007	62087.43
2008	50933.67
2009	74666.18
2010	54389.5
2011	-999

Data source: http://nsidc.org/data/docs/daac/nsidc0079_bootstrap_seaice.gd.html

QUICK FACTS:

- ✓ In August or September (the middle of winter), sea ice covers over 19 x 10^6 km^2 of the Southern Ocean (an area larger than Europe). In February (the middle of summer), only 3 x 10^6 km^2 of the ocean is covered by sea ice.
- ✓ Sea ice keeps the air of the Antarctic region cool by reflecting most of the solar radiation back into space.
- ✓ Open water absorbs solar radiation instead of reflecting it and converts it to heat. This heat warms up the atmosphere.
- ✓ Sea ice reduces evaporation of the ocean, thus reducing the amount of moisture that is released to the atmosphere.
- ✓ As sea ice melts, bacteria and other particles are released into the atmosphere. These particles can form condensation nuclei, which grow into rain or snow.
- ✓ Rain helps to stabilize the sea ice by freezing on the surface.
- ✓ Sea ice can be broken up by strong winds that last a week or more.
- ✓ An icebreaker is a ship with a reinforced bow to break up ice and keep channels open for navigation. Icebreakers were first used in the Antarctic in 1947, and have been commonly used to support scientific research in the last 25 years.
- ✓ Once sea ice covered the area near the north peninsula year round.
- ✓ Changes in sea ice cover affect the inshore and offshore ocean dynamics allowing the wind to be a major environmental factor affecting ecosystem dynamics.
- ✓ With sea ice in decline, there is now more light penetrating the ocean surface to favor plankton production which has increased more than 60%.

Palmer Station, Antarctica
Beth E. Simmons

METEOROLOGIST (DATA SET)

PERCENT (%) OF PRECIPITATION EVENTS THAT WERE SNOW

Year	% SNOW
1947	66
1948	74
1949	76
1950	81
1951	66
1952	80
1953	80
1954	73
1955	81
1956	71
1957	68
1958	86
1959	87
1960	76
1961	84
1962	76
1963	79
1964	73
1965	75
1966	78
1967	87
1968	82
1969	87
1970	78
1971	80
1972	79
1973	82
1974	76
1975	80
1976	81
1977	81
1978	75
1979	73
1980	83
1981	81
1982	74
1983	78
1984	73
1985	77
1986	82
1987	82
1988	72
1989	64
1990	74
1991	81
1992	74
1993	75
1994	74
1995	68
1996	76
1997	78
1998	66
1999	76
2000	80
2001	72
2002	81
2003	67
2004	70
2005	79
2006	66
2007	69
2008	66
2009	78
2010	71

Data source: British Antarctic Survey from the Faraday/Vernadsky station http://www.antarctica.ac.uk/cgi-bin/metdb-form-2.pl?

QUICK FACTS:

- ✓ In the winter, most of the precipitation in the western Antarctic Peninsula occurs as snow. There is an even mix of snow and rain the rest of the year.
- ✓ It is difficult to accurately measure the amount of snowfall in the Antarctic because strong winds blow the snow from the gauges.
- ✓ The Antarctic Peninsula has a relatively warm maritime climate, so gets more rain and snow than the rest of the Antarctic continent.
- ✓ Most of the rain and snow in the western Antarctic Peninsula is generated by depression tracks from outside the Southern Ocean. Depressions are areas where warm and cold are collide and create changing wind patterns.
- ✓ When there is less sea ice covering the ocean, there is more open ocean causing more evaporation of the ocean and therefore more moisture in the atmosphere to cause snow events.
- ✓ As sea ice melts, bacteria and other particles are release into the atmosphere. These particles can form condensation nuclei, which grow into rain or snow.

ZOOPLANKTON ECOLOGIST (KRILL DATASET)

Palmer LTER

ANTARCTIC KRILL
(Euphausia superba)

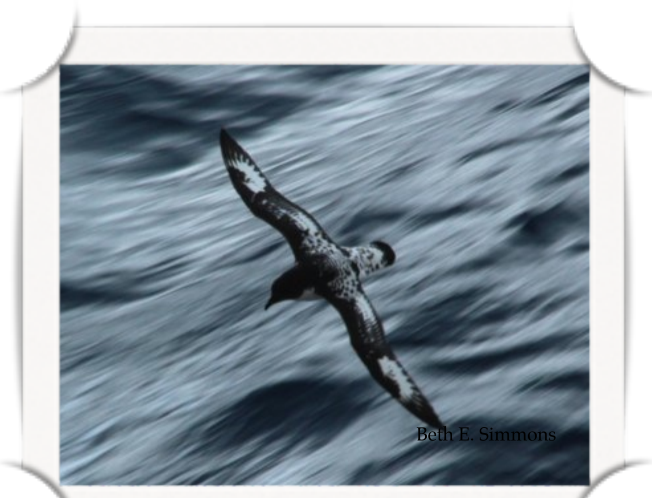
KRILL ABUNDANCE 1993 - 2011
(individuals / m^3)

Year	Mean *E. superba* Abundances (ind/m^3)
1993	0.468
1994	0.029
1995	0.016
1996	0.144
1997	0.133
1998	0.153
1999	0.054
2000	0.008
2001	0.007
2002	0.14
2003	0.059
2004	0.023
2005	0.016
2006	0.017
2007	0.079
2009	0.062
2010	0.012
2011	0.065

Data Source: Bernard et. al., 2012

QUICK FACTS:

- ✓ Krill are a keystone species, meaning it is one species that supports vast populations of sea life.
- ✓ Many of the vertebrate animals in the Antarctic either eat krill or eat another animal that eats krill.
- ✓ Krill feed mostly on algae found on the underside of sea ice.
- ✓ *E. superba* have feeding appendages and mouth parts that are adapted to selectively filter out particle sizes > 10 μm.
- ✓ *E. superba* seem to graze at the coast and over the shelf not offshore.
- ✓ The recruitment of young krill (*E. superba)* depend on sea ice to feed and grow.
- ✓ When phytoplankton biomass (algae) changes in an area, krill abundances shift.
- ✓ Several countries have been harvesting krill since the mid-1960s.
- ✓ Climate change can alter the zooplankton community structure which changes energy flow in the Antarctic food web.
- ✓ Salps, which are small, marine animals that look like blobs of jelly, compete with krill for phytoplankton food resources.
- ✓ Salps favor small size phytoplankton and can ingest higher concentrations when they graze in the same area as krill.



CAPE PETRAL
(Daption capense)

CLIMATOLOGIST (AIR TEMPERATURE DATASET)

65°15'S, 64°16'W

Data Source : http://www.nerc-bas.ac.uk/icd/gjma/faraday.temps.html

Annual Mean AIR TEMPERATURE ° C

Year	Annual Mean °C	Year	Annual Mean °C	Year	Annual Mean °C	Year	Annual Mean °C	Year	Annual Mean °C	Year	Annual Mean °C
1947	-4.48	1958	-8.07	1969	-5.49	1980	-6.59	1991	-4.02	2002	-3.91
1948	-6.24	1959	-8.51	1970	-3.55	1981	-5.23	1992	-4.65	2003	-2.38
1949	-7.39	1960	-5.45	1971	-2.28	1982	-4.23	1993	-3.28	2004	-3.55
1950	-5.68	1961	-5.16	1972	-2.4	1983	-2.59	1994	-4.27	2005	-3.97
1951	-4.71	1962	-3.88	1973	-3.97	1984	-2.8	1995	-4.33	2006	-2.28
1952	-5.57	1963	-5.75	1974	-2.54	1985	-2.35	1996	-2.59		
1953	-8.21	1964	-5.2	1975	-3.65	1986	-4.29	1997	-3.47		
1954	-6.45	1965	-4.83	1976	-5.41	1987	-6.56	1998	-1.84		
1955	-3.87	1966	-5.74	1977	-5.54	1988	-3.07	1999	-3		
1956	-2.17	1967	-4.74	1978	-5.64	1989	-1.45	2000	-2.4		
1957	-5.26	1968	-3.9	1979	-4.77	1990	-3.03	2001	-2.4		

QUICK FACTS:

- ✓ The British Antarctic Survey (BAS) have had a long term relationship with Palmer station and their meteorological observations at Faraday/ Vernadsky Station have been especially helpful due to the 5+ decades of consistency.
- ✓ Seasonal analysis of the air temperature data has resulted in significant changes.
- ✓ The annual progression of temperatures and the amount of variability associated with those temperatures usually suggests to a scientist that a shift is evident.
- ✓ The temperatures in this region are influenced by the sea ice decline which results in more open ocean.
- ✓ Increased winds are also associated with a warmer and more moist (maritime) climate as opposed to the continental environment which is typically cold and dry.

SPECIALIST REPORT SHEET

Name: ______________________________**Specialist Group:**______________________________

☐ Analyze the data sets. Graph your data.

☐ Interpret your graphs by describing possible explanations for your findings. Summarize the general trends or patterns in your data. Attach a graph of your data to the back of this sheet. Support your explanations.

☐ Write out how you will introduce yourself when you return back to your base group. For example: *"Welcome! I'm a X climatologist. I study long-term patterns in climate. My colleagues and I have tracked changes in air temperatures on the Antarctic Peninsula since 1947. We have observed that although temperature cycles up and down, it has increased overall. We think this might be occurring because of an increase of greenhouse gases, but we are unsure of the impacts on the Antarctic ecosystem. Your team's job is to describe the interconnected effects of warming on Antarctica's living and nonliving systems."*

☐ Consider the following questions with your Specialists group and record your answers:

Q: How has the ecosystem of the Antarctic Peninsula changed in the last 50 years? What are the most likely mechanisms for these changes?

Q: Is there sufficient evidence to support these explanations? Why or why not? What further questions are left unanswered?

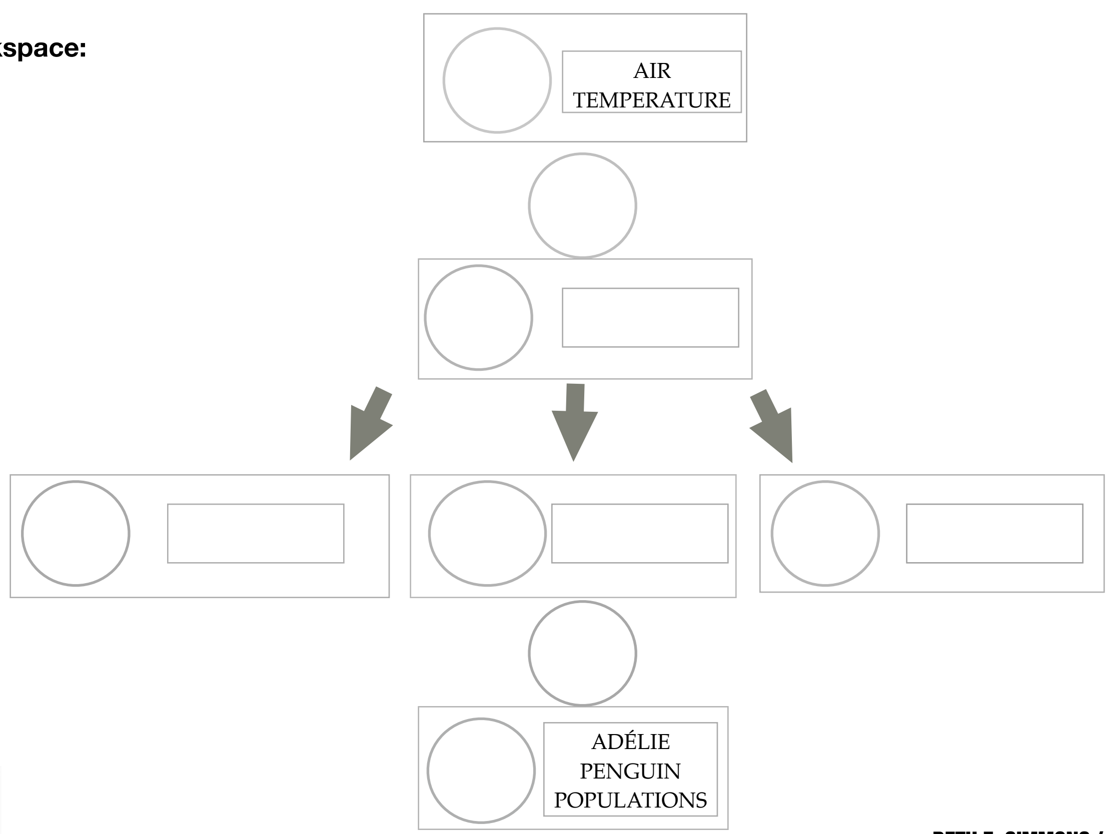
Q: Did your specialist group come up with any explanations that you think are not very likely (or not even possible!), based on the complete story presented by your base group?

☐ **Broader Connections:** How can ecosystems changes pose such a threat to the breeding success of a charismatic species like the Adélie penguin? Demonstrate the connections you have learned by first filling in the variable boxes □ adding words like sea ice, Chinstraps/Gentoos, krill densities, and precipitation from you unique specialist perspective. Then, add up ↑and down ↓ arrows in the flow chart circles ◯. See how your chart compares to the others in your base group when you return.

☐ As a base group build a flow chart that your entire group agrees upon taking into account all the various perspectives. Raise your hand and check with your instructor when your base group is ready to have their flow chart checked.

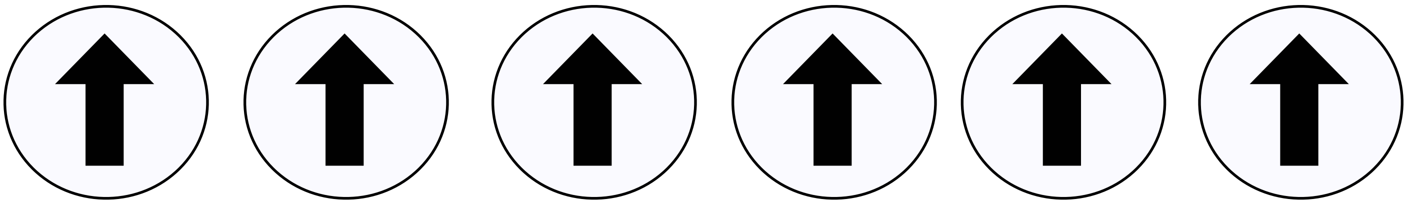
☐ Participate in class discussions when instructed by your teacher and when everyone is finished.

Workspace:

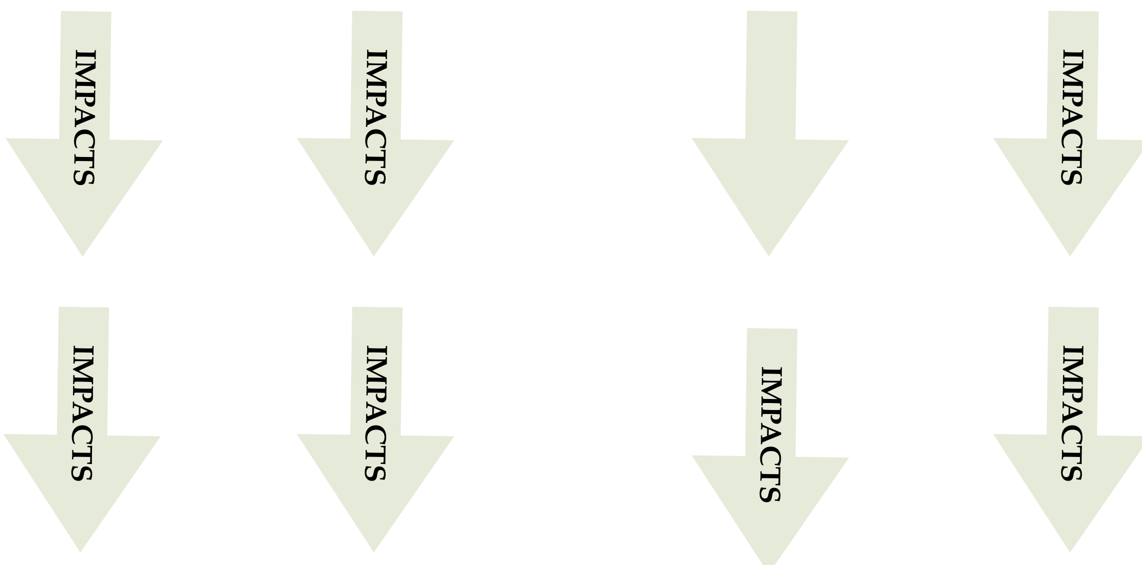


DIRECTIONS: Cut out the following pieces to construct a flow chart with your base group that represents how the western Antarctic Peninsula (WAP) has changed over time. Rearrange the pieces until you feel you have correctly shown the relationships that exist among all the research components. Then check your understanding by comparing your chart to the answer key with the teacher.

INCREASE / DECREASE ARROWS: Place one increase/decrease arrow within a research component box indicating how they have changed over time.



INTEGRATION ARROWS to be placed in between research components to demonstrate impact.



RESEARCH COMPONENTS:

AIR TEMPERATURE	KRILL DENSITIES	CHINSTRAP/GENTOO POPULATIONS
ADÉLIE PENGUIN POPULATIONS	SEA ICE EXTENT	WINTER SNOW