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How can we predict extreme winter weather?

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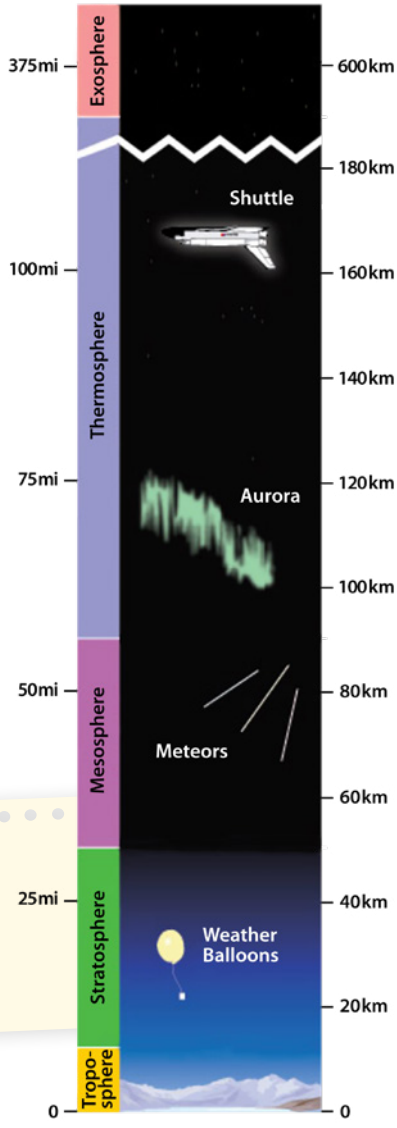
Abstract

Some winter days are so cold and snowy that you feel like you are living at the North Pole. But what causes the weather to be so cold? Freezing temperatures and heavy snow at lower latitudes often follow a weak polar vortex. A polar vortex is a band of strong winds that traps a large mass of cold air above the North and South Poles. When the polar vortex weakens, extreme cold air moves away from the poles. We wanted to work out what factors cause a weak Arctic polar vortex event. We found that warmer ocean temperatures cause air pressure changes. This change in air pressure causes a shift in the polar vortex in the upper atmosphere. Our results can help predict weak polar vortex events in winter. Predicting these events will improve the ability to forecast extreme cold and snow.

Introduction

Predicting the weather is a challenging task. That's because there are many factors that can cause weather patterns to change. Sometimes what happens in the **stratosphere** affects the weather patterns in the **troposphere**. For example, a **polar vortex** in the stratosphere above the North and South Poles affects the weather in the troposphere of the **middle latitudes**. A polar vortex is a band of strong winds that traps a large mass of cold air. The polar vortex affects the location of the polar **jet stream**. A jet stream is a narrow band of strong winds in the upper part of the troposphere. The polar jet stream is the boundary between the cold air at the poles and the warmer air at mid-latitude.

The polar vortex above the North Pole is known as the Arctic polar vortex. The polar vortex is strong when there is lower **air pressure** over the Arctic and higher air pressure in the northern Pacific and Atlantic Oceans. A strong polar vortex allows the polar jet stream to shift northward. It also has fewer curves. A smoother northern polar jet stream



Layers of the atmosphere.
Image: NOAA

causes cold air to stay at the pole. That means the mid-latitudes experience weather that is milder than usual. But sometimes there is higher air pressure over the Arctic and lower air pressure over the northern Pacific and Atlantic Ocean. This change in air pressure causes the polar vortex to become weak. A weak polar vortex could move off the pole. Or even split into two! This change causes the stratosphere to warm. It also causes the polar jet stream to become wavy. That means warm air moves toward the pole while very cold air moves into the mid-latitudes.

We wanted to figure out what causes a weak Arctic polar vortex. We hypothesized that there are events on the surface that cause the stratosphere to warm. Knowing what these events are will help improve weather predictions.

Methods

We analyzed 29 weak Arctic polar vortex events that occurred between 1979 and 2022. We divided them into two groups based on the type of weak polar vortex event. Group 1 showed movement of the polar vortex off the pole. Group 2 showed a polar vortex that split.

Then we focused on Group 1 to work out what might cause a shift of the polar vortex. We analyzed the surface conditions in the troposphere and in the ocean before the weak polar vortex events in this group. Data included observations of air pressure, air temperatures, sea surface temperatures, and sea ice concentrations. We used a computer to find patterns in the data.

Results

We found changes in surface pressure conditions in the 15 days leading up to events from Group 1 (Fig. 1). This happened for 65% of the events. During these events, there was low pressure over the Northern Pacific Ocean and high pressure over Europe and Asia. We also found that before a Group 1 event, the Northern Pacific Ocean was warmer. There was also a decrease in sea ice in the Barents-Kara Seas in the Arctic.

How did the temperature of the northern Pacific Ocean near Alaska change before a weak polar event occurred?

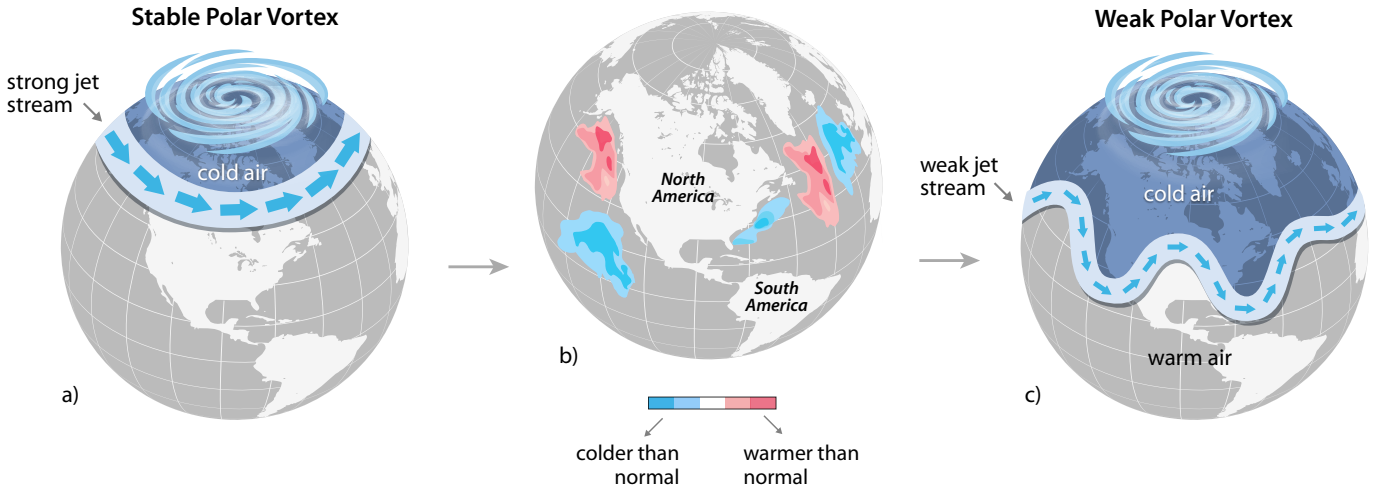


Figure 1: (a) A stable polar vortex causes a smooth jet stream. (b) The change in ocean temperature in the 15 days leading up to the Group 1 weak polar vortex events. (c) The impact of changes in ocean temperature on the polar vortex. As the polar vortex weakens, it results in the jet stream becoming wavy.

Discussion

Changes in ocean temperatures and sea ice can cause weak polar vortex events. Warmer ocean temperatures and a decrease in sea ice change the air pressure. The air pressure becomes lower over the Northern Pacific. But it becomes higher over North Europe and Asia. The pressure difference allows atmospheric waves to travel to the stratosphere. This disrupts the steady vortex, causing it to weaken and move off the pole.

Weak polar vortex events cause the weather to become extremely cold and snowy. During the February 2025 event, temperatures were as low as -22°C and -39°C in some places. Our findings can improve the ability to predict these weak polar vortex events. The effects of Group 1 events on mid-latitude weather occur about 2–4 weeks after the event. That means predicting an event helps forecasters predict weather changes earlier.

Knowing why ocean temperatures and sea ice change is also important. Causes could include human activities that cause the atmosphere to warm. A warmer atmosphere causes a warmer ocean and less sea ice. That means human activities can affect the number of weak polar vortex events.

Conclusion

A weak polar vortex event can cause freezing temperatures and heavy snow. When these events occur, it is important to make sure you are safe. Stay inside whenever possible, especially during snow storms. If you need to go outside, make sure to wear clothes that can protect you from the cold temperatures. This includes wearing layers of clothing. You should also wear gloves or mittens, a coat, and a hat. Plus, you'll want to make sure that your pets are wearing clothes that keep them warm if they need to be outside. Staying warm during a polar vortex event is important for everyone!

Glossary of Key Terms

Air pressure - the force exerted by atoms and molecules of air. Sinking air pushes down on Earth's surface, causing higher air pressure. Rising air lifts off of Earth's surface, causing low air pressure.

Jet stream - a narrow band of strong winds in the upper part of the troposphere.

Middle latitudes - a region of the Earth located between the tropics and North and South Poles.

Polar vortex - a band of strong winds that traps a large mass of cold air at the North and South Poles.

Stratosphere - the second layer of the atmosphere located about 10–50 km above Earth's surface.

Troposphere - the lowest level of the atmosphere where humans live and where weather occurs.

REFERENCES

Mostafa E. Hamouda, Alice Portal, and Claudia Pasquero (2024) *Polar vortex disruptions by high latitude ocean warming*. Advancing Earth and Space Sciences: Geophysical Research Letter.
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023GL107567

NOAA Climate.Gov: Understanding the Arctic polar vortex
https://www.climate.gov/news-features/understanding-climate/understanding-arctic-polar-vortex

Kids Konnect: Polar vortex facts & worksheets
https://kidskonnect.com/geography/polar-vortex/

Check your understanding

1. How does the polar jet stream change when the polar vortex weakens?

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2. How does a weakening in the Arctic polar vortex cause changes in the weather at middle latitudes?

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3. How does ocean warming and a decrease in sea ice cause a change to the polar vortex in the stratosphere?

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4. With a partner, brainstorm a list of human activities that could contribute to changes in ocean temperatures in the Northern Pacific.

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5. Imagine you are a meteorologist for your local news network. Write a weather forecast informing people about a future weak polar vortex event. Include how they can prepare for the predicted changes in the weather.

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