The Road to Recovery: Is the Ozone Layer Finally Healing?

Educator guide

PAPER DETAILS

Original title: Emergence of healing in the Antarctic ozone layer

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DISCUSSION QUESTIONS

	LEARNING STANDARDS
1. Which human-made chemicals do the authors identify as being responsible for creating the hole in the ozone layer, and why are they so effective at depleting stratospheric ozone?	Cause and effect STB-4.A.2 ERT-4.D.1 ERT-4.D.2 RST.11-12.2
2. Why is it important to separate the effects of human activity on the ozone layer from natural variations? How do the authors separate the two?	Cause and effect SP1 STB-4.A.2 VC1 VC6 RST.11-12.6 ESS3.C
3. What role do volcanic eruptions play in the depletion of the ozone layer?	SP1 Cause and effect STB-2.D.2 ESS3.B
4. Why are computer models and simulations important in describing processes in the stratosphere? How do the authors make use of computer simulations in this work?	SP4 SEP2 SEP5 Systems and system models ERT-4.D.2 VC3 RST.11-12.1
5. How is the effort to heal the ozone layer similar to the effort to stop human-caused global warming? How are the two issues different?	SP7 Cause and effect STB-4.E.1 ESS3.C ESS3.D

ACTIVITIES FOR INTERACTIVE ENGAGEMENT

	LEARNING STANDARDS
Science in the news Students explore news stories in the Related Resources tab and evaluate the stories for tone, accuracy, missing information, etc. They may then write their own news stories on the article.	RST.9-10.5 RST.11-12.5 RST.9-10.6 RST.11-12.6 RST.9-10.8 RST.11-12.8
TEDx Talk Watch the TEDx talk “Can we solve global warming? Lessons from how we protected the ozone layer.” https://www.youtube.com/watch?v=08z_xW-szwM List the key lessons that can be learned from the Montreal Protocol.	Cause and effect STB-4.E.1 STB-4.A.3 STB-4.A.2 RST.11-12.7 VC6
Results and conclusions Read the World Meteorological Organization’s (WMO) announcement on the record-breaking large hole in the ozone layer in the year 2020. https://public.wmo.int/en/media/news/record-breaking-2020-ozone-hole-closes Summarize the key reason given by WMO for this large hole, and explain whether this reasoning is consistent with the ozone-depletion factors described in the paper.	Cause and effect VS1 NS1 SP3 RST.11-12.9 SEP7
The next steps Students design a follow-on experiment to this study that either addresses flaws or unanswered questions in the research at hand or builds on it to explore a new question.	SEP4 EK4.A.5 Cause and effect SP5

ARTICLE OVERVIEW

Article summary (recommended for educator use only)

The Montreal Protocol was adopted more than 30 years ago to phase out the use of human-made chemicals such as chlorofluorocarbons (CFCs) that are responsible for creating the hole in the Antarctic ozone layer. This article investigates whether there are any signs that the Antarctic ozone layer is healing by using both ozone measurement data and computer models and simulations. The authors used simulation data to separate the human-made chemical effects from natural factors such as temperature variations and volcanic eruptions. They found that while a sizable hole continues to form over the Antarctic every year, the hole tends to open later in the year, and it is generally decreasing in size. The authors noted that the record large holes in 2011 and 2015 were attributable to volcanic eruptions.

Importance of this research

This study was completed to determine whether the Antarctic ozone hole is beginning to heal in response to the reduction of ozone-depleting substances. Much of the previous work looked at ozone data in the month of October because this is the month when the hole was originally discovered. However, the current study also looks at September data to find signs of healing. Since this study was completed several years ago in 2016, it could be extended by looking for ozone hole trends in more recent years. Also, further research is needed to understand how global climate change will impact the healing of the ozone layer.

Experimental methods

- Ozone Observations:
    - Ground Measurements:
        - Dobson Spectrophotometer
        - Balloon Ozonesondes
    - Satellite Measurements:
        - Solar Backscatter Ultraviolet (SBUV) satellite
        - Total Ozone Mapping Spectrometer (TOMS) and ozone monitoring instrument (OMI) Data
- Ozone Model Calculations:
    - Community Earth System Model 1 (CESM1) Whole Atmosphere Community Climate Model (WACCM)
    - Full Model with chemistry, dynamic meteorological factors, and volcanic particles ("chem-dyn-vol")
    - Volcanically clean model that removes effect of volcanic particles ("vol-clean")
    - Chemistry-only model in which meteorological factors are fixed at 1999 conditions and effects of volcanic particles have been removed ("chem-only")

Conclusions

- The ozone hole over the Antarctic is beginning to heal due to a reduction of ozone-depleting substances.
- The hole is starting to open later in the year, and while its size is generally decreasing from year to year, there is significant variability due to natural factors.
- Natural factors which lead to year-to-year variability in the ozone hole's size include stratospheric temperature and volcanic eruptions. Colder stratospheric temperatures accelerate depletion of the ozone layer, and volcanic eruptions release aerosol particles that also promote ozone depletion.
- The record large ozone holes in 2011 and 2015 were due to large volcanic eruptions. Simulations show that if the volcanic eruptions were not a factor, the hole would have shown signs of healing in those years as well.

LEARNING STANDARDS ALIGNMENT

The following tables provide an overview of the learning standards covered by this article, including A Framework for K-12 Science Education (Framework), Common Core State Standards English Language Arts & Literacy (CCSS ELA), Common Core State Standards Statistics and Probability (CCSS HSS), AP Science Practices, and Vision and Change in Undergraduate Biology Education. Where applicable, activities and information will be marked with specific standards to which they are linked.

A Framework for K-12 Science Education		
Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models (SEP2) Used in science and engineering as either structural, functional, or behavioral analogs, albeit simplified, conceptual models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. **Using Mathematics and Computational Thinking (SEP5)** Computational tools enhance the power of mathematics by enabling calculations that cannot be carried out analytically. For example, they allow the development of simulations, which combine mathematical representations of multiple underlying phenomena to model the dynamics of a complex system. **Engaging in Argument from Evidence (SEP7)** Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.	**ESS3.B: NATURAL HAZARDS** Natural processes can cause sudden or gradual changes to Earth's systems, some of which may adversely affect humans. Through observations and knowledge of historical events, people know where certain of these hazards—such as earthquakes, tsunamis, volcanic eruptions, severe weather, floods, and coastal erosion—are likely to occur. **ESS3.C: HUMAN IMPACTS ON EARTH SYSTEMS** The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources. When the source of an environmental problem is understood and international agreement can be reached, human activities can be regulated to mitigate global impacts (e.g., acid rain and the ozone hole near Antarctica). **ESS3.D: GLOBAL CLIMATE CHANGE** Though the magnitudes of humans' impacts are greater than they have ever been, so too are humans' abilities to model, predict, and manage current and future impacts. Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities, as well as to changes in human activities.	**Cause and effect** Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts. **Systems and system models** Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

Common Core State Standards English Language Arts & Literacy		
Key Ideas and Details	Craft and Structure	Integration of Knowledge and Ideas
RST.9-10.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. **RST.9-10.2** Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. **RST.11-12.1** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. **RST.11-12.2** Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.	**RST.9-10.4** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 9-10 texts and topics*. **RST.9-10.6** Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address. **RST.11-12.4** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*. **RST.11-12.6** Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.	**RST.9-10.7** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. **RST.9-10.8** Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. **RST.9-10.9** Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts. **RST.11-12.7** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. **RST.11-12.9** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. **RST.11-12.8** Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

AP Science Standards	
AP Science Practices	AP Biology Content Standards
Science Practice 1 (SP1) Explain environmental concepts, processes, and models presented in written format. **Science Practice 3 (SP3)** Analyze sources of information about environmental issues. **Science Practice 4 (SP4)** Analyze research studies that test environmental principles. **Science Practice 7 (SP7)** Propose and justify solutions to environmental problems.	**Essential knowledge 4.A.1 (STB-4.A.1)** The stratospheric ozone layer is important to the evolution of life on Earth and the continued health and survival of life on Earth. **Essential knowledge 4.A.2 (STB-4.A.2)** Stratospheric ozone depletion is caused by anthropogenic factors, such as chlorofluorocarbons (CFCs), and natural factors, such as the melting of ice crystals in the atmosphere at the beginning of the Antarctic spring. **Essential knowledge 4.A.3 (STB-4.A.3)** A decrease in stratospheric ozone increases the UV rays that reach the Earth's surface. Exposure to UV rays can lead to skin cancer and cataracts in humans. **Essential knowledge 4.B.1 (STB-4.B.1)** Ozone depletion can be mitigated by replacing ozone-depleting chemicals with substitutes that do not deplete the ozone layer. Hydrofluorocarbons (HFCs) are one such replacement, but some are strong greenhouse gases. **Essential knowledge 4.E.1 (STB-4.E.1)** Global climate change, caused by excess greenhouse gases in the atmosphere, can lead to a variety of environmental problems including rising sea levels resulting from melting ice sheets and ocean water expansion, and disease vectors spreading from the tropics toward the poles. **Essential knowledge 4.D.1 (ERT-4.D.1)** The atmosphere is made up of major gases, each with its own relative abundance. **Essential knowledge 4.D.2 (ERT-4.D.2)** The layers of the atmosphere are based on temperature gradients and include the troposphere, stratosphere, mesosphere, thermosphere, and exosphere. **Essential knowledge 2.D.2 (STB-2.D.2)** There are a variety of natural sources of particulate matter.

Connections to the Nature of Science	
Vision and Change in Undergraduate Biology Education Core Competencies and Disciplinary Practices	A Framework for K-12 Science Education Understandings About the Nature of Science
Ability to apply the process of science (VC1) All students need to understand the process of science and how scientists construct new knowledge by formulating hypotheses and then testing them against experimental and observational data about the living world. **Ability to use modeling and simulation (VC3)** All students should understand how mathematical and computational tools describe complex systems. As new computational approaches improve our ability to study the dynamics of complex systems, mathematical modeling and statistical approaches are becoming an important part of the scientist's tool kit. **Ability to understand the relationship between science and society (VC6)** Scientists have an increasing opportunity to address critical issues affecting human society by advocating for the growing value of science in society, by educating all students about the need for science to address pressing global problems, and by preparing the future workforce.	**Scientific Investigations Use a Variety of Methods (NS1)** Scientific inquiry is characterized by a common set of values that include logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings.