11-12-2019

Lessons from the Ozone Hole

Carl P. Fictorie
Dordt University, carl.fictorie@dordt.edu

Lessons from the Ozone Hole

Abstract

"Good science works with evidence from creation, follows logically from that evidence, and avoids bias on the part of the scientist."

Posting about current environmental challenges from *In All Things* - an online journal for critical reflection on faith, culture, art, and every ordinary-yet-graced square inch of God's creation.

https://inallthings.org/lessons-from-the-ozone-hole/

Keywords

In All Things, creation, ozone layer depletion, ultraviolet radiation

Disciplines

Atmospheric Sciences | Christianity

Comments

In All Things is a publication of the Andreas Center for Reformed Scholarship and Service at Dordt University.

in all things

November 12, 2019

Lessons from the Ozone Hole

Carl Fictorie

Recently, NASA reported that the 2019 ozone hole was the smallest it's been since 1982.[1] The ozone hole was discovered in 1985, and after about 15 years of research began to show the possibility of ozone destruction due to planned supersonic aircraft and the increasing use of chlorofluorocarbons (CFCs). How did the ozone hole go from being non-existent in 1980, to peaking in size in 2006, and now reaching a new low 40 years later?

Ozone, a form of oxygen containing three oxygen atoms, O_3, is formed naturally in the stratosphere (15-50 km above sea level). Only a very small fraction of the air molecules are ozone, about 1 in 100,000, but this is enough to provide a protective shield as it absorbs harmful UV radiation from the Sun.

The ozone hole is a seasonal weather phenomenon that occurs in Antarctica during September and October. As the sun rises over the Antarctic during its spring season, the sunlight instigates a series of chemical reactions involving ozone and catalysts derived from CFCs, most notably atomic chlorine. These reactions convert a large fraction of the ozone into the more stable molecular oxygen, O_2. The consequence of this is that a much larger amount of harmful UV light is able to reach the surface of Earth. As the Antarctic spring continues, the polar vortex formed during the dark winter breaks up, and the air above Antarctica is able to mix with air from the southern latitudes. The ozone hole then disappears until the following spring.

In 1995, Paul Crutzen, Mario Molina, and F. Sherwood Rowland were awarded the Nobel prize for their work in developing theories to understand the particular reactions involved in ozone destruction.[2] Their theory started with the original work by Sidney Chapman who in the 1930s developed a reaction mechanism that explained how ozone is naturally formed in the stratosphere. This mechanism, now called the Chapman mechanism, involves a group of reactions that both create and destroy ozone. In a normal atmosphere, these reactions result in a steady-state concentration of ozone, a concentration that results in a small, but stable amount of ozone.

Crutzen, in the early 1970s, showed that exhaust fumes from jet engines include nitrogen oxides that also catalyze the destruction of ozone very effectively. Nitrogen oxides are generated in any petroleum fueled vehicle due to reactions of oxygen and nitrogen in the engine. At ground level, these nitrogen oxides produce smog. At the time, supersonic flight was being developed, with planes flying high enough to emit their exhaust in or near the stratosphere where the ozone concentration peaks.

CFCs were widely produced from the 1950s to the 1970s. They were ideal in many ways—nonflammable, nontoxic, and nonreactive—which led to their use in a wide range of products.[3] The most notable of these products included: air conditioners, refrigerators, aerosol cans, and degreasing solvents. The latter two of these, when used, emit those CFCs into the atmosphere, and disposal of the former often involved venting the CFCs to the air. Because of their chemical stability, CFCs migrate up into the stratosphere where UV rays from sunlight breaks them down to form atomic chlorine. Atomic chlorine is also a potent catalyst for the destruction of ozone. Molina and Rowland then showed that CFCs stay in the atmosphere for decades—and the effects of their presence would last for decades, even if CFC use stopped immediately. Given this concern, these scientists then called for a ban on CFC use.[4] In 1985, the British Antarctic Survey reported on a multiyear study showing a major decrease in the ozone concentration above Antarctica. The ozone hole had been discovered.[5]

The threat of ozone depletion was of enough significant concern to world leaders that in 1987 a United Nations treaty, called the Montreal Protocol, was signed in order to phase out the use of CFCs over the past three decades around the world. CFCs are no longer being produced in developed countries and other materials have replaced CFCs for the products described above. Research continues in developing chemicals that have the desirable properties of CFCs but do not present risks to the ozone layer or the climate.[6]

The graph below shows the maximum size of the ozone hole for each year since 1980. The ozone hole increased steadily from 1980 through the early 2000s. It peaked in 2006 (noted in red) and has been decreasing ever since. The news report was careful to note that the 2019 value is unusual, and likely due to a warm stratosphere this year. However, the general pattern is showing a slow decline in the ozone hole over time. NASA's Ozone Watch continues to monitor the ozone hole and will continue to do so indefinitely until the ozone hole heals. This is expected to take until the end of the century.[7] That is, 30 years of producing and using a group of chemicals results in a century's worth of harm to the atmosphere.

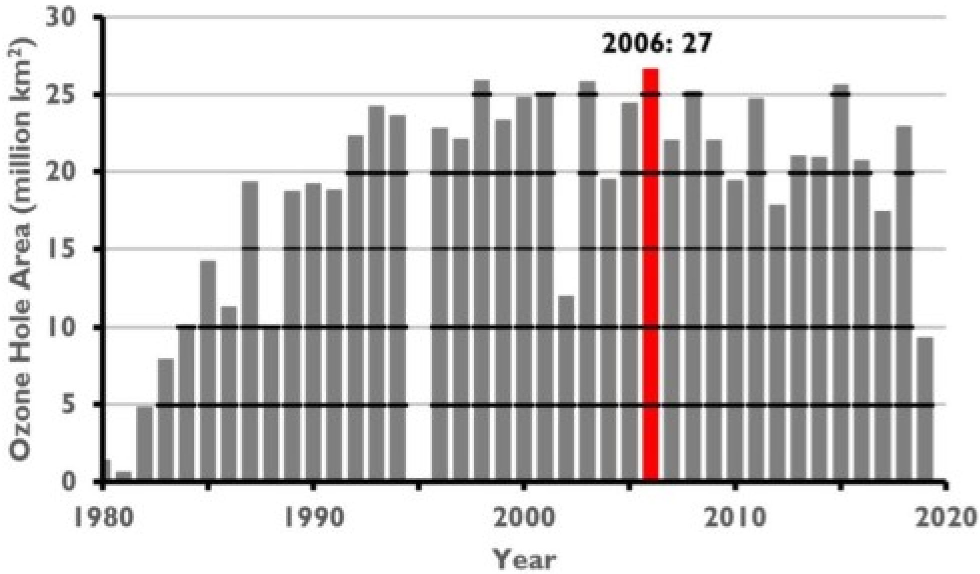

Figure 1. The maximum size of the Antarctic ozone hole for each year from 1980-2019. Data from NASA Ozone Watch, https://ozonewatch.gsfc.nasa.gov/.

So, what had Cruzten, Sherwood, and Molina done? They did science. Motivated by a curiosity about how nature works, they discovered, studied, and talked about chemistry that would have negative global implications if left alone. Sherwood and Molina were not looking for ozone depletion. Rather, they were merely trying to learn what would happen to CFCs in the atmosphere.[8] Their studies, building on theories, models, and data published earlier, developed the model of ozone destruction that is now the standard model included in textbooks.[9] [10] In the span of two decades, scientific research had collected sufficient evidence and developed a good theory to explain the phenomenon of ozone destruction which led to an international effort to address and mitigate the problem. Consequently, this story has become a case study for those interested in understanding science based public policy.[11] If this is a case study, what lessons might we, as Christian stewards of the creation, take from this story?

First, we see the providential work of God in action. It is good to remind ourselves that the very fact that creation operates in a consistent and law-like manner is a direct result of God sustaining it through his almighty hand.[12] The natural formation and destruction of ozone in the atmosphere, the decomposition of CFCs by ultraviolet radiation, the catalytic activity of chlorine atoms, and climate events that enable the formation of the ozone hole are all held in God's hand.

It is important to recognize that God's faithfulness to nature extends to poor choices made by humans. While the ozone hole may be the result of a fairly innocent failure to predict the climate effects of CFCs, God did not miraculously intervene to prevent humanity from hurting itself. On this side of glory, we likely will never know if God worked in the hearts of people to nudge them into a particular discovery or action. Yet, we can be confident that all these things will work themselves out for God's glory.

Second, we see in this study that humans are able to understand how creation works. God calls us to be stewards of his creation.[13] Our role of stewards gives us authority to use creation, but not to destroy it.[14] I teach my students that the foundation of science in grounded in this notion of stewardship. If we are to be good stewards that properly use and care for creation, we must understand how nature works. Science provides the tools and methods to gain that knowledge.

In the case of the ozone hole, the chemistry and physics involved all fall well within the bounds of well-established science. CFCs were designed to have specific properties using known chemical principles. The chemistry of the Chapman cycle follows well understood rules of chemical kinetics. Even Sherwood and Molina used previous published research about the catalytic activity of chlorine atoms. There is more science involved in the ozone hole than this essay can describe, but it suffices to say that the overall system, while unique and novel for its time, did not overturn any fundamental chemical or physical ideas.

In general, scientists work to develop models and theories that are faithful to the natural world they investigate.[15] Good science works with evidence from creation, follows logically from that evidence, and avoids bias on the part of the scientist. It follows from these points that science, when practiced rightly, can reflect the wisdom of God, even if the scientists do not believe in God themselves.

Third, acceptance of the ideas and conclusions of scientific investigations is a reasonable thing to do.[16] Because God faithfully sustains his creation, and because scientists approach nature objectively and reasonably, we do well to respect that work. All truth is God's truth,[17] and this should be true of good science as well.

That is not to say science is infallible or that scientists are never biased. The knowledge obtained through science is never perfect. Humans are finite creatures and our theories and models are at best approximations. Scientists can, and do, let their biases and sinful tendencies get in the way. Yet, science does have mechanisms to correct for errors and to improve despite these weaknesses.

Fourth, given what we have learned about the causes and effects of the ozone hole, it is clear that humans have the ability to affect the atmosphere on a global scale.

Fifth, because of humanity's ability to affect the climate on a global scale, it also stands to reason that our role as stewards of the creation has to take this ability into account[18] This is a place where science on its own fails us. Science is an excellent means to understand the creation, and its theories and concepts can provide useful knowledge, but as modern scientists currently practice it, science does not give moral guidance on what to do with that knowledge. Science does not provide the wisdom needed to judge how to use the knowledge science provides.

In the press release overviewing the 1995 award, The Nobel Committee comments as follows: "By explaining the chemical mechanisms that affect the thickness of the ozone layer, the three researchers have contributed to our salvation from a global environmental problem that could have catastrophic consequences."[19] While scientists tend to focus on the knowledge their studies generate, the work of Sherwood and Molina point to the moral obligations of scientists as well. Upon realizing the implications of the continued use and emission of CFCs into the atmosphere, they called for action. While this formally lies outside the ordinary work of scientists, sometimes one has to don a prophetic hat. We do well to consider these lessons as we face similar global challenges in this time.

FOOTNOTES

1. E. Gray and T. Stein, "2019 Ozone Hole is the Smallest on Record Since Its Discovery", Oct 21, 2019, **https://www.nasa.gov/feature/goddard/2019/2019-ozone-hole-is-the-smallest-on-record-since-its-discovery**
2. Press release. NobelPrize.org. Nobel Media AB, 1995, **https://www.nobelprize.org/prizes/chemistry/1995/press-release/**.
3. C. Baird and M. Cann, *Environmental Chemistry*, 5th ed., New York: W. H. Freeman, 2012, pp 37-65.
4. F. S. Rowland with R. Cowen, "The Ozone Depletion Phenomenon", in *Beyond Discovery: The Path from Research to Human Benefit*, Washington, D.C.: National Academy of Sciences, 1996, **https://www.nap.edu/read/9042/chapter/1#5**.
5. *Environmental Science* by R.T. Wright and D. F. Boorse (11th ed., Boston: Benjamin Cummings, 2011, pp 36-38 and 509-515) uses the ozone hole as a case study in scientifically informed public policy.

6. See, for example, J. B. Burkholder et al. "Atmospheric Degradation of Ozone Depleting Substances, Their Substitutes, and Related Species," *Chem. Rev.* 2015, 115, 10, 3704-3759, **https://doi.org/10.1021/cr5006759**.
7. World Meteorological Organization (WMO), *Executive Summary: Scientific Assessment of Ozone Depletion: 2018*, World Meteorological Organization, Global Ozone Research and Monitoring Project—Report No. 58, 67 pp., Geneva, Switzerland, 2018, **https://www.esrl.noaa.gov/csd/assessments/ozone/2018/**.
8. *Environmental Science* by R.T. Wright and D. F. Boorse (11th ed., Boston: Benjamin Cummings, 2011, pp 36-38 and 509-515) uses the ozone hole as a case study in scientifically informed public policy.
9. World Meteorological Organization (WMO), *Executive Summary: Scientific Assessment of Ozone Depletion: 2018*, World Meteorological Organization, Global Ozone Research and Monitoring Project—Report No. 58, 67 pp., Geneva, Switzerland, 2018, **https://www.esrl.noaa.gov/csd/assessments/ozone/2018/**.
10. F. S. Rowland with R. Cowen, "The Ozone Depletion Phenomenon", in *Beyond Discovery: The Path from Research to Human Benefit*, Washington, D.C.: National Academy of Sciences, 1996, **https://www.nap.edu/read/9042/chapter/1#5**.
11. *Environmental Science* by R.T. Wright and D. F. Boorse (11th ed., Boston: Benjamin Cummings, 2011, pp 36-38 and 509-515) uses the ozone hole as a case study in scientifically informed public policy.
12. Heidelberg Catechism Q & A 27 and the Belgic Confession Article 13.
13. R. J. Berry, *The Care of Creation: Focusing Concern and Action*. IVP, 2000, pp 17-22.
14. I. Hore-Lacy, *Responsible Dominion: A Christian Approach to Sustainable Development*, Vancouver: Regent College Publishing, 2006.
15. American Association for the Advancement of Science, *Science for All Americans*, Oxford University Press, 1989, chapter 1.
16. D. Ratzsch, *Science & Its Limits: The Natural Sciences in Christian Perspective*, Intervarsity Press, 2000.
17. A. F. Holmes, *All Truth is God's Truth*, Intervarsity Press, 1977.
18. R. J. Berry, *The Care of Creation: Focusing Concern and Action*. IVP, 2000, pp 17-22.
19. Press release. NobelPrize.org. Nobel Media AB, 1995, **https://www.nobelprize.org/prizes/chemistry/1995/press-release/**.