The case for continual ozone research

Ozone plays a critical role in balancing Earth's energy budget, but it can also be harmful to humans, plants, and agriculture near the surface of the Earth. Although scientists have been studying this important compound for decades, we are still learning more about the unique chemical and physical properties of ozone and how they affect life on our home planet.

Thirty years of the Montreal Protocol

This September marks the 30th anniversary of the Montreal Protocol, the international agreement largely attributed with solving one of society's greatest environmental challenges: the thinning of the stratospheric ozone layer.

The Montreal Protocol put into place key restrictions on chemical compounds known to damage the ozone layer. For thirty years, signatories to the agreement have avoided, regulated, and created substitutes for these harmful compounds; and now, we're beginning to see the results.

Three satellites, dozens of airborne campaigns, and countless balloon launches later, we're finally beginning to see the ozone hole recover. Scientific studies using NASA data have concluded that from 2000 to 2015, the average extent of the September Antarctic ozone hole shrank by about 4.5 million square kilometers[1]—this during a season when the ozone hole typically increases in size. In addition, a 2014 assessment by the World Meteorological Organization found that the ozone hole had even begun to recover at high elevations in mid- and low-latitudes.[2]

Although scientists believe the Montreal Protocol is to thank for much of this success, it's only a piece of the larger puzzle. In fact, the observed rate of ozone recovery has been much faster than originally anticipated with the Montreal Protocol alone, leading many in the scientific community to conclude that the real reason is much more complicated and that there's still more to learn.

Settled science? What we still don't know about ozone

After decades of research, there are still many things about ozone that we do not understand.

What we do know:

- We know O_3 column amount and stratospheric profiles from satellites
- We understand the main chemical pathways to O_3 from formation to depletion in the stratosphere
- We know that volatile organic compounds from man-made (e.g. power plants and cars) and naturally occurring (large forested areas) sources create ozone near the Earth's surface.
- We know that chlorine- based compounds are especially harmful to stratospheric ozone.

What we don't know:

- We don't know how ozone transported throughout the atmosphere. How often does ozone from stratosphere—where want it—ever sink down into the troposphere—where we don't want it?

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[1] http://www.sciencenews.org/article/despite-volcanic-setback-antarctic-ozone-hole-healing
[2] Scientific Assessment of Ozone Depletion: 2014
http://www.wmo.int/pages/prog/arep/gaw/ozone_2014/ozone_asst_report.html

- We don't know how to dynamic meteorological events, such as severe storms, affect the distribution of ozone in the atmosphere.
- We don't know how will changes in Earth's climate will affect the distribution of ozone vertically in the atmosphere and around the world.
- We don't know how chemical compounds of the future might affect the ozone layer.

Comment [AS1]: These bulleted lists are very rough—I will refine them.

The need for NASA Earth Science: Protecting the environment, public health and safety

Investing in ozone research protects the environment and contributes to our public health and safety. Up in the stratosphere, ozone serves as a protective shield, blocking us from the sun's harmful ultraviolet (UV) rays; down in the troposphere, however, ozone acts as a pollutant: clogging our air and harming our lungs.

High levels of tropospheric ozone negatively affect humans and plants. According to the U.S. Environmental Protection Agency (EPA), unsafe levels of ozone in the troposphere are associated with higher risk of respiratory related deaths; and the U.S. Department of Agriculture has reported that unhealthy ozone concentrations have ruined more than X percent of crops.

Unsafe ozone concentrations are a global problem, and NASA's Earth Science Division (ESD) provides the tools for decision makers to find a global solution. Ozone molecules disperse throughout the atmosphere regardless of natural and manmade boundaries, and ESD's global network of satellites, aircraft, ozone balloons, and ground-based systems help provide the bigger picture of ozone around the world.

Research conducted across NASA's Earth Science Division has helped advance what we know about ozone, its chemical precursors, and how humans influence ozone depletion and creation.

- What we're learning from current satellite missions and instruments
  - S-NPP (OMPS)
  - ISS (SAGE III)
- What we're learning from recent airborne campaigns
  - DISCOVR-AQ
- What we've learned from ozonesondes
  - SHADOZ
- What we've learned from ground retrieval systems
  - AERONET
- What we've learned from modeling

Comment [AS2]: These will be bulleted paragraphs highlighting science results from each method of measuring ozone (satellites, airborne campaigns, ozonesondes, ground systems, and modeling). There will be a separate pop-out box listing ALL current and historical NASA assets we have used to measure ozone.

The importance of comprehensive, long-term datasets

NASA modeling efforts indicate the ozone hole will get better, but its recovery will take many decades. It's critical that we continue to monitor the progress of the ozone hole for all of our health and safety. The path to recovery for the ozone hole will be very long, and we must make sure that the actions we're taking have the intended effect. Therefore, we must continue to monitor any slight variations that may occur in the ozone hole to ensure its continued recovery, and monitor for any other smaller disturbances that might signal larger things to come.

New and emerging chemicals could delay the recovery of the ozone layer (ex: dichloromethane could delay ozone recovery by 30 years). Are people are adhering to the Montreal Protocol.

Important to maintain integrity of the data and we're still not sure how the ozone hole will react. We expect it will get better, but this is something that takes time that we must continue to monitor for our health and safety.

Climate change and ozone

Comment [AS3]: Based on feedback from Steve Platnick, I will include a separate section for climate change and ozone: e.g. ozone affects a Earth's climate, but also how Earth's climate affects ozone.

Pop-out box: Measuring ozone from the ground up (and space down)

We are really good at using satellites to see ozone in the stratosphere. We are not good at using satellites to see ozone in the troposphere.

Size comparison. Cost comparison. What other chemical compounds they see. What we've learned. Drawn to scale?