Ozone depletion: chemistry, trends and dynamics, the extent of recovery and prospects through the 21st century

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Overview

• **Findings:** WMO/UNEP Scientific Assessment of Ozone Depletion: 2014
  – ODSs and their trends
  – Ozone trends
  – Future projections of stratospheric ozone
  – Impact of GHGs on ozone and the stratosphere

• **Plans:** WMO/UNEP Scientific Assessment of Ozone Depletion: 2018
  – Parties have agreed to a very broad “Terms-of-Reference” for this Assessment at the Meeting of the Parties (Nov. 2015)
  – A review of our scientific knowledge, including the topics covered in WMO/UNEP 2014
  – Assessment of recent volcanic effects and of possible climate engineering methods on future stratospheric ozone
  – A Protocol amendment that controls hydrofluorocarbons (HFCs) is being negotiated this year (Rwanda, Oct. 2016)
Chapter 1: Update on Ozone-Depleting Substances (ODSs) and Other Gases of Interest to the Montreal Protocol
Lucy Carpenter (University of York, UK), Stefan Reimann (Empa, Switzerland)
Andreas Engel (Germany), Steve Montzka (USA)

Chapter 2: Update on Global Ozone: Past and Future
Steven Pawson (NASA GSFC, USA), Wolfgang Steinbrecht (Deutscher Wetterdienst, Germany)
Vitali Fioletov (Canada), Ulrike Langematz (Germany)

Chapter 3: Update on Polar Ozone: Past and Future
Martin Dameris (DLR, Institut für Physik der Atmosphäre, Germany), Sophie Godin-Beekmann (LATMOS/CNRS/UVSQ/UPMC, France)
Judith Perlwitz (USA), Slimane Bekki (France)

Chapter 4: Stratospheric Changes and Climate
Julie Arblaster (Australian Bureau of Meteorology, Australia), Nathan Gillett (Environment Canada, Canada)
Lesley Gray (UK), David Thompson (USA)

Chapter 5: Scenarios, Information, and Options for Policymakers
Neil Harris (Cambridge University, UK), Don Wuebbles (University of Illinois, USA)
Mack McFarland (USA), Guus Velders (Netherlands)
What is the Montreal Protocol?

- The *Vienna Convention for the Protection of the Ozone Layer (1985)* is a multilateral environmental agreement. It is a framework for efforts to protect the ozone layer, but has no binding actions.
  - Recognized the need to protect the ozone layer
  - Established a Secretariat & regular meeting for ozone layer issues
  - Established a framework for science research
- The *Montreal Protocol on Substances That Deplete the Ozone Layer (1987)* is an agreement that supplements the Vienna Convention.
  - Regulates the production and consumption of specific substances that modify the ozone layer. Prohibits trade with non-signatory countries.
  - Multi-Lateral Fund (Article 10), regular reporting of production & consumption (Article 7), re-examination of control measures.
  - Assessment process (Article 6), every 4 years, Science Assessment Panel (SAP), Technology and Economics Assessment Panel (TEAP), and Environmental Effects Assessment Panel (EEAP).
What is the Scientific Assessment Panel (SAP)?

**Article 6: Assessment and review of control measures**

Beginning in 1990, and **at least every four years** thereafter, the Parties shall assess the control measures provided for in Article 2 and Articles 2A to 2I on the basis of available **scientific, environmental, technical and economic information**.

- UNEP initiated the assessment panel process in 1988 pursuant to Article 6 of the Montreal Protocol.

- The SAP Co-chairs are chosen and approved by the Parties to the Protocol, and serve at the pleasure of the Parties to the MP. Members of the SAP (Lead Authors, Coauthors, Chapter Editors, Steering Committee) are selected by the Co-chairs, approved by the Parties, and then serve for the duration of the assessment process.

- Assessments are now performed every 4 years, but in the early years the frequency was much higher.
Ozone-depleting substances (ODSs) are decreasing

Tropospheric Chlorine Source Gases

- CH$_3$CCl$_3$
- CCl$_4$
- CFC-113
- CFC-11
- CFC-12
- CH$_3$Cl

1996
- 3522 ppt

2012
- 3210 ppt

HCFCs

312 ppt (9%) decline of chlorine
Ozone-depleting substances (ODSs) are decreasing

### Tropospheric Chlorine Source Gases

- **CH$_3$CCl$_3$**: 3522 ppt → 3210 ppt
- **CCI$_4$**: 1996 → 2012
- **CFC-113**: 1996 → 2012
- **CFC-11**: 1996 → 2012
- **CFC-12**: 1996 → 2012
- **HCFCs**: Anthropogenic

### Tropospheric Bromine Source Gases

- **CH$_3$Br**: 17.1 ppt → 15.1 ppt
- **other**: Anthropogenic
- **halon1301**: 1996 → 2012
- **halon1211**: 1996 → 2012
- **CH$_3$Cl**: Natural

*2 ppt (12%) decline of Br*
Banks are the largest future contributors to future cumulative ODS emissions
Banks are comparable to future cumulative production for GHG emissions.

![Graph showing banks comparable to future GHG emissions](image-url)
Ozone-depleting substances were projected to decline in WMO (2011)
In spite of lifetime and bank changes from 2011, the WMO (2015) scenario was about the same
Stopping all future production of HCFCs has only a limited effect on the 2015 scenario.
Destruction of all ODS banks by 2020 also has limited impact on the evolution of ODSs.
Stopping all future emissions advances ODS recovery by about 11 years
HFCs are increasing in the atmosphere

HFC-23 global abundance is growing, and emissions continue to increase
ODS contributions to climate forcing were large, but should soon start to decline.
HFC contributions are growing because of the MP, and will eventually offset the climate gains achieved by the regulation of ODSs

- Radiative forcing by future HFC emissions could be ~25% of that of CO$_2$ future emissions
- Future HFC emissions could hinder the 450 ppm CO$_2$ stabilization target
- Replacement of current mix of high-GWP HFCs with low-GWP compounds and not-in-kind technologies could avoid these HFC climate effects
- TFA from HFO-1234yf, a potential substitute, is considered to be negligible over the next few decades. Potential longer-term impacts require future evaluations
Carbon tetrachloride (CCl$_4$) emissions derived from obs. are much larger than can be explained by reported emissions

60 Gg/yr
Controlled methyl bromide (CH$_3$Br) emissions continue to decline, while QPS emissions remain flat

QPS now exceeds controlled emissions
GEOSCCM simulations of the ozone hole show a maximum depletion in ~2000.
The ozone hole should return to 1980 levels in the 2070s
The ozone hole likely returns to 1960 levels in the 22\textsuperscript{nd} century
Ozone profile information (e.g., OMPS-LP) shows a slow recovery
Ozone is now increasing in the upper stratosphere

During the 1979-1997 period, ODSs were increasing, ozone was declining.

During the 2000-2013 period, ODSs were declining, and ozone appears to be increasing.

Observations (black) 35-60°N
Models are able to **reproduce** both the 1979-97 depletion and the 2000-13 increase.

Observations (black) 35-60°N
Model trends and uncertainty (grey)
We cannot attribute the increase **solely** to ODS decline. GHG increases are also partly responsible.

ADM Fig. 3-2

Observations (black) 35-60°N
Model trends and uncertainty (grey)

Model with only GHGs
Models with only ODSs
Levels of ozone-depleting substances were rapidly rising in the 1979-1987 period.

Ozone levels were declining, and the ozone hole had opened up over Antarctica.

Oct. 1985
Levels of ozone-depleting substances continued to grow till mid-1990s.

Ozone levels continue to decline. The ozone hole worsened till then.
Levels of ozone-depleting substances have been declining since the mid-1990s to the present.

Ozone levels seem to have improved, but we cannot say that this is “statistically significant.”
Ozone-depleting substances are projected to continue to decline through the 21st century—assuming continued compliance with the Protocol.
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Models simulate current global ozone levels reasonably well, and indicate the ozone layer should recover to 1980 levels ~2030.
Model uncertainties and differences suggest that recovery to 1980 levels will occur in the 2025-2040 period.
Models show differing amounts of ozone changes for different greenhouse gas Scenarios - ozone layer recovery is influenced by climate change.
Tropical ozone evolution is strongly dependent on future abundances of CO$_2$, N$_2$O, and CH$_4$.

The evolution of the ozone layer in the late 21$^{st}$ century is governed by both ODSs and GHGs.
Ozone-climate is a 2-way interaction

- Ozone recovery will be strongly influenced by the future trajectory of greenhouse gases (GHGs), through
  - Stratospheric temperature changes
  - Changes in the stratospheric circulation
  - Chemical changes induced by the reactive GHGs, methane and nitrous oxide

- Climate has been affected by ozone loss and will be influenced by the trajectory of ozone recovery
  - Stratospheric temperatures
  - Tropospheric circulation, temperatures and precipitation
Lower stratospheric ozone depletion has been the dominant cause of the observed Antarctic cooling since ~1980.
The $O_3$ hole cools the lower stratosphere during the Austral spring and summer.
The cooling causes an increase of the tropospheric midlatitude jet to strengthen and shift poleward.
The hole contributes to a Hadley circulation expansion, with an associated increase of summer subtropical precip.
The increased tropospheric jet increases surface wind stress, thereby changing the ocean’s circulation.
Findings of the 2014 Ozone-Layer Assessment

We have highlighted a few key issues:
2. The emerging issue of hydrofluorocarbons (HFCs) and connection to climate change.
3. Some important information about the connections between climate change and ozone layer.

For further details, we refer you to:
- The Executive Summary — key findings
- The ADM — more detail
- The full report
Where do we go for the 2018 Assessment?
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Decision XXVII/6: Potential areas of focus for the 2018 quadrennial reports of the Scientific Assessment Panel, the Environmental Effects Assessment Panel and the Technology and Economic Assessment Panel

5. To request the assessment panels to bring to the notice of the parties any significant developments which, in their opinion, deserve such notice, in accordance with decision IV/13;

7. To request the Scientific Assessment Panel to undertake, in its 2018 report, a review of the scientific knowledge as dictated by the needs of the parties to the Montreal Protocol, as called for in the terms of reference for the panels, taking into account those factors stipulated in Article 3 of the Vienna Convention, including estimates of the levels of ozone-layer depletion attributed to the remaining potential emissions of ozone-depleting substances and an assessment of the level of global emissions of ozone depleting substances below which the depletion of the ozone layer could be comparable to various other factors such as the natural variability of global ozone, its secular trend over a decadal timescale and the 1980 benchmark level;
2018 Assessment Timeline

- Discussion Paper circulated for comments by scientific community
- Lead Authors and Chapter Editors established
- Chapter author teams assembled, early preparation steps begin
- Draft of Chapter outlines
- 1st meeting of Lead Authors, CoChairs, Steering Committee, Chapter Editors
- Individual Chapter team meetings
- Chapter summary bullets submitted for review

- 1st drafts of Chapters completed (15 Sep.)
- Drafting of Executive Summary begins
- Chapter 1st drafts reviews due

- 2nd draft of Chapters completed
- Open review meeting of 2nd draft
- Final drafts of Chapters completed
- Panel Rev. Meeting [Les Diablerets] (Jul. 15)
Can we explain the CCl₄ discrepancy?

Where is this CCl₄ coming from?

Top Down

Bottom up

60 Gg/yr


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We need to have a complete description of the HFC impacts.

The MP will likely control HFCs. What are their full effects?
Is the upper strat ozone trend statistically significant? Can we attribute it?

Is upper stratospheric ozone really increasing? Can we attribute this to the MP?

Observations (black) 35-60°N
Model trends and uncertainty (grey)

ADM Fig. 3-2
2015 was the 4th largest ozone hole

Is the Antarctic ozone hole getting better? Can we attribute this to the MP?

See also Solomon et al. (2016) and the next talk!
Do we understand the impact of geo-engineering on ozone and the stratosphere?
The QBO is modified by geoengineering

RCP 4.5
Control run

Geoengineering
G4 simulation
Emerging issue: What happened to the QBO in 2015-16?

Potential Chapters

- Source gases
- HFCs
- Ozone (global and polar)
- Climate and Ozone
- Geoengineering, rockets, …
- Policy options and implications
Questions?

The Assessment discussion letter will soon be mailed to various members of the community. Please respond if you receive this letter.

If you would like to serve as an author of the assessment, please provide your names and areas of interest to Drs. Newman, Fahey, Pyle, and/or Safari

Thank you for your attention!


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