Overview of Global Warming, Ozone Depletion, and Air Quality

AOSC / CHEM 433 & AOSC 633

Ross Salawitch & Walt Tribett

Class Web Sites:
http://www.atmos.umd.edu/~rjs/class/spr2019
https://myelms.umd.edu/courses/1256337
Email addresses:
Ross: either rsalawit@umd.edu or rjs@atmos.umd.edu
Walt: wtribett@umd.edu

https://www.videoblocks.com/video/earth-sunset-spacewalk-view-from-space-station-r7dydlcsgjd23vml0

Lecture 2

5 February 2019

Overview of Global Warming, Ozone Depletion, and Air Quality

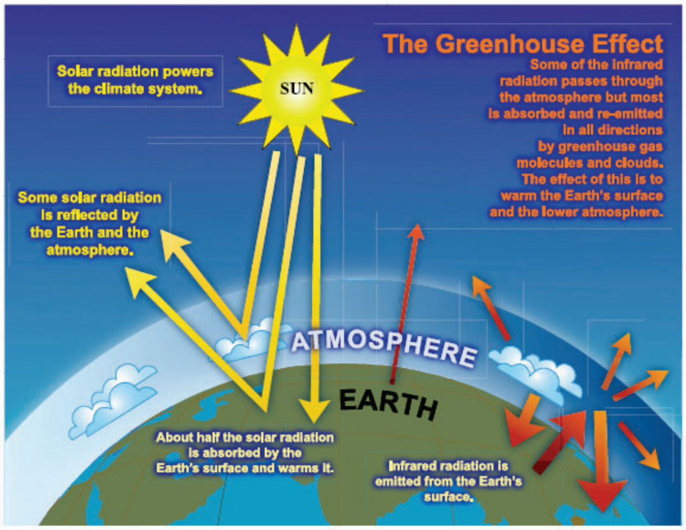
Course theme: effect of human activity on:

- **climate change**
- **air quality**
- **stratospheric ozone depletion and recovery**

Today's goals:

1) Overview of climate change, air quality, and ozone depletion
2) Will provide lots of "detail" today … **do not expect all of these details to "stick"**. Do expect, however, that when you review this lecture at the end of semester, details will be understandable
3) Current events & linkages between topics, often thought of as "disparate" but connected in **profoundly important manners**

Greenhouse Effect



FAQ 1.3, Figure 1. *An idealised model of the natural greenhouse effect. See text for explanation.*

Question 1.3, IPCC, 2007

Radiative Forcing of Climate, 1750 to 2011

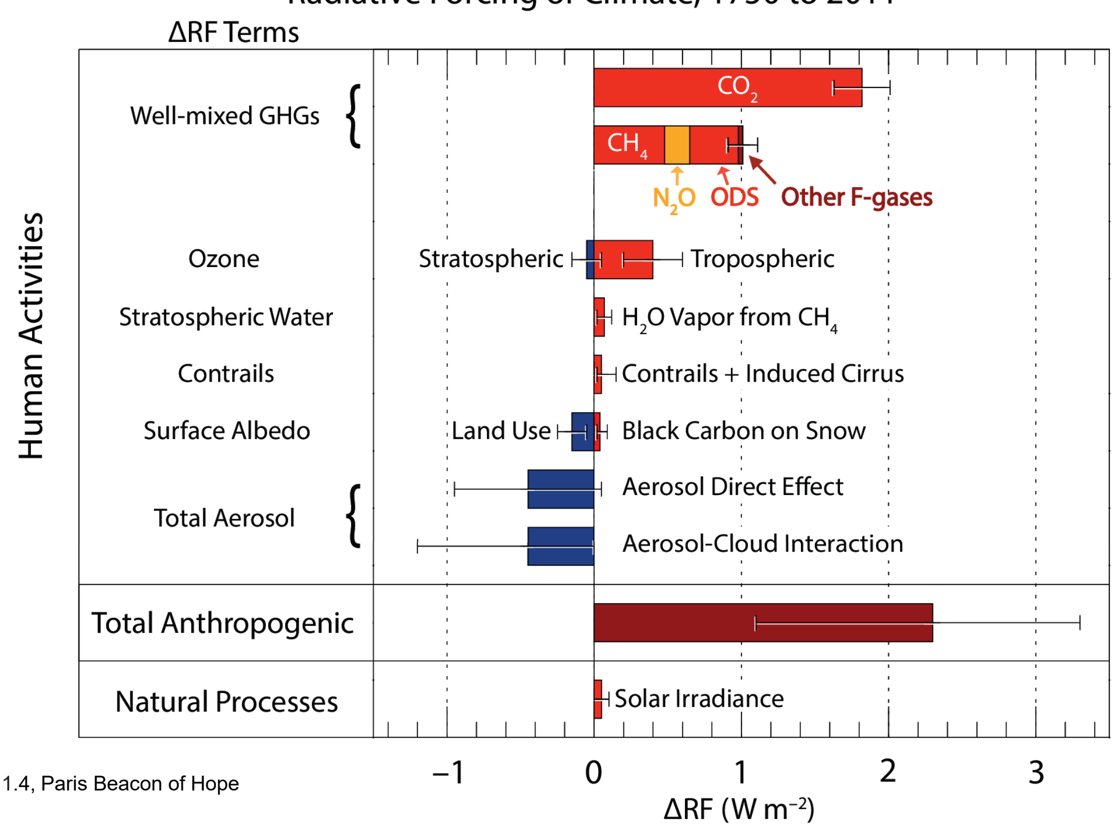
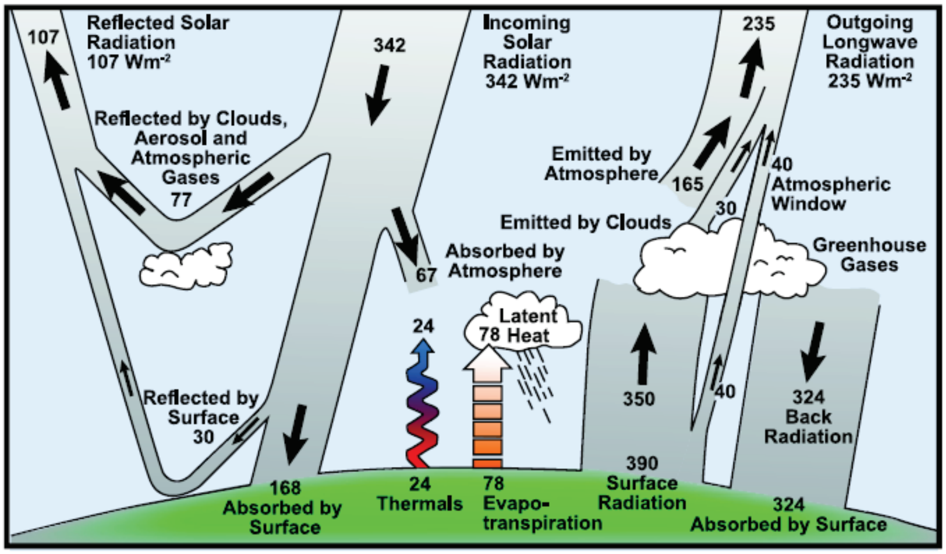


Figure 1.4, Paris Beacon of Hope

Radiative Forcing



FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*

Question 1.1, IPCC, 2007

Radiative Forcing of Climate **is** ***Change in Energy***
reaching the lower atmosphere (surface to tropopause) as GHGs rise.
"Back Radiation" is most important term.

Radiative Forcing of Climate, 1750 to 2011

CO_2 is dominant anthropogenic (human) greenhouse gas (GHG). Once released, CO_2 persists in the atmosphere for <u>hundreds of years</u>.

Between 1750 and 2011, the rise in atmospheric CO_2 caused RF of climate to rise by 1.8 W m^{-2}

Methane (CH_4) is the 2nd most important human GHG. Once released, CH_4 persists in the atmosphere for <u>about decade</u>.

On a per molecule basis, CH_4 causes 30 times more warming than CO_2 over a 20-yr time horizon.

Between 1750 and 2011, the rise in atmospheric CH_4 caused RF of climate to rise by 0.48 W m^{-2}

Nitrous oxide (N_2O) is commonly identified as the third most important anthropogenic GHG.

On either a per molecule or a per mass basis, N_2O causes 264 times more warming than CO_2 over a 20-yr time horizon.

Between 1750 and 2011, the rise in atmospheric N_2O caused RF of climate to rise by 0.17 W m^{-2}

The rise in RF of climate due to both CH_4 and N_2O was about 35% of the the rise in RF of climate due to CO_2

Radiative Forcing of Climate, 1750 to 2011

CFCs and other ozone depleting substances (ODS) also act as GHGs.

Between 1750 and 2011, the rise in ODS caused RF of climate to rise by 0.33 W m^{-2}

The rise in RF of climate due to CH_4, N_2O, and ODS was *about half* of the the rise in RF of climate due to CO_2

Industrial production of CFCs and other ODS was banned by the _____ _____.

Atmospheric levels of CFCs have declined, although not quite as fast as had been expected.

Ozone (O_3) acts as a GHG.

Between 1750 and 2011, the rise in tropospheric O_3 caused RF of climate to rise by 0.40 W m^{-2}

This rise is due to increasing levels of O_3 in Earth's troposphere leading to poor public health. Efforts to combat the ruse in tropospheric O_3 are led by air quality agencies.

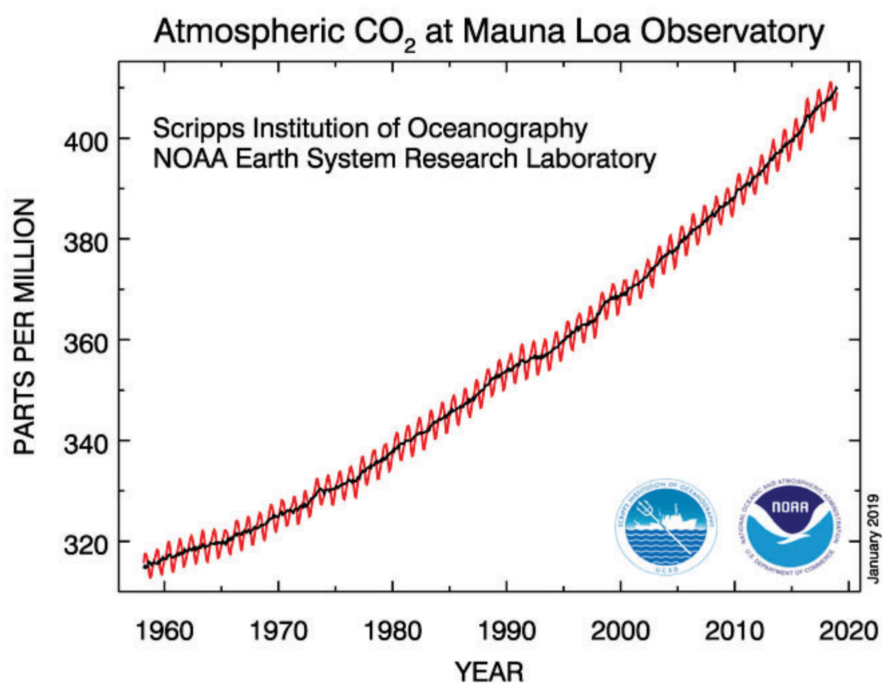
Aerosols (small particulate matter) tend to cool climate, counter-acting the RF of climate due to GHGs. However, magnitude of this counter-action is not well known.

Emissions of pollutants that lead to aerosols are regulated worldwide by air quality agencies.

Aerosol levels are on the decline, which will either "unleash" a small amount, moderate amount, or perhaps a large amount of additional warming due to GHGs that are presently "masked".

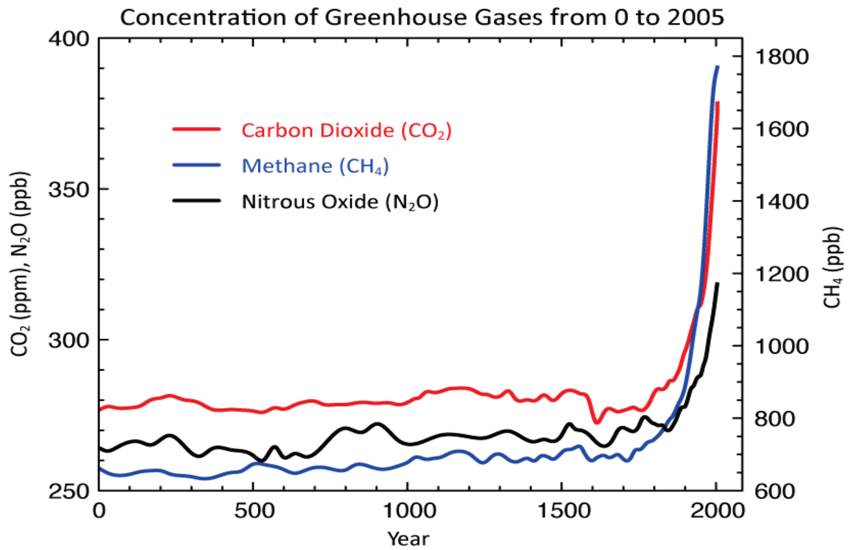
Modern CO_2 Record

CO_2 at MLO on 20 Jan 2019: 412 parts per million (ppm) and rising !



Legacy of Charles Keeling, Scripps Institution of Oceanography, La Jolla, CA
https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html
See also https://www.co2.earth/daily-co2

GHG Record Over Last Several Millennia



FAQ 2.1, Figure 1 (Errata). *Revised figure showing atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Using the combined and simplified data from Chapters 6 and 2, the original figure displayed the CH_4 curve incorrectly. The revised figure shows the same data correctly plotted. For further details please refer to the original figure caption.*

Question 2.1, IPCC, 2007 … corrected
https://www.ipcc.ch/site/assets/uploads/2018/05/ar4-wg1-errata.pdf

Correction issued upon realization line for CH_4 had been plotted incorrectly

GHG Record Over Last Several Millennia

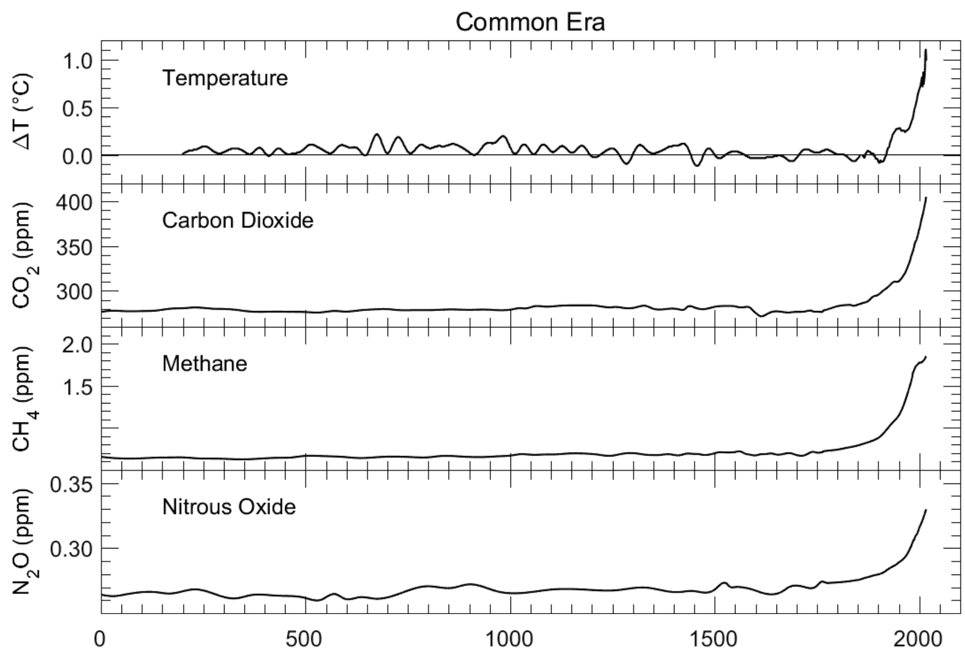
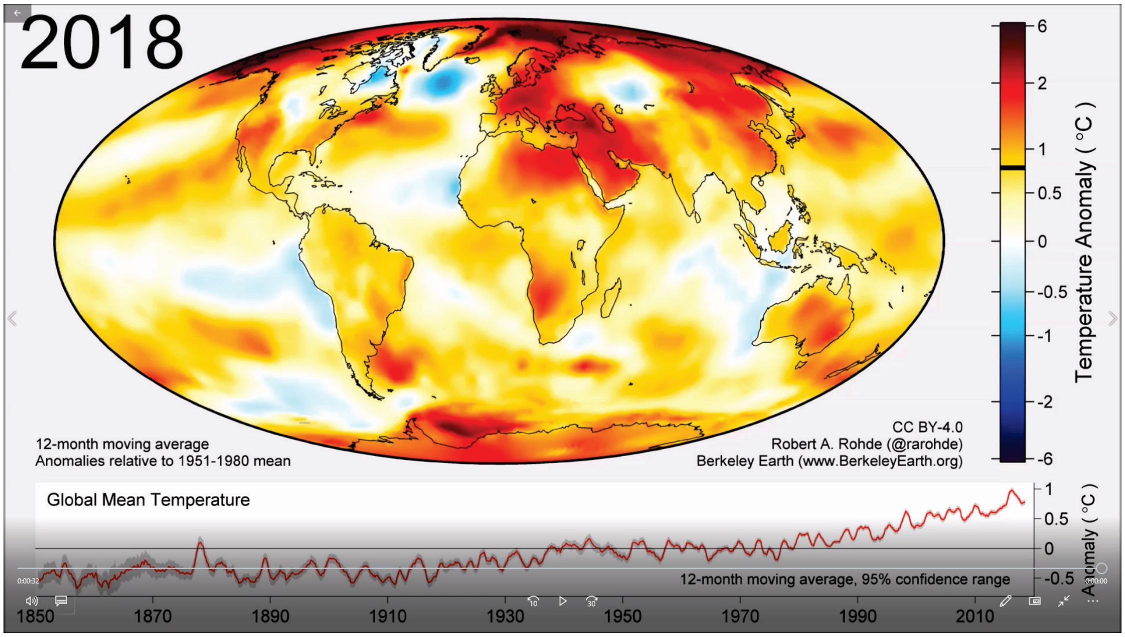


Figure 1.2, Paris Beacon of Hope

Berkeley Earth Animation of Global Warming



Work of Robert Rohde and the Berkeley Earth Team
http://berkeleyearth.org
http://berkeleyearth.org/2018-temperatures/

GWP – Global Warming Potential

$$\mathrm{GWP}\,(\mathrm{CH_4}) = \frac{\int_{\text{time initial}}^{\text{time final}} a_{\mathrm{CH4}} \times [\mathrm{CH_4}(t)]\, dt}{\int_{\text{time initial}}^{\text{time final}} a_{\mathrm{CO2}} \times [\mathrm{CO_2}(t)\, dt]}$$

where:

a_{CH4} = Radiative Efficiency (W m^{-2} kg^{-1}) due to an increase in CH_4

a_{CO2} = Radiative Efficiency (W m^{-2} kg^{-1}) due to an increase in CO_2

CH_4 (t) = time-dependent response to an instantaneous release of a pulse of CH_4

CO_2 (t) = time-dependent response to an instantaneous release of a pulse of CO_2

$$\mathrm{GWP}\,(\mathrm{N_2O}) = \frac{\int_{\text{time initial}}^{\text{time final}} a_{\mathrm{N2O}} \times [\mathrm{N_2O}(t)]\, dt}{\int_{\text{time initial}}^{\text{time final}} a_{\mathrm{CO2}} \times [\mathrm{CO_2}(t)\, dt]}$$

GWP – Global Warming Potential

Table TS.2. *Lifetimes, radiative efficiencies and direct (except for CH_4) global warming potentials (GWP) relative to CO_2. {Table 2.14}*

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency ($W\ m^{-2}\ ppb^{-1}$)	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]1.4×10^{-5}	1	1	1	1
Methane[c]	CH_4	12[c]	3.7×10^{-4}	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03×10^{-3}	310	289	298	153

from IPCC 2007 "Physical Science Basis"

Notes:

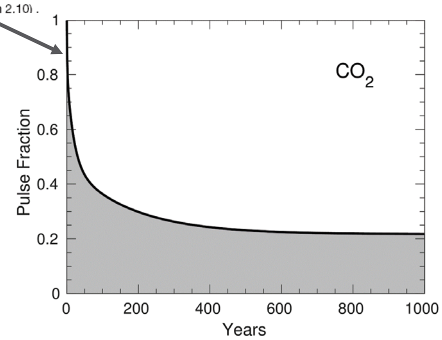
‡ SAR refers to the IPCC Second Assessment Report (1995) used for reporting under the UNFCCC.

[a] The CO_2 response function used in this report is based on the revised version of the Bern Carbon cycle model used in Chapter 10 of this report (Bern2.5CC; Joos et al. 2001) using a background CO_2 concentration value of 378 ppm. The decay of a pulse of CO_2 with time t is given by

$a_0 + \sum_{i=1}^{3} a_i \cdot e^{-t/\tau_i}$ where $a_0 = 0.217$, $a_1 = 0.259$, $a_2 = 0.338$, $a_3 = 0.186$, $\tau_1 = 172.9$ years, $\tau_2 = 18.51$ years, and $\tau_3 = 1.186$ years, for $t < 1,000$ years.

[b] The radiative efficiency of CO_2 is calculated using the IPCC (1990) simplified expression as revised in the TAR, with an updated background concentration value of 378 ppm and a perturbation of +1 ppm (see Section 2.10.2).

[c] The perturbation lifetime for CH_4 is 12 years as in the TAR (see also Section 7.4). The GWP for CH_4 includes indirect effects from enhancements of ozone and stratospheric water vapour (see Section 2.10) .



$$CO_2(t) = 0.217 + 0.186 \times CO_2(t{=}0)\, e^{-t/1.286} + 0.338 \times CO_2(t{=}0)\, e^{-t/18.59} + 0.249 \times CO_2(t{=}0)\, e^{-t/172.9}$$

where all times are given in units of year

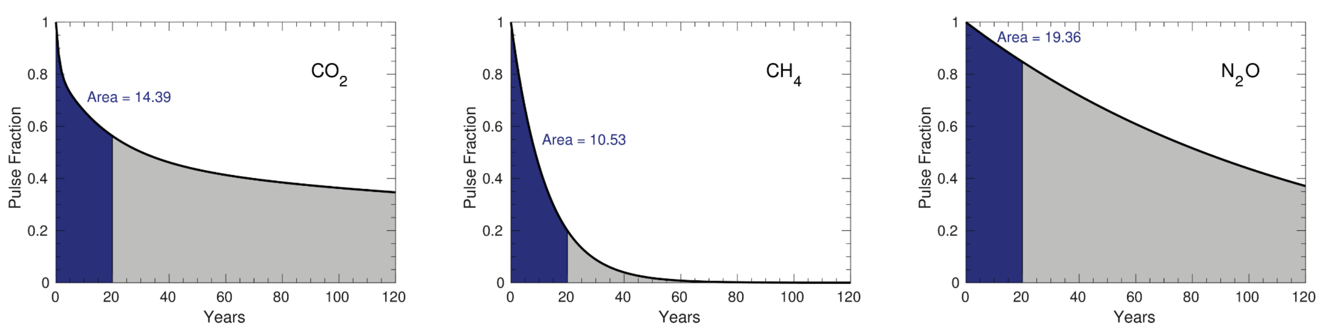
GWP – Global Warming Potential

Table 1-1, Paris Beacon of Hope

$$GWP(CH_4) = \frac{\int_{\text{time initial}}^{\text{time final}} a_{CH4} \times [CH_4(t)]\, dt}{\int_{\text{time initial}}^{\text{time final}} a_{CO2} \times [CO_2(t)\, dt]}$$

$$GWP(N_2O) = \frac{\int_{\text{time initial}}^{\text{time final}} a_{N2O} \times [N_2O(t)]\, dt}{\int_{\text{time initial}}^{\text{time final}} a_{CO2} \times [CO_2(t)\, dt]}$$

GHG	IPCC (1995)	IPCC (2001)	IPCC (2007)	IPCC (2013)
100 Year Time Horizon				
CH_4	21	23	25	28, 34*
N_2O	310	296	298	265, 298*
20 Year Time Horizon				
CH_4	56	62	72	84 86*
N_2O	280	275	289	264 268*
*Allowing for carbon cycle feedback				



$$CO_2(t) = 0.217 + 0.186 \times CO_2(t{=}0)\, e^{-t/1.286} + 0.338 \times CO_2(t{=}0)\, e^{-t/18.59} + 0.249 \times CO_2(t{=}0)\, e^{-t/172.9}$$

$$CH_4(t) = CH_4(t{=}0)\, e^{-t/12.4}$$

$$N_2O(t) = N_2O(t{=}0)\, e^{-t/121.0}$$

where all times are given in units of year

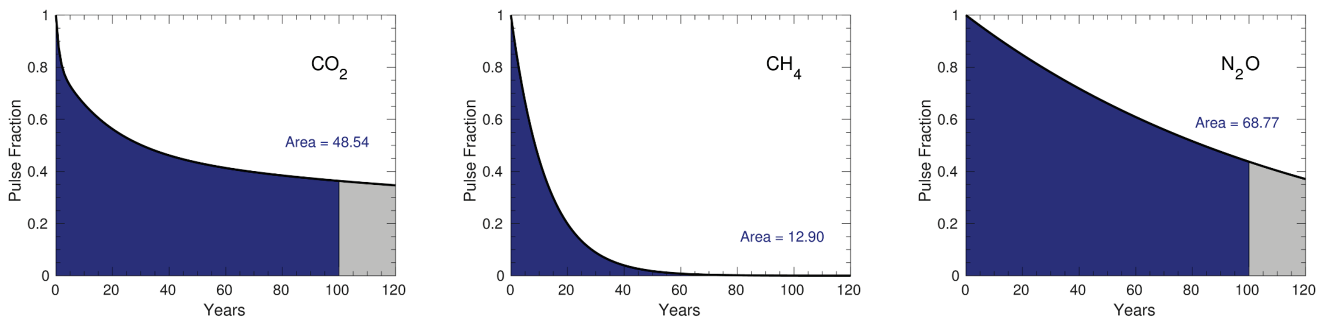
GWP – Global Warming Potential

Table 1-1, Paris Beacon of Hope

$$\text{GWP}(CH_4) = \frac{\int_{\text{time initial}}^{\text{time final}} a_{CH4} \times [CH_4(t)]\, dt}{\int_{\text{time initial}}^{\text{time final}} a_{CO2} \times [CO_2(t)\, dt]}$$

$$\text{GWP}(N_2O) = \frac{\int_{\text{time initial}}^{\text{time final}} a_{N2O} \times [N_2O(t)]\, dt}{\int_{\text{time initial}}^{\text{time final}} a_{CO2} \times [CO_2(t)\, dt]}$$

GHG	IPCC (1995)	IPCC (2001)	IPCC (2007)	IPCC (2013)
100 Year Time Horizon				
CH_4	21	23	25	28 34*
N_2O	310	296	298	265 298*
20 Year Time Horizon				
CH_4	56	62	72	84, 86*
N_2O	280	275	289	264, 268*
*Allowing for carbon cycle feedback				



$$CO_2(t) = 0.217 + 0.186 \times CO_2(t{=}0)\, e^{-t/1.286} + 0.338 \times CO_2(t{=}0)\, e^{-t/18.59} + 0.249 \times CO_2(t{=}0)\, e^{-t/172.9}$$

$$CH_4(t) = CH_4(t{=}0)\, e^{-t/12.4}$$

$$N_2O(t) = N_2O(t{=}0)\, e^{-t/121.0}$$

where all times are given in units of year

GWP – Global Warming Potential

Table 1-1, Paris Beacon of Hope

$$\text{GWP}(CH_4) = \frac{\int_{\text{time initial}}^{\text{time final}} a_{CH4} \times [CH_4(t)]\, dt}{\int_{\text{time initial}}^{\text{time final}} a_{CO2} \times [CO_2(t)\, dt]}$$

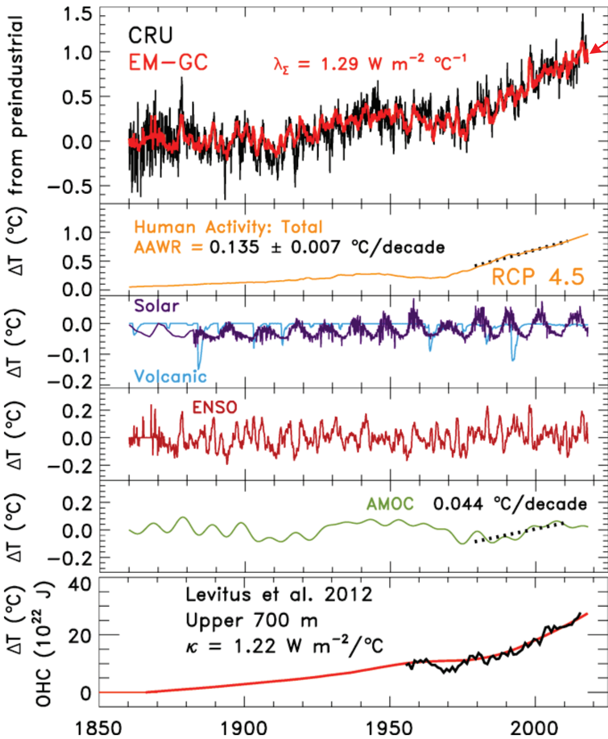
$$\text{GWP}(N_2O) = \frac{\int_{\text{time initial}}^{\text{time final}} a_{N2O} \times [N_2O(t)]\, dt}{\int_{\text{time initial}}^{\text{time final}} a_{CO2} \times [CO_2(t)\, dt]}$$

GHG	IPCC (1995)	IPCC (2001)	IPCC (2007)	IPCC (2013)
100 Year Time Horizon				
CH_4	21	23	25	28 34*
N_2O	310	296	298	265 298*
20 Year Time Horizon				
CH_4	56	62	72	84 86*
N_2O	280	275	289	264 268*
*Allowing for carbon cycle feedback				

CO_2 – equivalent emissions = Emissions of CO_2 +
Emissions of CH_4 × GWP of CH_4 +
Emissions of N_2O × GWP of N_2O +
etc.

Commonly, GWPs on 100 year time horizon are used although entities such as the Sierra Club prefer the 20 year time horizon

Are humans responsible?



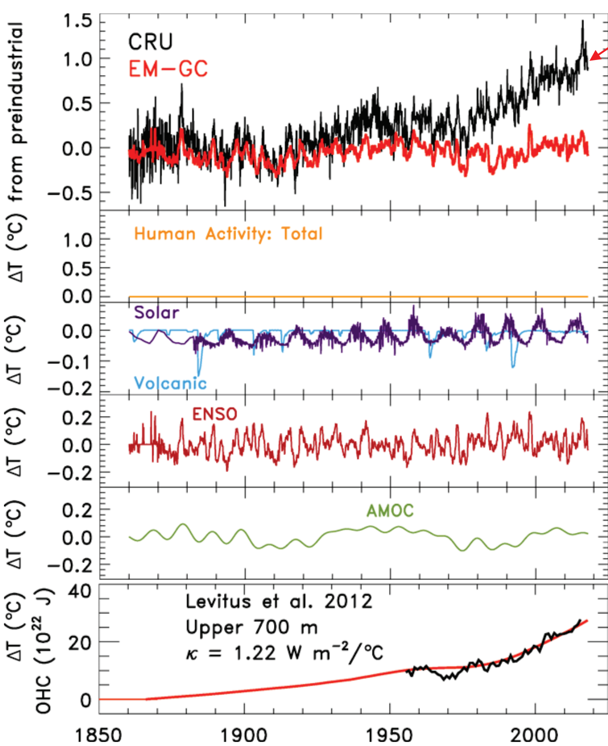
$$\Delta T_{MDL\,i} = (1+\gamma)\left(\frac{GHG\ RF_i + LUC\ RF_i + Aerosol\ RF_i}{\lambda_p}\right) + C_0 + C_1 \times SOD_{i-6} + C_2 \times TSI_{i-1} + C_3 \times ENSO_{i-2} + C_4 \times AMOC_i - \left(\frac{Q_{OCEAN\,i}}{\lambda_p}\right)$$

where:

- i denotes month
- $\lambda_p = 3.2\ \mathrm{W\,m^{-2}\,°C^{-1}}$
- $1+\gamma = \{1 - \lambda_\Sigma/\lambda_p\}^{-1}$
- GHG RF = RF due to all anthropogenic GHGs
- LUC RF = RF due to Land Use Change
- Aerosol RF = RF due to Tropospheric Aerosols
- SOD = Stratospheric Optical Depth
- TSI = Total Solar Irradiance
- ENSO = El Niño Southern Oscillation
- AMOC = Atlantic Meridional Overturning Circulation
- Q_{OCEAN} = Ocean heat export = $\kappa(1+\gamma)\{\Delta T_{MDL\,i} - \Delta T_{OCEAN\ SURFACE\,i}\}$

Canty *et al.*, *ACP*, 2013
https://www.atmos-chem-phys.net/13/3997/2013/acp-13-3997-2013.html
updated by Austin Hope & Laura McBride

Are humans responsible?



$$\Delta T_{MDL\,i} = (1+\gamma)\left(\frac{GHG\ RF_i + LUC\ RF_i + Aerosol\ RF_i}{\lambda_p}\right) + C_0 + C_1 \times SOD_{i-6} + C_2 \times TSI_{i-1} + C_3 \times ENSO_{i-2} + C_4 \times AMOC_i - \left(\frac{Q_{OCEAN\,i}}{\lambda_p}\right)$$

where:

- i denotes month
- $\lambda_p = 3.2\ \mathrm{W\,m^{-2}\,°C^{-1}}$
- $1+\gamma = \{1 - \lambda_\Sigma/\lambda_p\}^{-1}$
- ~~GHG RF = RF due to all anthropogenic GHGs~~
- ~~LUC RF = RF due to Land Use Change~~
- ~~Aerosol RF = RF due to Tropospheric Aerosols~~
- SOD = Stratospheric Optical Depth
- TSI = Total Solar Irradiance
- ENSO = El Niño Southern Oscillation
- AMOC = Atlantic Meridional Overturning Circulation
- ~~Q_{OCEAN} = Ocean heat export = $\kappa(1+\gamma)\{\Delta T_{MDL\,i} - \Delta T_{OCEAN\ SURFACE\,i}\}$~~

Canty *et al.*, *ACP*, 2013
https://www.atmos-chem-phys.net/13/3997/2013/acp-13-3997-2013.html
updated by Austin Hope & Laura McBride

Are humans responsible?

Orbital variations: drive the ice ages but too small to drive modern warming

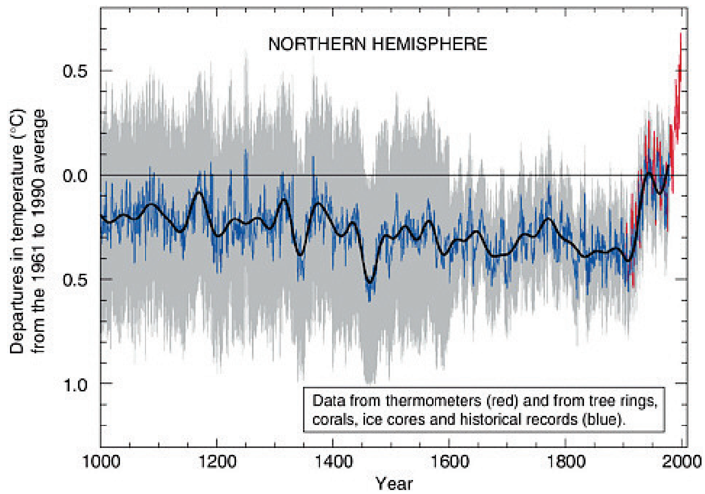
Volcanoes: no sustained forcing

Solar variability:

- **Perhaps dominant forcing of Medieval Warming and Little Ice Age**
- **Small effect since ~1860**

Internal variability (eg, El Niño / La Niña) :

- **Climate record from 1000 to 1850 shows nothing like sustained, present rate of warming**



https://www.nap.edu/read/11676/chapter/3#14

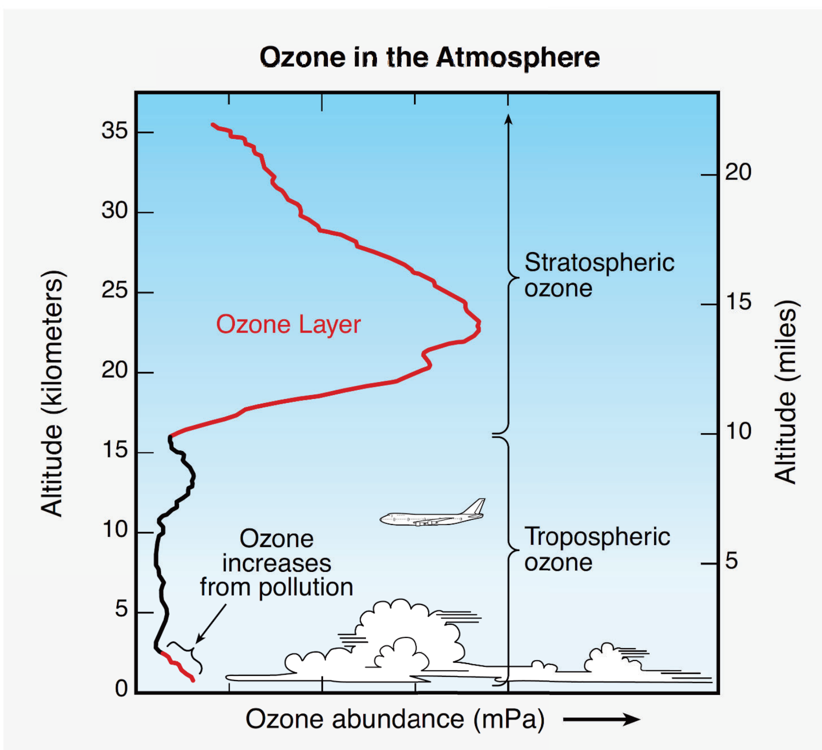
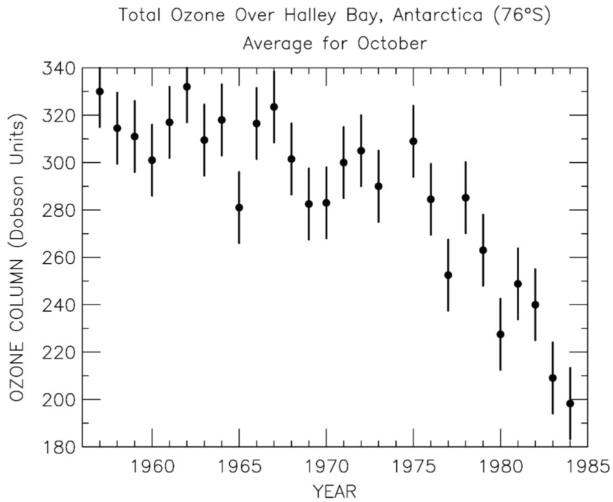


Fig. Q1-2, 20 QAs about O_3

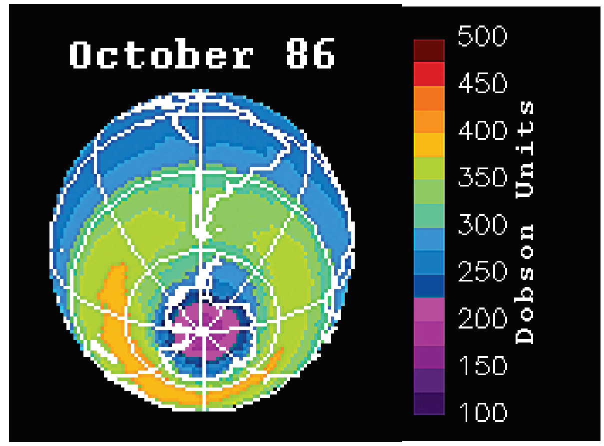
It is incredible that human activity both destroys stratospheric ozone (so-called good ozone) and produces tropospheric ozone (so-called bad ozone)

Earth's Atmosphere – Effect of Humans

Stratospheric Ozone – shields surface from solar UV radiation



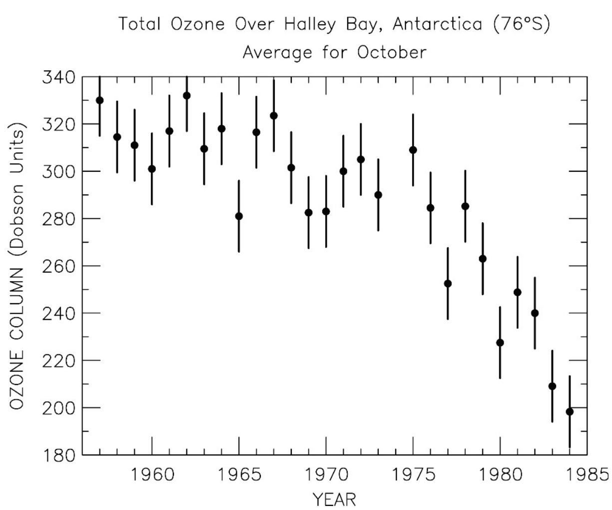
After Farman *et al*., Large losses of total ozone in Antarctica reveal Seasonal ClOx/NOx interaction, Nature, 315, 207, 1985.



Stolarski *et al*., Nature, 1986.

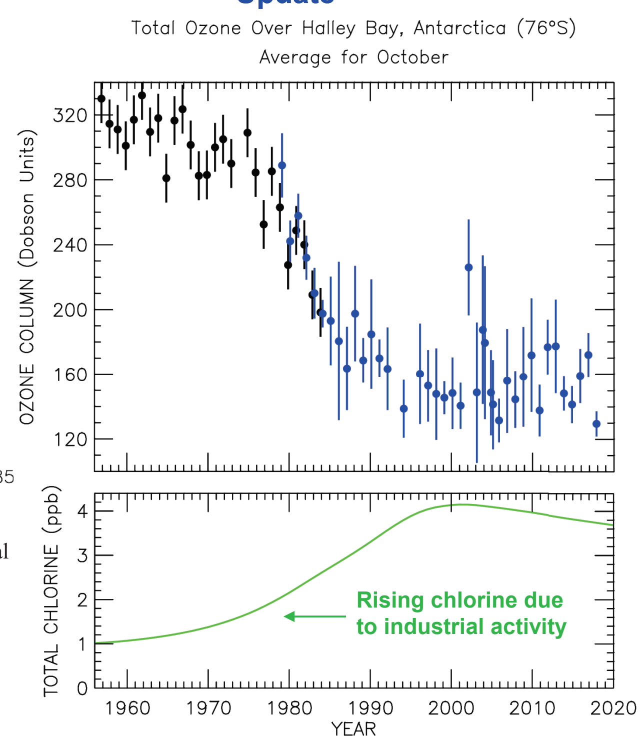
Earth's Atmosphere – Effect of Humans

Stratospheric Ozone – shields surface from solar UV radiation

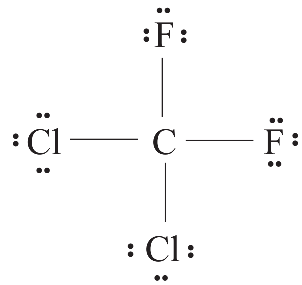


After Farman *et al*., Large losses of total ozone in Antarctica reveal Seasonal ClOx/NOx interaction, Nature, 315, 207, 1985.

Update



CFC-12



How is it eventually removed from the atmosphere ?

What does it produce upon its removal ?

See pages 71 to 75, Ch 2, Chemistry in Context, for description of Lewis Dot Structures of atmospherically important species

Note: you will not be tested on Lewis Dot Structures.
But, we want the non-chemists to at least have been exposed to this concept for tracking the position of electrons, central for understanding atmospheric chemical reactions.

Measurements of Reactive Chlorine From Space

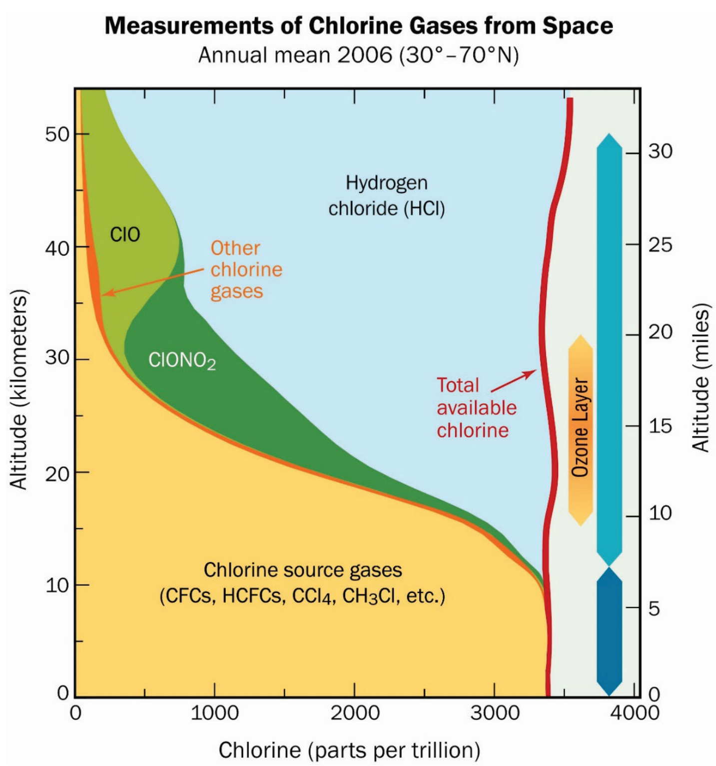


Fig. Q8-2, 20 QAs about O_3

The 1994 northern midlatitude budget of stratospheric chlorine derived from ATMOS/ATLAS-3 observations

R. Zander,[1] E. Mahieu,[1] M. R. Gunson,[2] M. C. Abrams,[3] A. Y. Chang,[2] M. Abbas,[4] C. Aellig,[5] A. Engel,[6] A. Goldman,[7] F. W. Irion,[8] N. Kämpfer,[9] H. A. Michelsen,[10] M. J. Newchurch,[11] C. P. Rinsland,[12] R. J. Salawitch,[2] G. P. Stiller,[13] and G. C. Toc

[1]Institute of Astrophysics, University of Liège, Belgium
[2]Jet Propulsion Laboratory, California Institute of Technology, CA
[3]Science Applications International Corporation, Hampton, VA
[4]NASA Marshall Space Flight-Center, AL
[5]Naval Research Laboratory, Washington, DC
[6]Forschungszentrum, Jülich, Germany
[7]University of Denver, Denver, CO
[8]California Institute of Technology, CA
[9]University of Bern, Switzerland
[10]Harvard University, Cambridge, MA
[11]University of Alabama, Huntsville, AL
[12]NASA Langley Research Center, Hampton, VA
[13]IMK-Forschungszentrum Karlsruhe, Germany

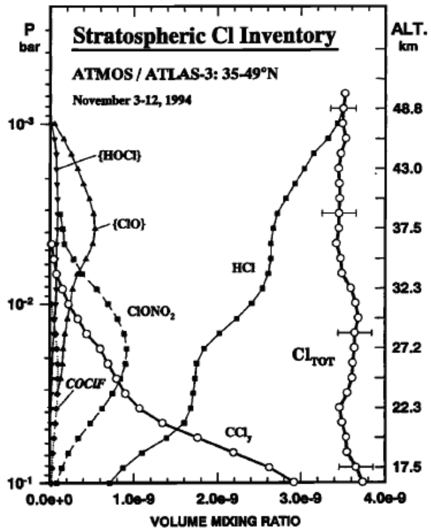


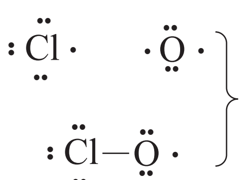
Figure 2. A linear-scale presentation of the key components entering in the total Cl-loading evaluation throughout the stratosphere at northern midlatitudes. The CCl_y curve refers to the total chlorine bound in all organic source gases listed in the text. Cl_{TOT} represents the summation over CCl_y, HCl, $ClONO_2$, ClO, HOCl and COClF.

Zander *et al.*, *GRL*, 1996
https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/96GL01792

ClO (Chlorine Monoxide) is a Radical

Radicals

- Odd number of electrons - unpaired electron in outer valence shell
- Go to great lengths to pair off lone electron
- Exceptionally reactive



ClO : Chlorine monoxide

See pages 71 to 75, Ch 2, Chemistry in Context, for description of Lewis Dot Structures of atmospherically important species

Note: you will not be tested on Lewis Dot Structures.
But, we want the non-chemists to at least have been exposed to this concept for tracking the position of electrons, which is central for understanding atmospheric chemical reactions.

Chlorine Radicals Lead to Ozone Loss

$$ClO + ClO + M \rightarrow ClOOCl + M$$
$$Cl + O_3 \rightarrow ClO + O_2$$
$$Cl + O_3 \rightarrow ClO + O_2$$
$$ClOOCl + h\nu \rightarrow ClOO + Cl$$
$$ClOO + heat \rightarrow Cl + O_2$$

Chlorine Radicals Lead to Ozone Loss

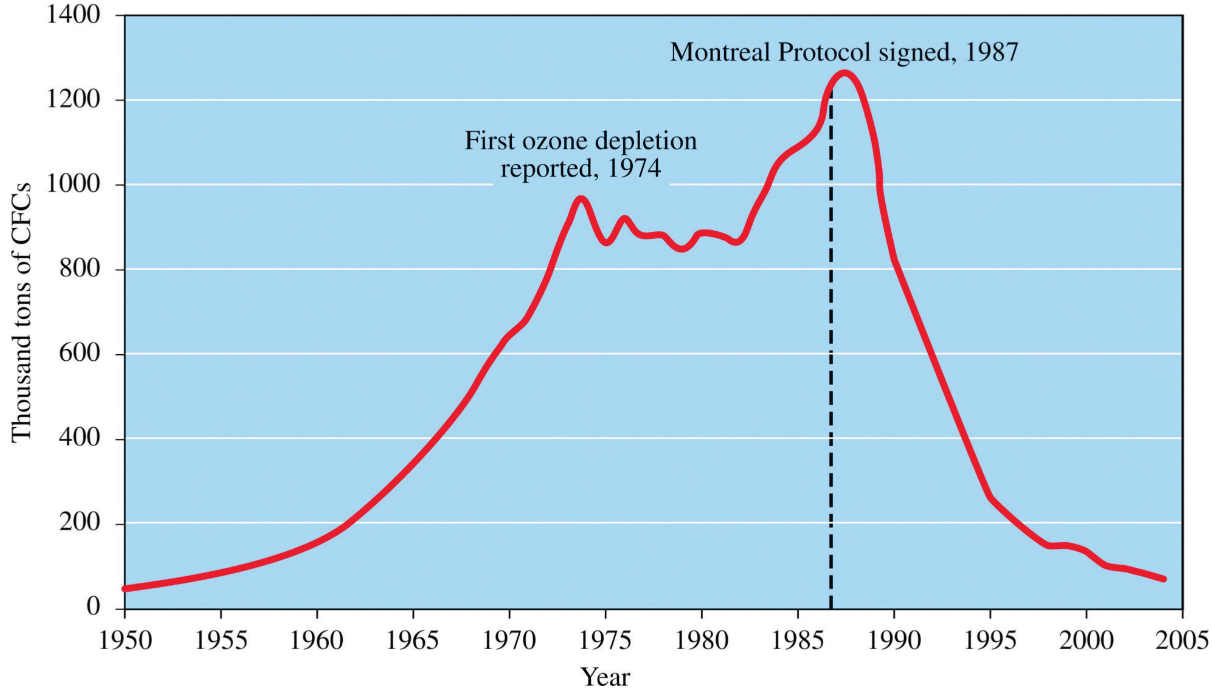
$$ClO + ClO + M \rightarrow ClOOCl + M$$
$$Cl + \mathbf{O_3} \rightarrow ClO + \mathbf{O_2}$$
$$Cl + \mathbf{O_3} \rightarrow ClO + \mathbf{O_2}$$
$$ClOOCl + h\nu \rightarrow ClOO + Cl$$
$$ClOO + heat \rightarrow Cl + \mathbf{O_2}$$

Net: $\mathbf{O_3 + O_3 \rightarrow 3\ O_2}$

Catalytic loss of ozone: this chemistry causes the Antarctic ozone hole

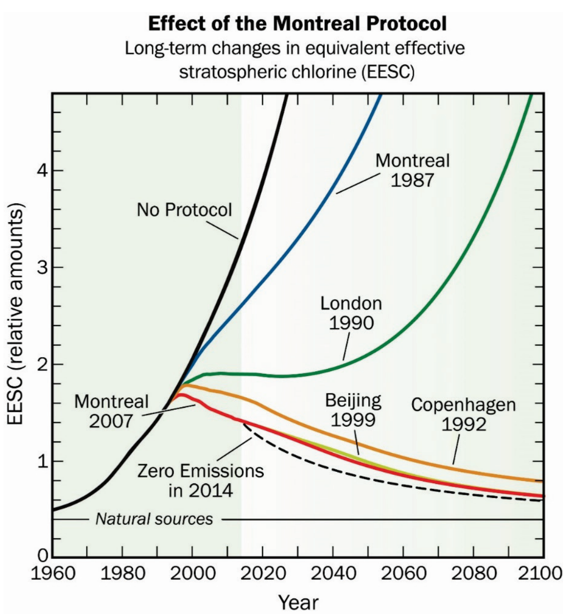
Copyright © 2019 University of Maryland.
This material may not be reproduced or redistributed, in whole or in part, without written permission from Ross Salawitch.

Montreal Protocol Has Banned Industrial Production of CFCs and Halons



Global Production of CFCs, Fig. 2.19, Chemistry in Context

And Atmospheric Levels of these Pollutants are Declining



CFC: Chlorofluorocarbon

Freons are a class of CFCs that contain chlorine

Bromocarbons:

Halons are a class of compounds containing bromine, perhaps chlorine, and at least one carbon

HCFC: Hydro-chlorofluorocarbons

Same as CFCs, except one or more hydrogen has replaced a chlorine

HFC: Hydrofluorocarbon

Contain some combination of hydrogen, fluorine, and carbon. These gases do not contain any bromine or chlorine, and hence pose no damage to the ozone layer. As we shall see, some HFCs are potent GHGs.

EESC: Equivalent, effective stratospheric chlorine. Reflects combined influence of chlorine and bromine on ozone.
In this figure, the unit of the y-axis is “relative amount”, which is an odd choice but c’est la vie.

Figure Q15-1, 20 QAs about O_3

CFC Usage Prior to the Montreal Protocol

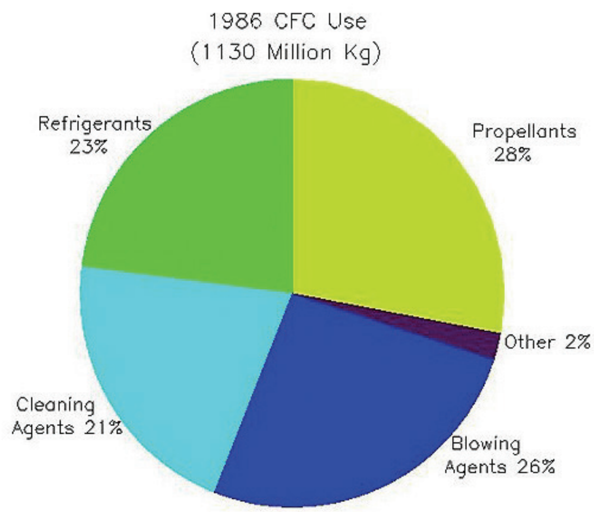
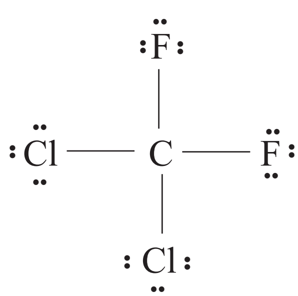


Figure 5b. Changing use patterns for CFCs (from Fisher and Midgley, 1994).

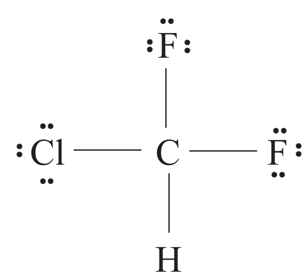
The uses of CFCs in various sectors before the 1987 Montreal Protocol, which required countries to phase out their production to protect the ozone layer.

Adapted by http://www.ccpo.odu.edu/SEES/ozone/class/Chap_10/index.htm
from https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/94JD00738

CFCs were replaced with HCFCs



CFC-12
or
Freon-12
or
R-12



HCFC-22
or
Freon-22
or
R-22

Phase out of CFCs and other Ozone Depleting Substances (ODSs)

CFCs & other ODSs → Phase 1 → HCFCs → Phase 2 → HFCs

CFCs & other ODSs	HCFCs	HFCs
CFC-11	HCFC-22	HFC-23
CFC-12	HCFC-141b	HFC-143a
CFC-113	HCFC-142b	HFC-125
CFC-114		HFC-134a
CFC-115		HFC-152a
CCl_4		
CH_3CCl_3		
Harmful to ozone layer	**Less harmful to ozone layer**	**Pose no risk to ozone layer, since no Cl or Br**

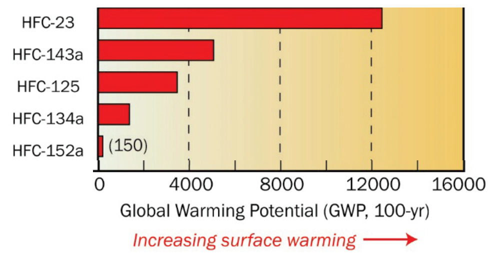
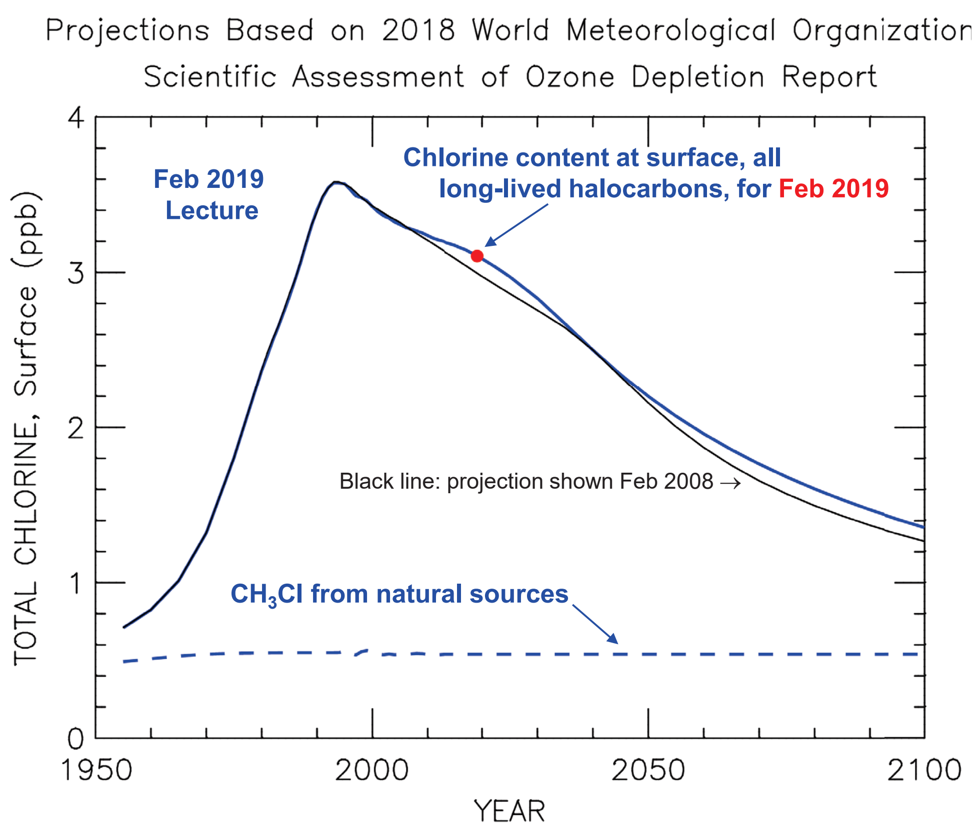


Figure Q18-3, 20 QAs about O_3

Montreal Protocol Has Banned Industrial Production of CFCs & Other ODS



2018 WMO Scientific Assessment of Ozone Depletion report issued 4 Feb 2019 (!):
https://www.esrl.noaa.gov/csd/assessments/ozone/2018

Montreal Protocol Had Banned Most Industrial Production of CFCs & Other ODS

The New York Times

In a High-Stakes Environmental Whodunit, Many Clues Point to China

Interviews, documents and advertisements collected by The New York Times and independent investigators indicate that a major source — possibly the overwhelming one — is factories in China that have ignored a global ban and kept making or using the chemical, CFC-11, mostly to produce foam insulation for refrigerators and buildings.

“You had a choice: Choose the cheaper foam agent that’s not so good for the environment, or the expensive one that’s better for the environment,” said Zhang Wenbo, owner of a refrigerator factory here in Xingfu, in Shandong Province, where he and many other small-scale manufacturers said that until recently, they had used CFC-11 widely to make foam insulation.

Billboards in Xingfu, China, promoting locally made refrigerators. The city has around 1,700 businesses involved in the production of cooking and refrigeration equipment. Gilles Sabrié for The New York Times

https://www.nytimes.com/2018/06/24/world/asia/china-ozone-cfc.html

Air Quality Index

Table 1.4 Levels for the Air Quality Index

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in this range:	*…air quality conditions are:*	*…as symbolized by this color.*
0–50	Good	Green
51–100	Moderate	Yellow
101–150	Unhealthy for sensitive groups	Orange
151–200	Unhealthy	Red
201–300	Very unhealthy	Purple
301–500	Hazardous	Maroon

- Computed for each criteria pollutant even though many newspapers only give a single value (usually for worse index)
- In the U.S. health officials are generally concerned about elevated O_3, $PM_{2.5}$, and ultra-fine particles

Tropospheric Pollutants (The Air We Breathe)

Table 1.2 U.S. National Ambient Air Quality Standards

Pollutant	Standard (ppm)	Approximate Equivalent Concentration (μg/m^3)
Carbon monoxide		
8-hr average	9	10,000
1-hr average	35	40,000
Nitrogen dioxide		
Annual average	0.053	100
Ozone		
8-hr average	0.075	147
1-hr average	0.12	235
Particulates*		
PM_{10}, annual average	—	50
PM_{10}, 24-hr average	—	150
$PM_{2.5}$, annual average	—	15
$PM_{2.5}$, 24-hr average†	—	35
Sulfur dioxide		
Annual average	0.03	80
24-hr average	0.14	365
3-hr average	0.50	1,300

*PM_{10} refers to all airborne particles 10 μm in diameter or less. $PM_{2.5}$ refers to particles 2.5 μm in diameter or less.

—The unit of ppm is not applicable to particulates.

†$PM_{2.5}$ standards are likely to be revised after 2011.

Source: U.S. Environmental Protection Agency. Standards also exist for lead, but are not included here.

Chapter 1
Chemistry in Context

Note: A standard also exists for lead, but lead does not appear in this table since most of the U.S. is in compliance

Criteria pollutant: identified as being common-place and detrimental to human welfare (i.e., ubiquitous pollutant)

Tropospheric Ozone Production

$$OH + CO \rightarrow CO_2 + H$$

$$H + O_2 + M \rightarrow HO_2 + M$$

$$HO_2 + NO \rightarrow OH + NO_2$$

$$NO_2 + h\nu \rightarrow NO + O$$

$$O + O_2 + M \rightarrow O_3 + M$$

NO & NO_2: Emitted by fossil fuel combustion & biomass burning

$$N_2 + O_2 \xrightarrow{\text{High T}} 2\,NO$$

CO: Emitted by fossil fuel combustion & biomass burning

Tropospheric Ozone Production

$$OH + \mathbf{CO} \rightarrow \mathbf{CO_2} + H$$
$$H + \mathbf{O_2} + M \rightarrow HO_2 + M$$
$$HO_2 + NO \rightarrow OH + NO_2$$
$$NO_2 + h\nu \rightarrow NO + O$$
$$O + \mathbf{O_2} + M \rightarrow \mathbf{O_3} + M$$
$$\text{Net:} \quad \mathbf{CO + 2\,O_2 \rightarrow CO_2 + O_3}$$

Oxidation of CO in the presence of elevated NO_x ($NO + NO_2$) leads to ***production*** of tropospheric ozone

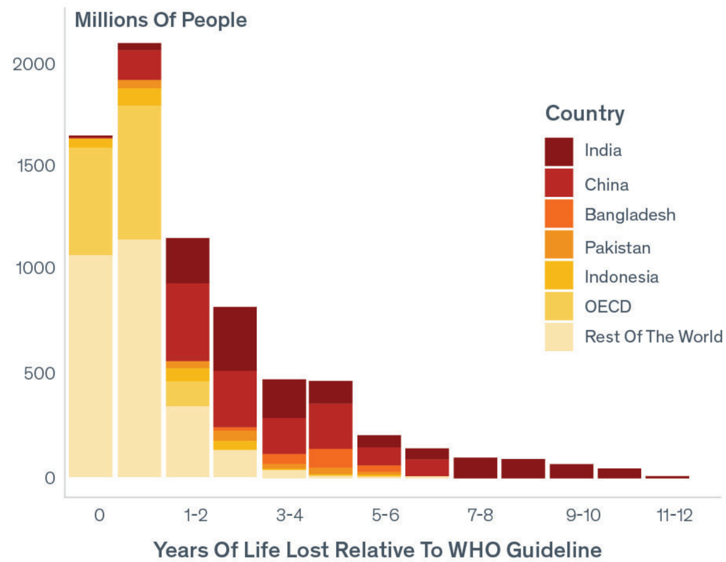
Air Quality Standards and Why We Care

For more information, have a look at:

https://www.weforum.org/agenda/2018/11/deadly-air-pollution-shortens-lives-by-nearly-2-years-researchers

https://aqli.epic.uchicago.edu/pollution-facts

Air Quality Standards and Why We Care

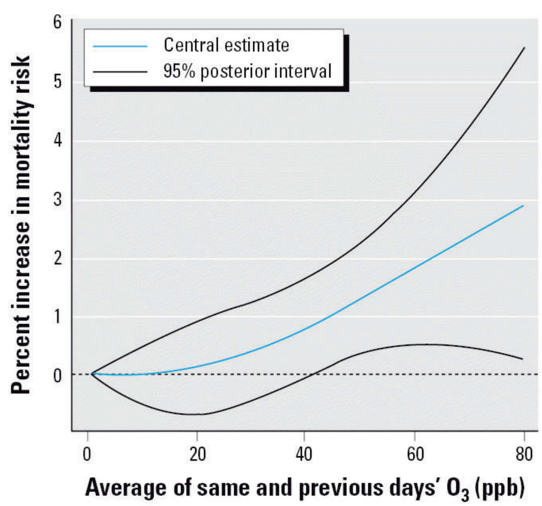


For more information, have a look at:

https://www.weforum.org/agenda/2018/11/deadly-air-pollution-shortens-lives-by-nearly-2-years-researchers

https://aqli.epic.uchicago.edu/pollution-facts

Air Quality Standards and Why We Care



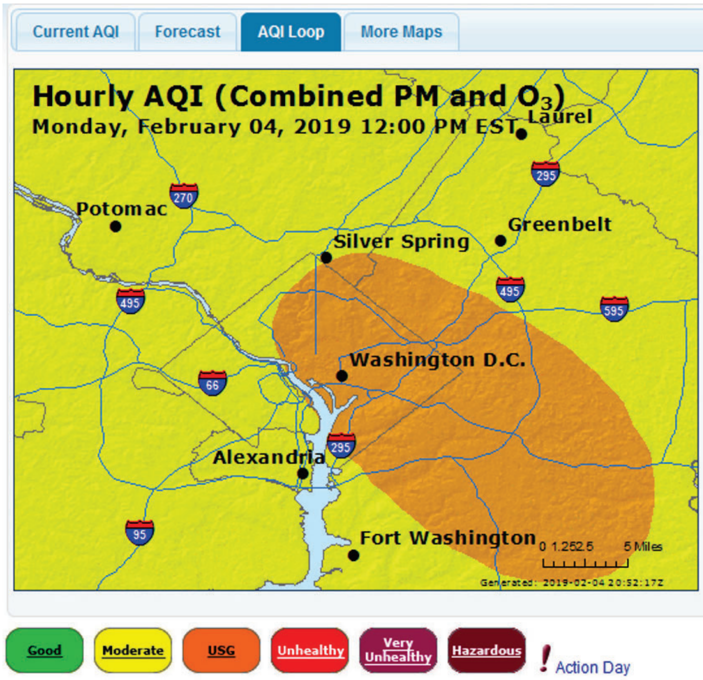
Increased risk of premature death (mortality) for all levels of surface O_3

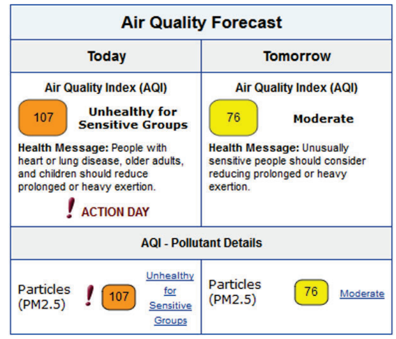
Reductions in surface ozone will benefit public health, regardless of present conditions

Bell et al., 2006

http://www.ncbi.nlm.nih.gov/sites/ppmc/articles/PMC1440776

Yesterday !!!!

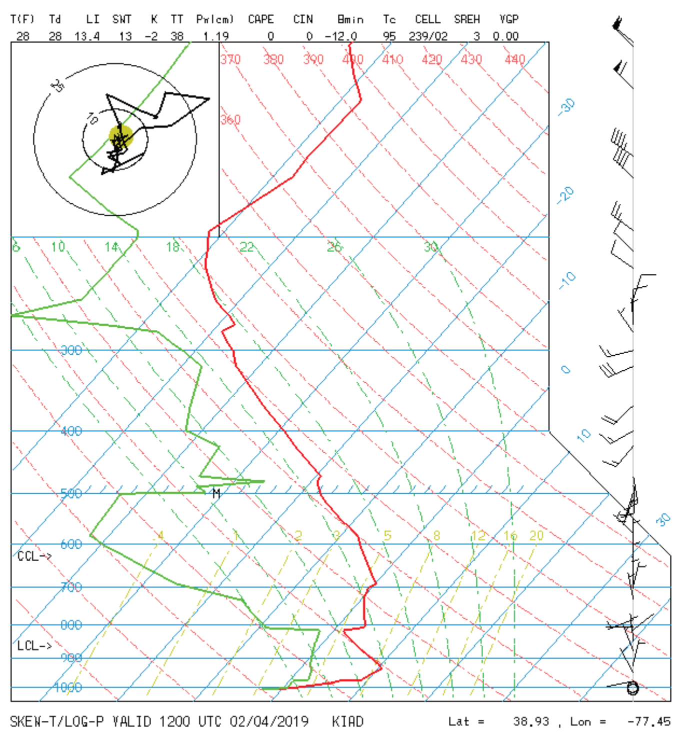




USG: Unhealthy for Sensitive Groups

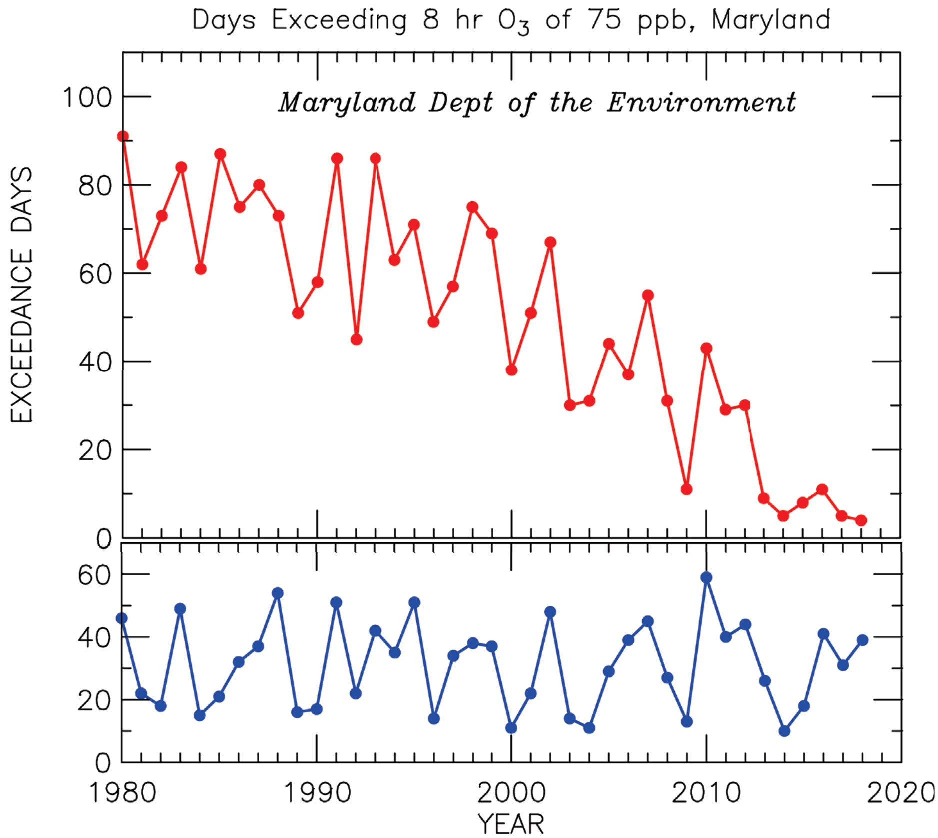
https://www.washingtonpost.com/weather/2019/02/04/theres-an-air-quality-alert-washington-sky-is-hazy-its-february-whats-going
Anyone with asthma or other respiratory or cardiovascular conditions should sign up for AQI alerts at https://airnow.gov or http://www.enviroflash.info

Air Quality Standards and Why We Care



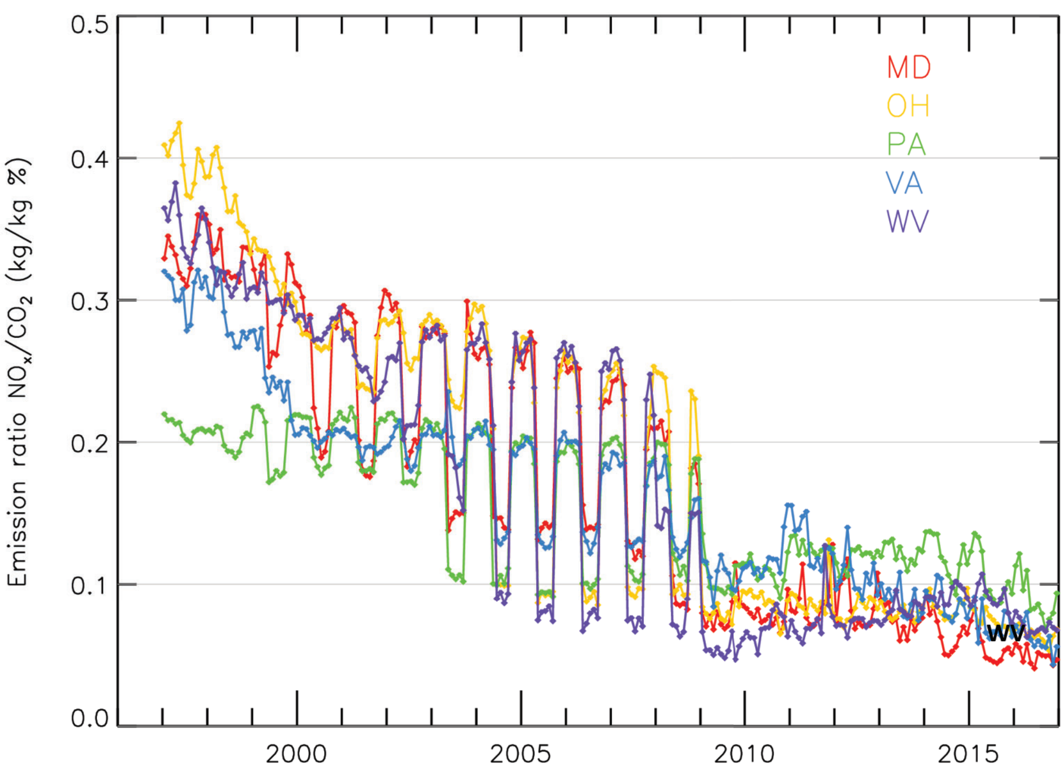
Yesterday's Air Quality alert was driven by a temperature inversion as recorded at Dulles Airport http://weather.rap.ucar.edu/upper/iad.gif and explained in the Washington Post:
https://www.washingtonpost.com/weather/2019/02/04/theres-an-air-quality-alert-washington-sky-is-hazy-its-february-whats-going

Significant Improvements in *Local* Air Quality since early 1980s



http://www.mde.state.md.us/programs/Air/AirQualityMonitoring/Pages/SeasonalReports.aspx

Trends in power plant emissions of NOx



Nitrogen Dioxide (NO_2): Combustion product that leads to formation of tropospheric ozone

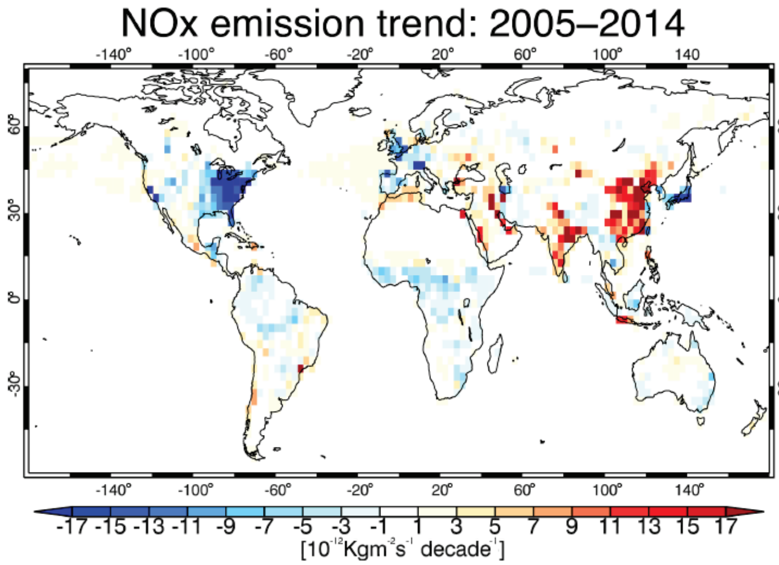


Figure 6. Global distribution of linear trend of the a posteriori surface NO_x emissions (in $10^{-12}\,kg\,m^{-2}\,s^{-1}$ per decade) for the period 2005–2014. The red (blue) colour indicates positive (negative) trends.

Miyazaki *et al*., *ACP*, 2017
https://www.atmos-chem-phys.net/17/807/2017/

Next Lecture: Fundamentals of Earth's Atmosphere

Great if you can complete Learning Outcome Quizzes to review salient "take away" messages

Next Reading:

Chemistry in Context, Secs 1.0 to 1.2,1.5 to 1.8, 1.14, 2.1, 3.6 & 3.7 (~28 pgs)
Copies available for those who do not yet have text

as well as 4 pages (433) or 7 pages (633) from
Atmospheric Environment by Michael McElroy

Admission Ticket for Lecture 3 was posted on ELMS on Sat

Please bring a calculator to class on Thursday