Overview of Global Warming, Ozone Depletion, and Air Quality

AOSC / CHEM 433 & AOSC / CHEM 633

Ross Salawitch

Class Web Sites:
http://www2.atmos.umd.edu/~rjs/class/spr2022
https://myelms.umd.edu/courses/137772

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

Lecture 2

1 February 2022

Announcements

1) AOSC Weekly Seminar Feb 3: 3:30 pm (Thursday)

3:30 PM EST
THURSDAY, FEBRUARY 3, 2022

PRESENTED IN HYBRID VIRTUAL/IN-PERSON FORMAT
SEMINAR LOCATION: ATLANTIC BUILDING, ROOM 2400
CONTACT: JACOB WENEGRAT (WENEGRAT@UMD.EDU) OR JOSEPH KNISELY (JKNISELY@UMD.EDU)

https://aosc.umd.edu/seminars

UNIVERSITY OF MARYLAND 1856
DEPARTMENT OF
ATMOSPHERIC &
OCEANIC SCIENCE

DR. RYAN STAUFFER

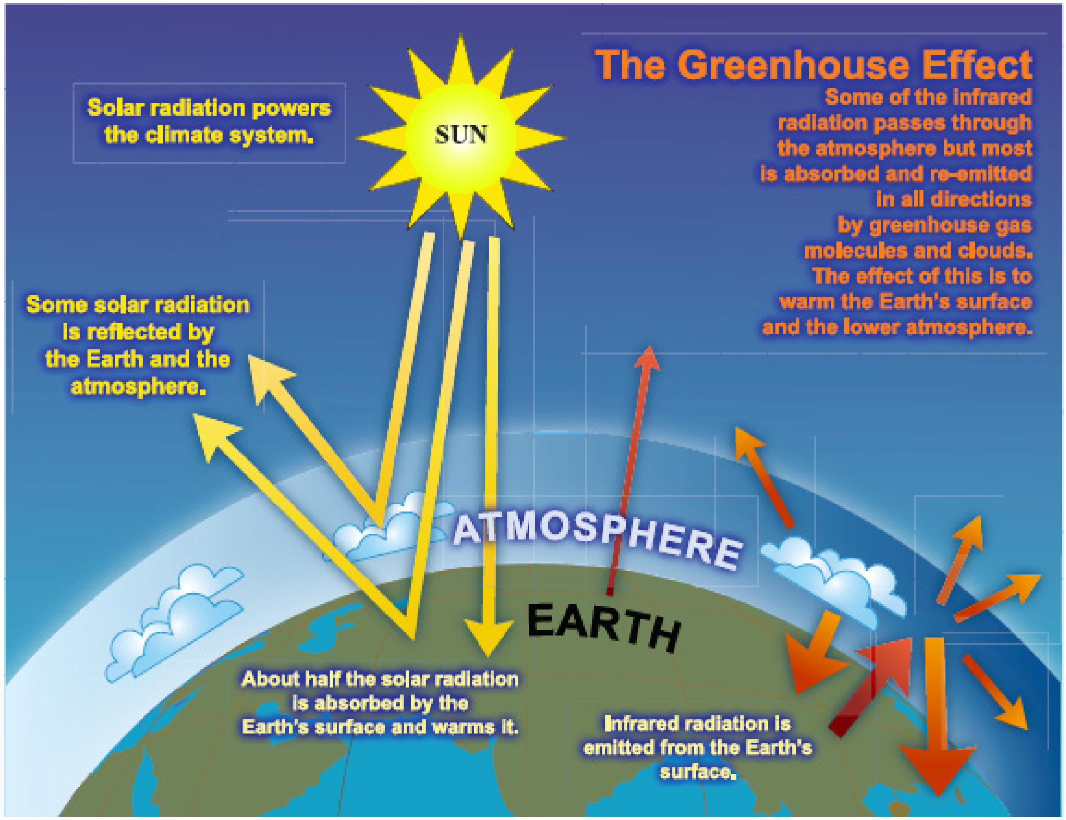
INSTITUTION: NASA/GSFC CHEMISTRY AND ATMOSPHERIC DYNAMICS LABORATORY

TITLE: 'SOUTHERN HEMISPHERE ADDITIONAL OZONESONDES (SHADOZ): ACCOMPLISHMENTS FROM 25 YEARS OF TROPICAL AND SUBTROPICAL OZONE PROFILING'

Abstract: Ozone (O3) is a vital trace gas in Earth's atmosphere. It shields life from harmful UV radiation, but is a strong oxidant and harmful pollutant when found in high quantities near the surface. Ozone is also a greenhouse gas in the troposphere, so characterizing the vertical distribution of O3 is critical to determining its role in climate and effects on air quality. Satellite observations give us excellent spatial coverage of the total column O3 in the atmosphere, but are unable to resolve the O3 vertical profile with accuracy, especially below the stratosphere. Balloon-borne ozonesondes bridge this gap by providing high vertical resolution measurements from the surface to over 30 km altitude. Before the late 1990s, ozonesonde measurements in the tropics were sparse, so the Southern Hemisphere Additional Ozonesondes (SHADOZ) strategic network organized over a dozen stations to frequently launch ozonesondes for pollution and climate studies. This talk features the history and accomplishments of SHADOZ from 1998-2021 including work on satellite and model validation, biomass burning, weather and climate links to O3, and O3 trends, as well as data reprocessing and quality assurance activities with global partners.

2) ***Please have a calculator available for class on Thursday***

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 2019

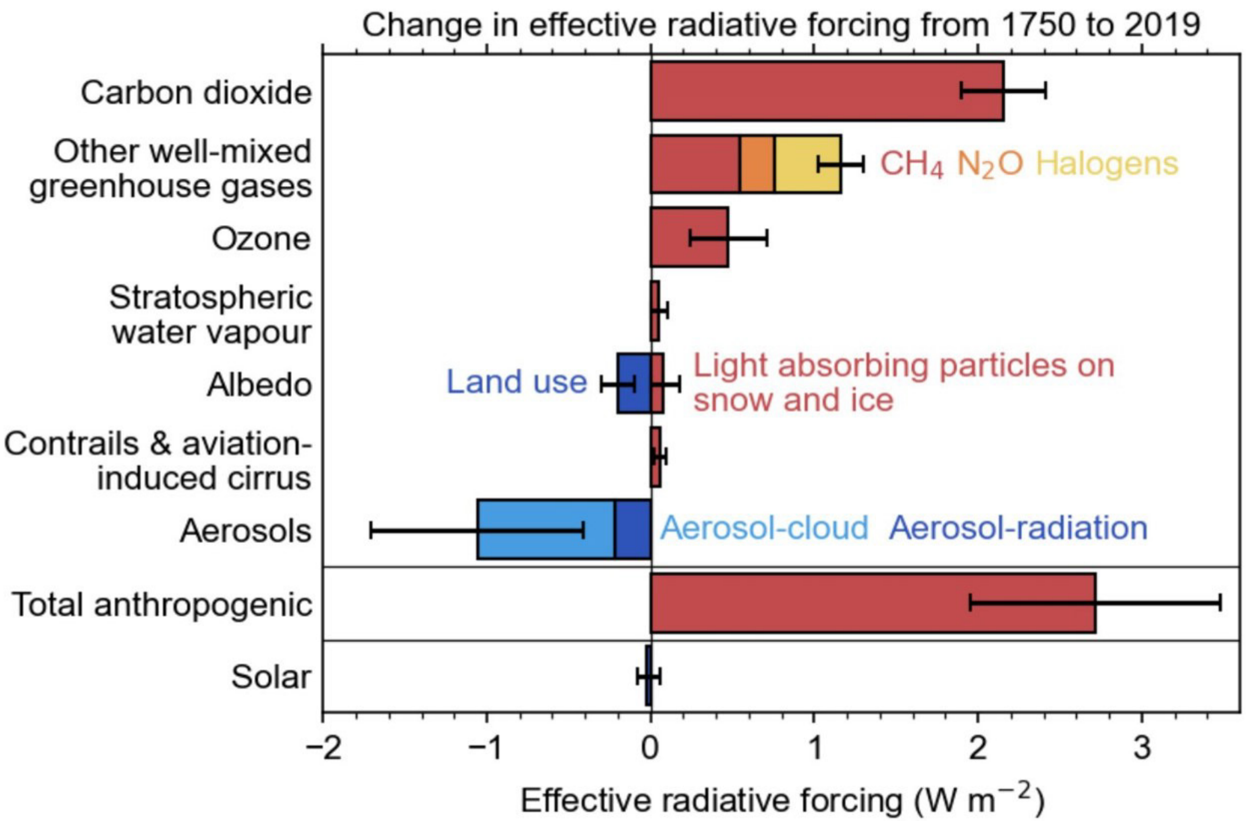
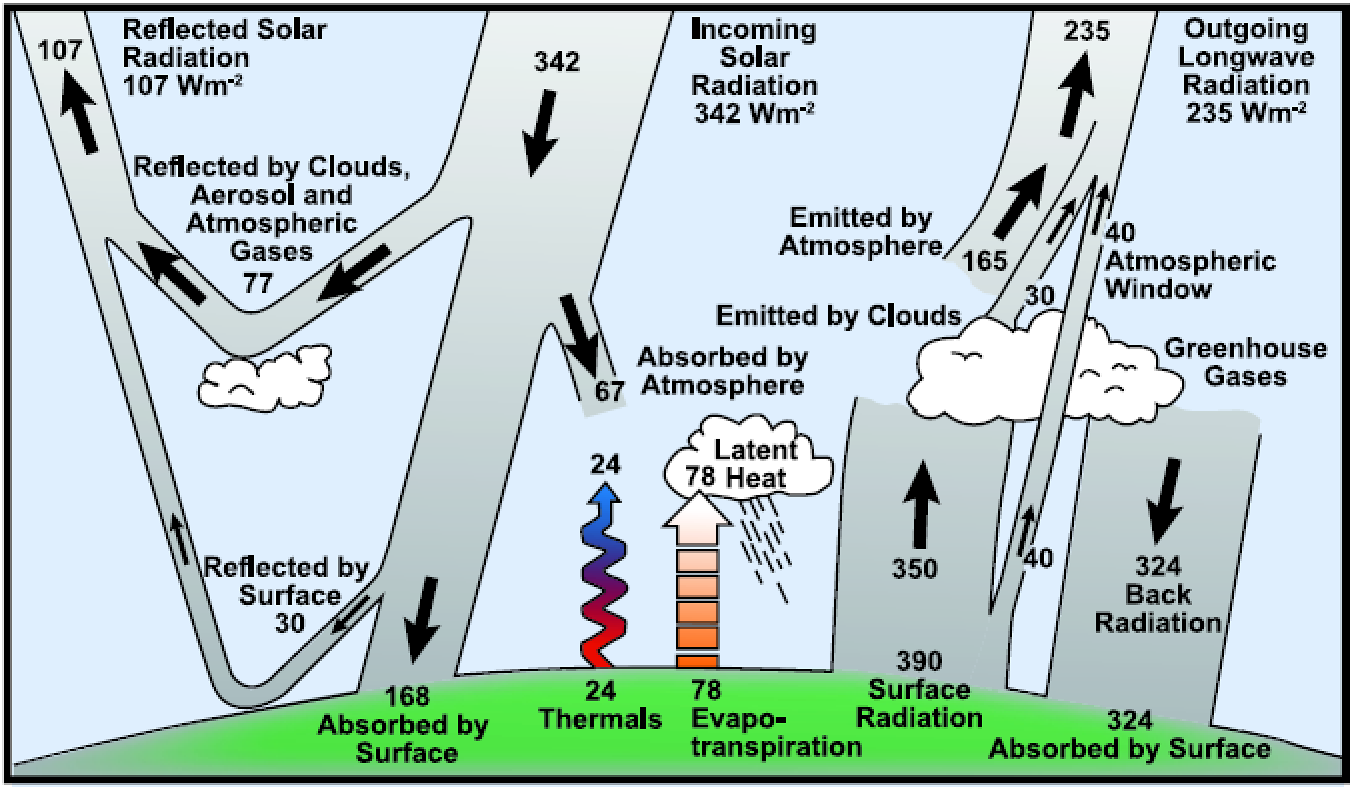


Figure 7.6, IPCC (2021)
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_TS.pdf

Radiative Forcing



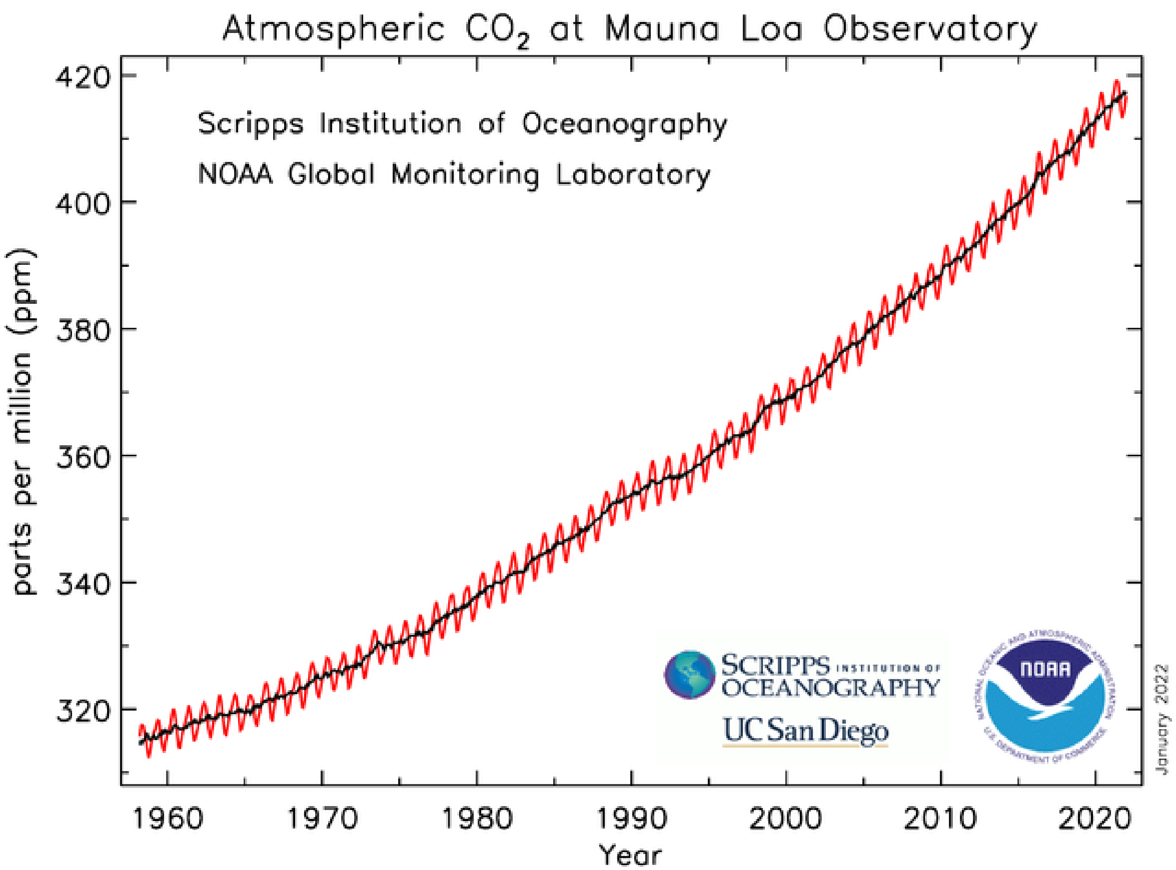
FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming 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.

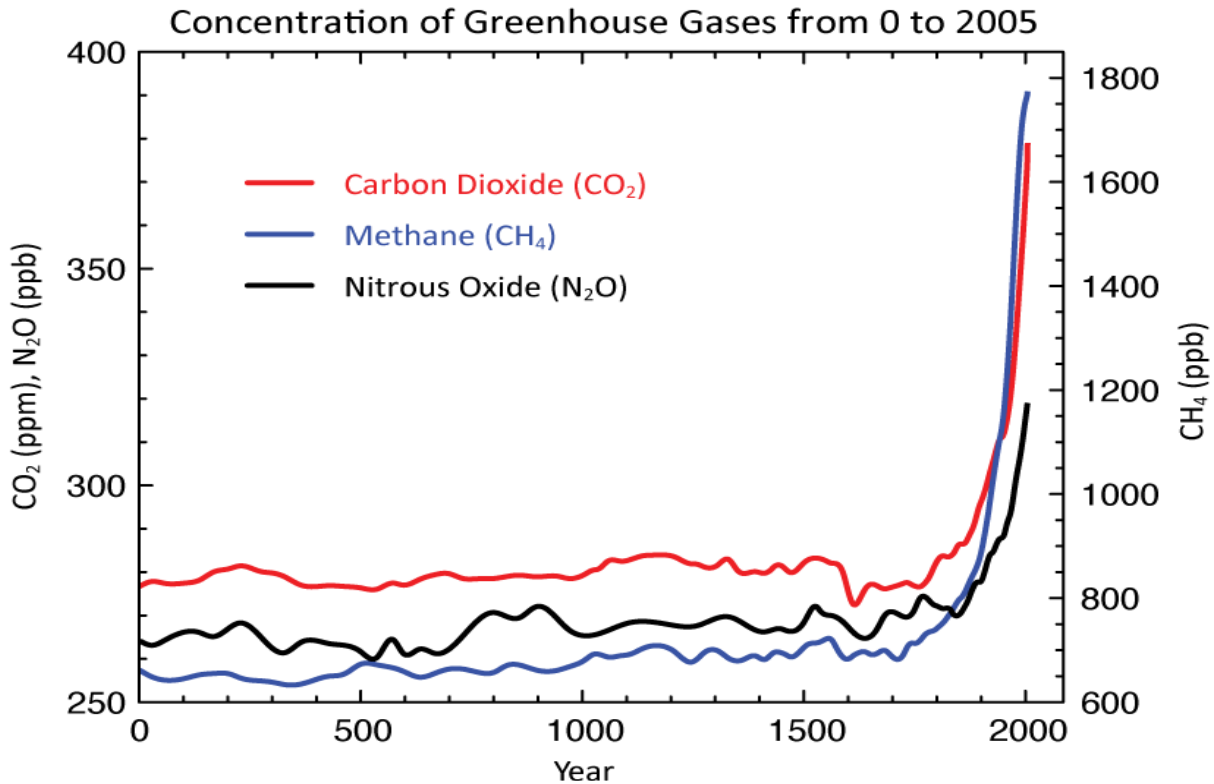
Modern CO_2 Record

Global Mean on 30 Jan 2022: 419.41 parts per million (ppm)
30 Jan 2021: 416.19 parts per million (ppm)
Annual Rise about 3.2 ppm (0.77%)



Legacy of Charles Keeling, Scripps Institution of Oceanography, La Jolla, CA
https://www.esrl.noaa.gov/gmd/webdata/ccgg/trends/co2_data_mlo.png
See also https://www.co2.earth/daily-co2

GHG Record Over Last Several Millennia

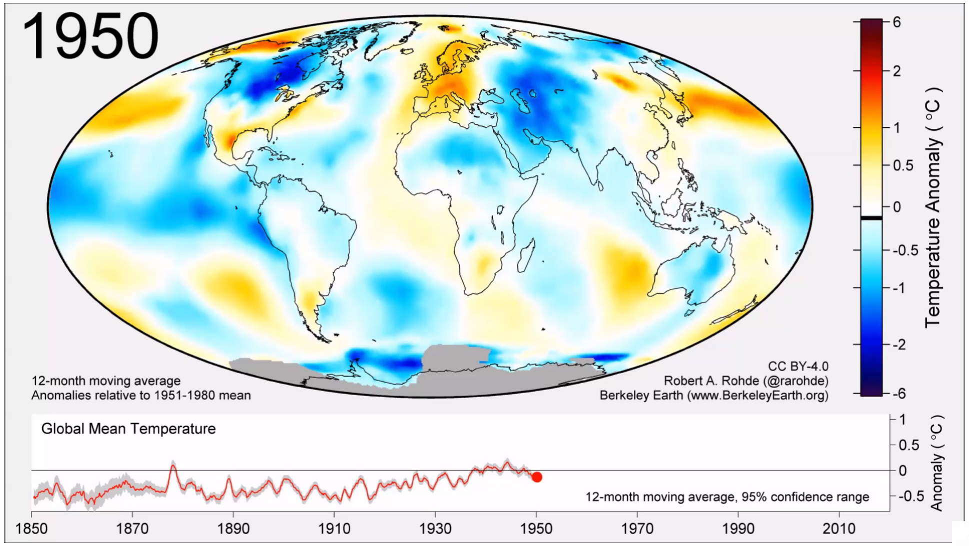


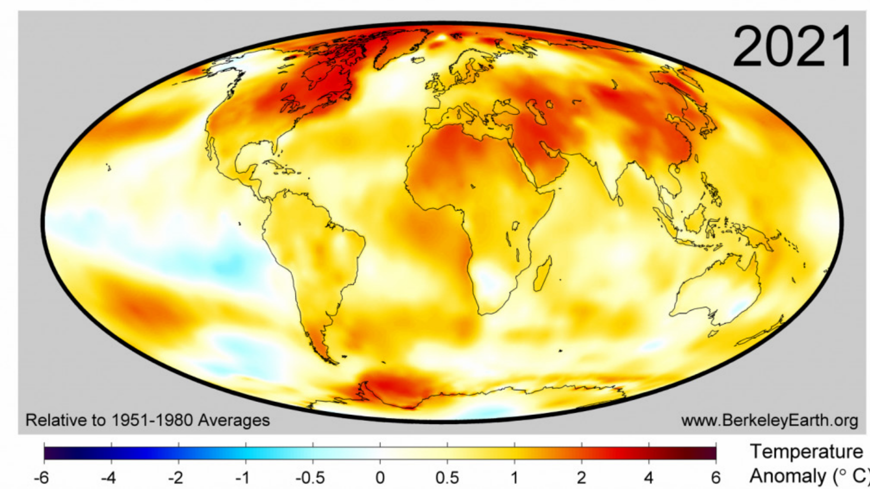
FAQ 2.1, Figure 1 (Errata). *Revised figure showing atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Using the combined and simplified data from Chapters 6 and 2, the original figure displayed the CH_4 curve incorrectly. The revised figure shows the same 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 the line for CH_4 had been plotted incorrectly

Berkeley Earth Animation of Global Warming

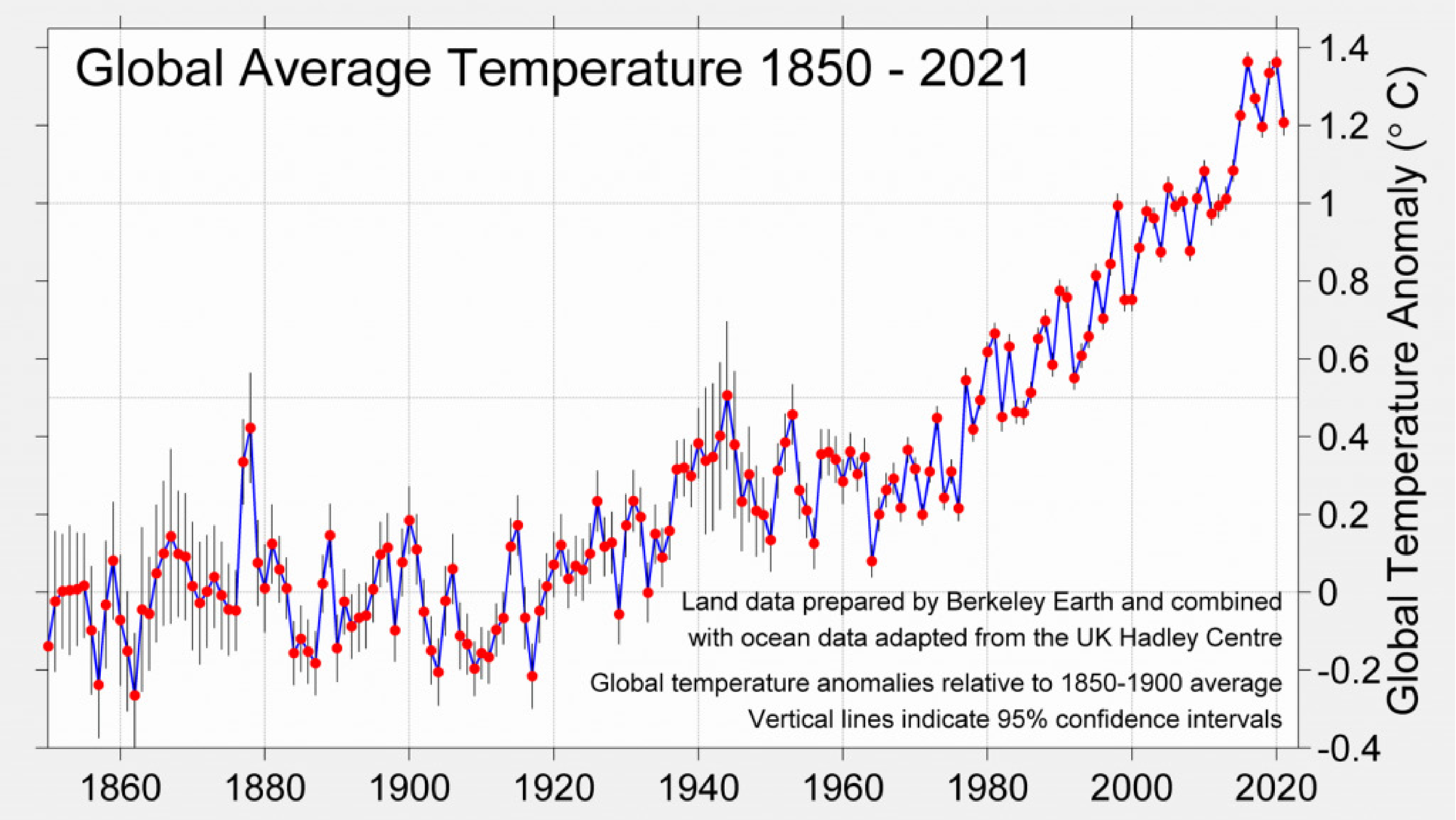




1°C (Celsius) warming is equivalent to 1.8°F (Fahrenheit) warming

Work of Robert Rohde and the Berkeley Earth Team
http://berkeleyearth.org
Animation at https://twitter.com/RARohde/status/1217496115429494786

Berkeley Earth Animation of Global Warming



The global mean temperature in 2021 was about 1.2°C above the average temperature from 1850-1900, a period often used as a pre-industrial baseline for global temperature targets. Nominally, 2021 was the 6th warmest year to have been directly observed, though 2015, 2018, and 2021 all cluster closely together relative to their uncertainty estimates. Hence, the 5th, 6th, and 7th warmest years are all essentially tied.

Work of Robert Rohde and the Berkeley Earth Team
http://berkeleyearth.org
http://berkeleyearth.org/global-temperature-report-for-2021/

GWP – Global Warming Potential

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

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

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

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:

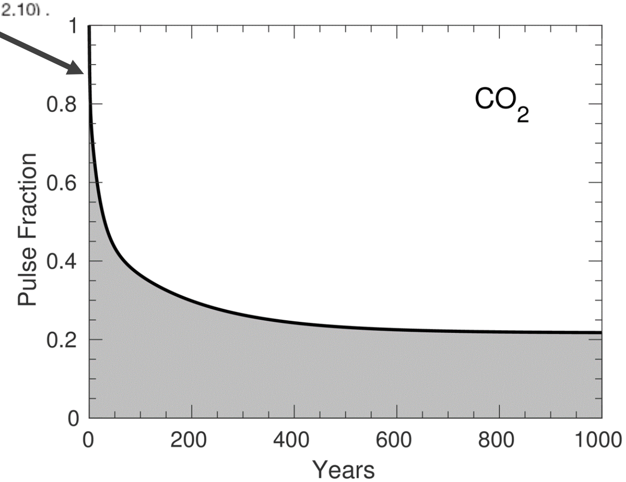
‡ SAR refers to the IPCC Second Assessment Report (1995) used for reporting under the UNFCCC.

[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

GWPs Now Come In **Two Flavors** (20 yr & 100 yr time horizons) And Are *Slight Moving Targets*

Global Warming Potentials (dimensionless)					
GHG	IPCC (1995) **SAR**	IPCC (2001) **AR3**	IPCC (2007) **AR4**	IPCC (2013) **AR5**	IPCC (2021) **AR6**
100 Year Time Horizon					
CH_4	21	23	25	28	27.2[a] or 29.8[b]
N_2O	310	296	298	265	273
20 Year Time Horizon					
CH_4	56	62	72	84	80.8[a] or 82.5[b]
N_2O	280	275	289	264	273

[a]CH_4 from non-fossil fuel sources such as agriculture
[b]CH_4 from fossil fuel sources

In part because best estimate of atmospheric lifetimes has evolved:

Atmospheric Lifetime (year)					
GHG	IPCC (1995) **SAR**	IPCC (2001) **AR3**	IPCC (2007) **AR4**	IPCC (2013) **AR5**	IPCC (2021) **AR6**
CH_4	12	12	12	12.4	11.8
N_2O	114	114	114	121	109

IPCC : Intergovernmental Panel on Climate Change
SAR : Second Assessment Report; AR3: Third Assessment Report; AR4: Fourth Assessment Report
AR5: Fifth Assessment Report; AR6: Sixth Assessment Report

100 yr time time-horizon GWPs from latest IPCC report supposed to be used for International Book-Keeping

IPCC Sixth Assessment Report Global Warming Potentials

<table>
<tr><th rowspan="2">Greenhouse Gas</th><th colspan="3">100 Year Time Period</th><th colspan="3">20 Year Time Period</th></tr>
<tr><th>AR4 2007</th><th>AR5 2014</th><th>AR6 2021</th><th>AR4 2007</th><th>AR5 2014</th><th>AR6 2021</th></tr>
<tr><td>CO_2</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>CH_4 fossil origin</td><td rowspan="2">25</td><td rowspan="2">28</td><td>29.8</td><td rowspan="2">72</td><td rowspan="2">84</td><td>82.5</td></tr>
<tr><td>CH_4 non fossil origin</td><td>27.2</td><td>80.8</td></tr>
<tr><td>N_2O</td><td>298</td><td>265</td><td>273</td><td>289</td><td>264</td><td>273</td></tr>
</table>

Does the new report mean your company has to update your calculations, and should you be adopting the 100-year or 20-year GWPs? The answer is not as simple as you might think and depends on regulation in your region and the purpose of your report. However, in the absence of any bespoke requirements, the best practice is to adopt the new AR6 100-year GWPs.

The Paris Rulebook states: ' *Each Party shall use the 100-year time-horizon global warming potential (GWP) values from the IPCC Fifth Assessment Report, or 100-year time-horizon GWP values from a subsequent IPCC assessment report as agreed upon by the 'Conference of the Parties serving as the meeting of the Parties to the Paris Agreement' (CMA), to report aggregate emissions and removals of GHGs, expressed in CO2-eq. Each Party may in addition also use other metrics (e.g., global temperature potential) to report supplemental information on aggregate emissions and removals of GHGs, expressed in CO2-eq*".

https://www.ercevolution.energy/ipcc-sixth-assessment-report

GWP – Global Warming Potential

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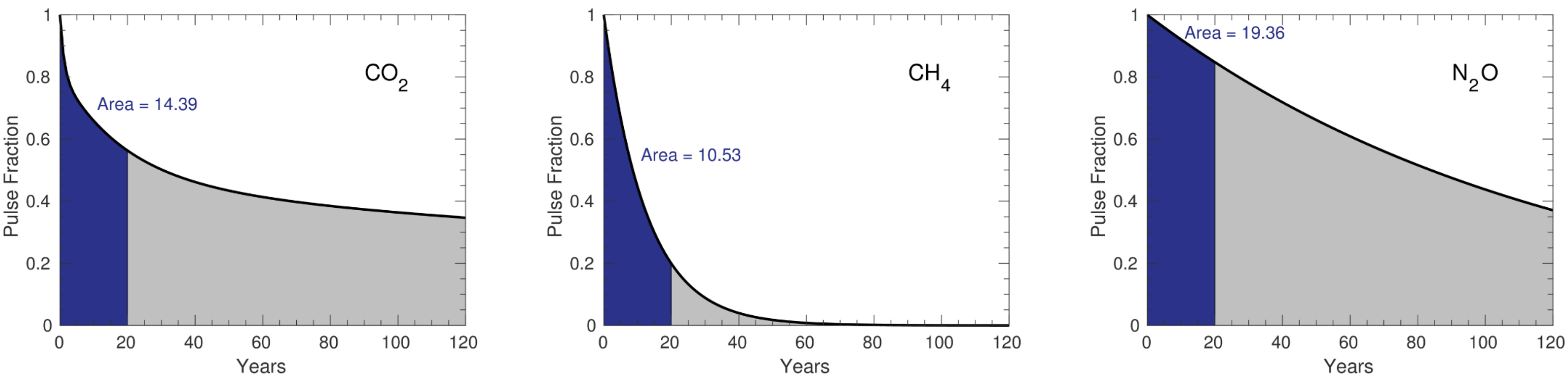
N_2O	280	275	289	264

20 Year Time Horizon means time final = 20 years in these integrals



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

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

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

where all times are given in units of year

GWP – Global Warming Potential

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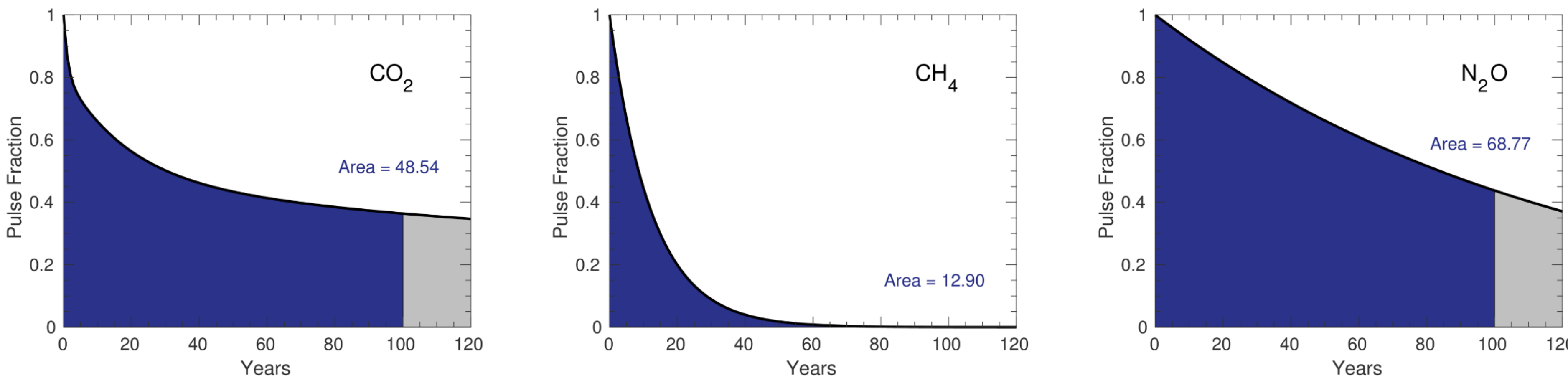
100 Year Time Horizon means time final = 100 years in these integrals



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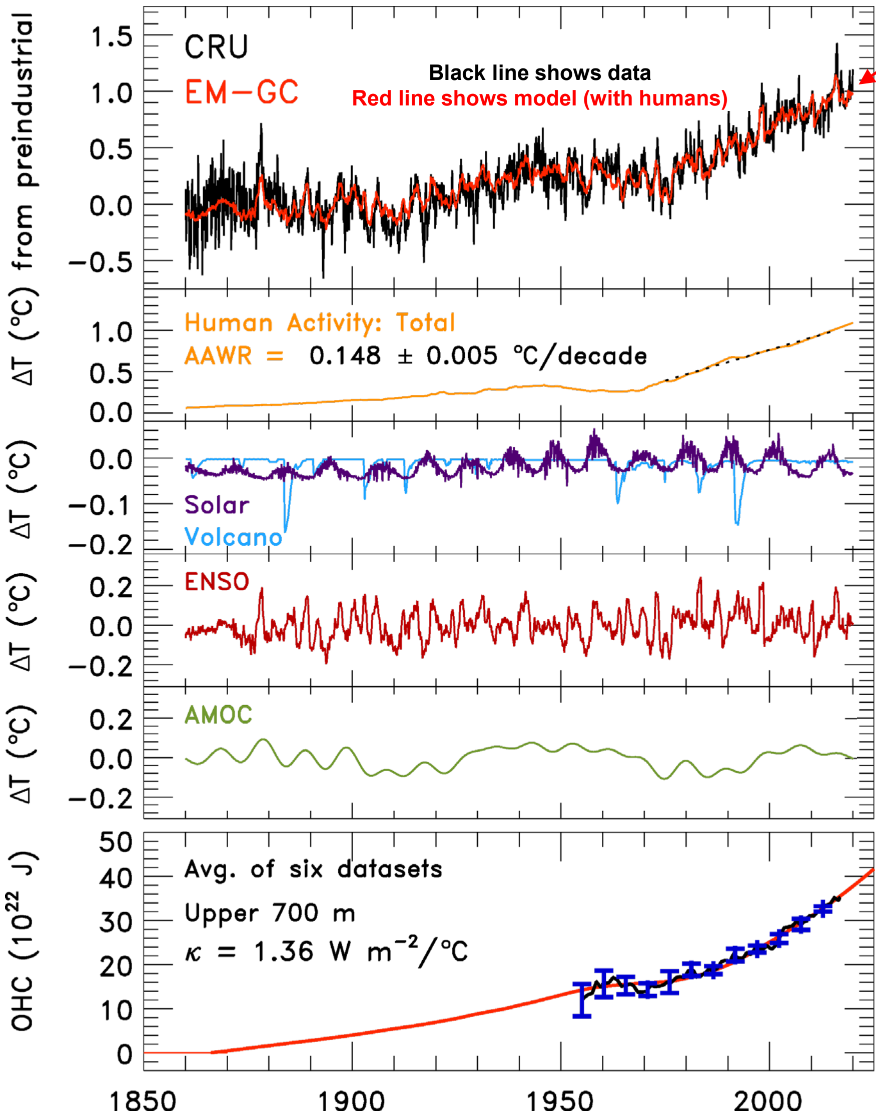
where all times are given in units of year

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 =

$\kappa(1+\gamma)\{\Delta T_{MDL\,i} - \Delta T_{OCEAN\,SURFACE\,i}\}$

CRU: Climate Research Unit of East Anglia, United Kingdom
EM-GC: Empirical Model of Global Climate, Univ of Maryland

Global warming is caused by CO_2, the greatest waste product of modern society, as well as CH_4, N_2O, and other GHGs.

Temperature will continue to rise until human emission of GHGs is curtailed

Canty *et al.*, 2013 https://www.atmos-chem-phys.net/13/3997/2013/acp-13-3997-2013.html
McBride *et al.*, 2021 https://esd.copernicus.org/articles/12/545/2021
Nicholls *et al.*, 2021 https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020EF001900
Figure provided by Laura McBride.

Are humans responsible?

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

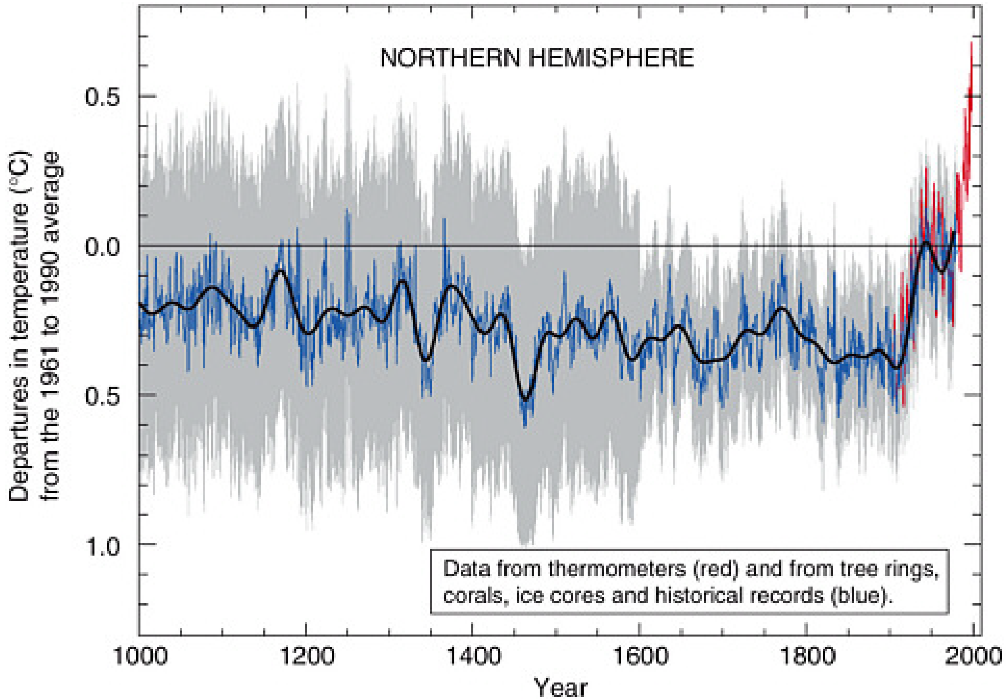
Volcanoes: no sustained forcing

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

Ozone in the Atmosphere

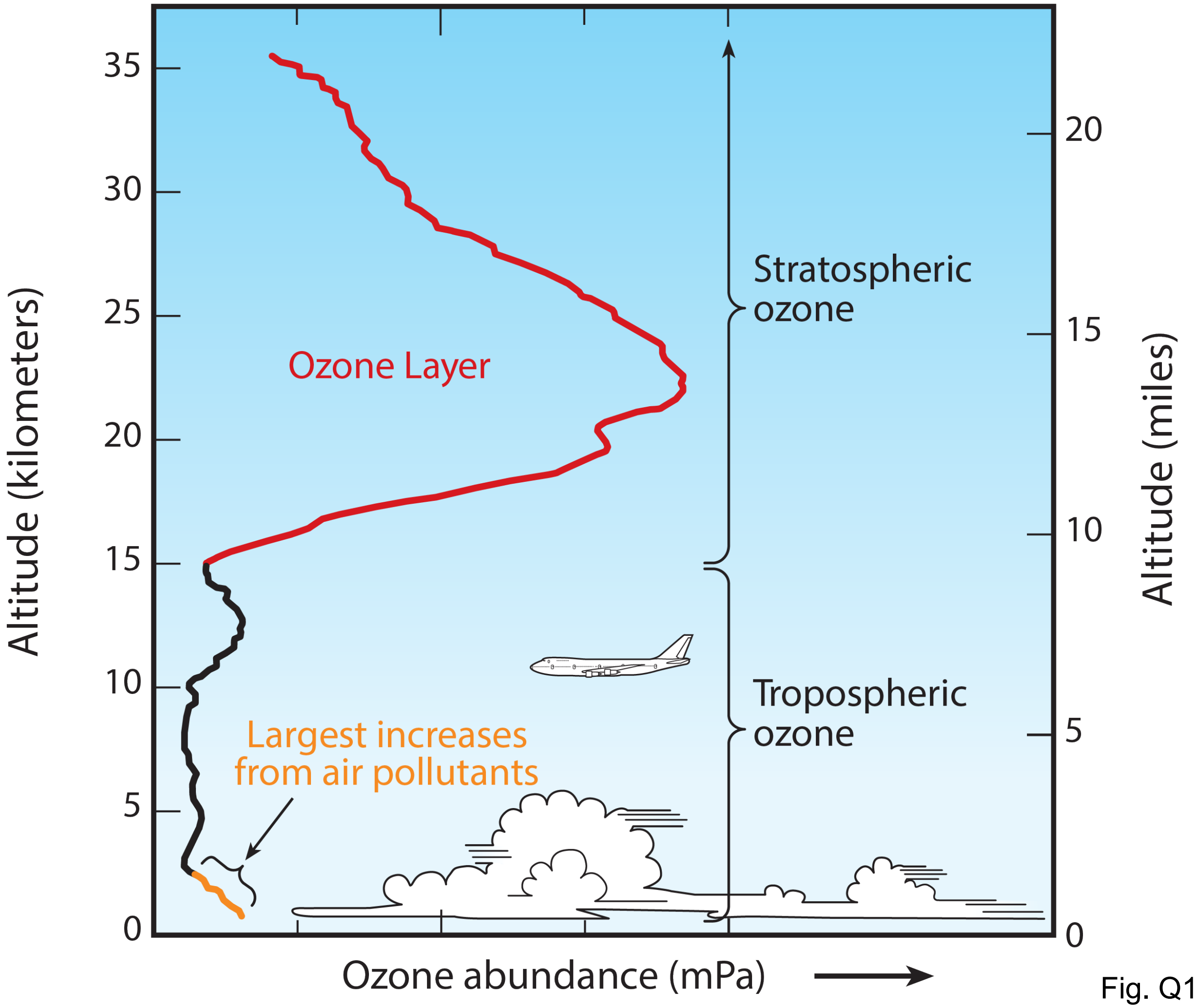
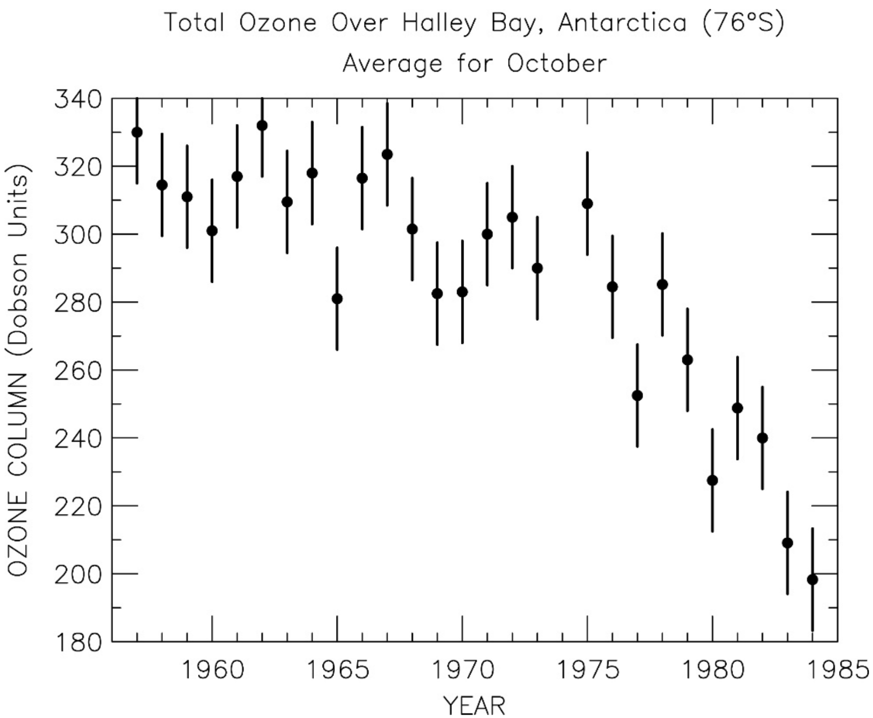


Fig. Q1-2
20 QAs about the Ozone Layer

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

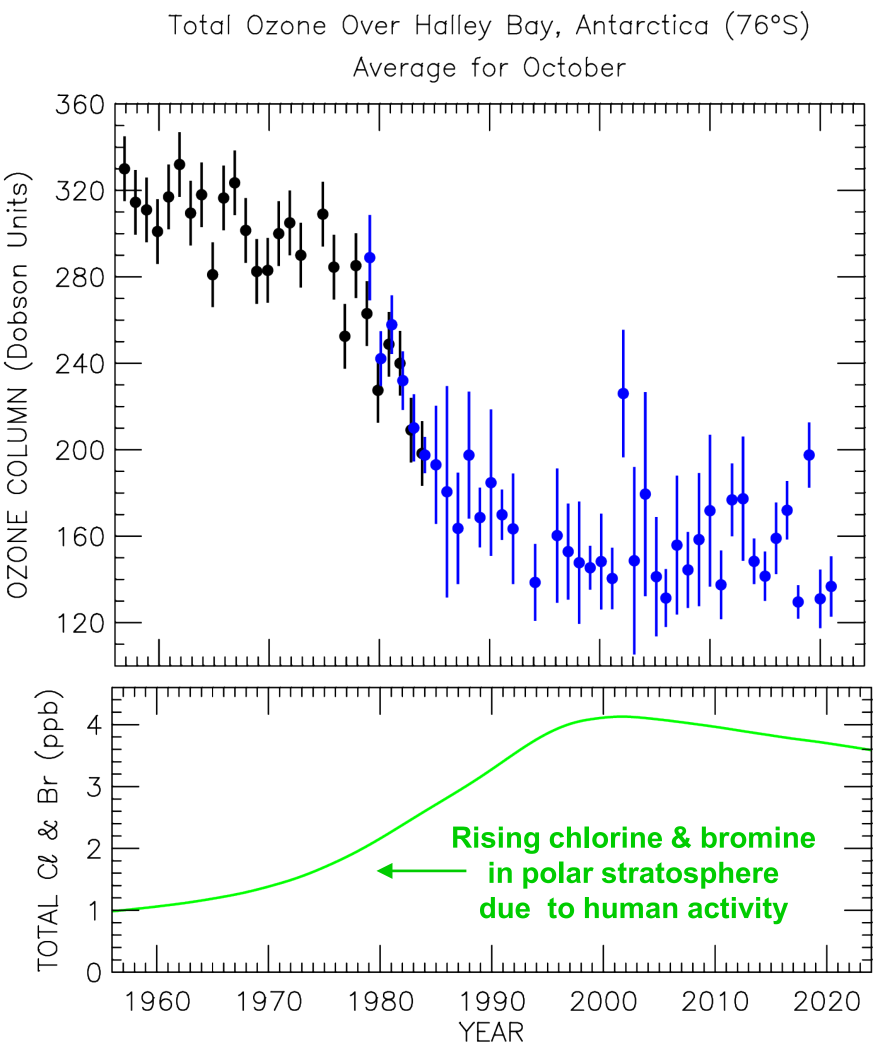
Earth's Atmosphere – Effect of Humans

Stratospheric Ozone – shields surface from solar UV radiation

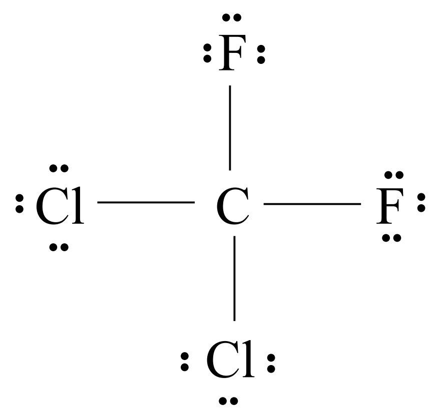


After Farman *et al*., Large losses of total ozone in Antarctica reveal Seasonal ClOx/NOx interaction, Nature, 315, 207, 1985.

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. However, we want 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

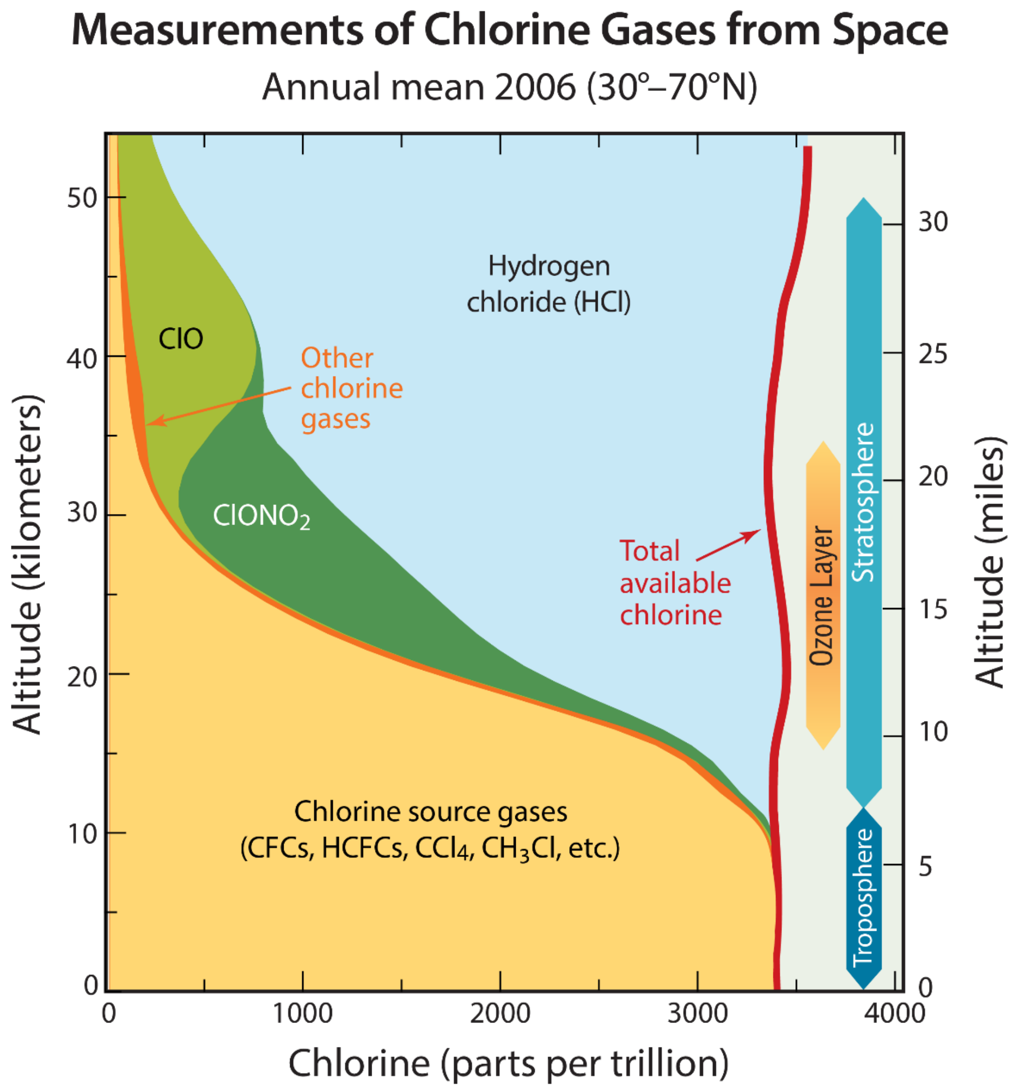
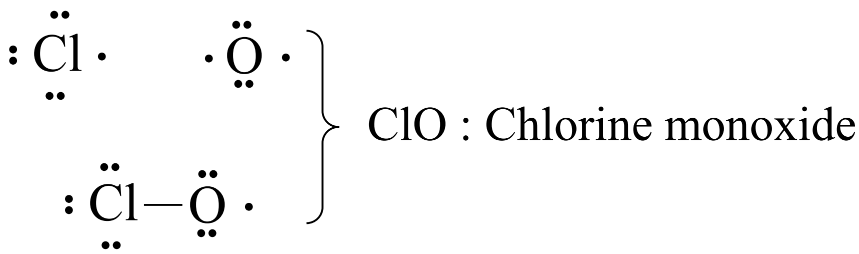


Fig. Q7-2, 20 QAs about the Ozone Layer

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



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Chlorine Radicals Lead to Ozone Loss

$$ClO + ClO + M \rightarrow ClOOCl + M$$

$$Cl + \mathbf{O_3} \rightarrow ClO + \mathbf{O_2}$$

$$Cl + \mathbf{O_3} \rightarrow ClO + \mathbf{O_2}$$

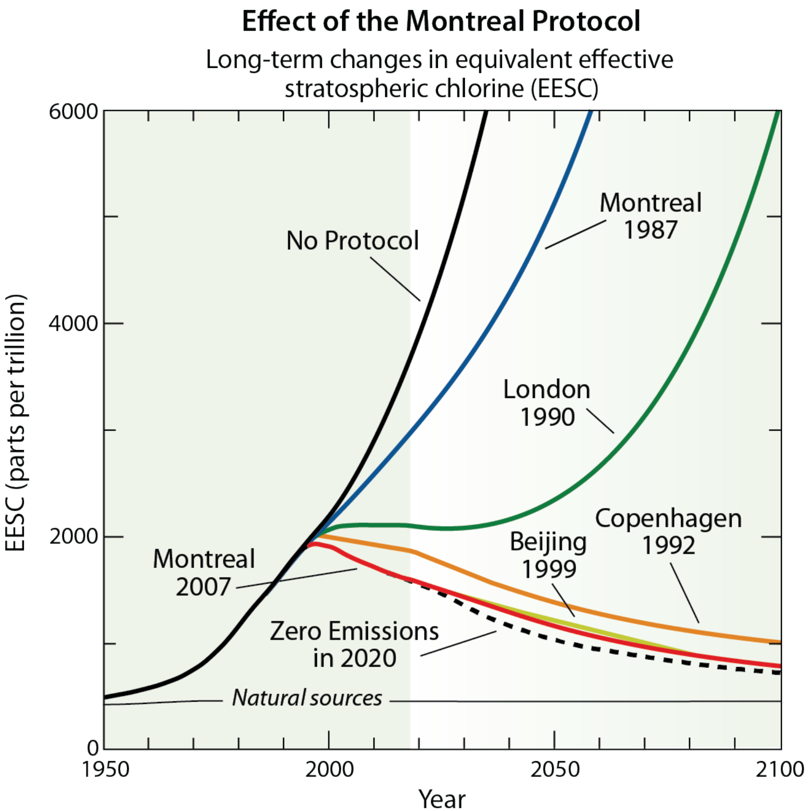
$$ClOOCl + h\nu \rightarrow ClOO + Cl$$

$$ClOO + \text{heat} \rightarrow Cl + \mathbf{O_2}$$

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

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

And Atmospheric Levels of these Pollutants are Declining



CFCs: Chlorofluorocarbons

Contain some combination of chlorine, fluorine, and at least one carbon. Freons are a trade name for CFCs.

Bromocarbons:

Contain bromine, perhaps chlorine, and at least one carbon. Halons are a trade name for bromocarbons.

HCFCs: Hydro-chlorofluorocarbons

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

HFCs: Hydrofluorocarbons

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.** Some HFCs are potent GHGs.

EESC: Equivalent, effective stratospheric chlorine. Reflects combined influence of chlorine and bromine on ozone, via a simple formula: [Chlorine] + 60 × [Bromine]

Figure Q14-1, 20 QAs about the Ozone Layer

CFC Usage Prior to the Montreal Protocol

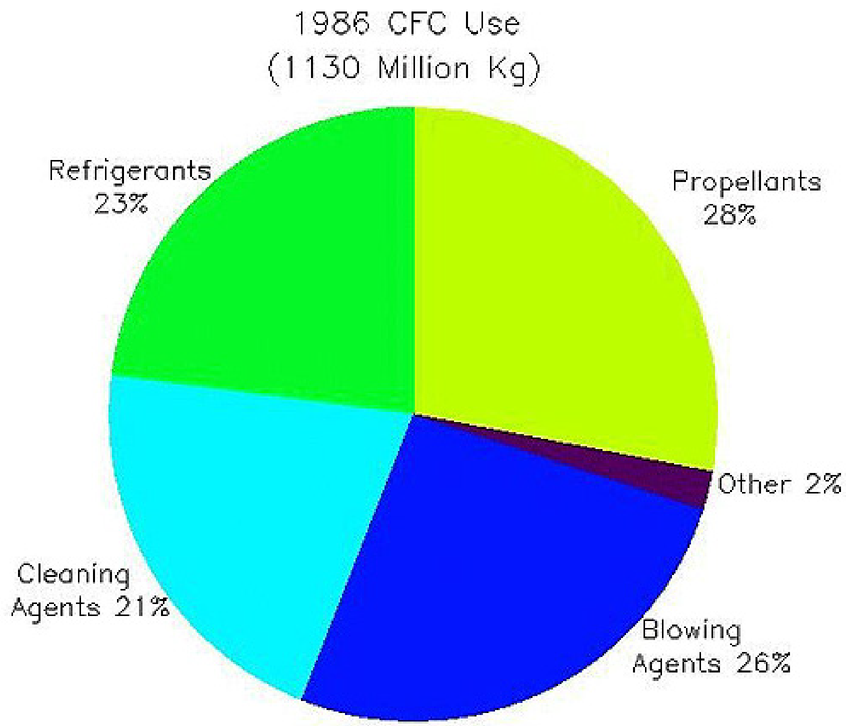
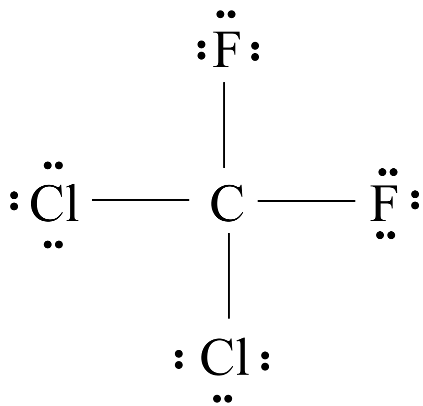


Figure 5b. Changing use patterns for CFCs (from Fisher and Midgley, 1994).

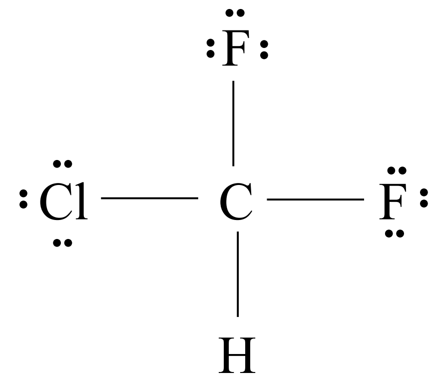
The uses of CFCs in various sectors before the 1987 Montreal Protocol, which required countries to phase out their production to protect the ozone layer.

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

CFCs were replaced with HCFCs



CFC-12
or
Freon-12
or
R-12

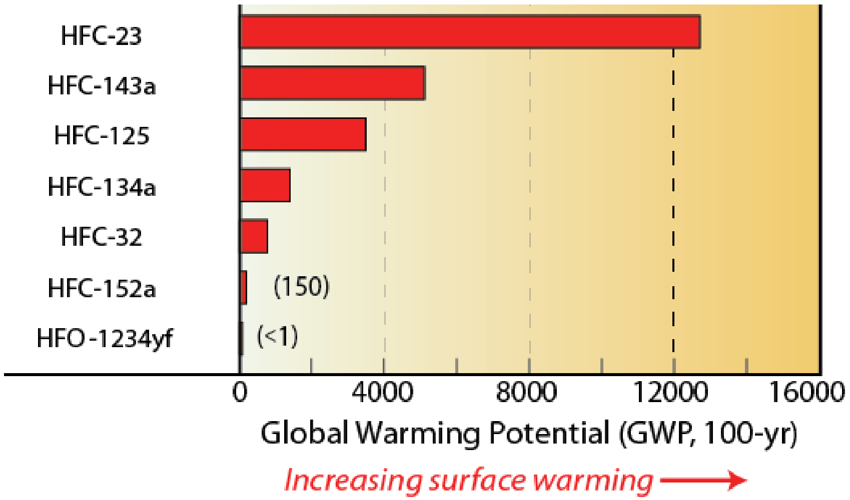


HCFC-22
or
Freon-22
or
R-22

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

CFCs & other ODSs	Phase 1 →	HCFCs	Phase 2 →	HFCs
CFC-11		HCFC-22		HFC-23
CFC-12		HCFC-141b		HFC-143a
CFC-113		HCFC-142b		HFC-125
CFC-114				HFC-134a
CFC-115				etc.
CCl_4				
CH_3CCl_3				
Harmful to ozone layer		**Less harmful to ozone layer**		**But very harmful to Earth's climate**

Figure Q17-3, 20 QAs about the Ozone L



See http://www.atmos.umd.edu/~rjs/class/spr2020/supplemental_readings/Naming_Convention_for_CFCs_Halons.pdf for a guide to CFC naming convention

Climate Benefit of the Kigali Amendment

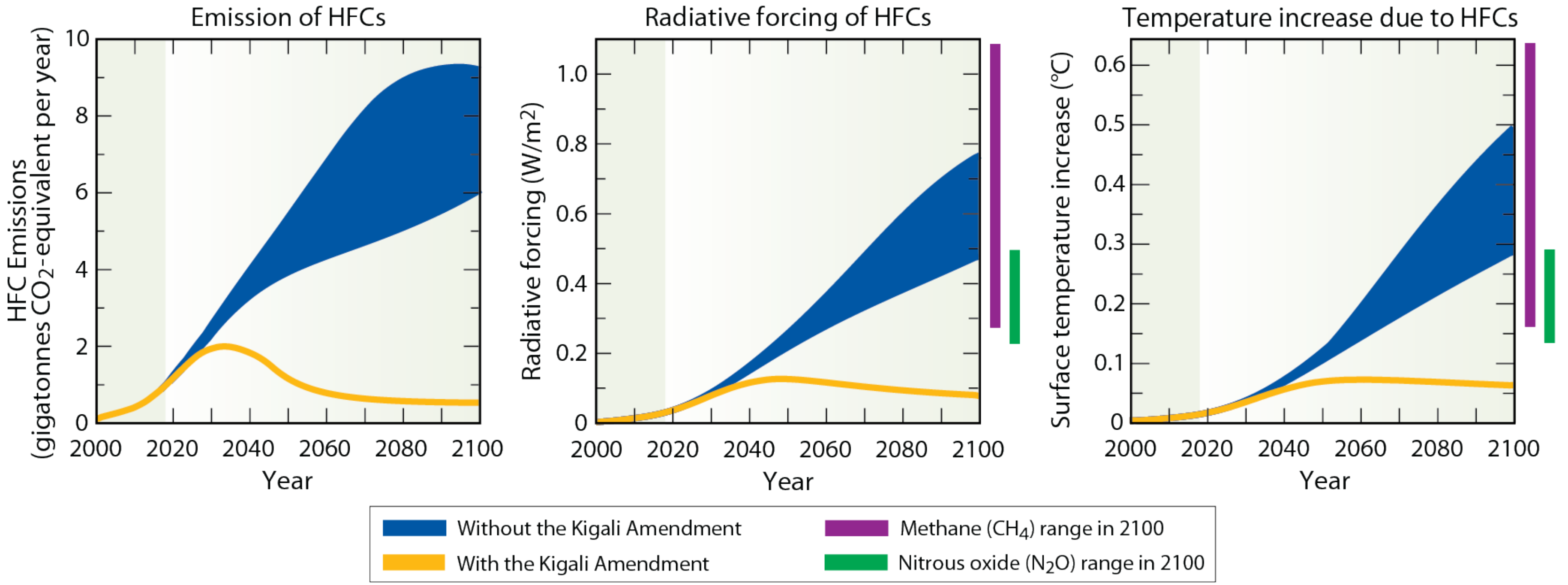


Figure Q19-2, 20 QAs about the Ozone Layer

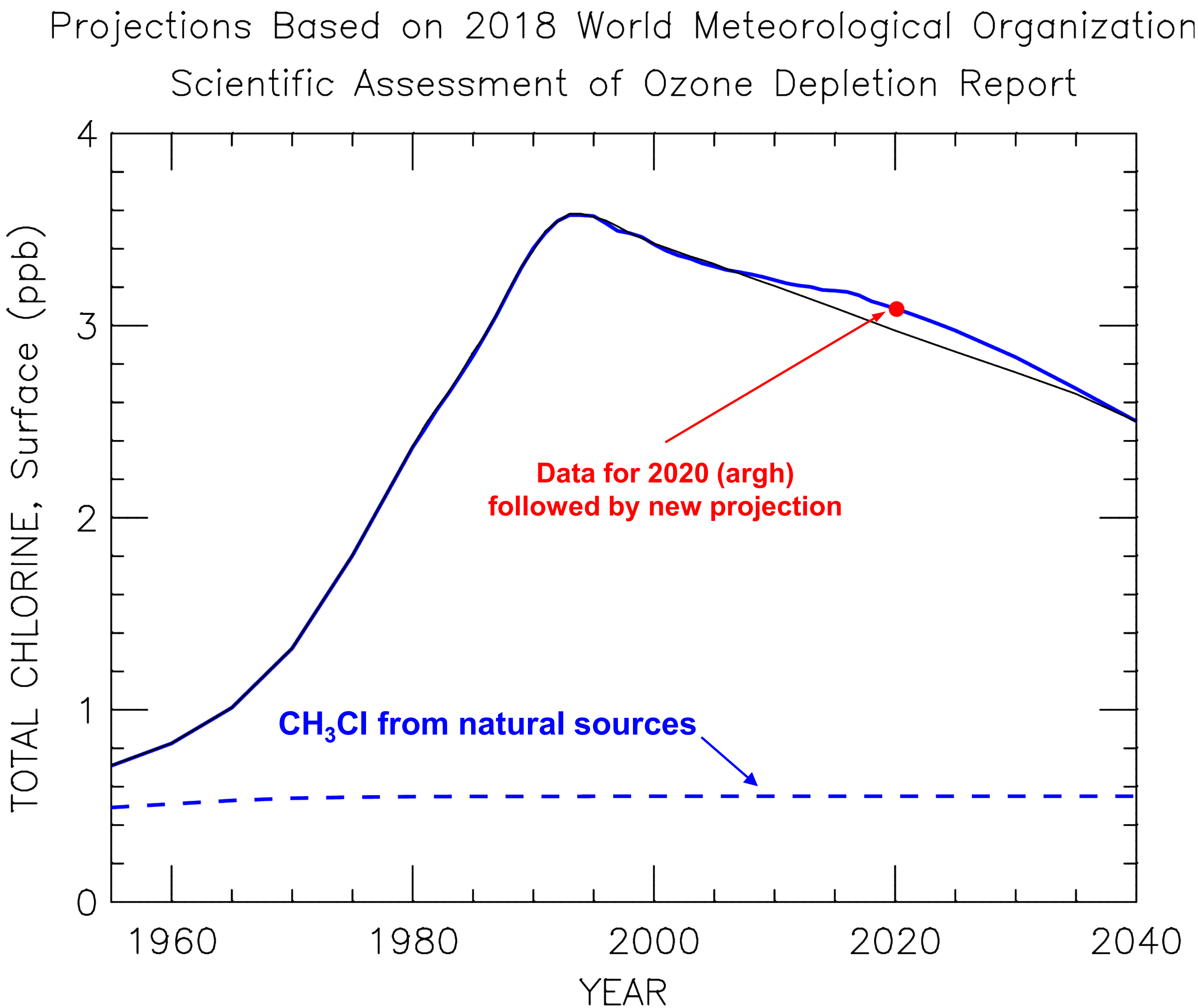
Senate to Consider Kigali Amendment Ratification

November 16, 2021 | Christina Theodoridi

The White House today sent the Kigali Amendment to the Montreal Protocol, the treaty to phase down hydrofluorocarbons (HFCs), to the Senate for its advice and consent to U.S. ratification. This action follows up on President Biden's executive order earlier this year.

https://www.nrdc.org/experts/christina-theodoridi/senate-consider-kigali-amendment-ratification

Montreal Protocol Has Banned Industrial Production of CFCs & Other ODS



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.

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

Chapter 1
Chemistry in Context

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

Tropospheric Ozone Production

$$OH + \mathbf{CO} \rightarrow \mathbf{CO_2} + H$$

$$H + \mathbf{O_2} + M \rightarrow HO_2 + M$$

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

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

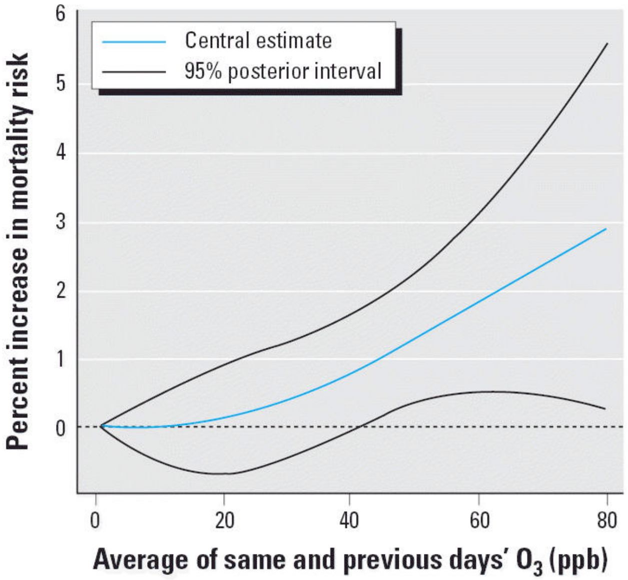
$$O + \mathbf{O_2} + M \rightarrow \mathbf{O_3} + M$$

$$\text{Net:} \quad \mathbf{CO} + \mathbf{2\ O_2} \rightarrow \mathbf{CO_2} + \mathbf{O_3}$$

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



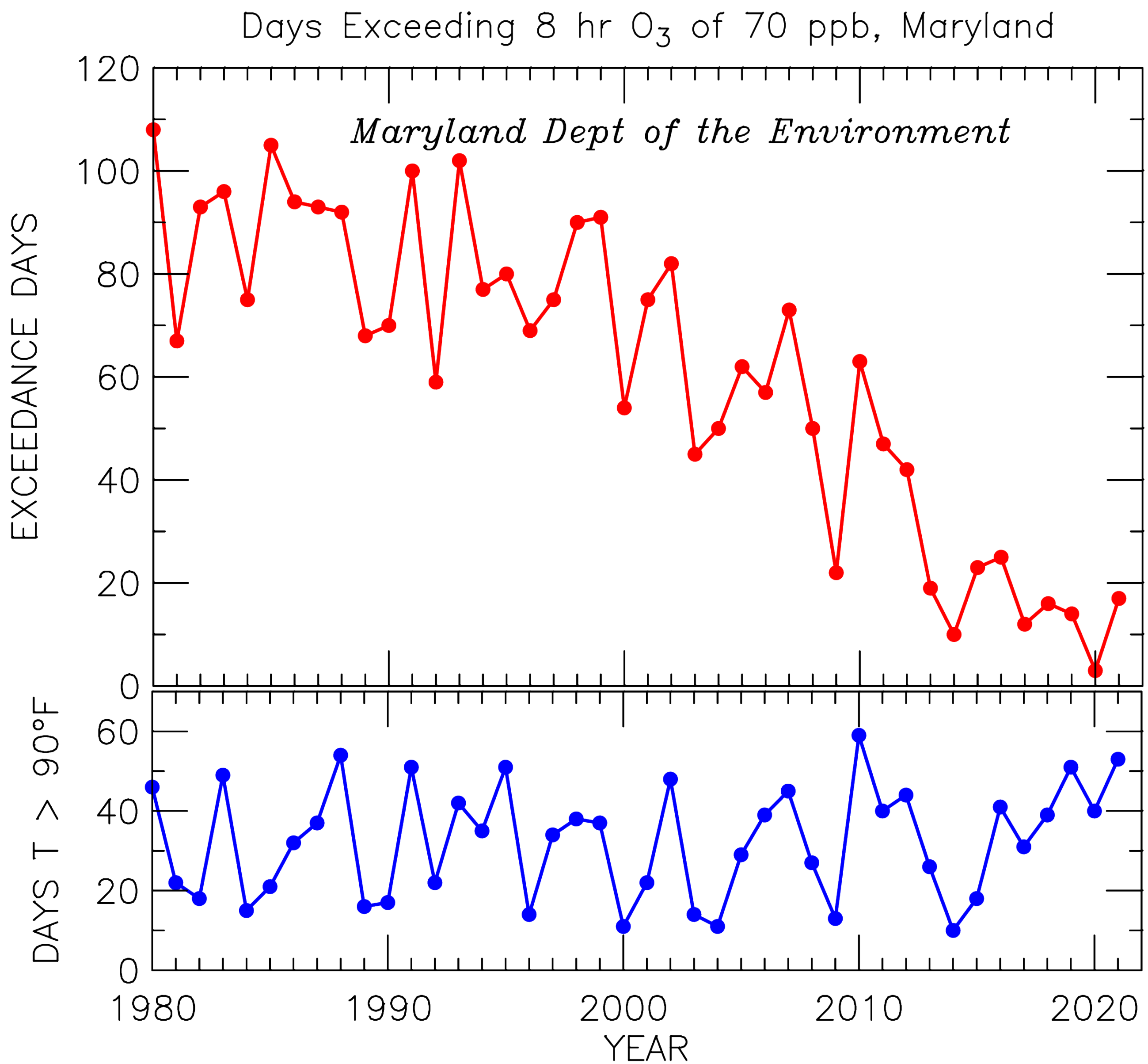
Increased risk of premature death (mortality) for all levels of surface O_3

Reductions in surface O_3 will benefit public health, regardless of present conditions

Bell *et al.*, 2006

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

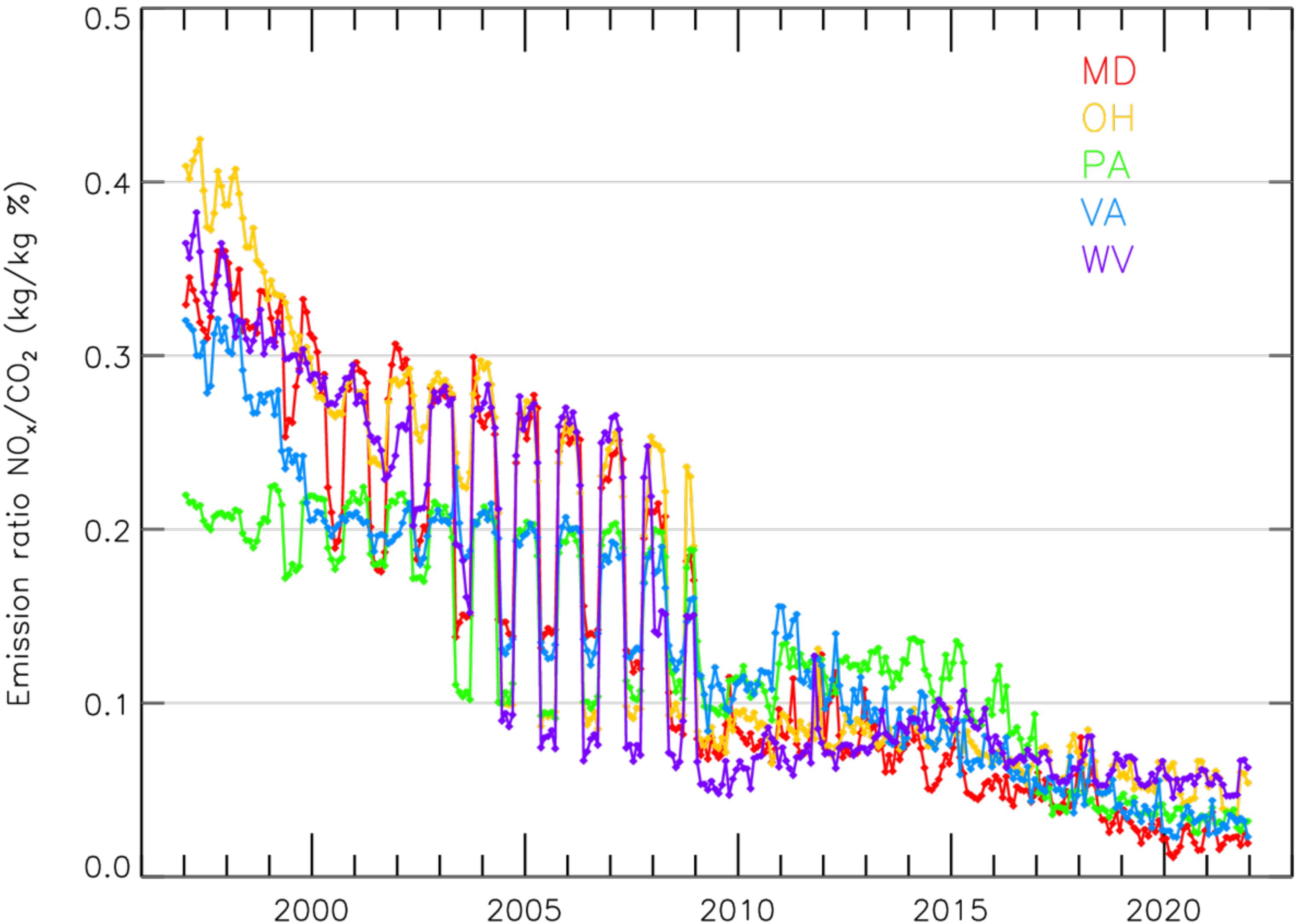
Significant Improvements in _Local_ Air Quality since early 1980s



Number of days, each summer, for which T at BWI exceeded 90°F at some part of the day

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

Trends in power plant emissions of NOx



Air Quality In The News

Biden Administration to Reinstate Mercury Pollution Rules Weakened Under Trump

The E.P.A. will resume enforcing limits on the release of mercury, a neurotoxin linked to developmental damage in children, from coal-burning power plants.

Brandon Shores Power Plant in Maryland, a plant that installed costly "scrubber" technology to reduce mercury emissions. Shannon Jensen for The New York Times

By Coral Davenport

Jan. 31, 2022 Updated 5:04 p.m. ET

WASHINGTON — The Biden administration on Monday reinstated a way of measuring the benefits of reducing air pollution, the first step in a plan that could tighten limits on the amount of mercury that can be discharged from coal-burning power plants.

Mercury is a neurotoxin that poses a particular danger to the brain development of children and fetuses.

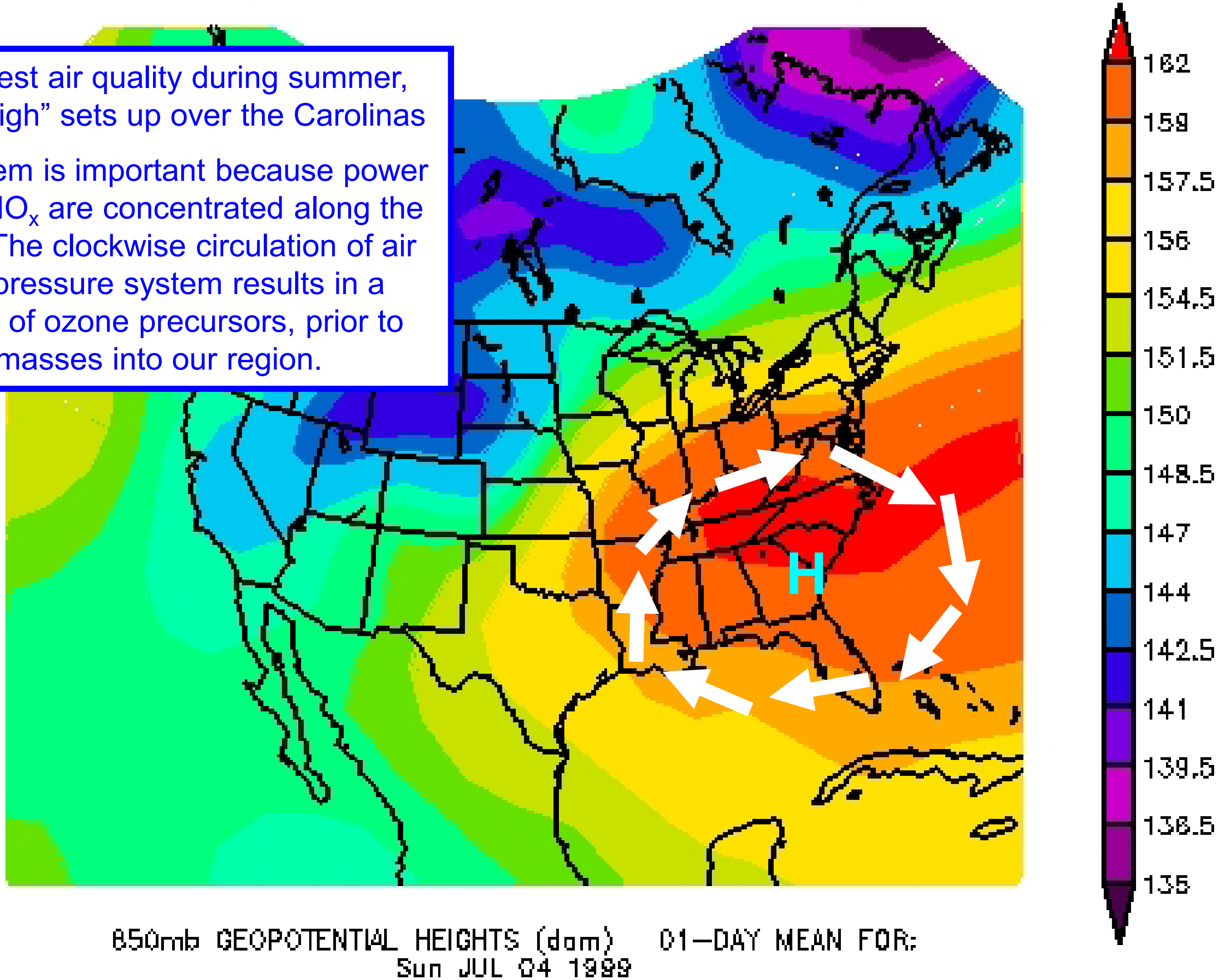
The mercury announcement is among several recent actions taken or planned by the Biden administration that are aimed at reducing pollution in air and water. After a first year in which President Biden tried to push ambitious climate legislation through Congress only to see it stall, the administration is using its regulatory machinery to try to curb pollution.

https://www.nytimes.com/2022/01/31/climate/epa-mercury-pollution-coal.html

Day-to-day meteorology (weather!) affects severity and duration of pollution episodes

Maryland has poorest air quality during summer, when a “Bermuda High” sets up over the Carolinas

This circulation system is important because power plant emissions of NO_x are concentrated along the Ohio River valley. The clockwise circulation of air around this high pressure system results in a significant build up of ozone precursors, prior to arrival of air masses into our region.



http://www.mde.state.md.us/assets/document/BJH%20-%20Basics%20on%20Ozone%20Transport.ppt

Temperature Inversions and Air Quality

Temperature inversion: increase in temperature with height

Inversions important for Air Quality because they inhibit vertical mixing of air

Air pollutants can accumulate in cities ringed by mountains, such as Los Angeles, Mexico City, Denver, etc.

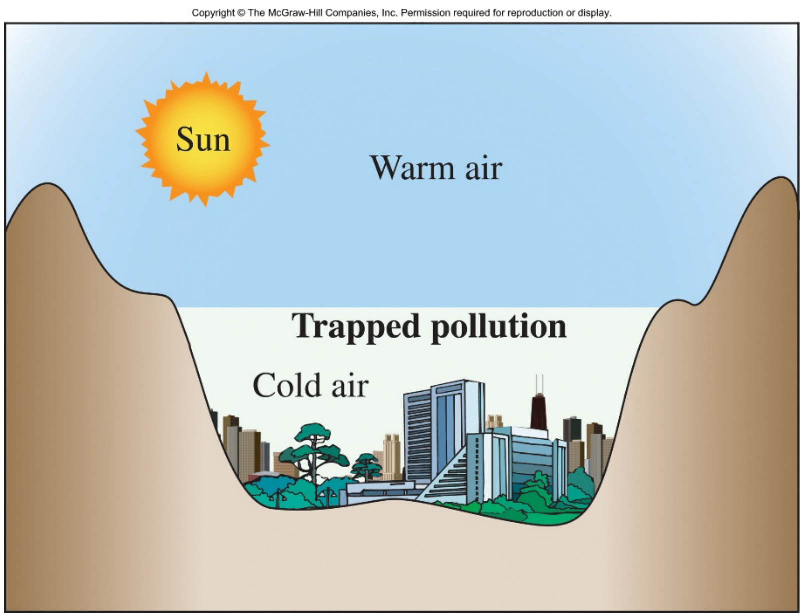
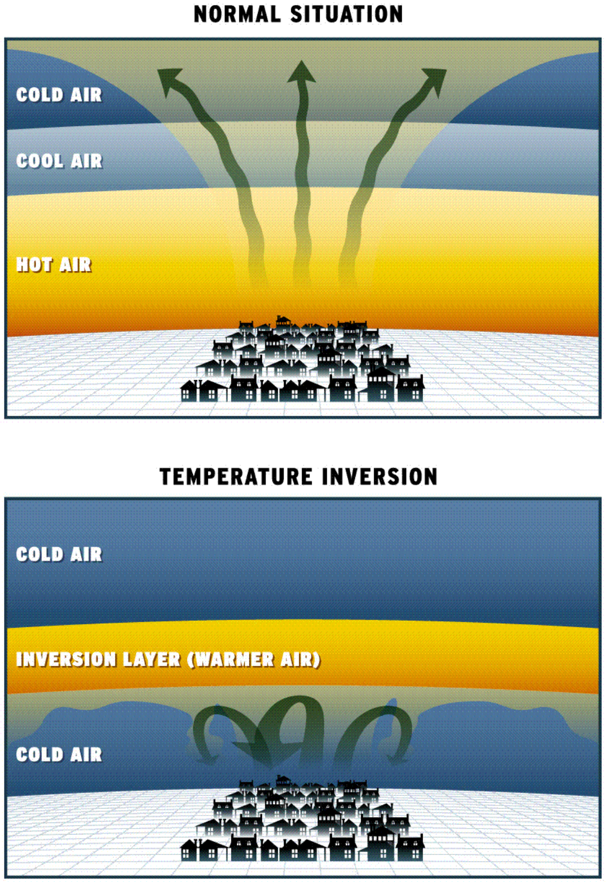
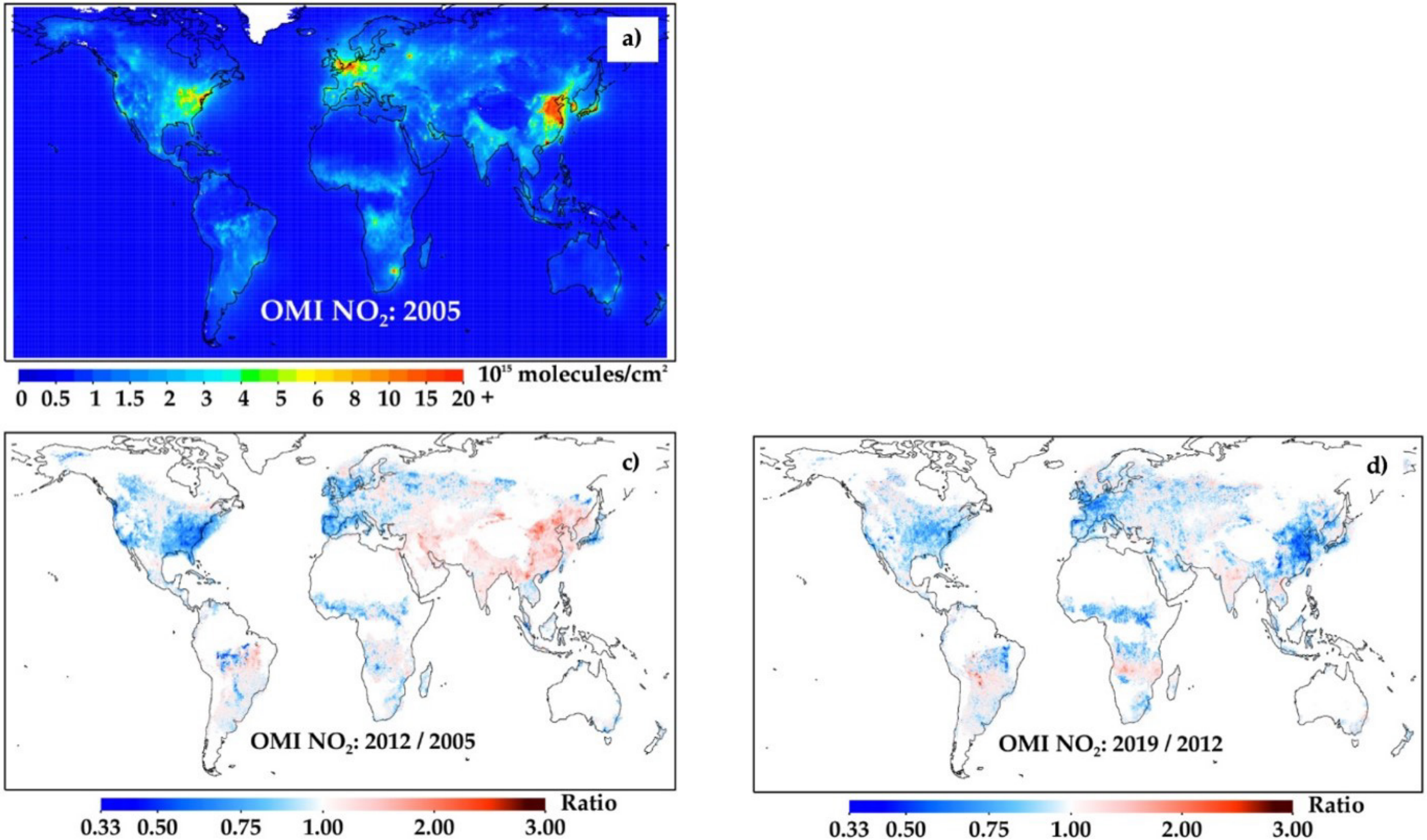


Figure 1.10, Chemistry in Context



http://geographygems.blogspot.com/2011/09/smog.html



Top: Tropospheric vertical column NO_2 (Trop NO_2) measured in 2005
Bottom Left: Ratio of Trop NO_2 measured in 2012 and 2005
Bottom Right: Ratio of Trop NO_2 measured in 2019 and 2012
All observations from the NASA OMI instrument

Goldberg *et al.*, *ERL*, 2021
https://iopscience.iop.org/article/10.1088/1748-9326/ac2c34/meta