Air Pollution - 1940s, 1950s

1940s: Smog severe in Los Angeles

1947: Los Angeles Air Pollution Control District forms

1949: National symposium on air pollution in Los Angeles

mid-1950s: Ozone levels in Los Angeles reach 650 ppbv

1955: Eisenhower asks Congress to examine air pollution

By 1960: 17 statewide air pollution agencies existed

U.S. Air Pollution Laws 1950s

U.S. Air Pollution Control Act of 1955
- Federal technical assistance to state air pollution control
- Funding of Public Health Service for studies of air pollution
- Amended 1960 to study health effects of automobile exhaust
- Did not impose regulations on air pollution
- Delegated regulation to state and local level

1959
- California Motor Vehicle Control Board set first automobile emission standard worldwide. 1963 model cars required to reroute crankcase hydrocarbon emissions back to manifold for re-burning.

U. S. Air Pollution Laws 1960s

Clean Air Act of 1963
- Gave federal government authority to regulate interstate pollution
- Emission standards for stationary sources (power plants, steel)
- No automobile controls

Motor Vehicle Air Pollution Control Act of 1965
- First regulation of automobiles at federal level
- Emission standards to reduce tailpipe HCs 72%, CO(g) 56%
- For 1968 model cars; patterned after California for 1966 cars
- More than half of 1968 and 1969 cars did not meet standards

Air Quality Act of 1967
- U.S. divided into Air Quality Control Regions (AQCR)
- Required publication of Air Quality Criteria (AQC) reports
  - Science reports about effects of pollutants on health/welfare
  - Provide suggestions about acceptable levels of pollution
  - States required to set own air quality standards based on AQC
- State Implementation Plans (SIP)
  - State plan for regulation submitted to federal government
  - If no state enforcement, federal government could sue state

Clean Air Act Amendments of 1970

Creation of U. S. Environmental Protection Agency (USEPA) – under President Nixon

Clean Air Act of 1970:

National Ambient Air Quality Standards (NAAQS)

- Primary: to protect public health (e.g., asthmatics, elderly)
- Secondary: to protect public welfare (e.g., visibility, buildings)

Criteria Air Pollutants

- Originally: CO(g), NO_2(g), SO_2(g), TSP (total suspended particulates), hydrocarbons, oxidants
- Lead added in 1976
- Oxidants change to O_3(g) in 1979
- Hydrocarbons removed in 1983
- TSP changed to PM_{10}, a $PM_{2.5}$ standard added in 1997

Clean Air Act Amendments of 1970

Attainment areas

- Regions where primary standards met

Nonattainment areas

- Regions where primary standards were not met

New Source Performance Standards (NSPS)

- Set by USEPA to limit emission from new stationary sources

National Emission Standards for Hazardous Pollutants (NESHAPS)

- For pollutants causing mortality, severe illness
- Initially, for, asbestos, beryllium, mercury. List expanded in 1984

Congressional control of automobile emissions

- Required 90% reduction HCs, CO(g) by 1975 and NO_x by 1976

Air quality regulation agencies

U.S. Environmental Protection Agency
→Federal Clean Air Act; National Ambient Air Quality Standards

Washington State Department of Ecology
→Emission testing/air monitoring
→overseeing WA local state agencies

Puget Sound Clean Air Agency (~50% of WA population)
→adopting and enforcing air quality regulations;
→sponsoring voluntary initiatives to improve air quality.

Clean Air Act Amendments of 1977

Prevention of Significant Deterioration (PSD) in areas already under attainment. Three classes of regions designated:

- Class I: Pristine areas (parks, wilderness) no new sources
- Class II: Moderate changes allowed but regulations desired
- Class III: Major growth allowed if NAAQS not exceeded
- PSD permit needed for growth in region allowing growth
- New source must use Best Available Control Technology (BACT)

Computer modeling mandated to check whether new pollution sources might result in standard exceedence

Control of Chlorofluorocarbons (CFCs)

Clean Air Act Amendments of 1990

1990: 96 cities still in violation of ozone NAAQS
- --> nonattainment areas divided into six categories
- "Extreme:" Los Angeles: must attain by 2010
- "Severe:" Baltimore, New York: must attain by 2007
- "Severe:" Chicago, Houston,…: must attain by 2005

New sources in nonattainment areas must achieve
- Lowest Achievable Emissions Rate (LAER) by adopting Reasonably Achievable Control Technology (RACT)

Hazardous Air Pollutants (HAPs)
- Emission limits for 189 toxic chemicals using Maximum Achievable Control Technologies (MACTs)

More control of CFCs

Clean Air Act Revision of 1997

Change in ozone standard
- 0.08 ppmv over 8-hour average instead of
- 0.12 ppmv over 1-hour average

Addition of $PM_{2.5}$ standard

Clean Air Act (1963) & Amendments

NAAQS	NESHAPS
Sulfur Dioxide (SO_2)	Asbestos
Particulate Matter (PM)	Arsenic
Carbon monoxide (CO)	Beryllium
Ozone (O_3)	Benzene
Nitrogen dioxide (NO_2)	Mercury
Lead	Vinyl Chloride
	Radionuclides
	Etc…

NAAQS=National Ambient Air Quality Standards
NESHAPS= National Emission Standards for Hazardous Pollutants

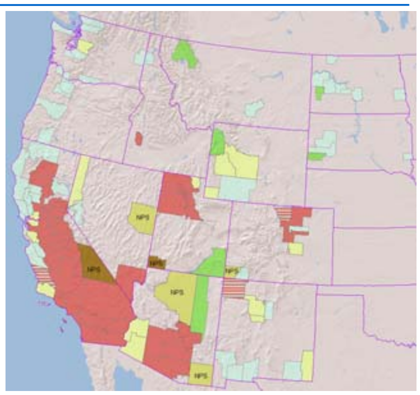
National Ambient Air Quality Standards (NAAQS) for 6 Criteria Air Pollutants

	Primary Standards		Secondary Standards	
Pollutant	Level	Averaging Time	Level	Averaging Time
Carbon Monoxide (CO)	9 ppm (10 mg/m^3)	8-hour[1]	None	
	35 ppm (40 mg/m^3)	1-hour[1]		
Lead	1.5 µg/m^3	Quarterly Average	Same as Primary	
Nitrogen dioxide (NO_2)	0.053 ppm (100 µg/m^3)	Annual (Arithmetic Mean)	Same as Primary	
Particulate matter (PM_{10})	150 µg/m^3	24-hour[2]	Same as Primary	
Particulate matter ($PM_{2.5}$)	15.0 µg/m^3	Annual[3] (Arithmetic Mean)	Same as Primary	
	35 µg/m^3	24-hour[4]	Same as Primary	
Ozone (O_3)	0.075 ppm (2008 std)	8-hour[5]	Same as Primary	
	0.08 ppm (1997 std)	8-hour[6]	Same as Primary	
	0.12 ppm	1-hour[7] (Applies only in limited areas)	Same as Primary	
Sulfur dioxide (SO_2)	0.03 ppm	Annual (Arithmetic Mean)	0.5 ppm (1300 µg/m^3)	3-hour[1]
	0.14 ppm	24-hour[1]		

New Ozone NAAQS 0.075

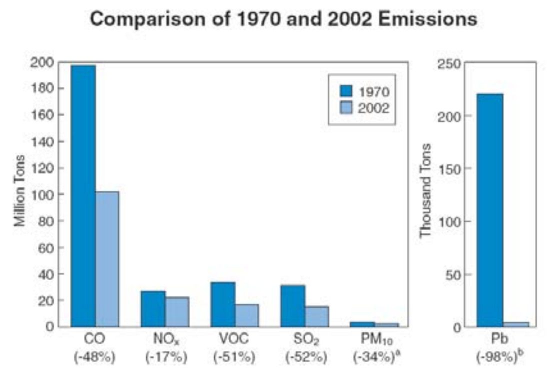
States in the WESTAR Region

- Counties with at least one ozone monitor
- Counties exceeding 0.075 NAAQS
- Counties exceeding with < 3 years of data
- Counties > 0.070 and < 0.076
- Counties with a NPS ozone monitor
- NPS monitors exceeding 0.075 NAAQS
- NPS monitors > 0.070 and < 0.076



Utah Department of Environmental Quality *Division of Air Quality*

April 16, 2008



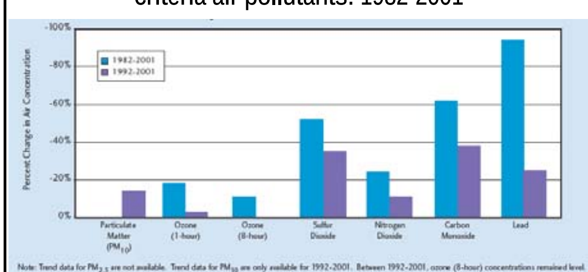
EPA: National Air Quality and Emissions Trends Report (2003)
http://www.epa.gov/air/airtrends/aqtrnd03/

Non-Attainment Areas for NAAQS Pollutants

Pollutants	1990	1996	2002
CO	42	31	16
Pb	12	10	3
NO_2	1	1	0
O_3	98	68	56
PM-10	70	81	67
SO_2	51	43	24

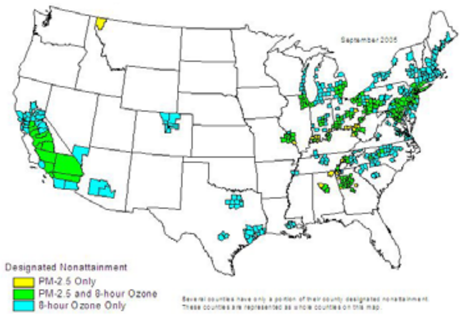
\# of Counties

Percent reduction in concentrations of 6 criteria air pollutants: 1982-2001



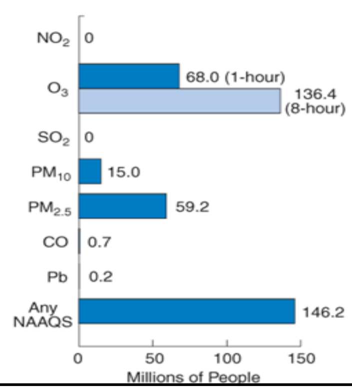
http://www.epa.gov/indicators/roe/html/roeAirOut.htm

Nonattainment counties for PM2.5 and/or 8-hour ozone standard



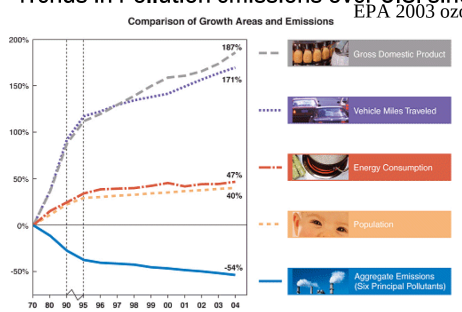
http://www.epa.gov/oar/oaqps/greenbk/mappm25o3.html

Number of people living in counties with air quality concentrations above the levels of NAAQS in 2002



Trends in Pollution emissions over U.S. since 1970

EPA 2003 ozone report



Between 1970 and 2004, gross domestic product increased 187%, vehicle miles traveled increased 171%, energy consumption increased 47%, and U.S. population grew by 40%. During the same time period, pollutant emissions have dropped by 54%.

Tightening of motor vehicle emission federal standards

grams per mile

	HC	CO	NO_x	Particles
PRE-CONTROL	10.6	84.0	4.1	
1970	4.1	34.0		
1975	3.0	28.0	3.1	
1980	0.41	7.0	2.0	
1985	0.41	3.4	1.0	
1990	0.41	3.4	1.0	0.2
1995	0.25	3.4	0.4	
2005	0.125	1.7	0.2	? < 0.1

Air Quality Standards Around the World today

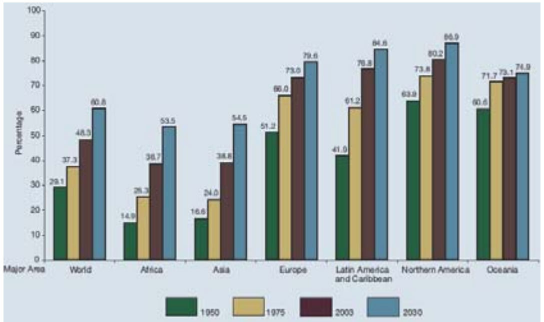
	O_3, ppbv	PM10, $\mu g/m^3$	CO, ppmv	SO_2 ppmv
US	75 (8h)	150 (24h)	35 (1h)	0.14 (24h)
WHO	60 (8 h)	/	26 (1h)	0.125 (24h)
Canada	50 (1h)	30	30 (1h)	0.06 (24h)
Mexico	110 (1 h)	150 (24h)	11 (8h)	0.13 (24h)
Europe	60 (8 h)	50 (24h)	35 (1h)	0.04 (24h)
China	60 (1 h)	50 (24h)	3.5 (24h)	0.019 (24h)

WHO = World Health Organization

The urban and rural populations of the world: 1950-2030

World Urbanization Prospects: The 2003 Revision

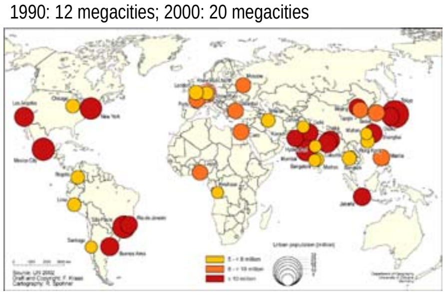
Percentage of population living in urban areas: 1950, 1975, 2003 and 2030



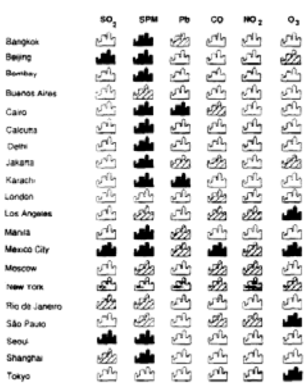
World Urbanization Prospects: The 2003 Revision

Megacities

What is a megacity?
A city with >10 million inhabitants
(high energy consumption and transportation needs)
1950: 3 megacities; 1980: 6 megacities;
1990: 12 megacities; 2000: 20 megacities



Overview of air quality in 20 megacities (WHO/UNEP, 1992)

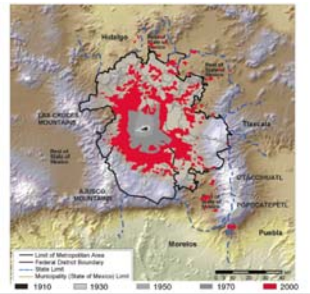


- •Serious problem. WHO guidelines exceeded by more than a factor of 2
- •Moderate to heavy pollution. WHO guidelines exceeded by up to a factor of 2.
- •Low pollution. WHO guidelines normally met.
- •No data available or insufficient data for assessment.

All 20 have at least one major pollutant exceeding WHO guidelines
15 megacities: at least 2
7 megacities: 3 or more pollutants exceeding WHO guidelines

Mexico City

Mexico City is one of the cities with the worst pollution worldwide. Sits in a basin surrounded by mountains and under influence of Pacific high pressure → frequent inversions: trapping of pollutants



Population:
1950: 3 million
2000: 18 million

Mexico City

Pollution sources: industry + cars (2.5 million vehicles = 44% of energy consumption)

Tropical latitudes: plenty of sunshine → ozone air pollution problem year-round

Effects of high altitude (2250 m)?
more air needs to be inhaled to get same O2 → higher dose of pollutants

China

- Contains 7 out of 10 most polluted cities worldwide
- Two-thirds of 338 cities monitored are polluted
- Largest producer/consumer of coal
- Coal-fired power-plants = 2/3 of China's energy; 1 powerplant built each day
- Indoor burning of coal and biomass a major problem
- Pollution levels could triple or quadruple within 15 years if the country does not curb its rapid growth in energy consumption and automobile use.

Song Yang/Imaginechina; NY Times
Smog hovers over Urumchi, of the Xinjiang Uighur Autonomous Region.

Beijing

- 11 million people, surrounded by heavy industry.
- Ozone > standard for 100 days (1998)
- Observed levels of particulates are very high:

Daily averages: PM10 = 190 $\mu g/m^3$; PM2.5=136 $\mu g/m^3$ (compare to US standards: 150 and 65 $\mu g/m^3$);

Annual averages: PM10= 230 $\mu g/m^3$; PM2.5=106 $\mu g/m^3$ (compare to US standards: 50 and 15 $\mu g/m^3$)

- Measures: Relocate industry and people into 20 towns outside Beijing; tougher standards on cars

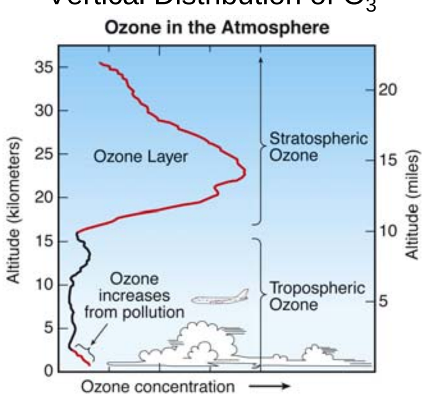
Greg Baker/Associated Press, NY Times

Ozone and Oxygen

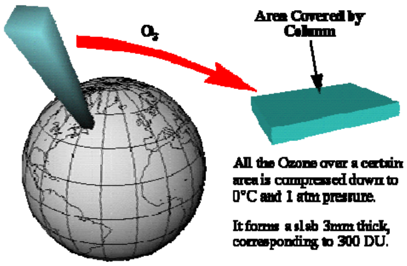
Oxygen Atom (O) | Oxygen Molecule (O_2) | Ozone Molecule (O_3)

Very Reactive | Very Un-reactive | Reactive

Vertical Distribution of O_3

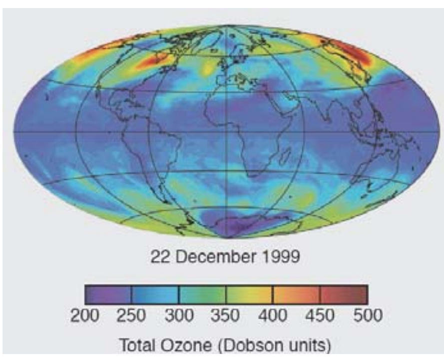


Dobson Units



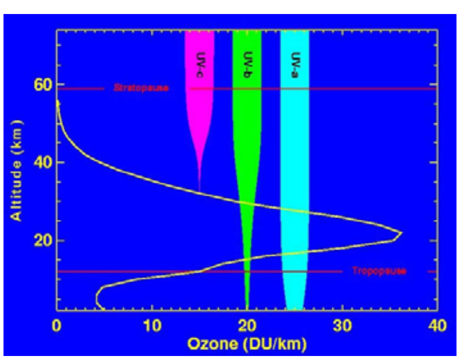
If you were to bring all O_3 molecules to the surface

Global ozone column abundance

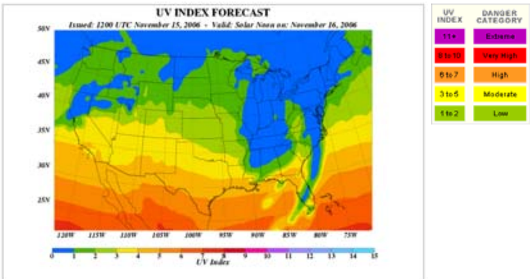


WMO, 2002, 20 questions

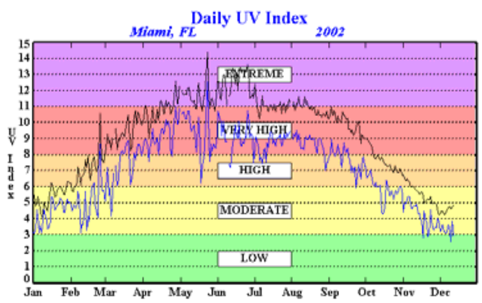
UV Protection by the Ozone Layer

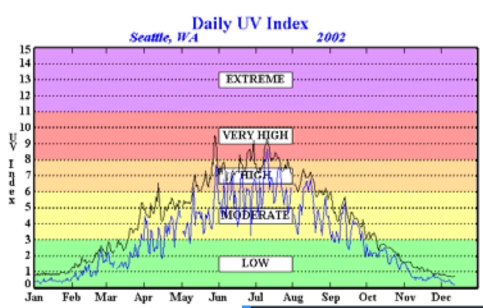


UV Index

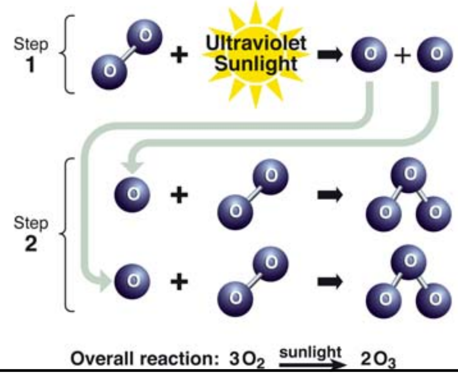


EPA's forecast UV maps
http://www.epa.gov/sunwise/uvindex.html





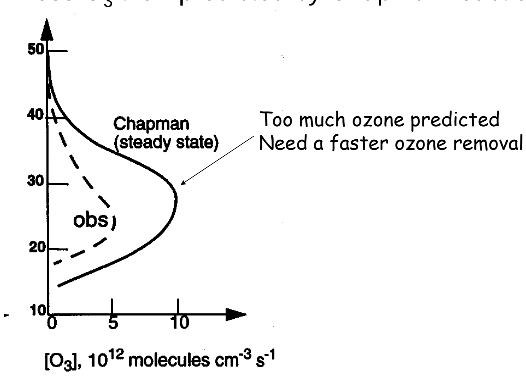
Stratospheric O_3 Production: Chapman Mechanism



Ozone formation animation

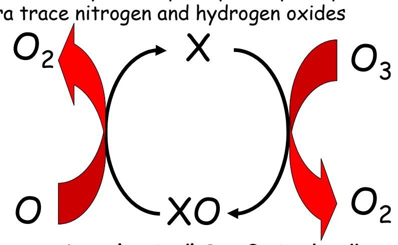
http://earthobservatory.nasa.gov/Library/Ozone/Anim/ozone_creation_final.mov

Less O_3 than predicted by Chapman reactions



Catalytic O_3 Destruction: Chapman Missed

O_3 is naturally destroyed by catalytic cycles involving ultra trace nitrogen and hydrogen oxides



Catalytic "O_3 Grinder"

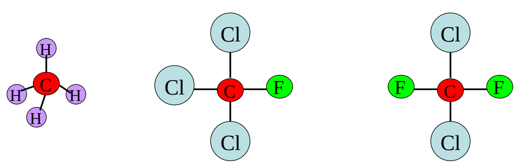
"X" can be NO, OH, Cl,… at parts per trillion levels

Chlorofluorocarbons (CFCs)

organic molecules where the H atoms have been completely replaced by fluorine and chlorine (synthetic molecules- entirely artificial)

Examples:

Methane CFC11 CFC12



Uses of CFCs

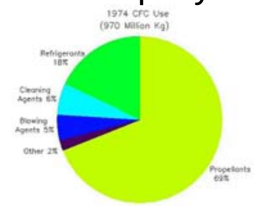
Non-toxic, non-flammable, easily compressible gases

Used as refrigerants and as propellants in spray cans

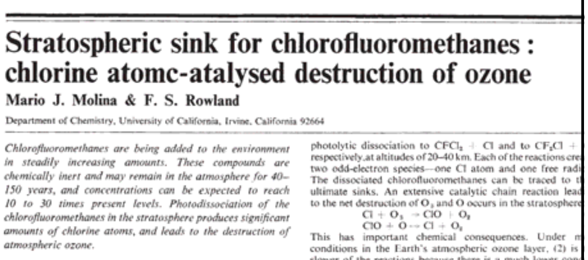
Thought to be ideal…due to safety and durability.

"Aerosol" Spray Cans: NOT SAME AS ATMOSPHERIC AEROSOL PARTICLES

Use of CFCs increases rapidly



Early Warning Signs



Stratospheric sink for chlorofluoromethanes : chlorine atomc-atalysed destruction of ozone

Mario J. Molina & F. S. Rowland

Department of Chemistry, University of California, Irvine, California 92664

Chlorofluoromethanes are being added to the environment in steadily increasing amounts. These compounds are chemically inert and may remain in the atmosphere for 40–150 years, and concentrations can be expected to reach 10 to 30 times present levels. Photodissociation of the chlorofluoromethanes in the stratosphere produces significant amounts of chlorine atoms, and leads to the destruction of atmospheric ozone.

photolytic dissociation to $CFCl_2$ + Cl and to CF_2Cl + respectively at altitudes of 20–40 km. Each of the reactions cre two odd-electron species—one Cl atom and one free radi The dissociated chlorofluoromethanes can be traced to t ultimate sinks. An extensive catalytic chain reaction lead to the net destruction of O_3 and O occurs in the stratosphere

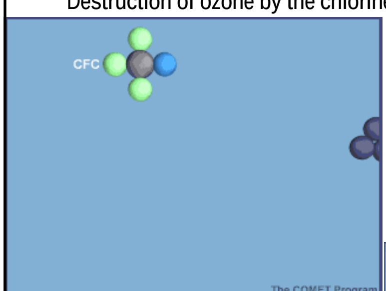
$$Cl + O_3 \rightarrow ClO + O_2$$
$$ClO + O \rightarrow Cl + O_2$$

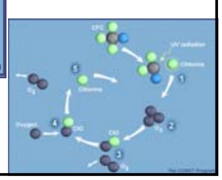
This has important chemical consequences. Under n conditions in the Earth's atmospheric ozone layer, (2) is slower of the reactions because there is a much lower con

Nature, June 28, 1974

Molina, Rowland, and Crutzen win Nobel Prize in 1994

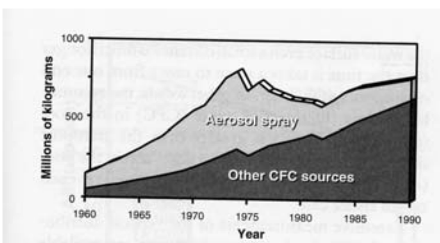
Destruction of ozone by the chlorine catalytic cycle





Animation: http://www.ucar.edu/learn/1_6_2_25t.htm

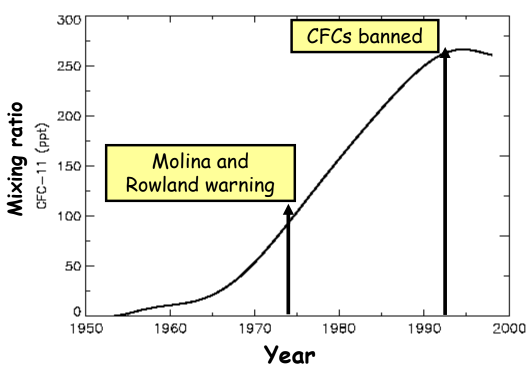
CFC emissions



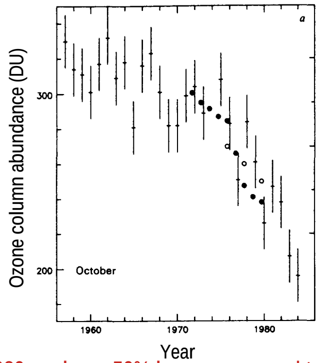
Turco,
Fig. 13.12

Atmospheric residence time of CFC's:
~ 100 yrs

CFC-11 Atmospheric Abundance



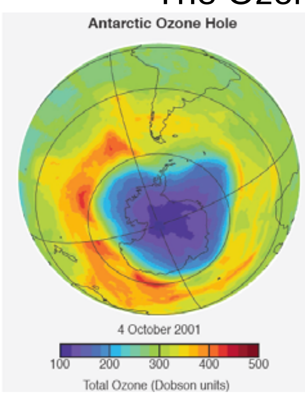
What is the ozone hole?



Farman et al. published 1985 this picture that shows that the total ozone column over Antarctica was decreasing each October (Spring)

1980s column 50% lower compared to 1960s values!

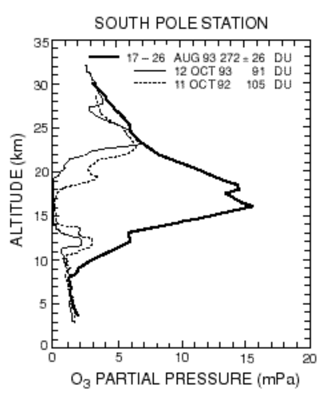
The Ozone Hole



The ozone hole covers an area larger than the Antarctic continent

http://www.epa.gov/ozone/science/unepSciQandA.pdf

Vertical Structure of Antarctic Ozone Hole



Antarctic Ozone Hole Conundrum

- What is the cause?
- Why only in springtime between 15 – 25 km ?
- Why primarily in the Antarctic?

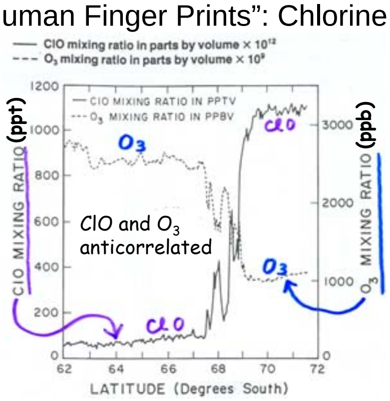
Antarctic Ozone Hole Theories


Sun
59¢
How Joan Van Ark beats agonizing feelings of guilt
UFO ALIENS FOUND AT SOUTH POLE
ETs are burning up our ozone
Rub pineapple on your face to
Psychic's touch removes 20 lbs

Also a scientific debate

- chemistry versus meteorology
- human versus natural
- solar cycles

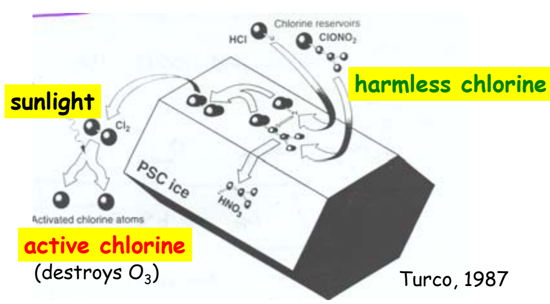
"Human Finger Prints": Chlorine

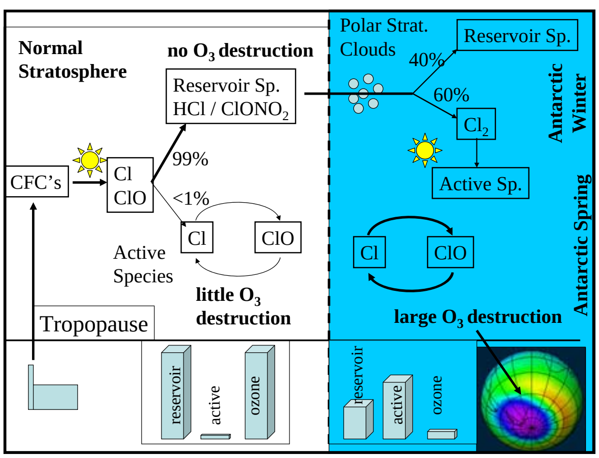


Polar Stratospheric Clouds (PSC's)

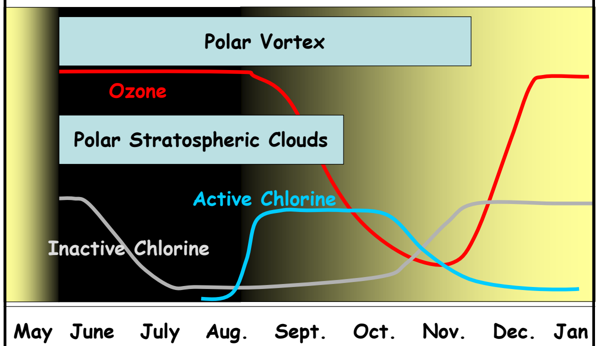
Chemistry on Polar Stratospheric Clouds

PSCs allow "inactive" chlorine to become "active"

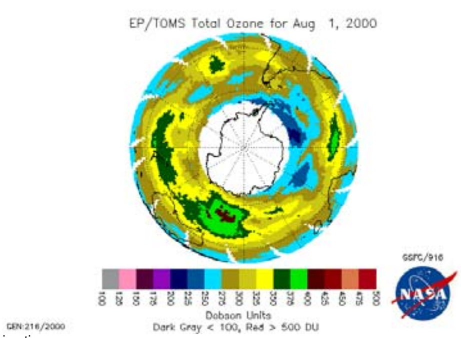




Seasonal Evolution of Ozone Hole



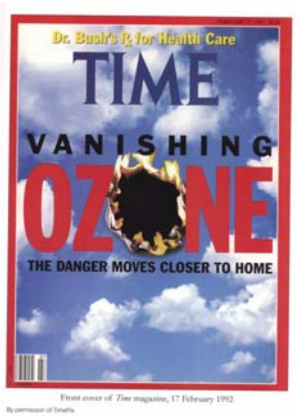
Animation of Antarctic Ozone Hole (Aug-Nov 2000)



View animation:
http://www.atmos.washington.edu/2006Q4/212/movie_toms_2000.gif

Ozone Watch Web page

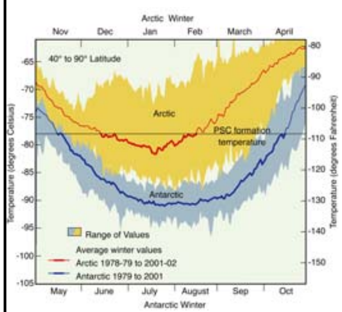
http://ozonewatch.gsfc.nasa.gov/



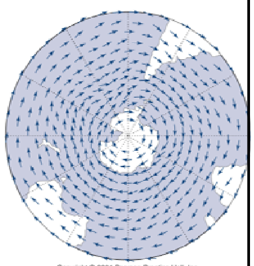
Front cover of *Time* magazine, 17 February 1992

Is there an ozone hole over the Arctic?

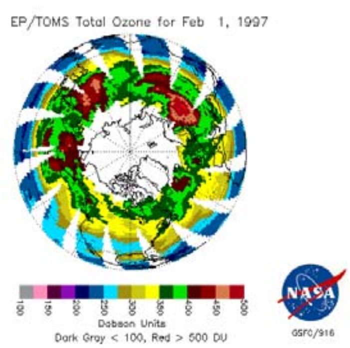
PSC Formation Requires Very Low T



Polar Vortex—
cuts off polar region

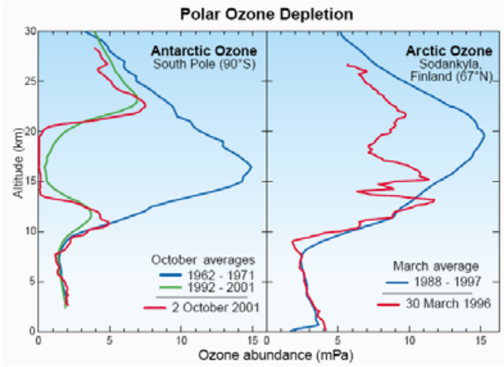


Animation of Arctic ozone depletion (Feb-Apr 1997)

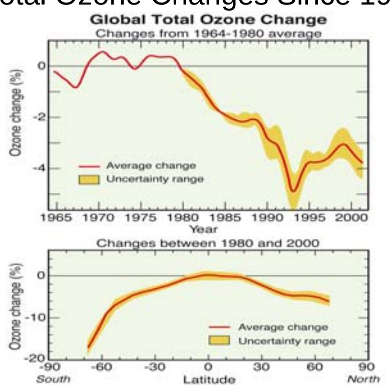


View animation:
http://www.atmos.washington.edu/2006Q4/212/movie_toms_1997.gif

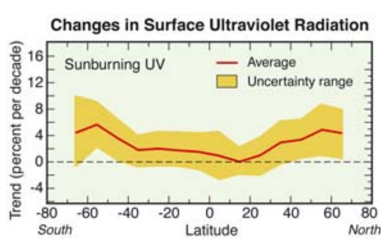
Antarctic and Arctic Ozone Depletion



Total Ozone Changes Since 1980



Does depletion of the ozone layer increase ground level UV radiation?



Yes, UV-B radiation (sunburning UV) at the surface increases as the amount of overhead ozone decreases. This increase is on the order of a few % per decade since 1980.

'I miss the ozone layer' *Bill Schorr*

Effects of enhanced UV-B radiation

Attack molecules in cells, particularly DNA → cellular dysfunction / mutation / formation of toxic species

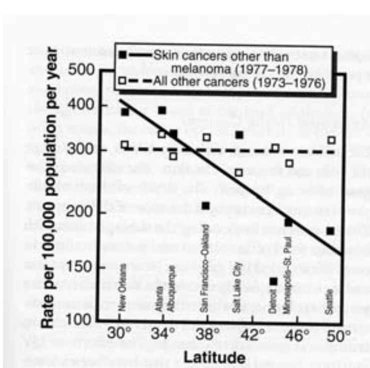
<u>Skin:</u>
→sunburn,
→premature aging of skin,
→skin cancer (basal cell carcinomas ; squanous cell carcinomas; melanoma (dark tumor-like growth)

<u>Eyes:</u> Affects cornea (covers iris+lens)
→Snow blindness
→Cataract (loss of transparency of cornea)

<u>Immune system:</u> UV-B kills cells which fight infections on skin

Affects crops, plants (slower growth, photosynthesis), animals, and microrganisms.

Evidence



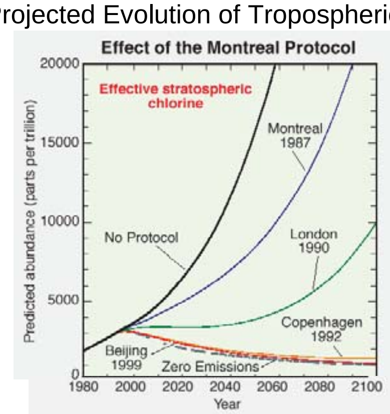
Turco,
Fig. 13.9

Regulations on the production of CFCs

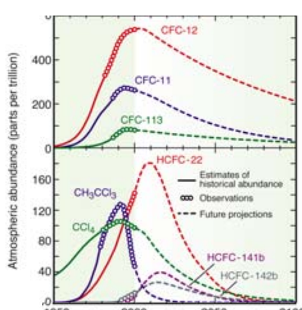
- Vienna convention (1985): "Convention for the Protection of the ozone layer" signed by 20 nations (research, future protocols)
- Montreal Protocol (1987): "Protocol on substances that deplete the ozone layer" ratified in 1989. Legally binding controls freezing production to 1985 levels.
- London Amendment (1990): phaseout of production by 2000 for developed nations and by 2010 for developing nations.
- Copenhagen Agreement (1992): Phaseout for developed nations by 1996.
- HCFC production allowed as short-term substitutes for CFCs. HCFC production to be phased out by 2030 (developed nations), 2040 (developing nations).

First environmental problem solved on an international basis!

Projected Evolution of Tropospheric Chlorine



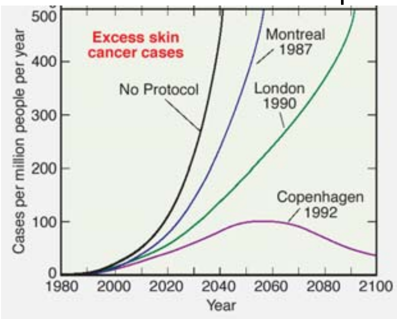
Has the Montreal Protocol been successful in reducing ozone-depeting gases in the atmosphere?



Yes!

WMO, 2002, 20 questions

Estimated excess cases of skin cancer if no controls had been imposed on CFCs



WMO, 2002, 20 questions

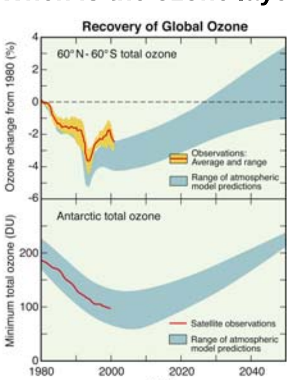
2050 no protocol: U.S. 33,000 excess skin cancer cases/year
Europe 14,000 excess skin cancer cases/year

The Montreal Protocol is Working!

- Without the Montreal Protocol, ozone depletion in 2050 would be at least 50% at midlatitudes in the Northern Hemisphere and 70% at midlatitudes in the Southern Hemisphere, about 10 times larger than today.
- Surface UV-B radiation in 2050 would at least double at midlatitudes in the Northern Hemisphere and quadruple at midlatitudes in the Southern Hemisphere compared with an unperturbed atmosphere. This compares to the current increases of 5% and 8% in the Northern and Southern Hemispheres, respectively, since 1980.

WMO 1998 Scientific Assessment of Ozone Depletion

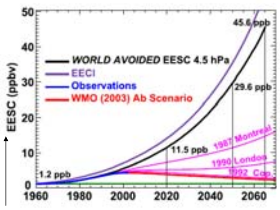
When is the ozone layer expected to recover?

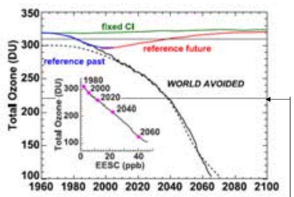


Back to pre-1980 levels by 2050s

What would have happened to the ozone layer if chlorofluorocarbons (CFCs) had not been regulated?

P. A. Newman[1], L. D. Oman[2], A. R. Douglass[1], E. L. Fleming[3], S. M. Frith[3], M. M. Hurwitz[4], S. R. Kawa[1], C. H. Jackman[1], N. A. Krotkov[5], E. R. Nash[3], J. E. Nielsen[3], S. Pawson[1], R. S. Stolarski[1], and G. J. M. Velders[6]





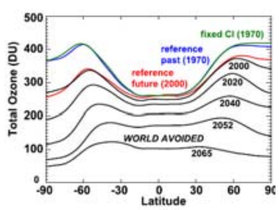
EESC = "Effective equivalent stratospheric chlorine" (takes Br into account)

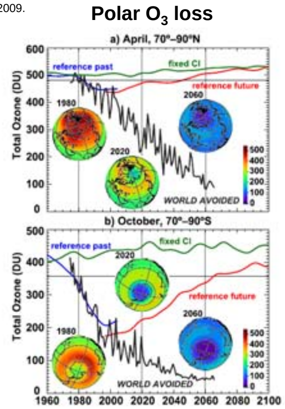
220 DU defines edge of Antarctic O_3 hole today

Newman et al., Atmos. Chem. Phys., 9, 2113-2128, 2009.

Polar O_3 loss

O_3 loss at all latitudes

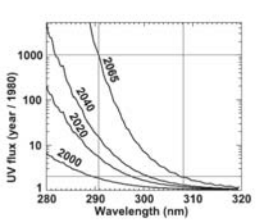


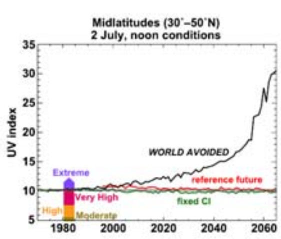


Impacts on UV flux at the surface

Newman et al., Atmos. Chem. Phys., 9, 2113-2128, 2009.

Large UV increases at λ < 310 nm





At λ < 308 nm the UV flux more than doubled by 2065, and increased by a factor of 1000 for λ < 291 nm.

Decreases sunburn time from 15 minutes to 5 minutes. DNA damaging UV for the NH midlatitudes increases by ~550% between 1980 and 2065.