GLOBAL WARMING: Epilogue

The news stories, commentaries, & documentaries keep streaming in day after day…

"Scientists: Pollution could combat global warming" *(Yikes, says Dr H!)*

http://www.cnn.com/2006/TECH/science/11/16/smog.warming.ap/index.html

The Competitive Enterprise Institute

http://www.cei.org/pages/co2.cfm

"The Denial Machine" (Canada CBC)

http://www.cbc.ca/fifth/denialmachine/index.html

(streaming video – good resource for Skeptic role)

FOR STUDENTS WHO WANT TO KNOW WHAT THEY CAN DO . . . . .

Just some of the many places to start – do it for a THINKING DEEPLY if you wish . . .

Inconvenient Truth site:
http://www.climatecrisis.net/takeaction/

Princeton University's Carbon Mitigation Initiative (CMI): 15 strategies
http://www.princeton.edu/~cmi/

Co-op America Quarterly Fall 2006 issue on CLIMATE SOLUTIONS
http://www.coopamerica.org/ →

Energy:

- improve your home's efficiency / generate your own green power / buy green power / Offset your emissions / Say no to coal / push for green power

Transportation:

Drive less / share a car / switch to biodiesel / drive a hybrid / encourage your workplace to help employees green their commute / push politicians to support higher fuel standards

Retail:

Buy less / buy used / buy local / buy green / take action

Food:

Grow your own / buy local food / eat less meat / talk to your supermarket / bring local food to schools

Topic # 18
OZONE DEPLETION IN THE STRATOSPHERE

AND LINKS TO OTHER GLOBAL CHANGE TOPICS THIS SEMESTER

(see pp 123- 127 in Class Notes Packet)

“[The Ozone Treaty is] the first truly global treaty that offers protection to every single human being.”

~ Mostofa K. Tolba,
Director of the UN Environment Programme

p 127 -- # the bullets 1 to 9

The real answer:

The ozone hole is:

-- a depletion of ozone in the lower stratosphere

-- that has occurred with increasing severity each spring (since measurements begin in 1970s)

Bullet 1, p 127

OZONE STORY = A very interesting illustration of the scientific process!

The THEORY that the ozone layer in the stratosphere might be damaged or depleted by human intervention (supersonic jets, CFC's, etc) . . . .

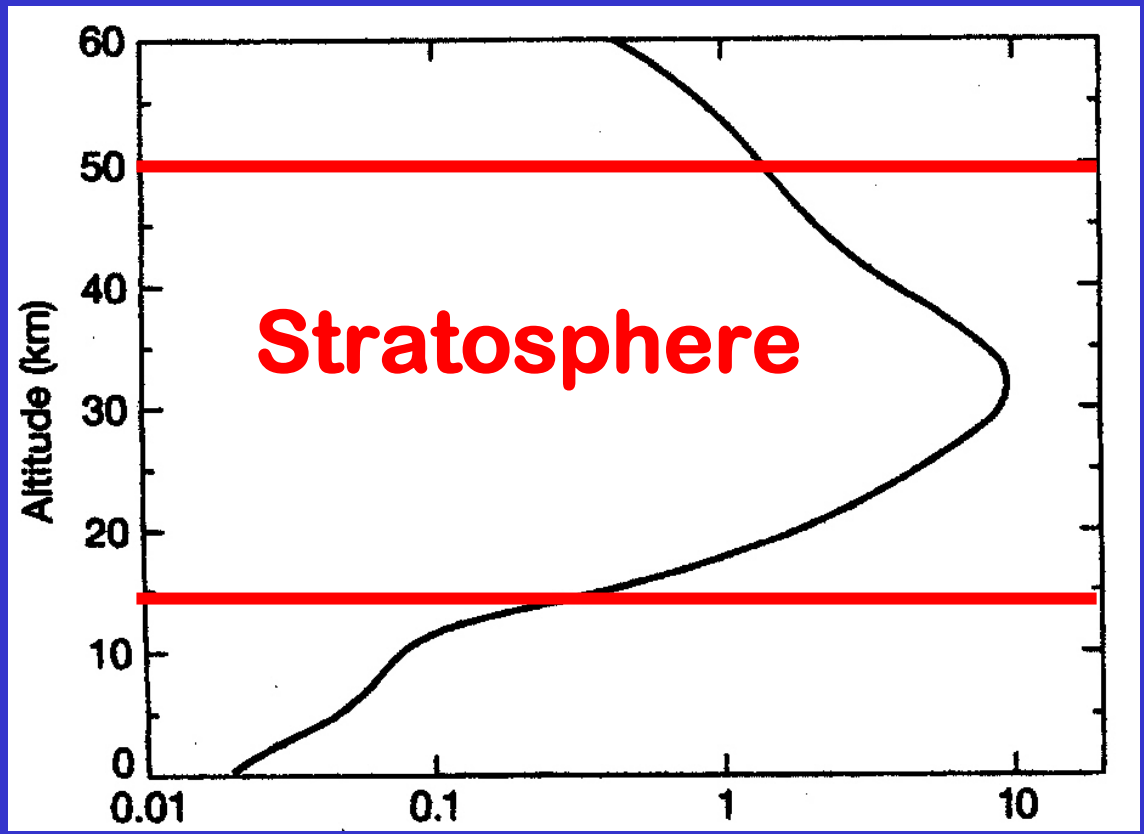
. . . preceded the actual OBSERVATION of the ozone hole.

Yet, when the hole WAS observed (via satellite) it was almost "missed" because it wasn't expected . . .

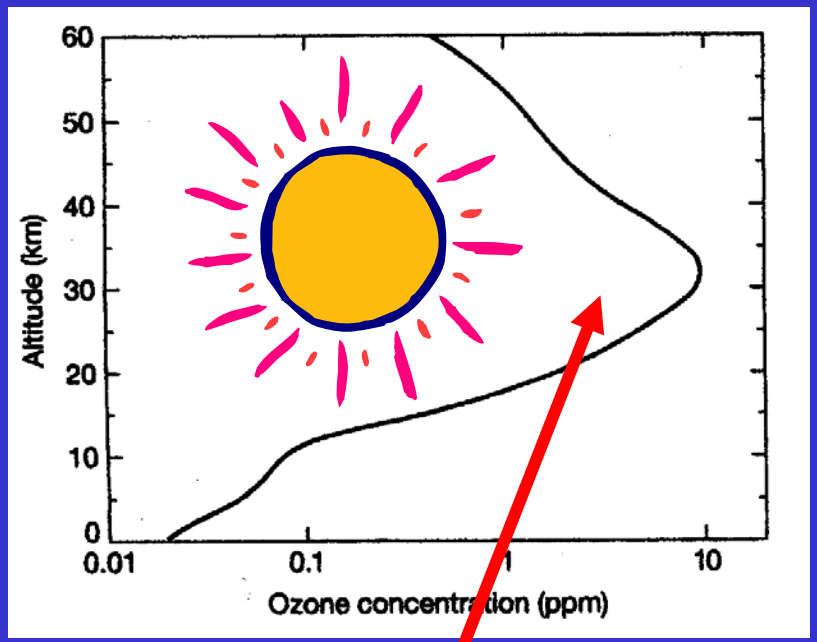
But let's begin with the stratospheric ozone layer itself . . . . . .

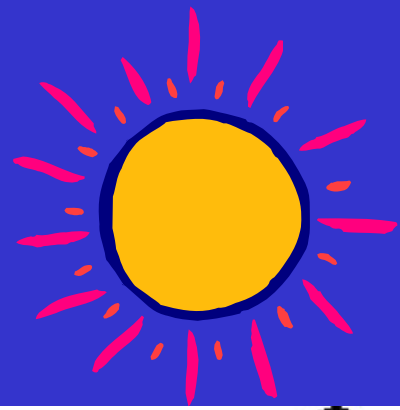
WHERE IS THE OZONE LAYER?

IGC
Fig. 3-11



OZONE: Sources





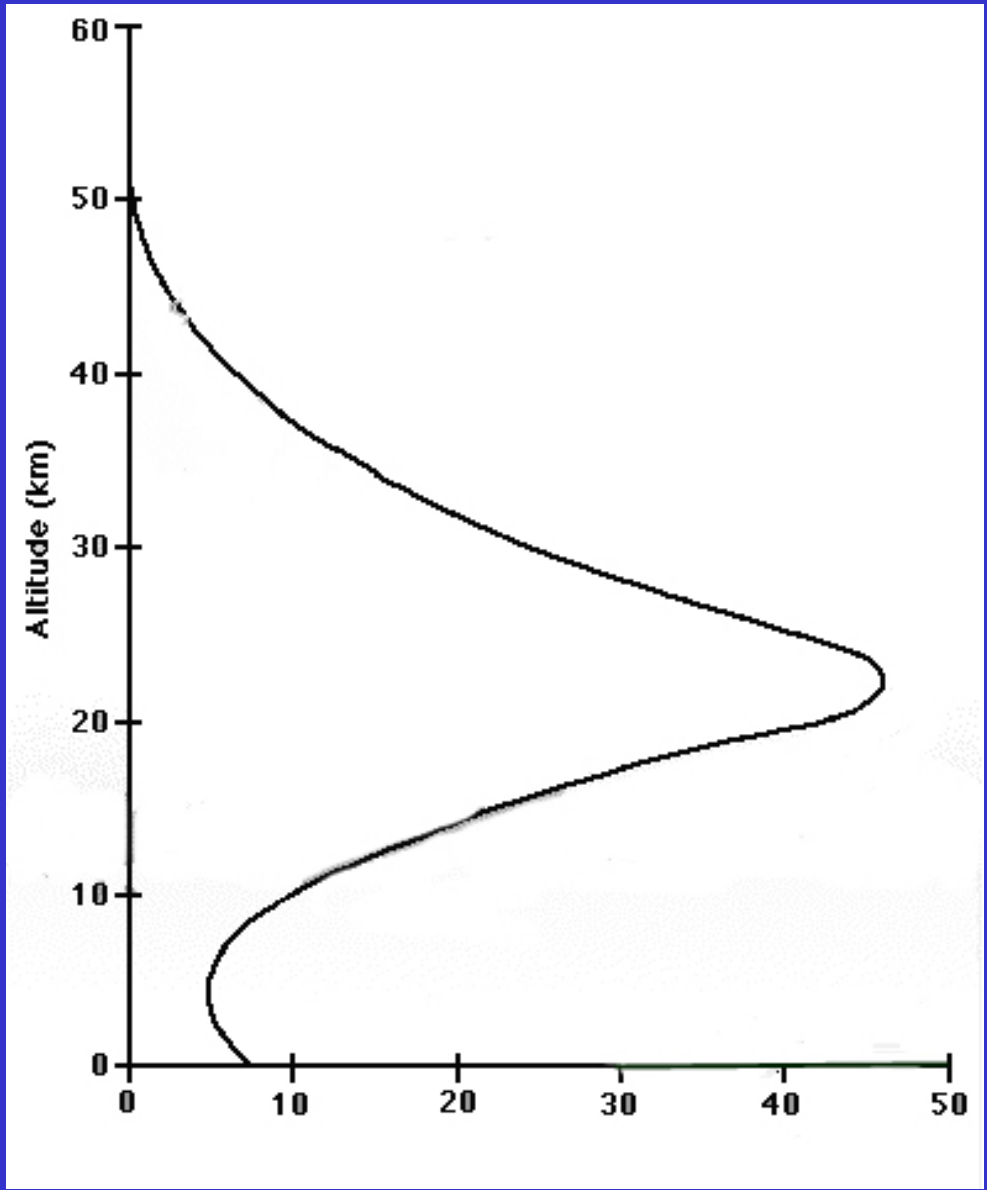
Produced naturally in photochemical reactions in stratospheric ozone layer - -"good ozone"

Has *increased* in troposphere due to photochemical smog reactions - - "bad ozone"

review

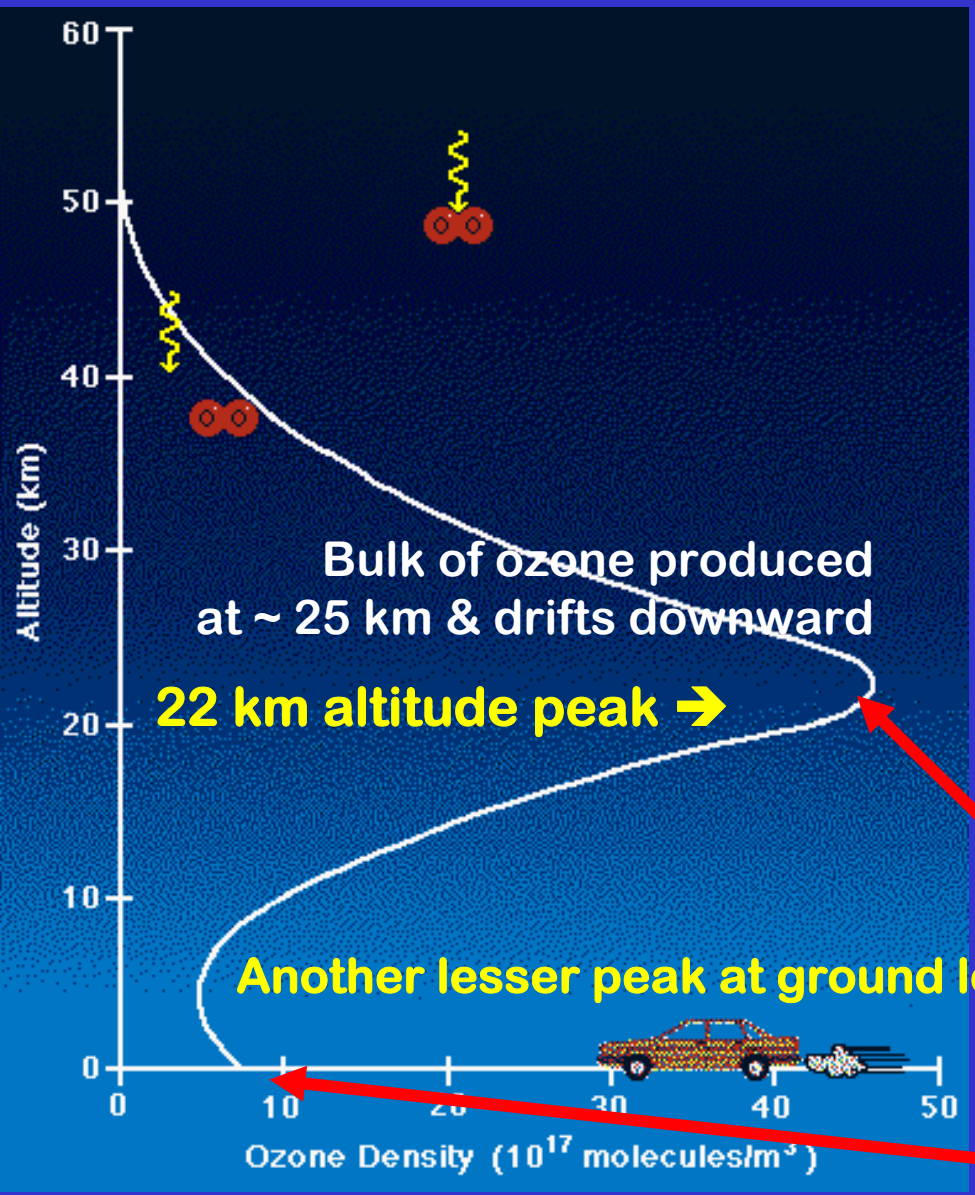
Here's a different version of the figure →

Shows 2 peaks, a major peak in O_3 density in the **stratosphere**, a smaller secondary peak in the **lower troposphere**



Ozone Density

(10^{17} molecules / m^{3})



Now let's focus on the "GOOD" ozone located in the STRATOSPHERE (the ozone that is being depleted leading to an ozone "hole")

"Good" ozone
&
"Bad" ozone

☺

THE OZONE LAYER IN THE STRATOSPHERE -- WHY IT'S THERE

Due to: the natural "Chapman Mechanism"

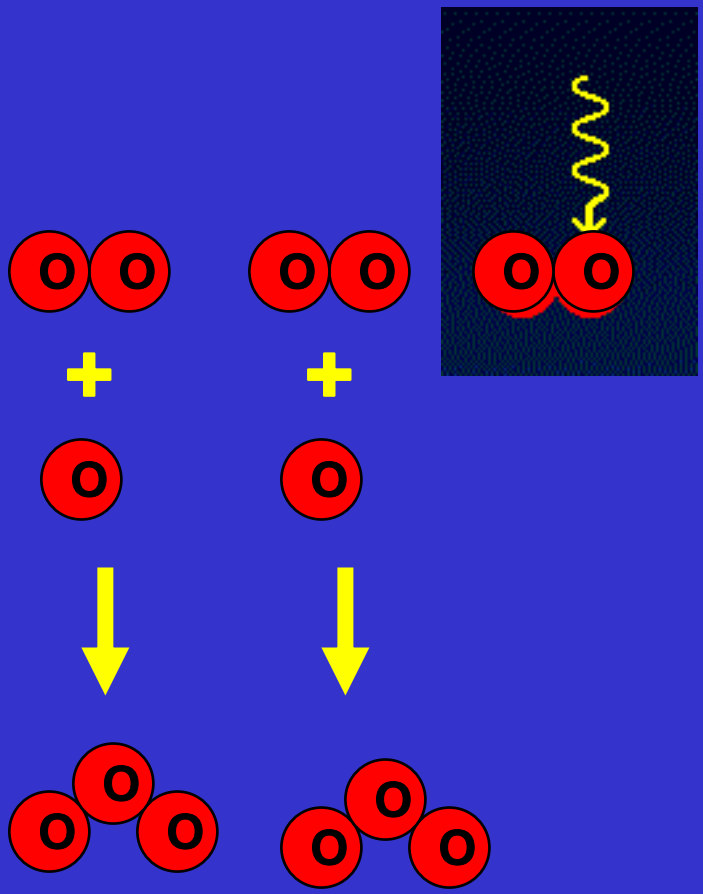
(a series of photochemical reactions)

THE CHAPMAN MECHANISM

(first proposed in 1930s)

- ozone is continuously produced and destroyed
- through **PHOTOCHEMICAL REACTIONS** in the stratosphere
- involves oxygen (O_2), molecular oxygen (O), photons of UV radiation, and OZONE (O_3).

Bullet 3, p 127



The Chapman Mechanism

Ozone exists in the upper atmosphere as a consequence of photochemical reactions between molecular oxygen and sunlight:

$$O_2 + O_2 + O_2 + \text{sunlight}$$

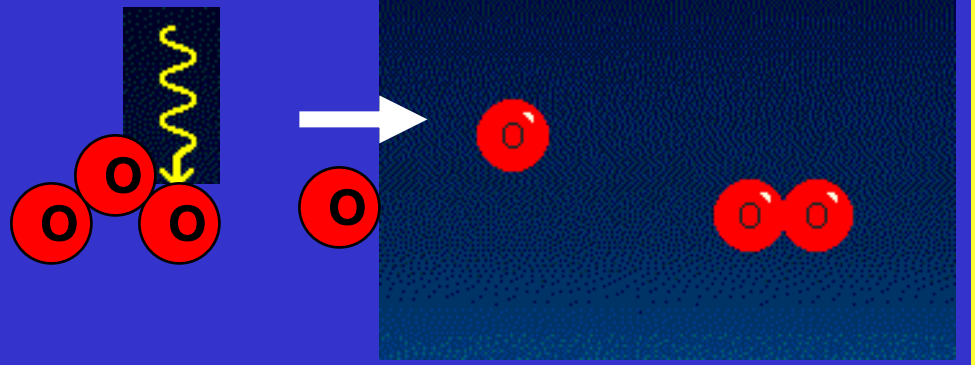
$$\rightarrow O_2 + O + O + O_2$$

$$\rightarrow O_3 + O_3$$

HOW the CHAPMAN MECHANISM Works

- ozone is continuously produced and destroyed
- through **PHOTOCHEMICAL REACTIONS** in the stratosphere
- involves oxygen, molecular oxygen, UV radiation, and ozone.

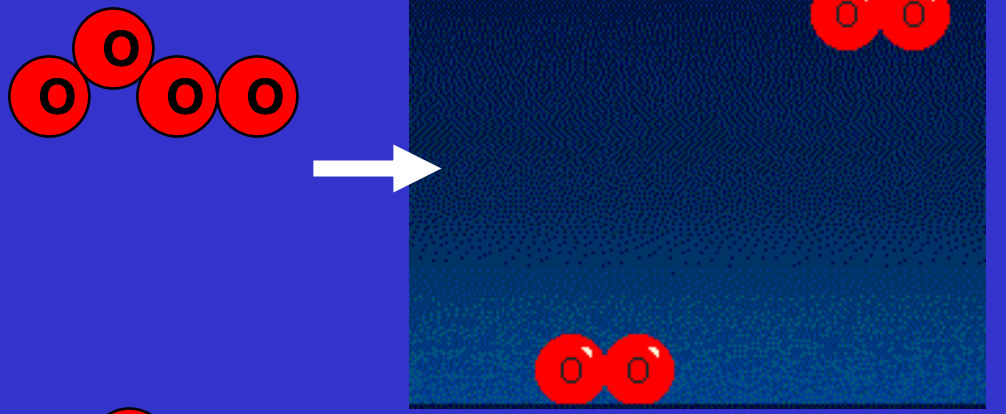
Bullet 3, p 127



Ozone is destroyed naturally by reaction with ultraviolet radiation:

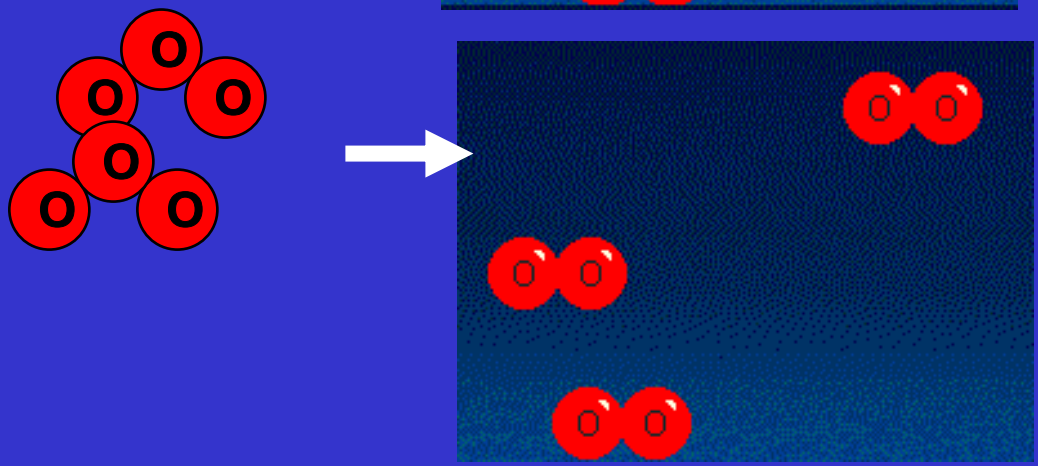
$$O_3 + UV \rightarrow O_2 + O$$

This is part of how the ozone layer protects the earth's surface from ultraviolet radiation.



Ozone is also destroyed naturally by reactions promoted by collisions with atomic oxygen:

$$O_3 + O \rightarrow 2\,O_2$$

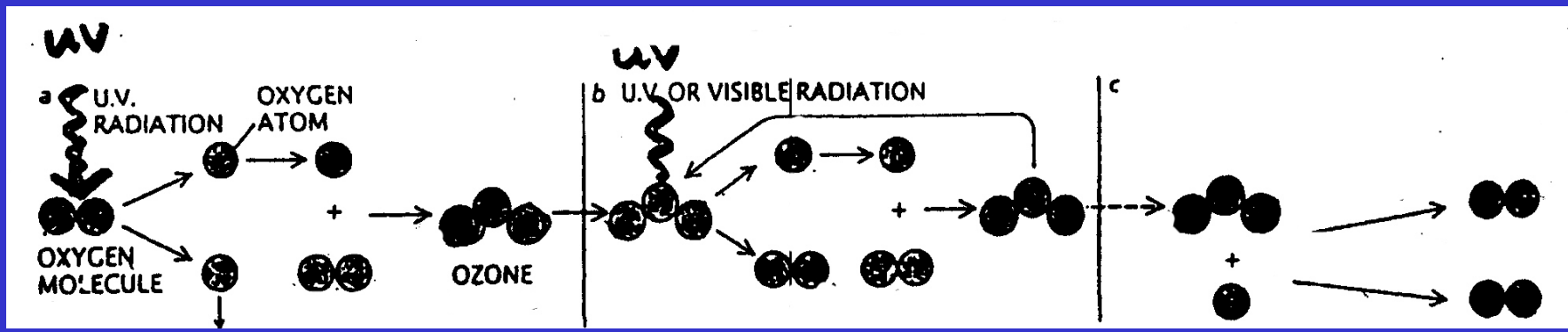


As well as being destroyed by collisions with itself:

$$O_3 + O_3 \rightarrow 3\,O_2$$

The Chapman Mechanism

(another view)



Ozone being formed naturally

Ozone being destroyed naturally

Ozone being formed naturally

Ozone being destroyed naturally

[Go to movie clip]

In theory:

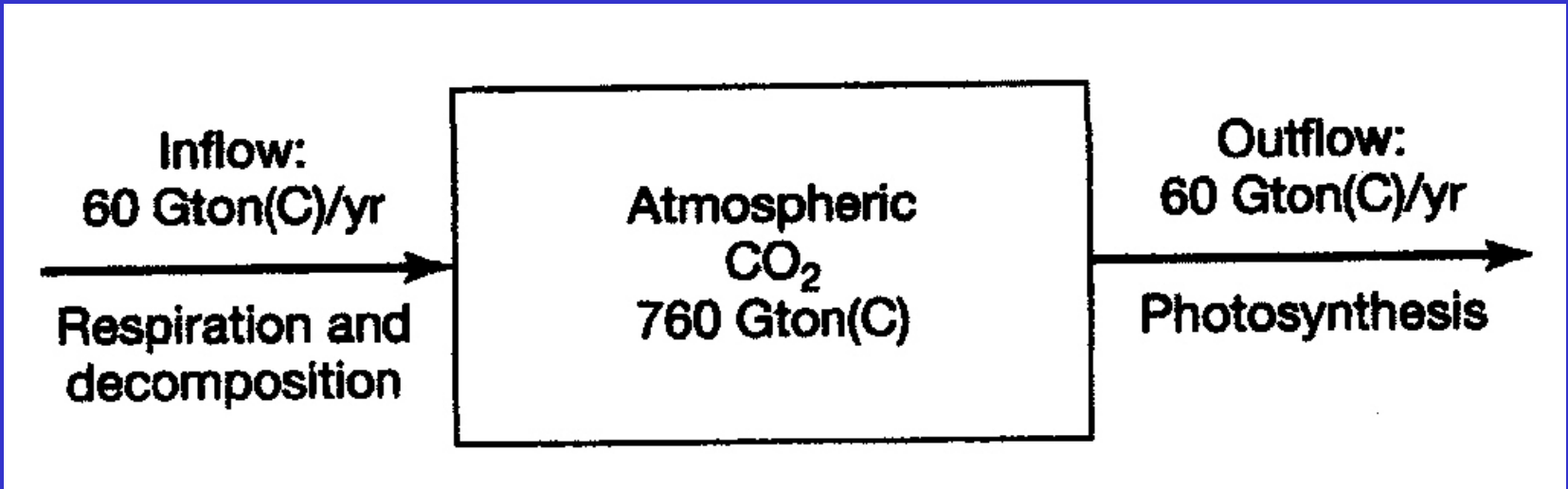
> a balance of ozone is established over time

> prevents much of the harmful UV radiation from reaching the earth's surface.

Leads to an “Equilibrium” or “Steady State”

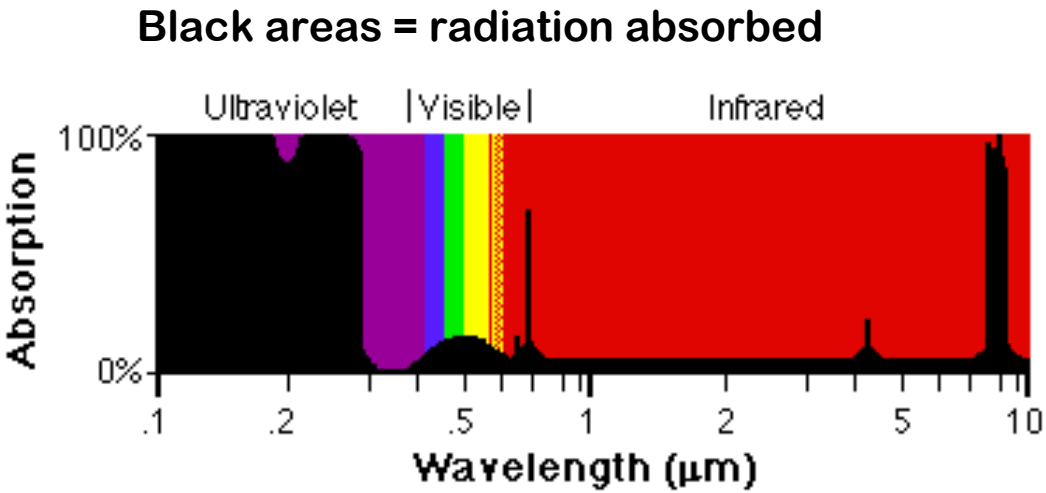
Bullet 3, p 127

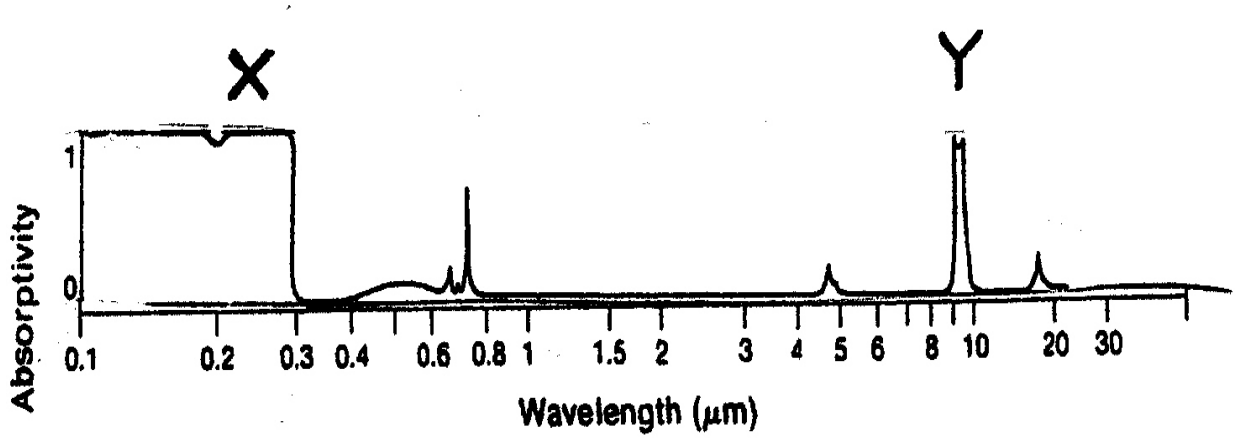
Where else have we seen A STEADY STATE?



review

Why stratospheric ozone is "Good":



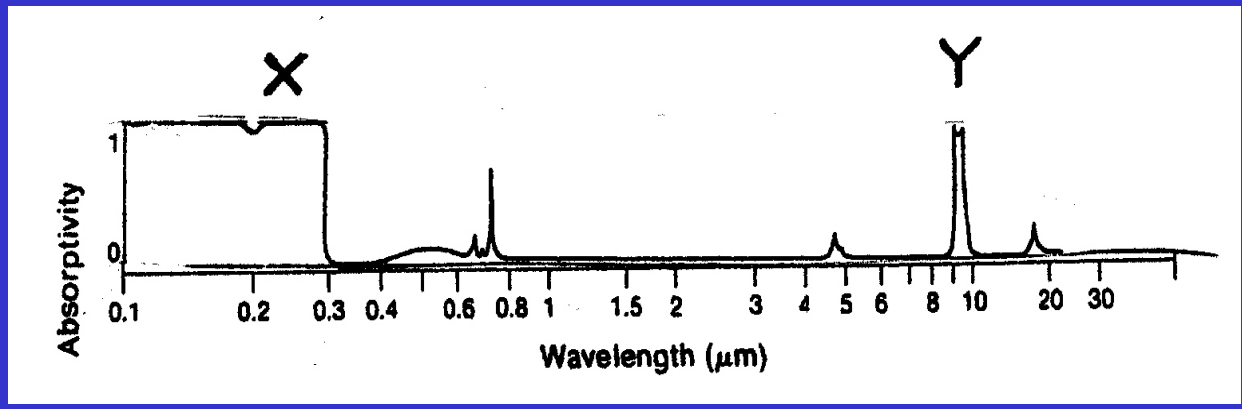


Ozone has the property of being a very strong absorber of ultraviolet radiation → nearly total absorption of wavelengths less than 0.3 μm

What is the wavelength range of visible light?

0.4 to 0.7 μm

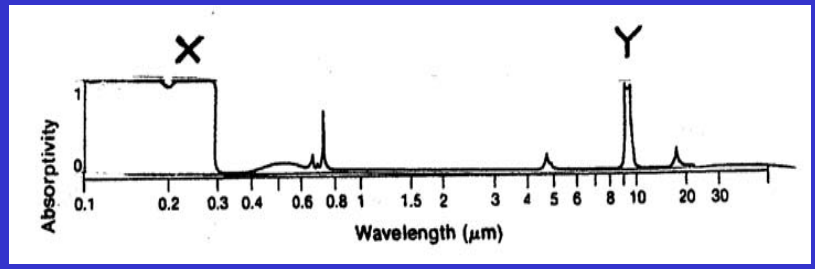
← remember this figure?



Circle the CORRECT completion to this sentence:

"The global change issue usually referred to as Stratospheric Ozone Depletion is related to the part of the absorption curve that is labeled . . ."

Stratospheric Ozone Depletion: X or Y? Why?

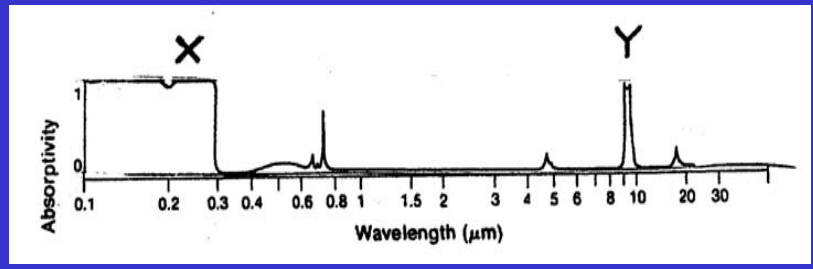


1. . . . X because X represents UV radiation being absorbed -- hence if ozone is depleted, MORE ultraviolet radiation will reach the Earth's surface.

2. . . . X because X represents TERRESTRIAL LONGWAVE radiation being absorbed -- and hence serves as a catalyst in the Chapman mechanism.

3. . . .Y because Y represents *easy transmission of wavelengths of terrestrial longwave radiation out to space* which then disappear through the "atmospheric window" also known as the ozone hole.

Stratospheric Ozone Depletion: X or Y? Why?

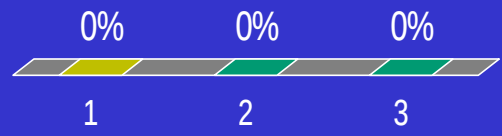


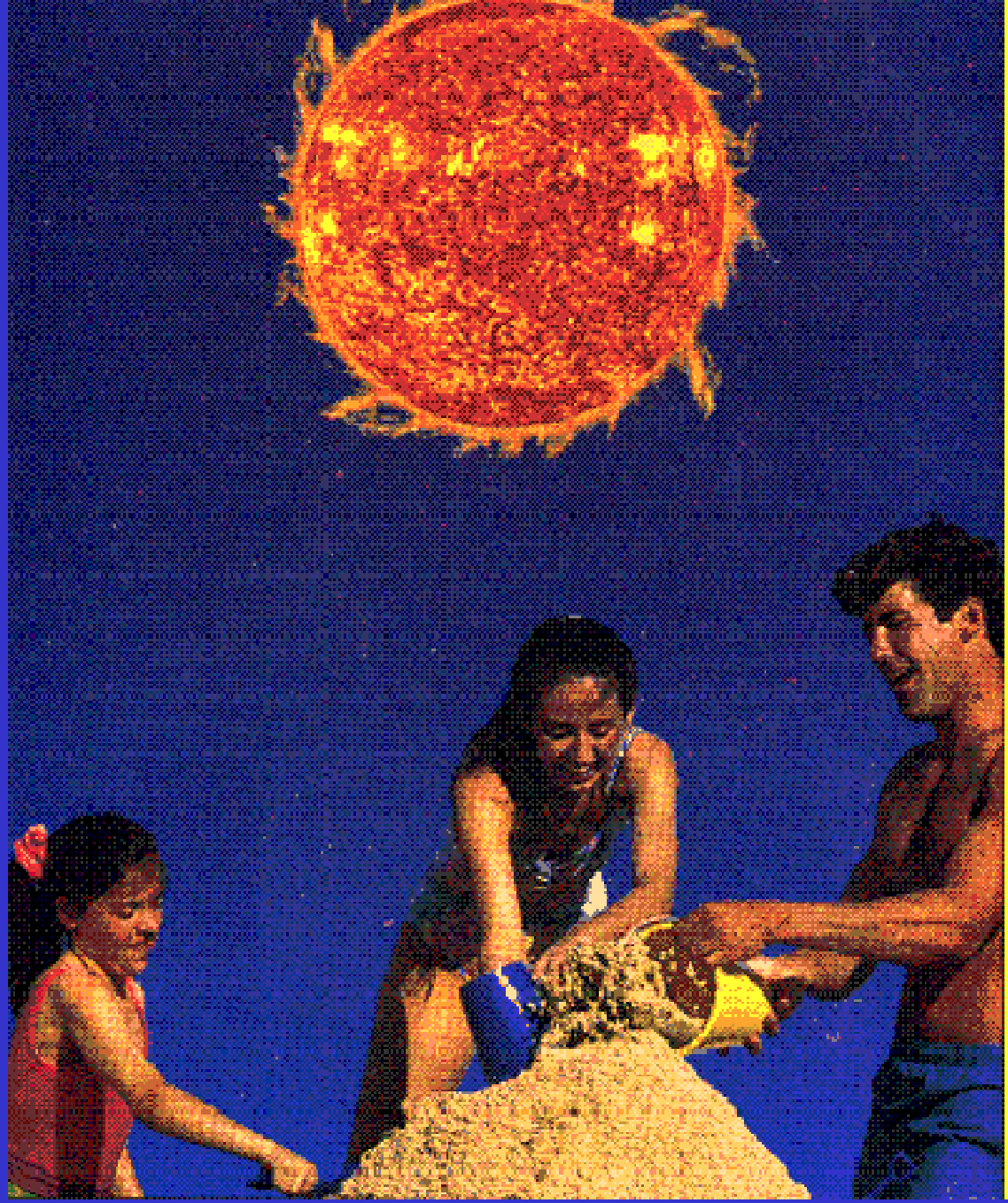
1. . . . X because X represents UV radiation being absorbed -- hence if ozone is depleted, MORE ultraviolet radiation will reach the Earth's surface.

Yellow = correct choice!

2. . . . X because X represents TERRESTRIAL LONGWAVE radiation being absorbed -- and hence serves as a catalyst in the Chapman mechanism.

3. . . . Y because Y represents *easy transmission of wavelengths of terrestrial longwave radiation out to space* which then disappear through the "atmospheric window" also known as the ozone hole.





The "B" component of ultraviolet light, which ranges from .29 to .32 µm, has been linked to two types of skin cancer: basal cell carcinoma and squamous cell carcinoma. Currently, there are 300,000 to 400,000 cases of basal cell carcinoma and 100,000 cases of squamous cell carcinoma reported each year in the United States.

UVA = .32 to .4 µm

(once thought to be relatively harmless, BUT causes wrinkles, premature aging and associated sun-related skin damage; new research indicates possible skin cancer link)

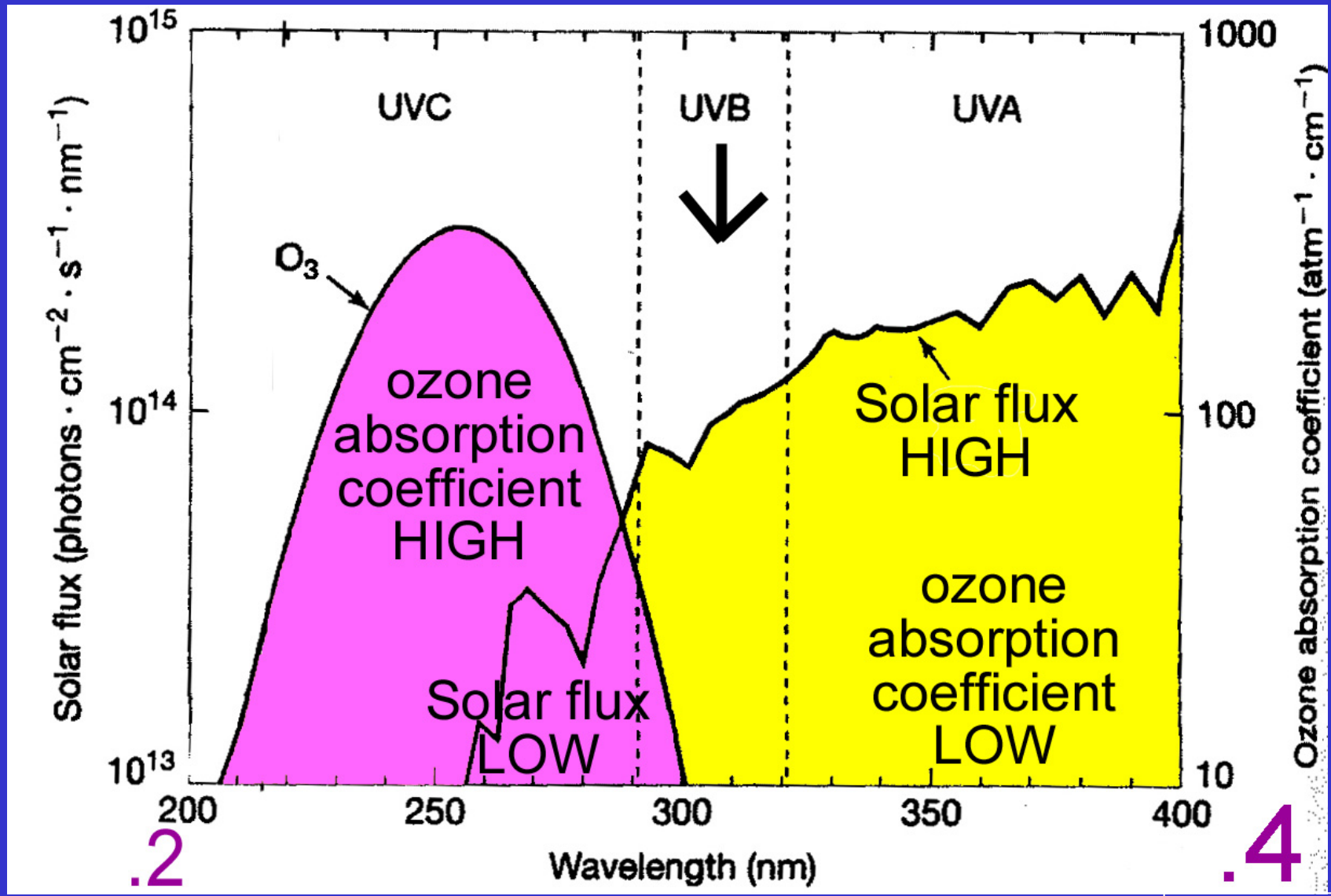
UVB = .29 to .32 µm

(harmful, sunburn, skin cancer)

UVC = .20 to .29 µm

(extremely harmful, damages DNA)

"GOOD" Stratospheric
OZONE absorbs harmful UVC & most harmful UVB

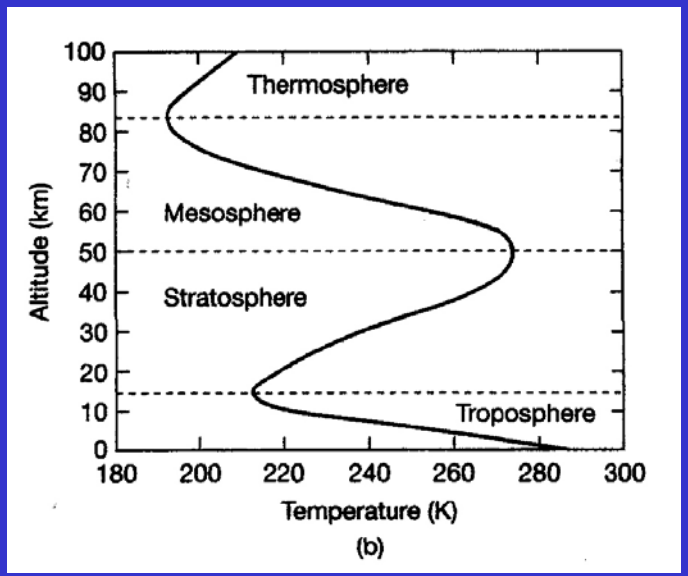


Wavelength Range	Name	Biological Effect
.32 to .4 µm (320-400 nm)	**UVA** **(SPF doesn't rate UVA protection!)**	once thought to be relatively harmless, BUT causes wrinkles, premature aging and associated sun-related skin damage; new research indicates possible skin cancer link
.29 to .32 µm (290-320 nm)	**UVB** **(see SPF for protection)**	harmful, causes sunburn, skin cancer, and other disorders
.20 to .29 µm (200 - 290 nm)	**UVC** **(almost completely absorbed by O3)**	extremely harmful, damages DNA -- but almost completely absorbed by ozone

p 123

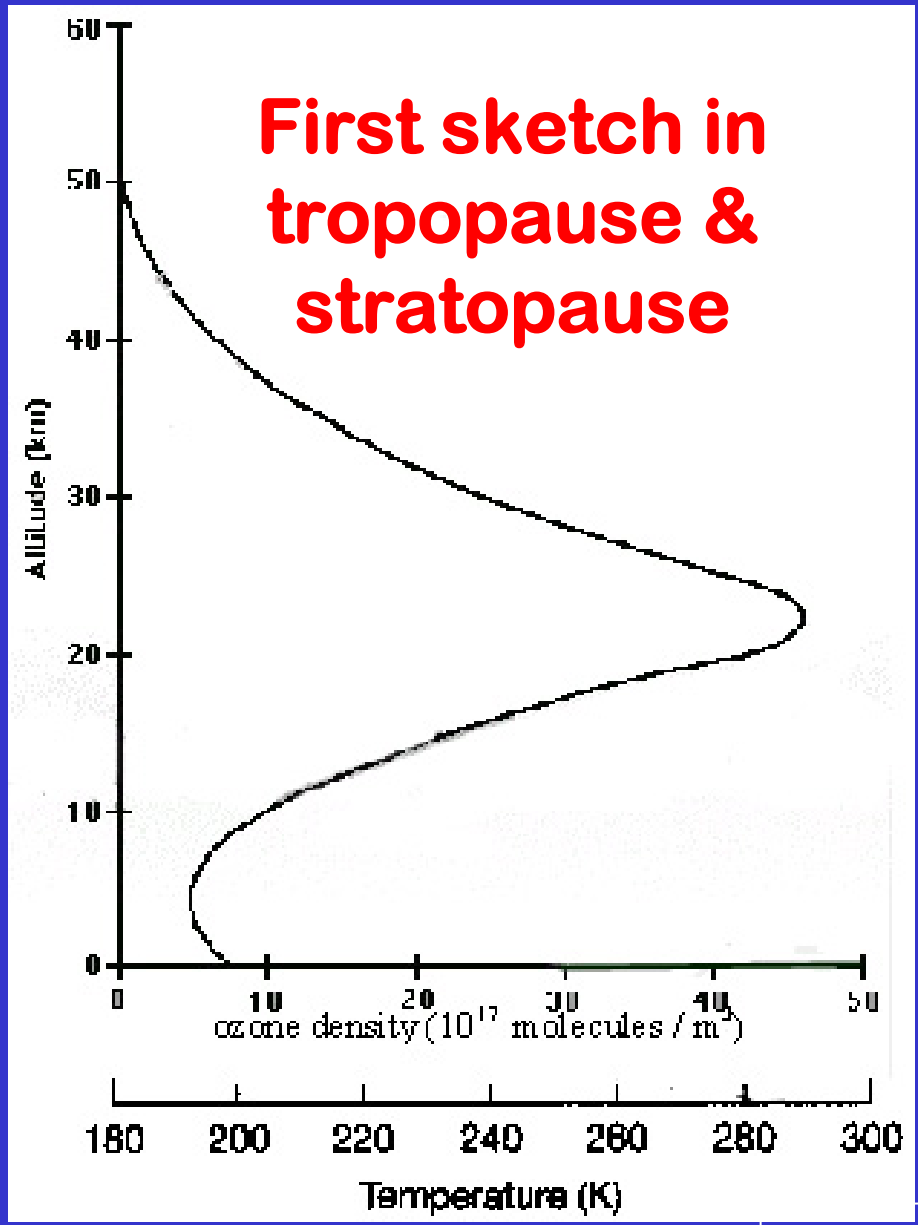
P. 124 in Class Notes:

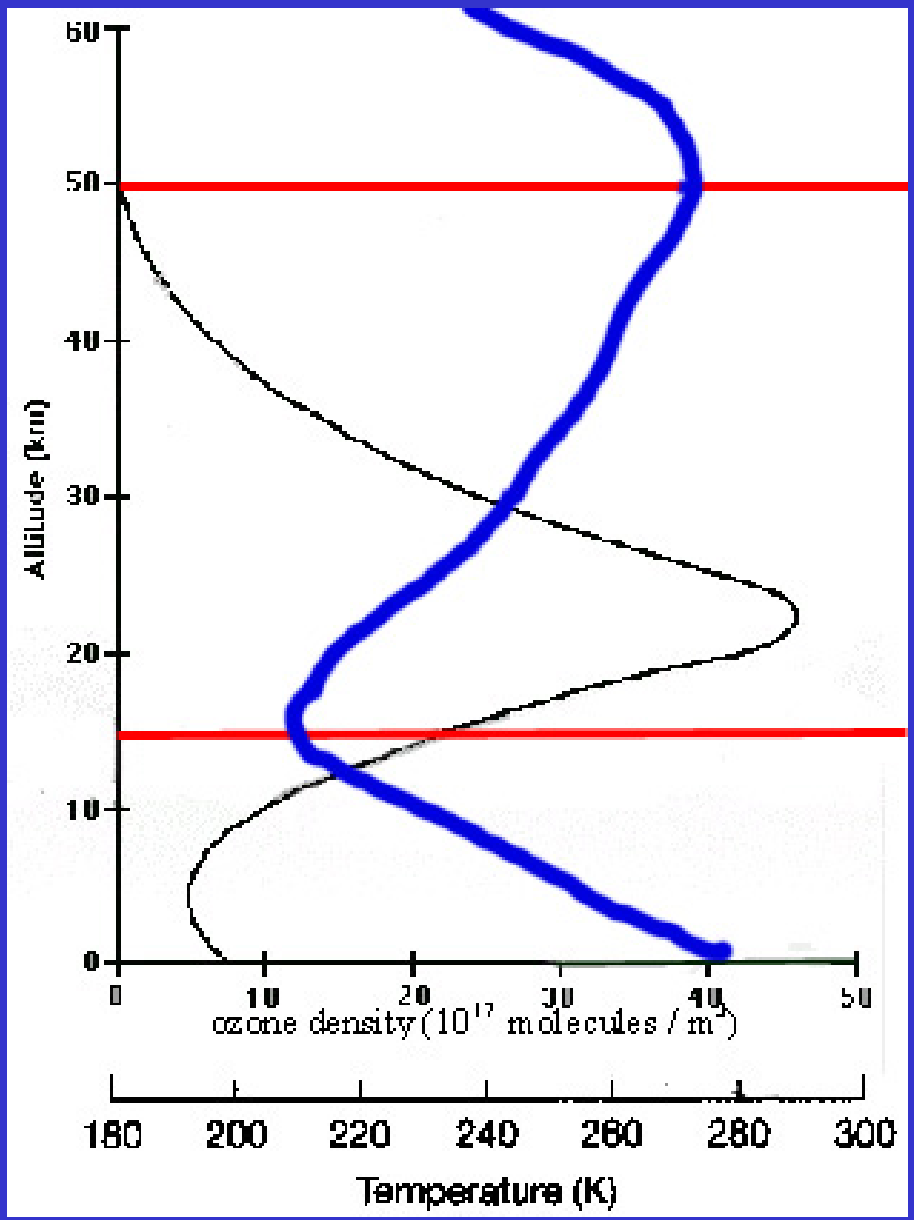
Temperature graph



Roughly sketch temperature line on ozone graph

Ozone Density graph





Temperature

[increases / decreases]

with increasing altitude in the stratosphere

WHY???

Why is there an increase in temperature with altitude in the STRATOSPHERE?

1. It is the **closest layer to the sun,** hence it closest to the solar "heat source."

2. It receives large amounts of UV radiation from the sun PLUS it has a high concentration of ozone to absorb this UV.

3. It is the layer which contains most of the **GH gases that absorb IR radiation** emitted by the Earth's surface.

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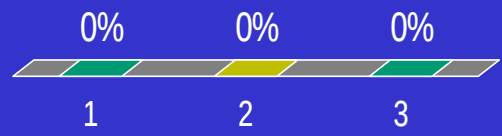
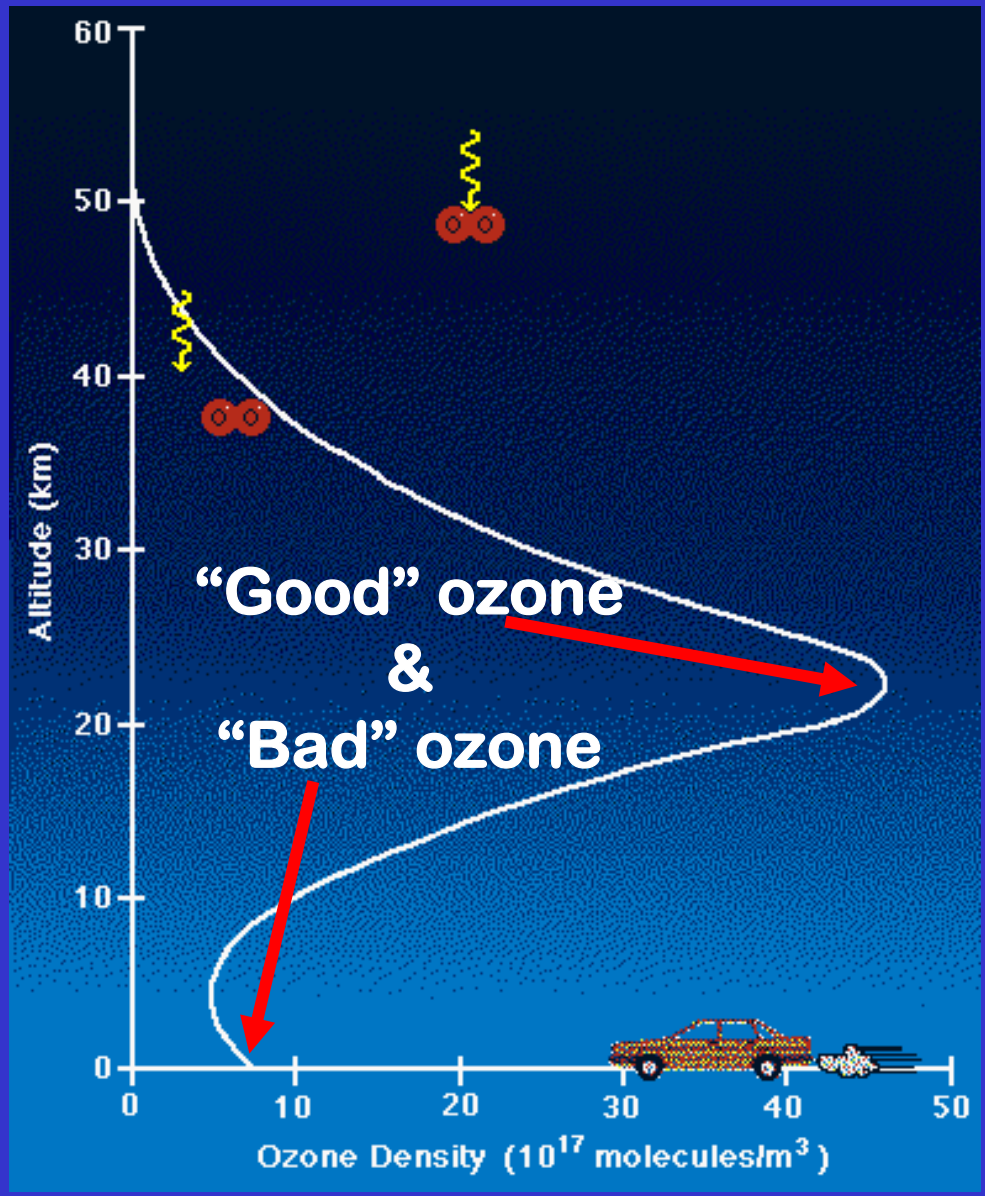
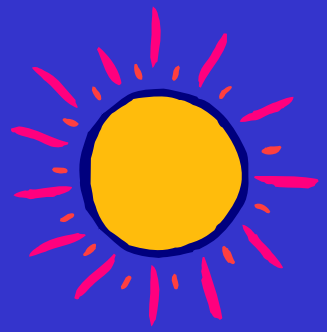


What about the "BAD" ozone located in the troposphere?

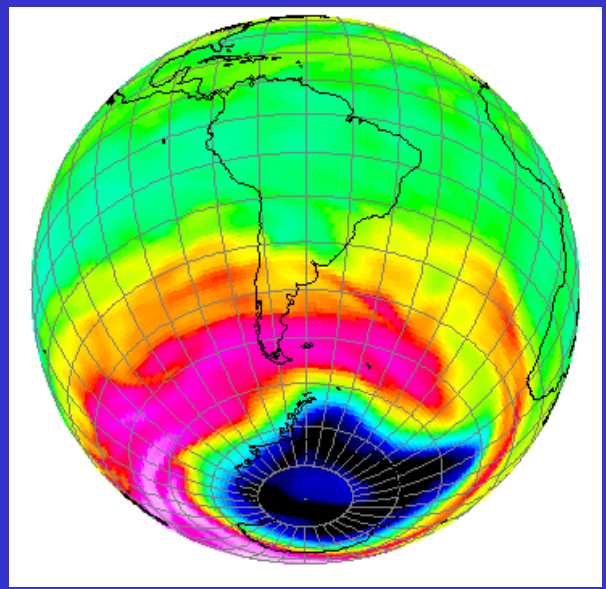


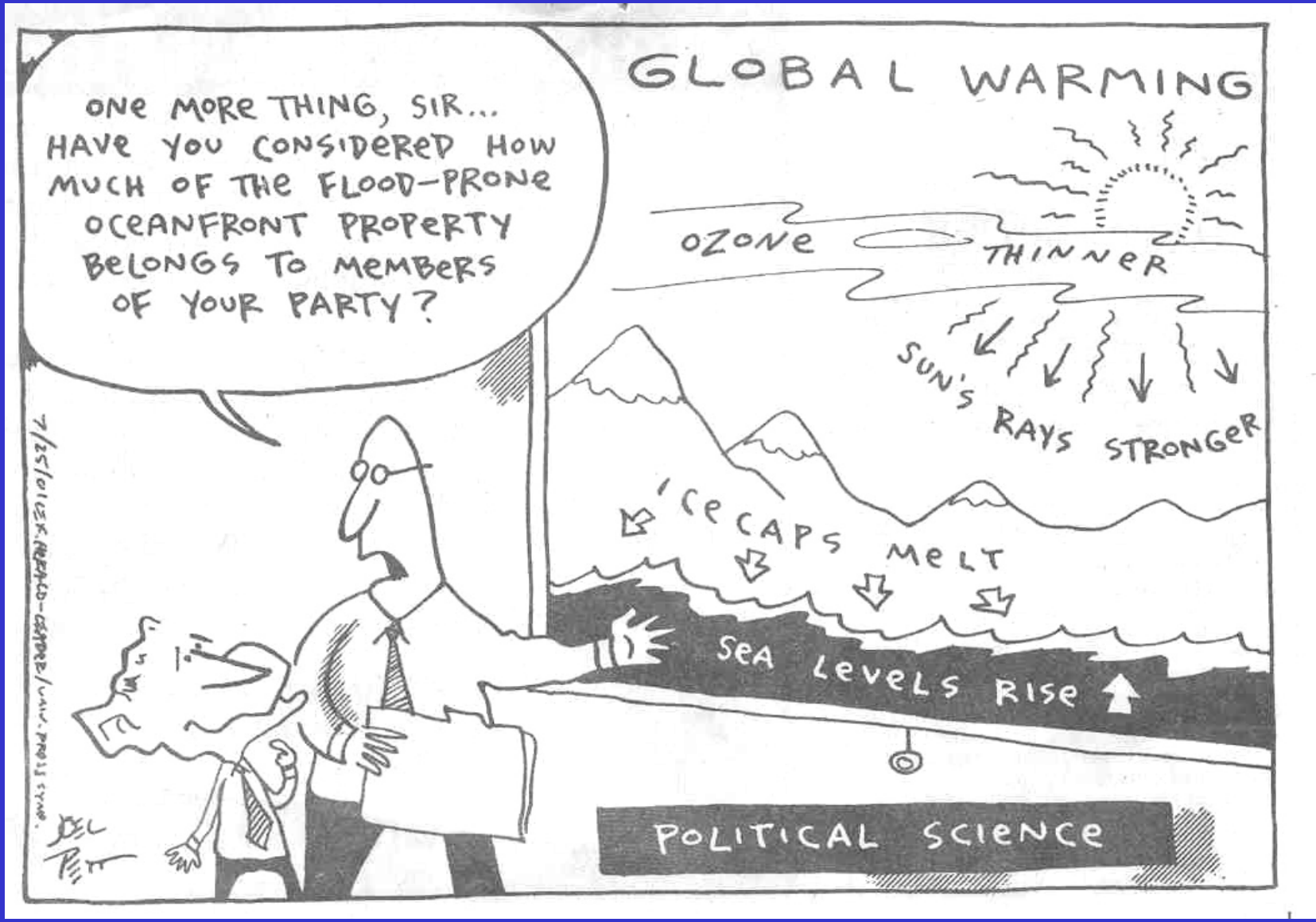


Ozone has ***increased*** in troposphere due to photochemical smog reactions -- "bad ozone"

NEXT:

THE DESTRUCTION OF STRATOSPHERIC OZONE





What – if anything -- is scientifically inaccurate in this cartoon?

☺

STRATOSPHERIC Ozone depletion is related to GLOBAL WARMING from an enhanced Greenhouse Effect in the following way:

1. If stratospheric ozone is depleted, then more UV wavelengths of SW energy will enter the troposphere – more UV radiation leads directly to an increase in the Greenhouse Effect.

2. If stratospheric ozone is depleted, then the Greenhouse Effect in the stratosphere will be reduced, leading to global cooling.

3. Stratospheric Ozone depletion will not cause Global Warming from an enhanced Greenhouse effect directly.

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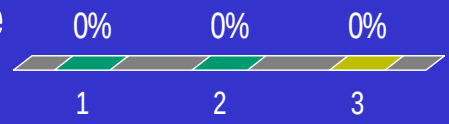
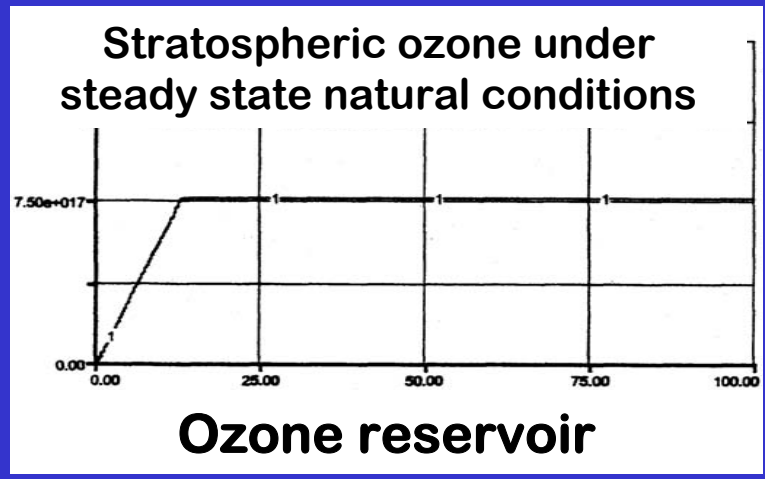
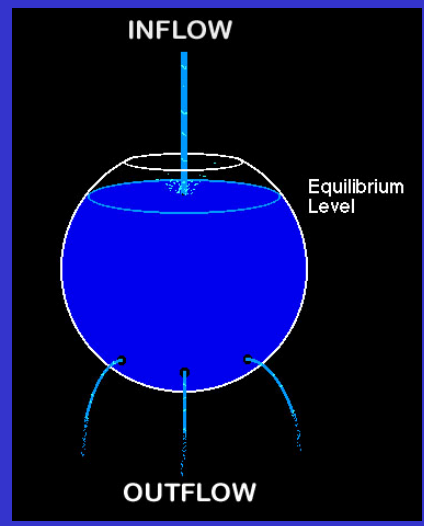


The Chapman Mechansim "balance" is being disrupted by the introduction of CFC's and other similar gases into the stratosphere:





> CFCs are photo-dissociated into **FREE CHLORINE ATOMS (Cl)** and other molecular fragments by UV rays

> **Chlorine** (and other gases such as Nitric oxide, NO) act as **catalysts** in ozone loss reactions

Bullet 4, p 127

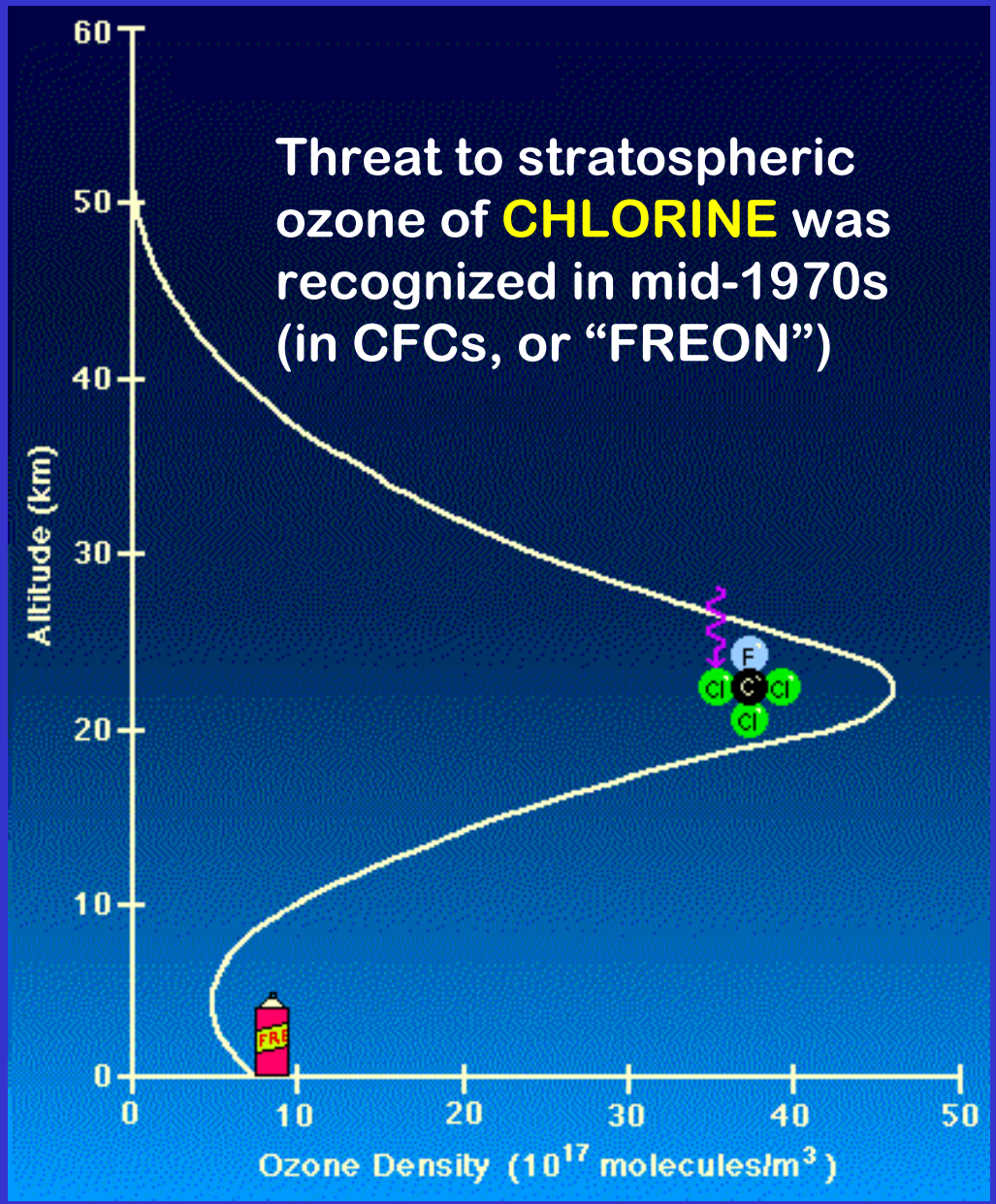
CATALYST =

A compound that increases the rate of a chemical reaction and is itself unchanged by the reaction

Through chemical reactions:

- **the chlorine removes ozone from the stratosphere**
- **and also frees more chlorine atoms to begin the process all over again**

Bullet 4, p 127



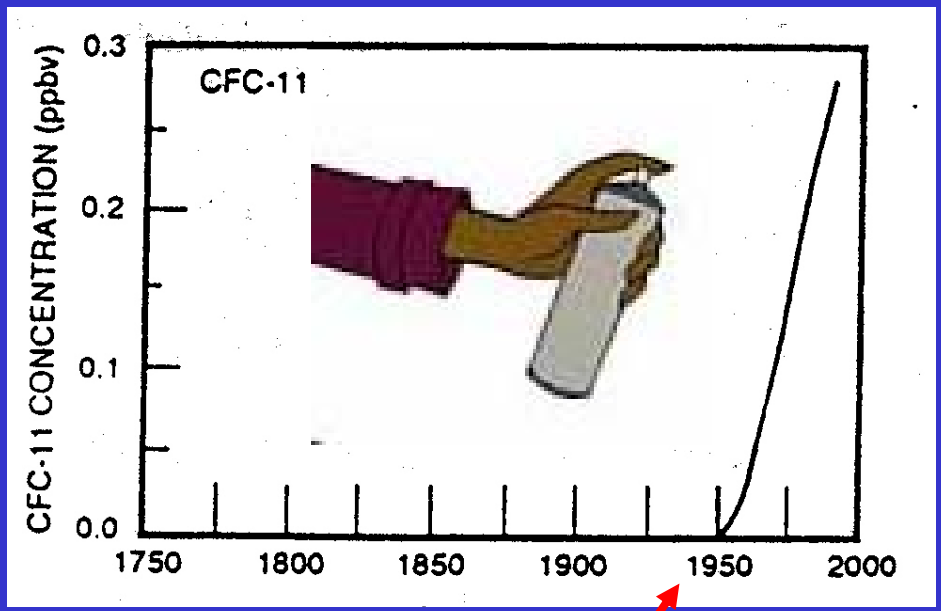
CFC compounds

chlorofluorocarbons

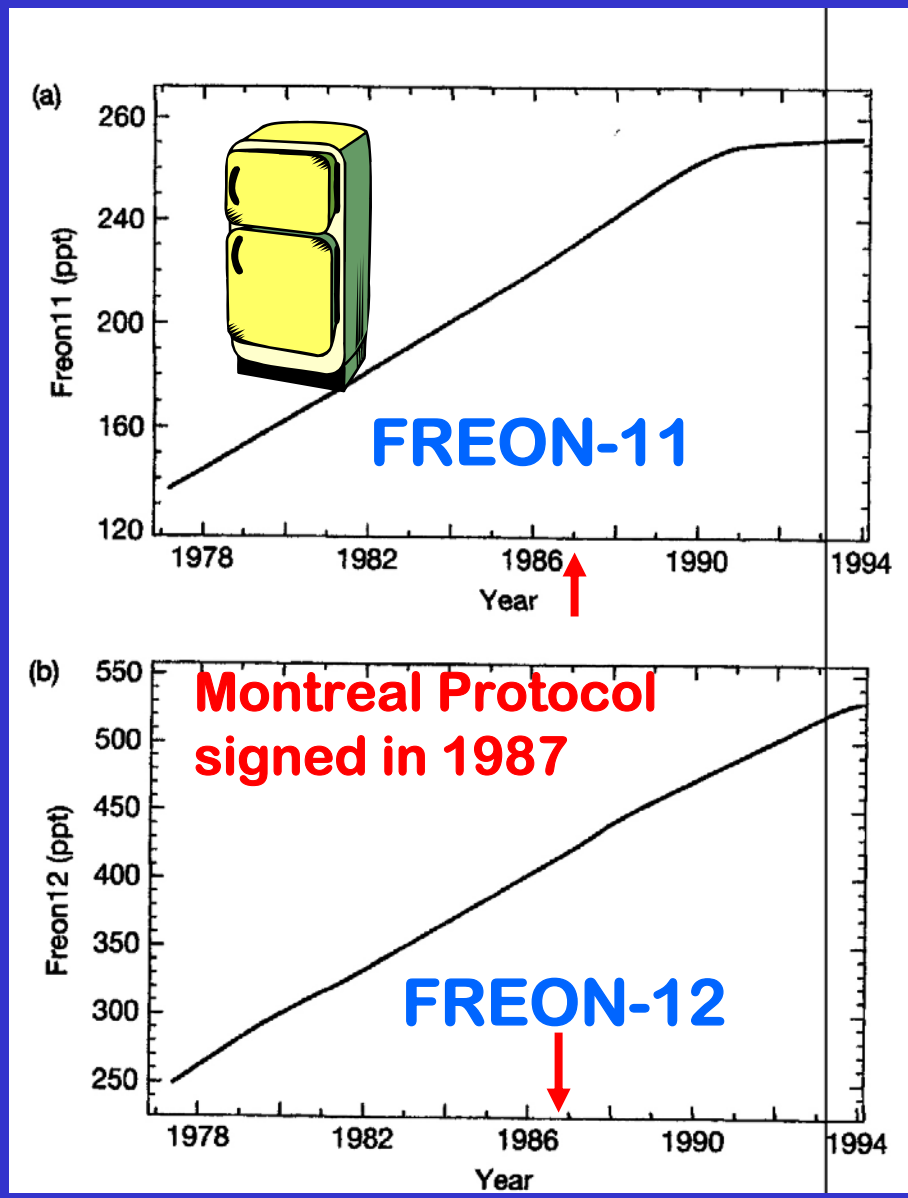
are unreactive at Earth's surface,

but if they get into the stratosphere, they can be broken down by high energy UV radiation → leads to release of highly reactive **CHLORINE atoms (Cl)**

CFCs: Trends



Human-made -- didn't exist before 1950!



review

CFC's & the CHLORINE CATALYST

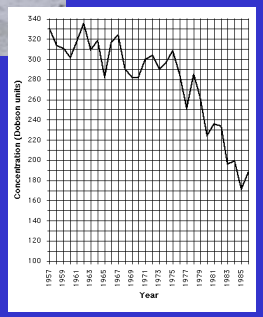
A single chlorine atom may destroy hundreds of thousands of ozone molecules during its residence in the stratosphere!

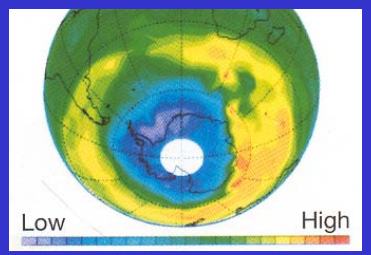
[Go to movie clip]

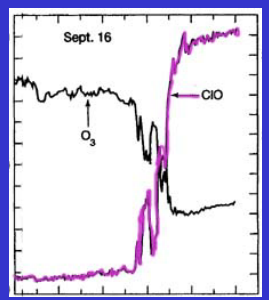
The theory of ozone destruction by CFC's proposed in 1974 – but no observations existed!

(Atmospheric chemists Crutzen, Molina, Rowland later given Nobel prize for this theory)

THE OZONE HOLE DISCOVERY STORY







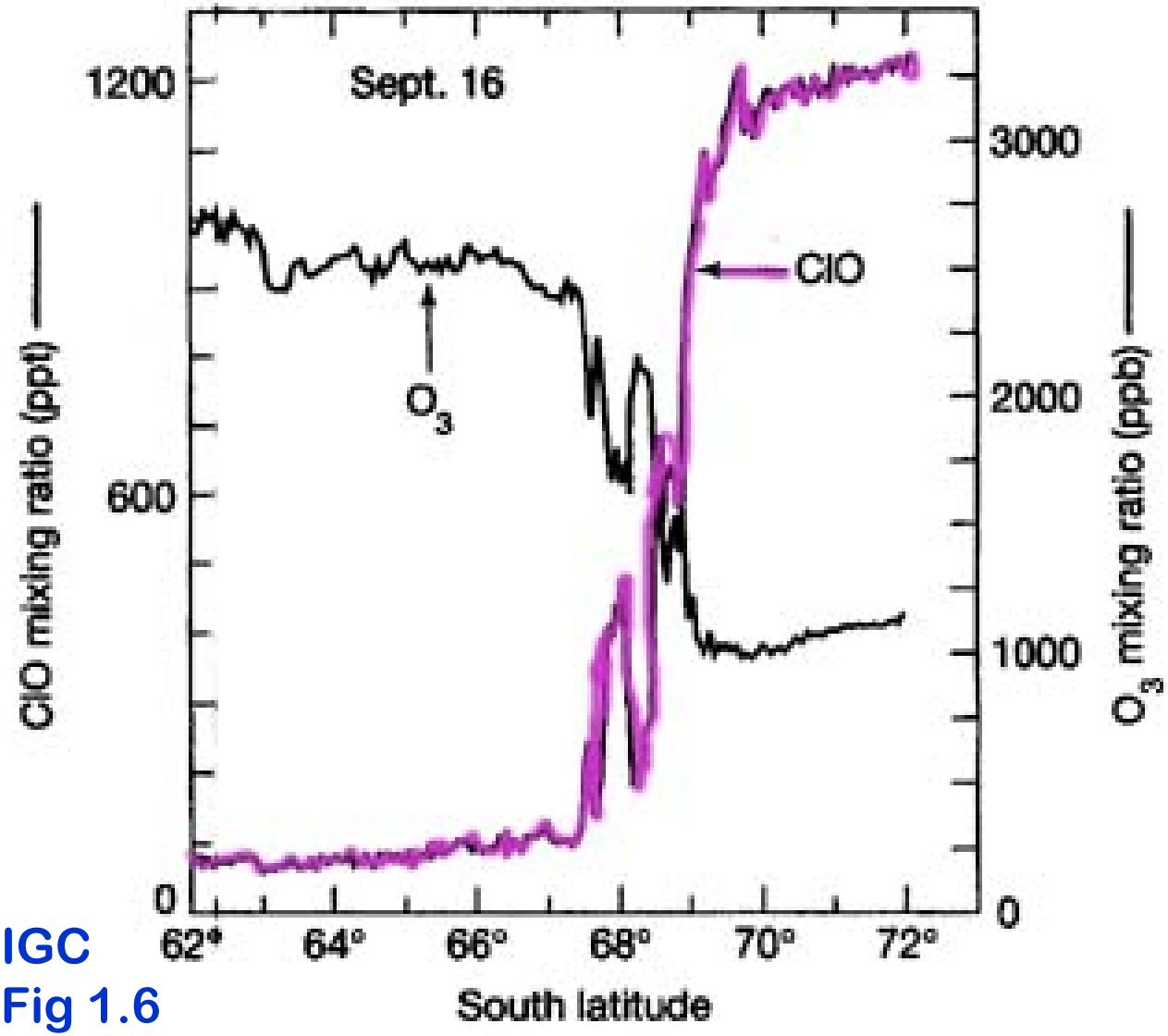
- Ground-based ozone measurements since 1956. (British survey team) Observed a new trend of decreasing ozone concentrations beginning in 1977

- Didn't believe measurements & delayed publication for several years while rechecking data & instruments -- Published in 1985; greeted skeptically!

- Meanwhile, the TOMS satellite instrument had been launched in 1979. It detected the developing hole, but the anomalously low readings were rejected as noise!!

- In 1986 Dr. Susan Soloman's expedition to Antarctica ➔ identified chlorine increase

- She devised the theory that correctly explained the destruction of ozone by chlorine compounds



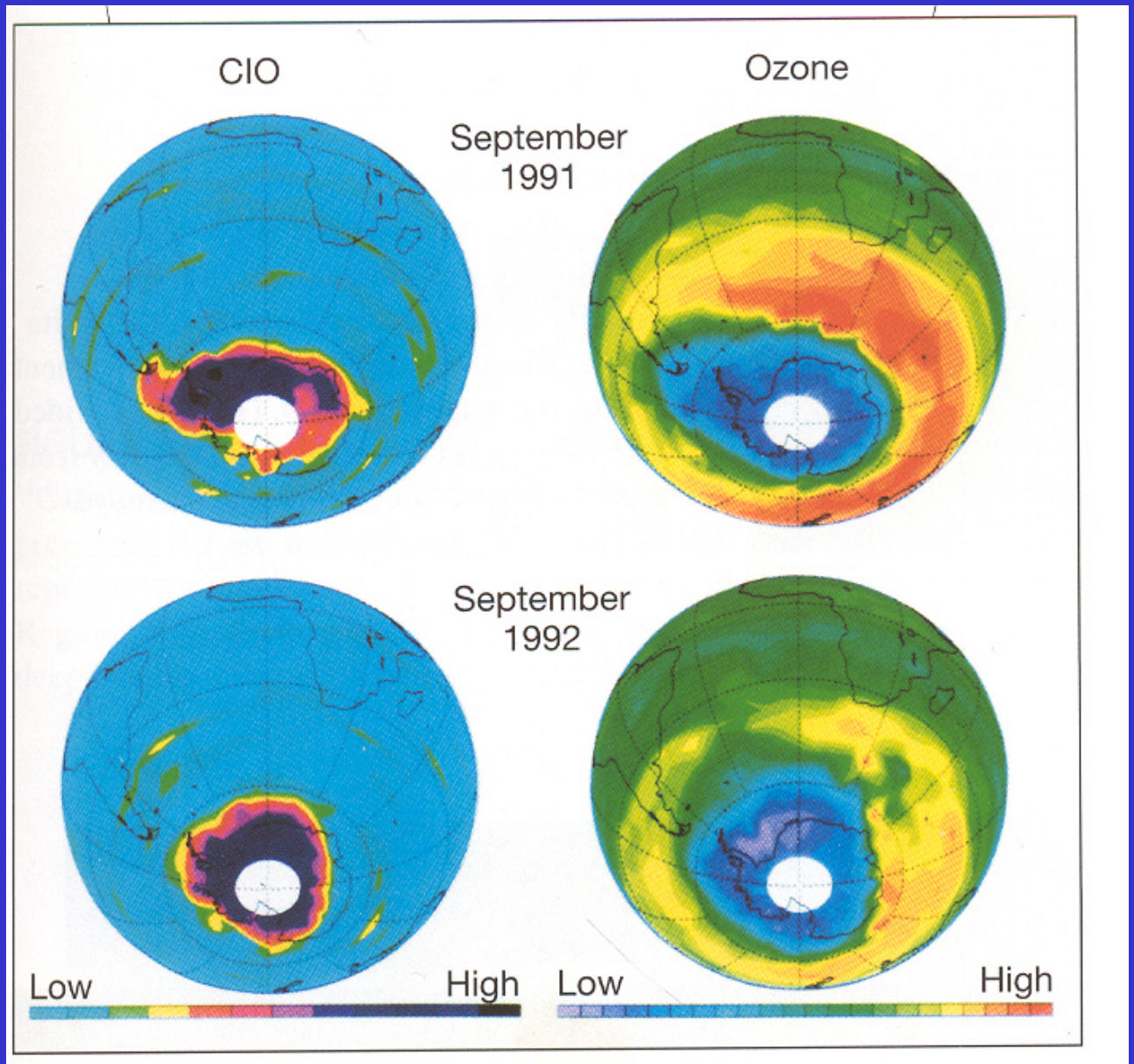
IGC
Fig 1.6

ClO (chlorine monoxide) from the chlorine catalytic cycle = **THE evidence of chemical reactions** occurring in hole region during time of greatest O_3 depletion (in September, spring in Southern Hemisphere)

ANTARCTIC LAND MASS

To the South Pole

Simultaneous measurements of ozone (O3) and chlorine monoxide (ClO)



Color version of IGC Fig 1.6

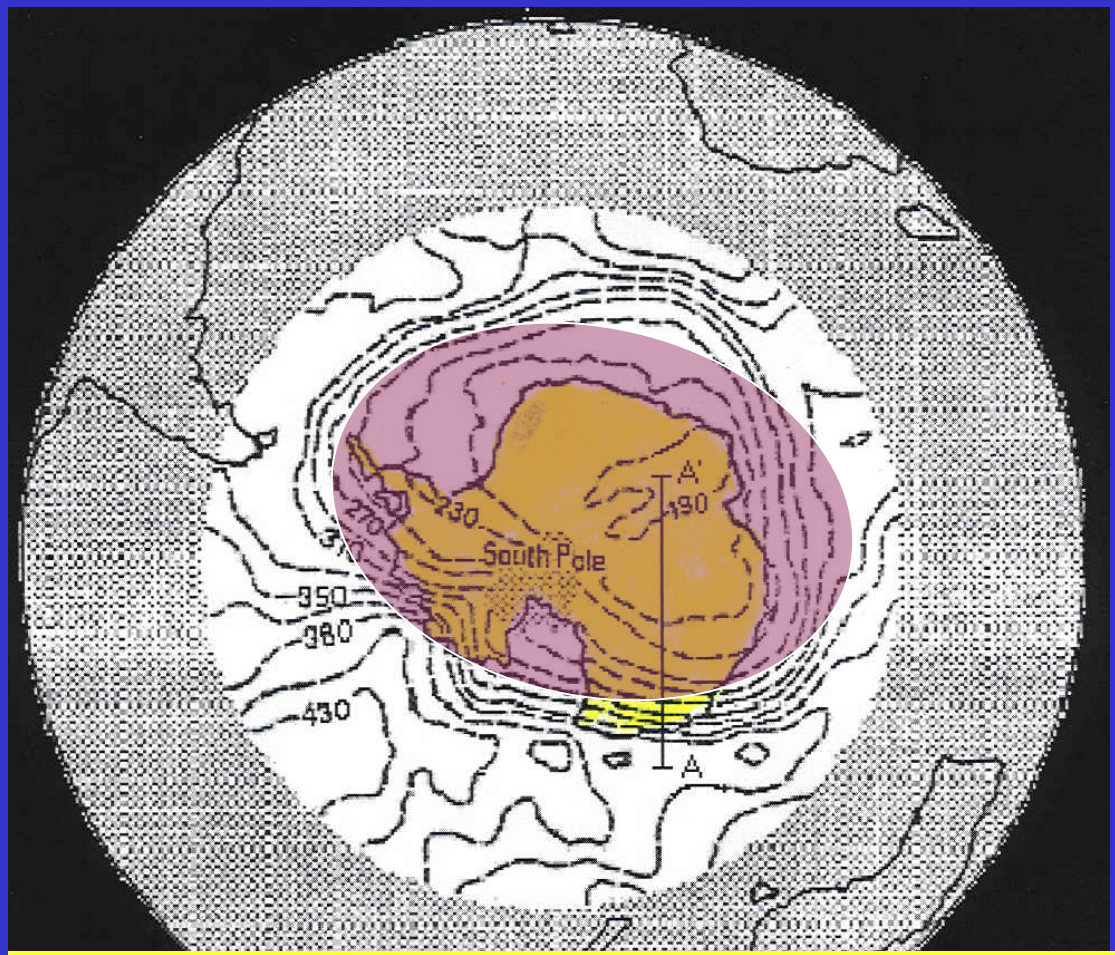
WHY ANTARCTICA?

The ozone "hole(s)" have a unique REGIONALITY and SEASONALITY :

> it is most severe over Antarctica in S.H. spring (Sep, Oct);

> a less severe depletion (not a true hole) occurs over the Arctic in N.H. spring (Feb, Mar)

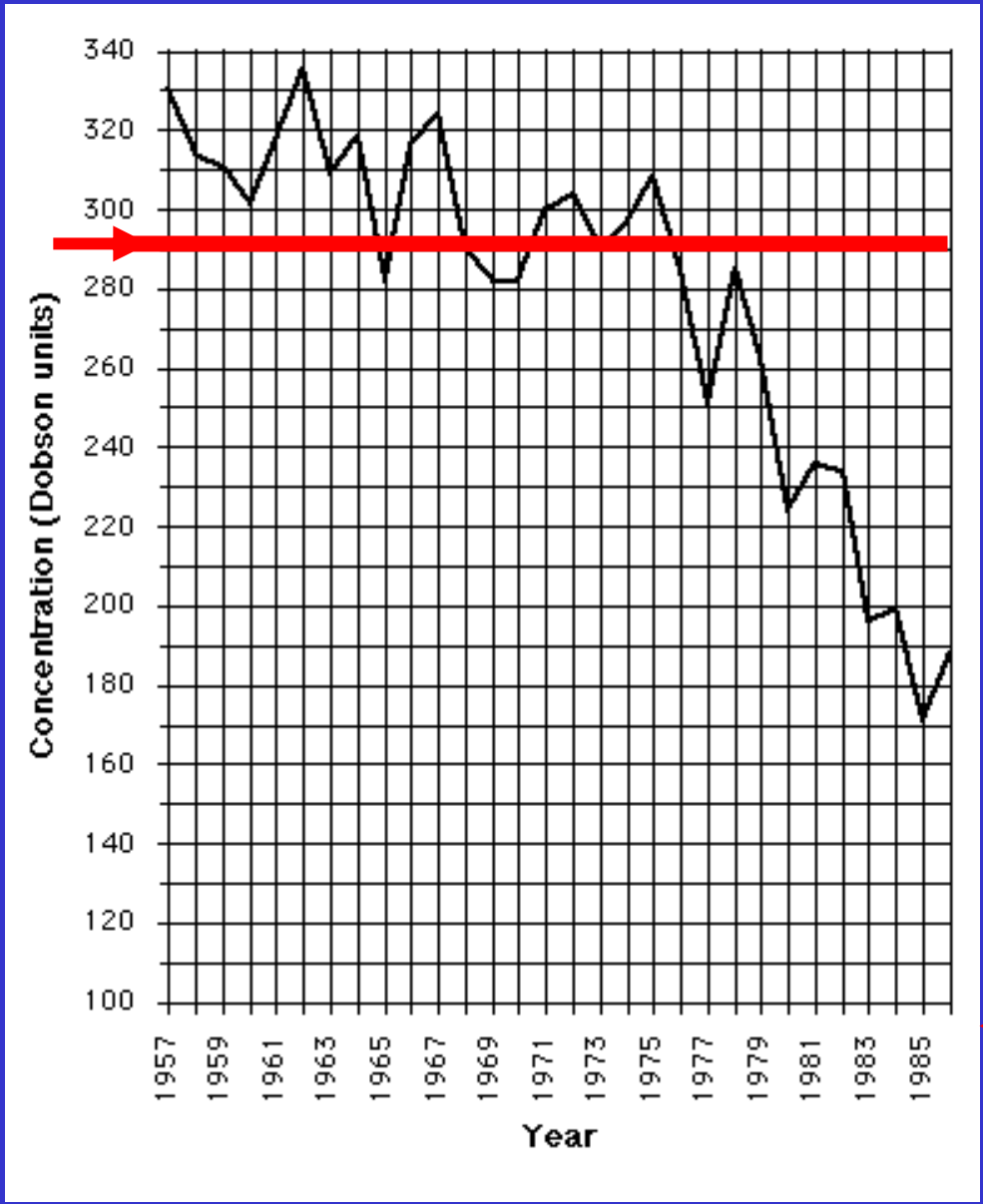
Bullet 5, p 127



Mapping the OZONE HOLE: Dobson Units

On this image, it is LARGER!

If the "ozone hole" is defined by the area that has concentrations lower than 290 Dobson units, is it larger or smaller than the Antarctic?



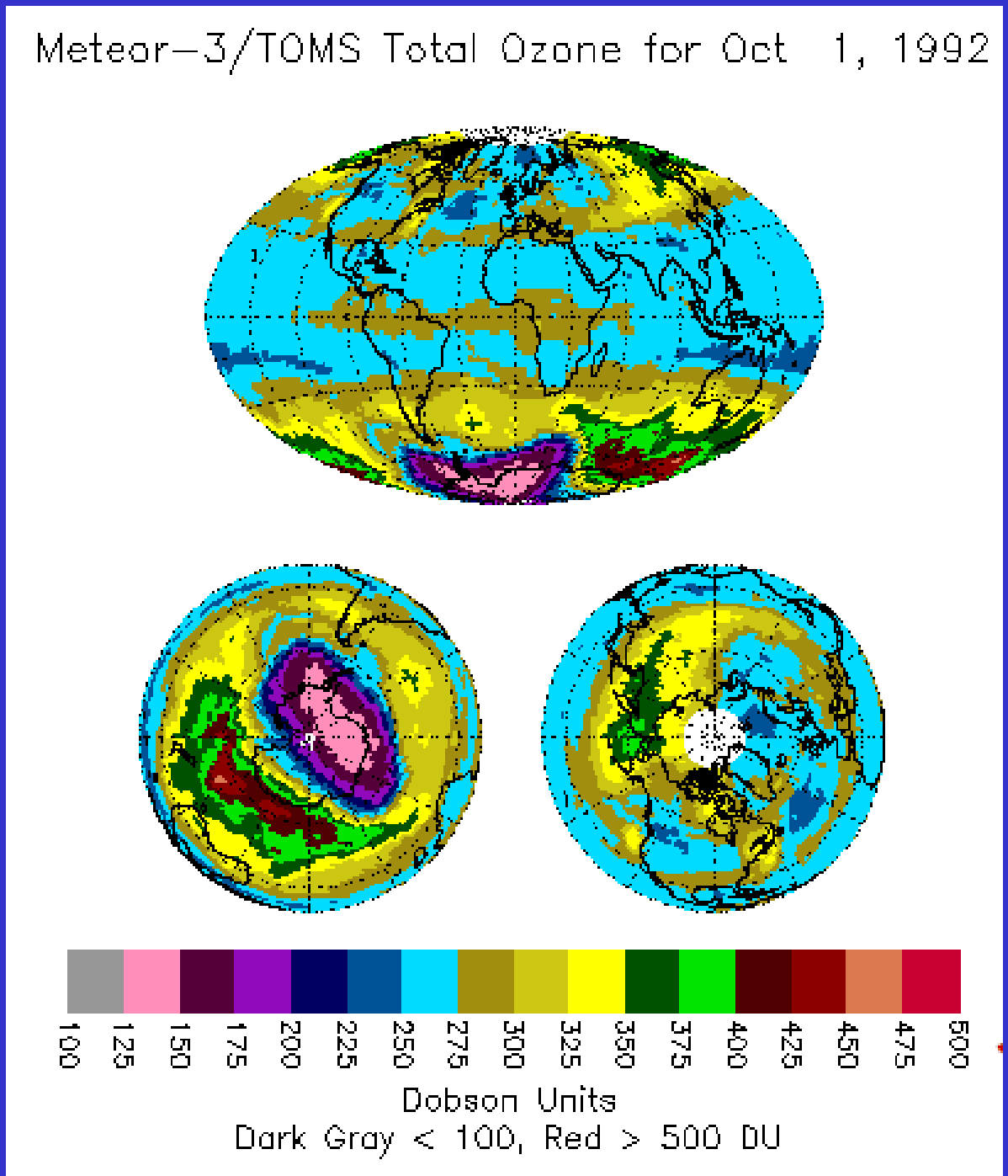
Declining OZONE CONCENTRATIONS (in Dobson units)

1957-1986

(over Antarctica)

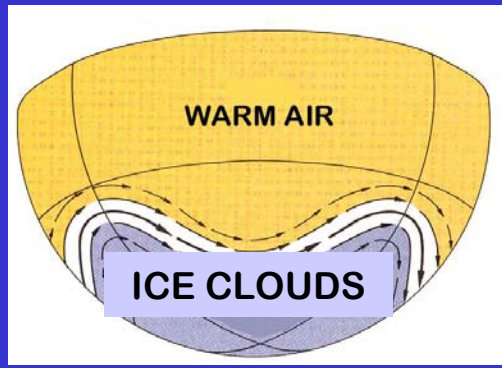
20 years later on Oct 8, 2006 . . . off the chart!

85 Dobson units!


Meteor-3/TOMS Total Ozone for Oct 1, 1992
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
Dobson Units
Dark Gray < 100, Red > 500 DU

The special conditions that make ozone depletion most severe over polar regions (esp. Antarctica) are:

(1) the unique **CIRCUMPOLAR CIRCULATION PATTERN** over Antarctica in winter which isolates the stratosphere inside the vortex and acts like a "containment vessel" in which chemical reactions may occur in near isolation;



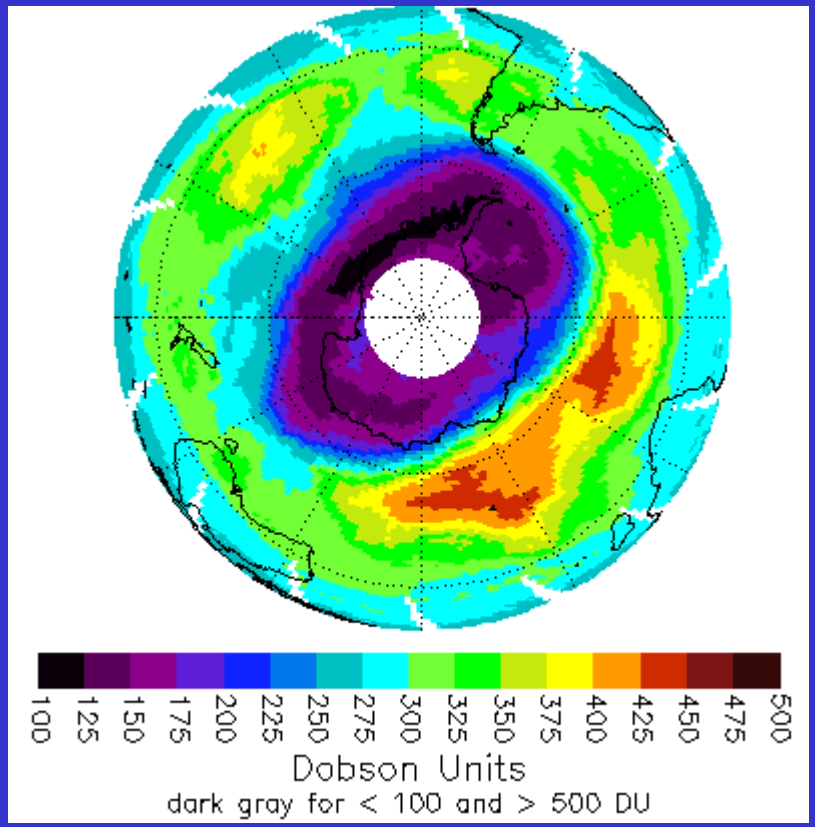
(2) The presence of **POLAR STRATOSPHERIC ICE CLOUDS** -- on the surfaces of these extremely cold cloud particles certain chemical reactions are more efficient and faster.

Bullet 7, p 127

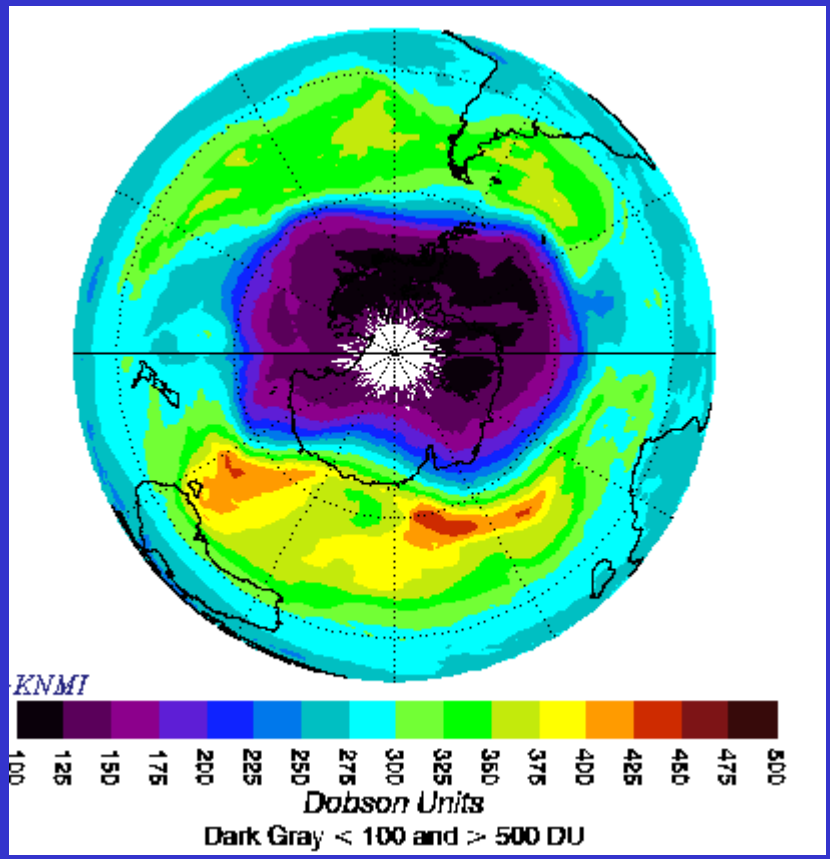
POLAR STRATOSPHERIC CLOUDS OVER ANTARCTICA

[Go to movie clip]

Sep 9, 2000



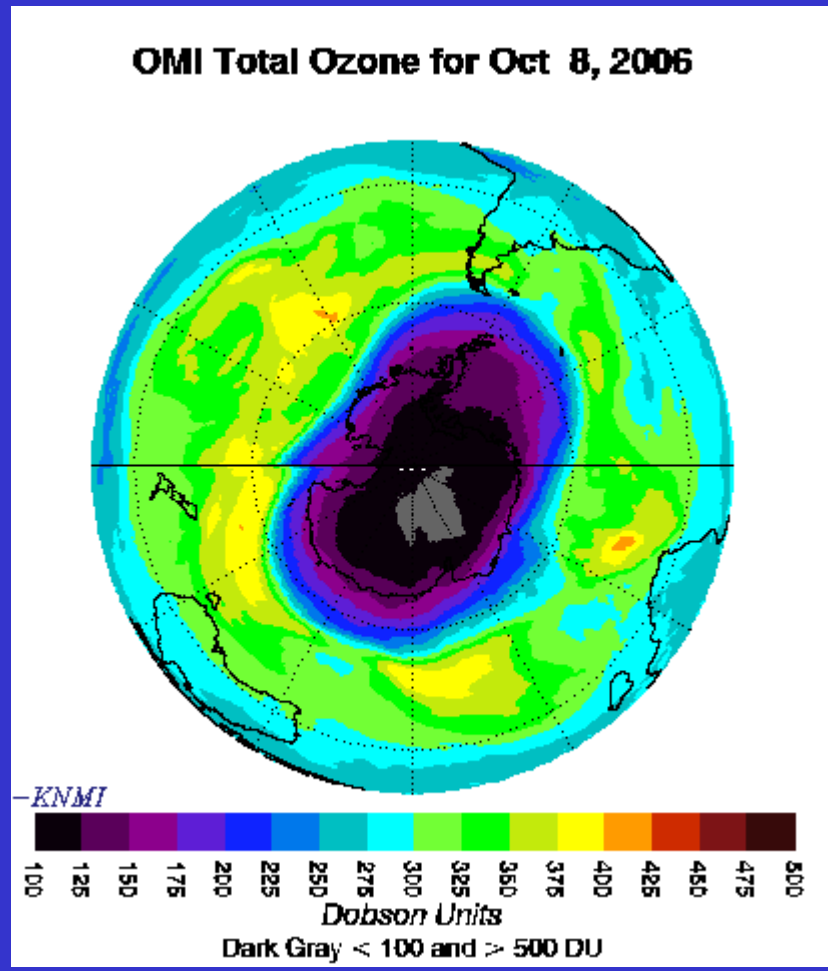
Sep 24, 2006



The area of 29 million square kilometers (11.4 million square miles) on September 24, 2006 tied the largest value (on September 9, 2000)

The value of 85 Dobson Units on October 8, 2006 was the second lowest ever recorded by satellite measurements.

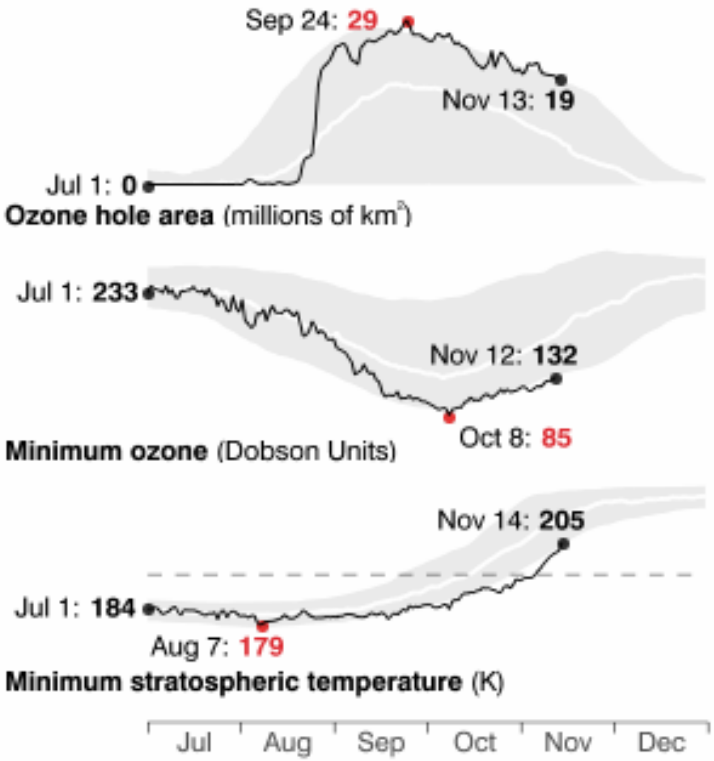
The year also saw the second largest sustained ozone hole. In September and October, temperatures in the middle stratosphere set many record lows.



Meteorology

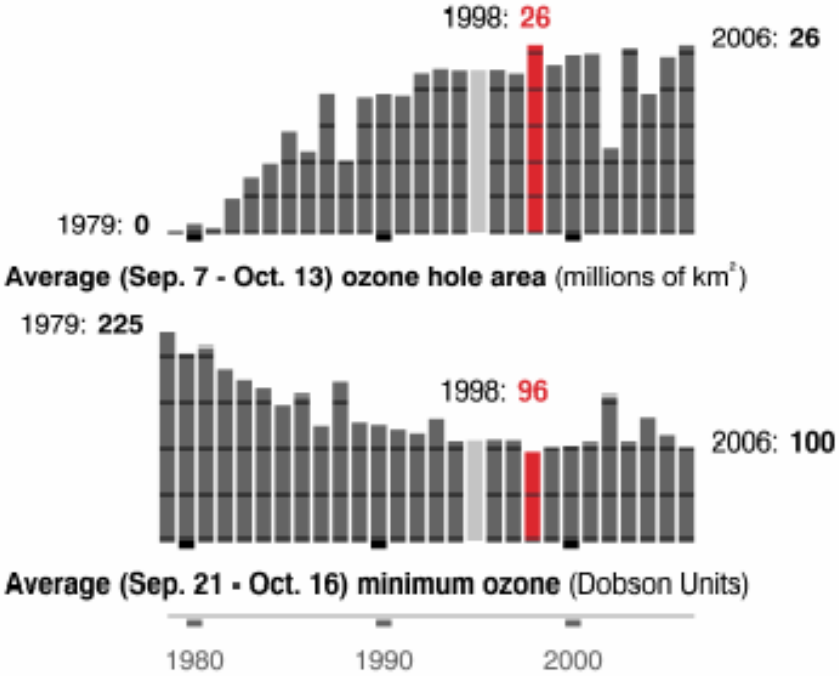
Year-to-date

The depth and size of the Antarctic ozone hole are governed by the temperature of the stratosphere and amount of sunlight reaching the south polar region. The graphs below show the progress of this year's ozone hole, compared to the highest and lowest values measured since 1979.



Annual record since 1979

The severity of the ozone hole varies somewhat from year to year. These fluctuations are superimposed on a trend extending over the last three decades. The graphs below show these variations. The red bars indicate the largest area and the lowest minimum value.



Note: No data were acquired during the 1995 season

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

HOLE IN OZONE LAYER EXPOSED A CITY

THE ASSOCIATED PRESS 10-6-00

WELLINGTON, New Zealand –

"The hole in the ozone layer over Antarctica stretched over a Chilean city when it ballooned to a record size last month, the first time it has reached a population center, scientists said yesterday. . . .

"Previously, the hole had only opened over Antarctica and the surrounding ocean.

"Citing data from NASA, atmospheric research scientist Stephen Wood said the hole covered 11.4 million square miles - an area more than three times the size of the United States - on Sept. 9 and 10.

"For those two days, the hole extended over Punta Arenas, a southern Chilean city of about 120,000 people, exposing residents to very high levels of ultraviolet radiation.

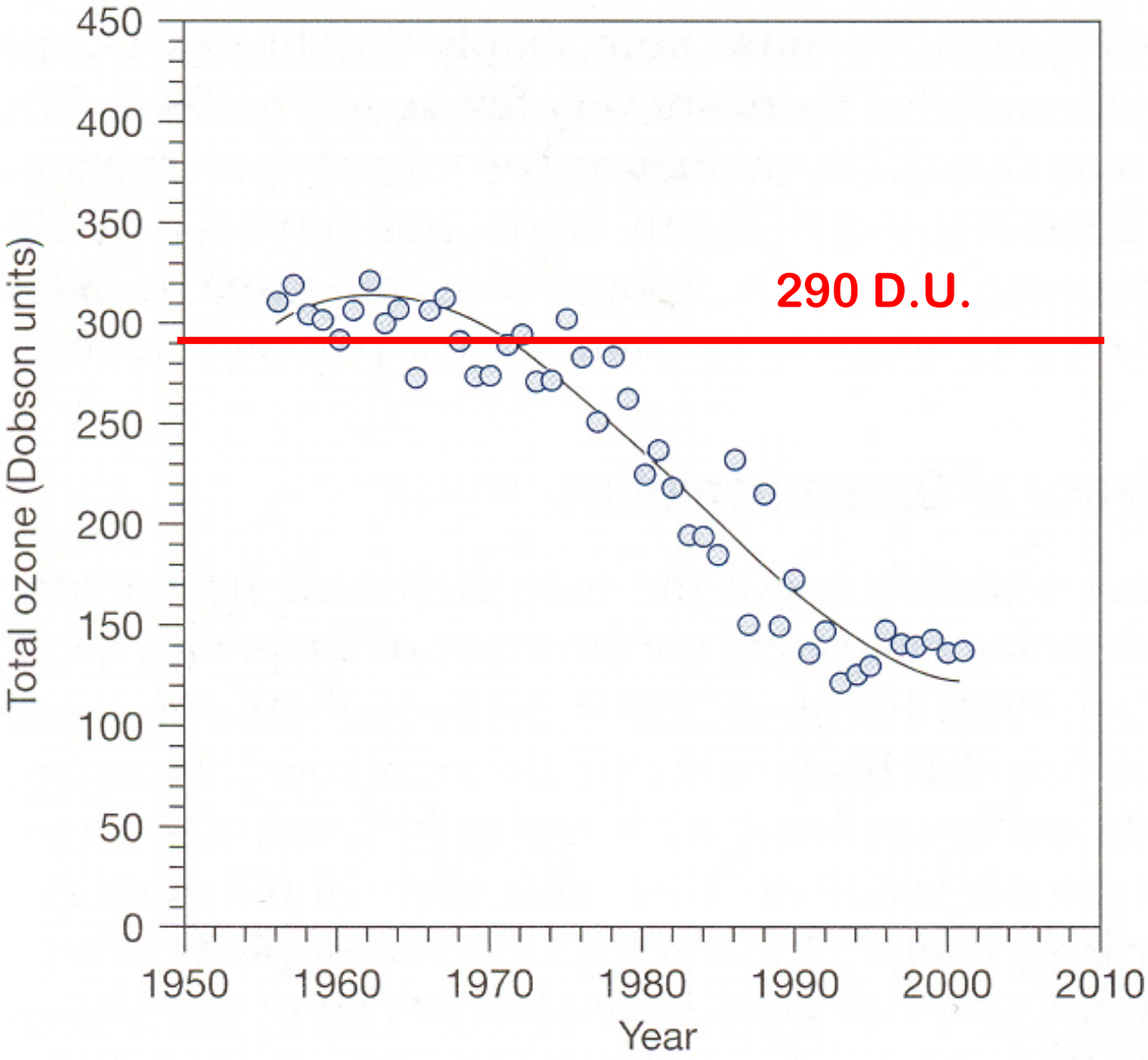
" . . . findings showed a city being exposed to the ozone hole for the first time."

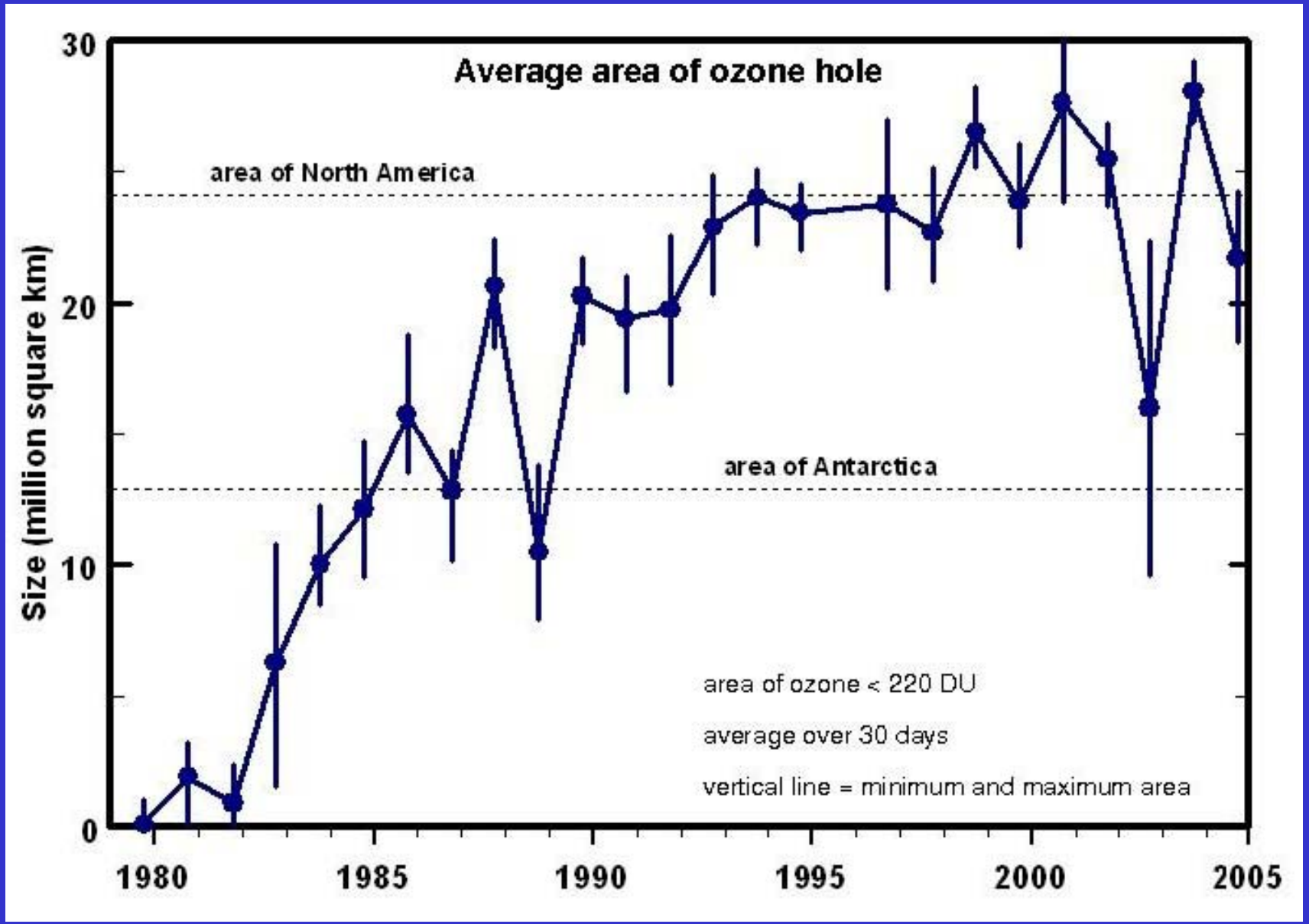
[In an Upside-Down World, Sunshine Is Shunned]
(New York Times 12-27-2002)

RATE OF OZONE DEPLETION

A variety of measurements (ground-based and satellite, e.g. TOMS) have shown that global levels of stratospheric ozone have fallen several percent between 1969 and the present.

Bullet 8, p 127


Total ozone (Dobson units)
450
400
350
300
250
200
150
100
50
0
290 D.U.
1950
1960
1970
1980
1990
2000
2010
Year



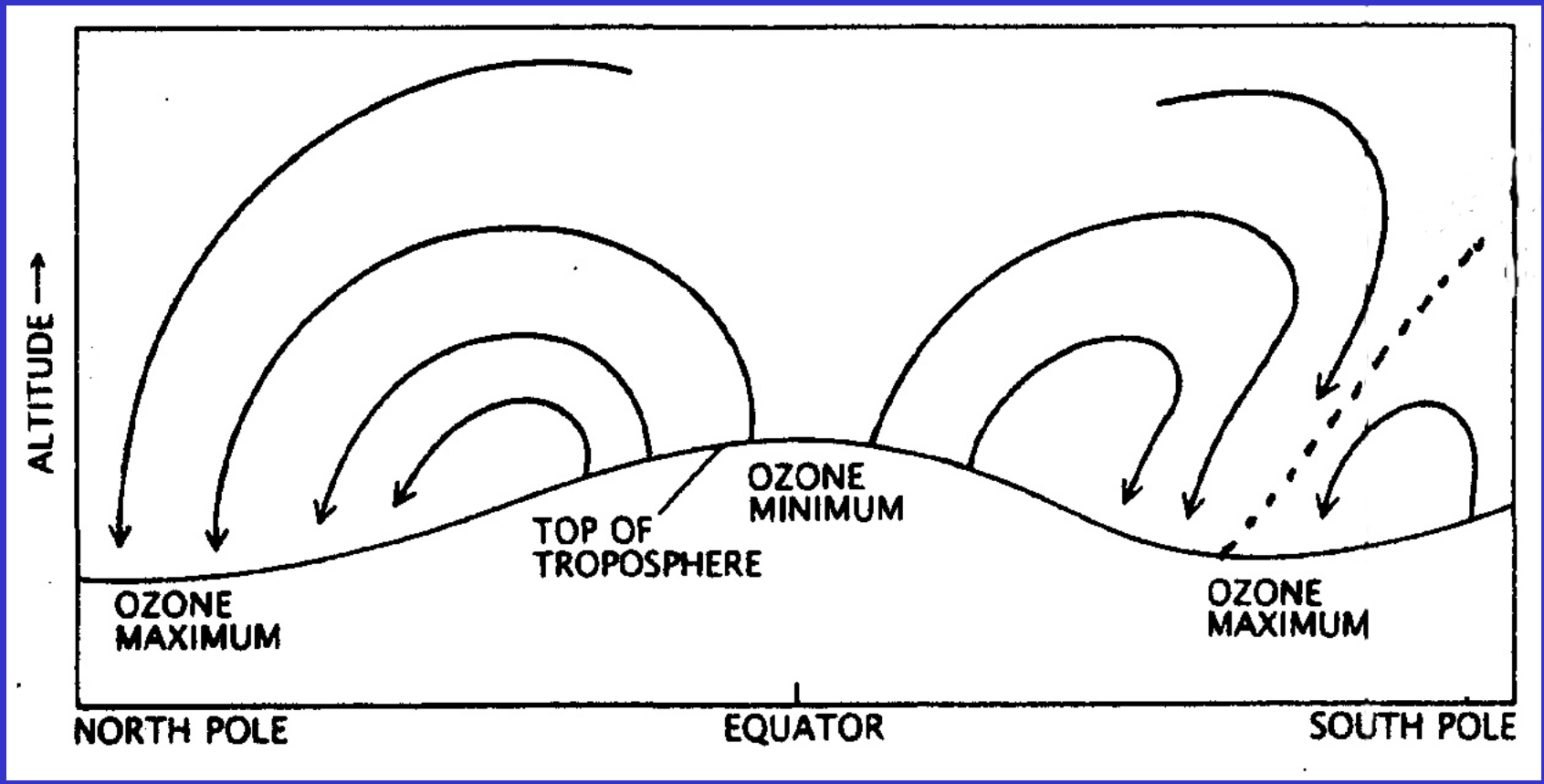
http://toms.gsfc.nasa.gov/

> Decreases in nearly all latitude zones have occurred (1.1 - 9% in S.H. and (1.1 - 3.7% in N.H.).

> Mid-latitude ozone has been decreasing by ~4% per decade in both hemispheres, whereas tropical ozone has remained more or less constant.

Bullet 9, p 127

Stratospheric Atmospheric Circulation Determines this Distribution

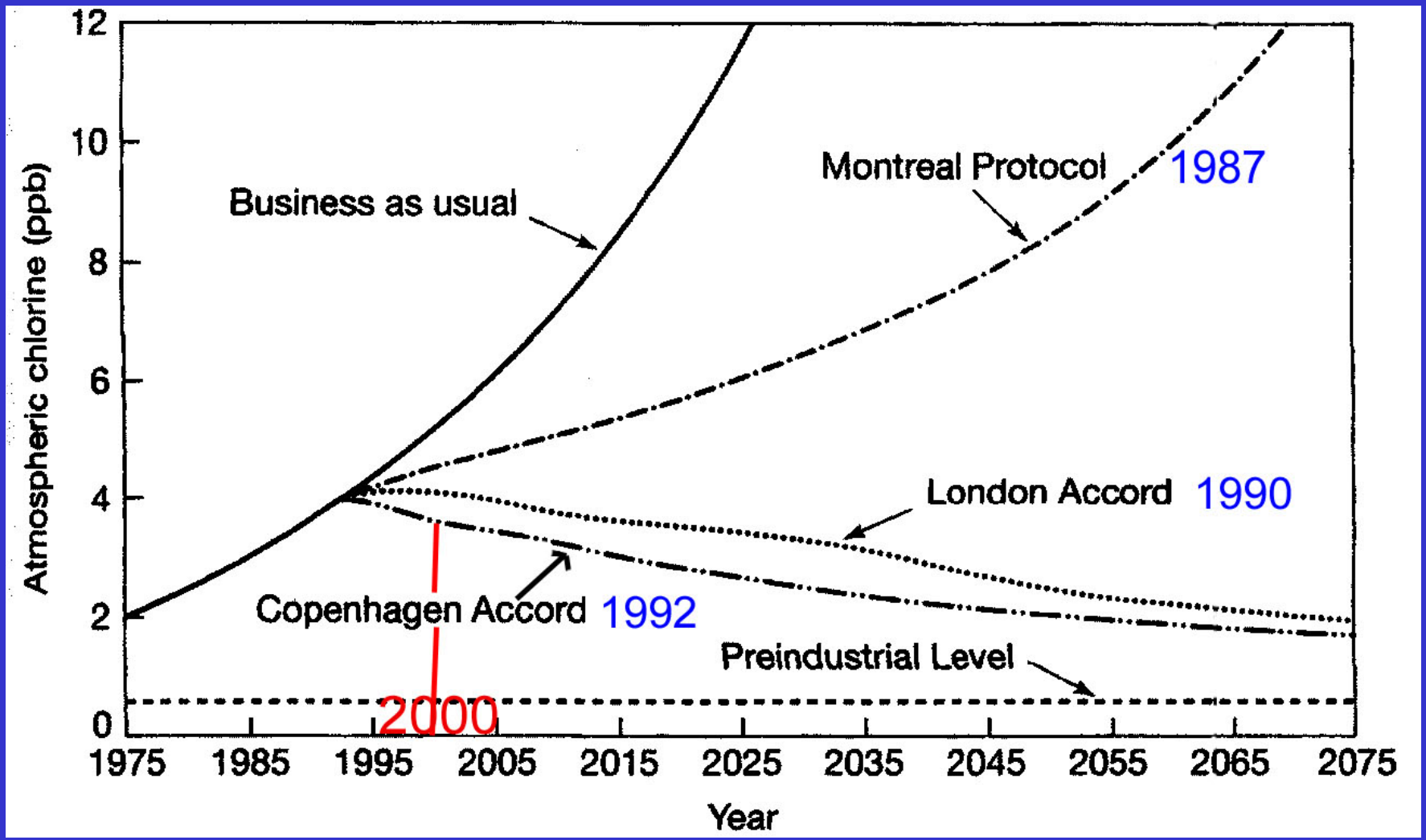


Ozone production highest in tropics but stratospheric circulation moves distributes it poleward

> Ozone is *increasing* in the troposphere due to car exhaust, etc ("bad ozone"), but only at the rate of about 1% per year,

> hence stratospheric levels of "good ozone" are going down at a rate faster than ozone is being added in the troposphere.

Bullet 9, p 127



Very long residence time of CFCs!

(IGC 17-14)

At Meetings, U.S. to Seek Support for Broad Ozone Exemptions

(New York Times 11-10-03)

Theories to explain the hole have included:

1) solar variability (sunspot cycle),
2) dynamical air motion, and
3) chemical mechanisms

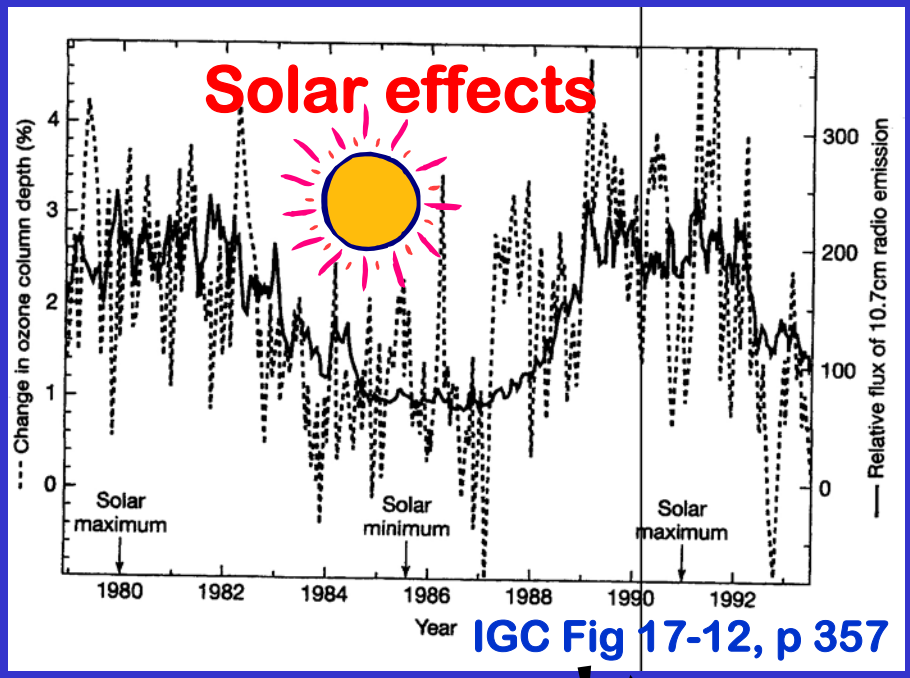
Also, natural causes due to volcanic eruptions, solar, etc. & anthropogenic causes due to CFCs)

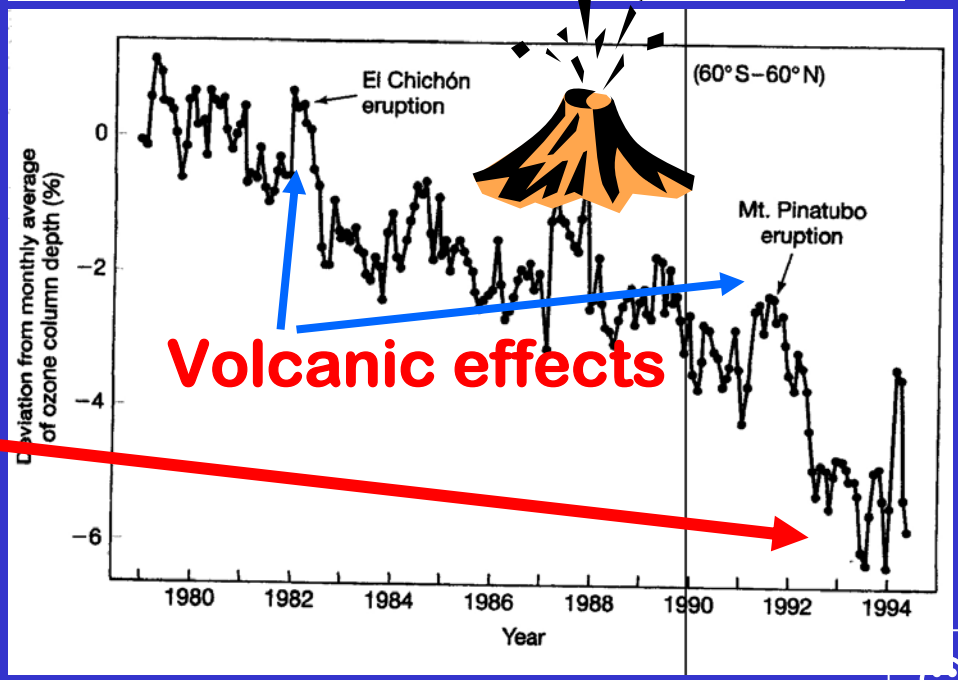
Bullet 6, p 127

OZONE trends can shed light on causes:

Stratospheric ozone varies by latitude and season -- is affected by solar radiation, volcanic eruptions & chemical reactions due to CFCs.

Overall, O3 is decreasing in the STRATOSPHERE





The chemical reaction theory – catalyzed by chlorine from CFCs -- is almost universally accepted as conclusive at present.

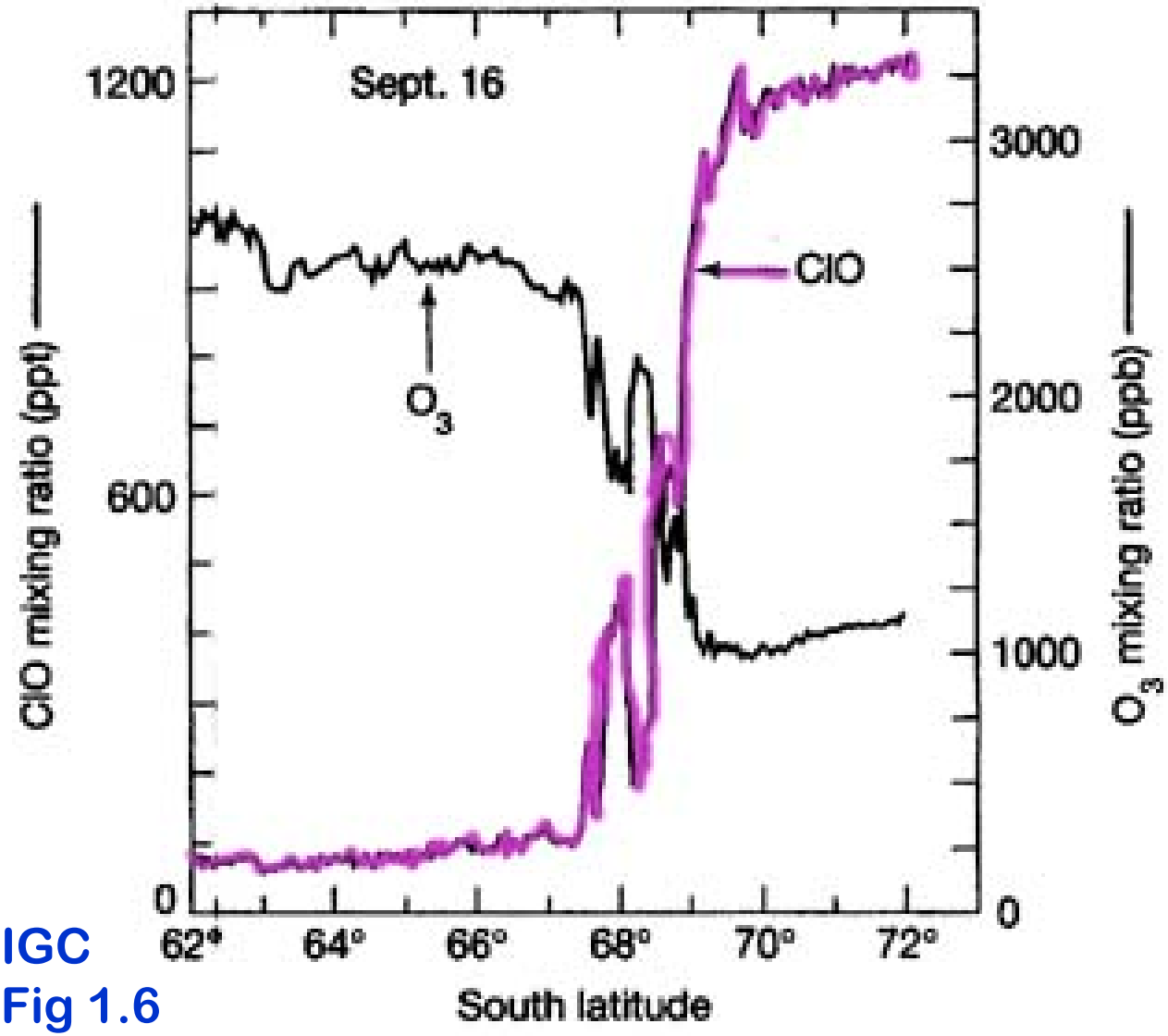
The prominent scientists involved in developing the chemical reaction theory were awarded the Nobel Prize for Physics in 1995.

Bullet 6, p 127

“Popular” dissenting hypotheses from skeptics to explain chlorine-related ozone depletion as natural, not anthropogenic:

sea salt
volcanic eruptions
biomass burning

- because Cl is soluble in water, nearly all Cl from natural sources gets rained out of lower atmosphere;
- eruption effect in stratosphere is short lived
- only INERT & INSOLUBLE CFCs have the staying power in the stratosphere to influence the huge amounts of observed ozone depletion

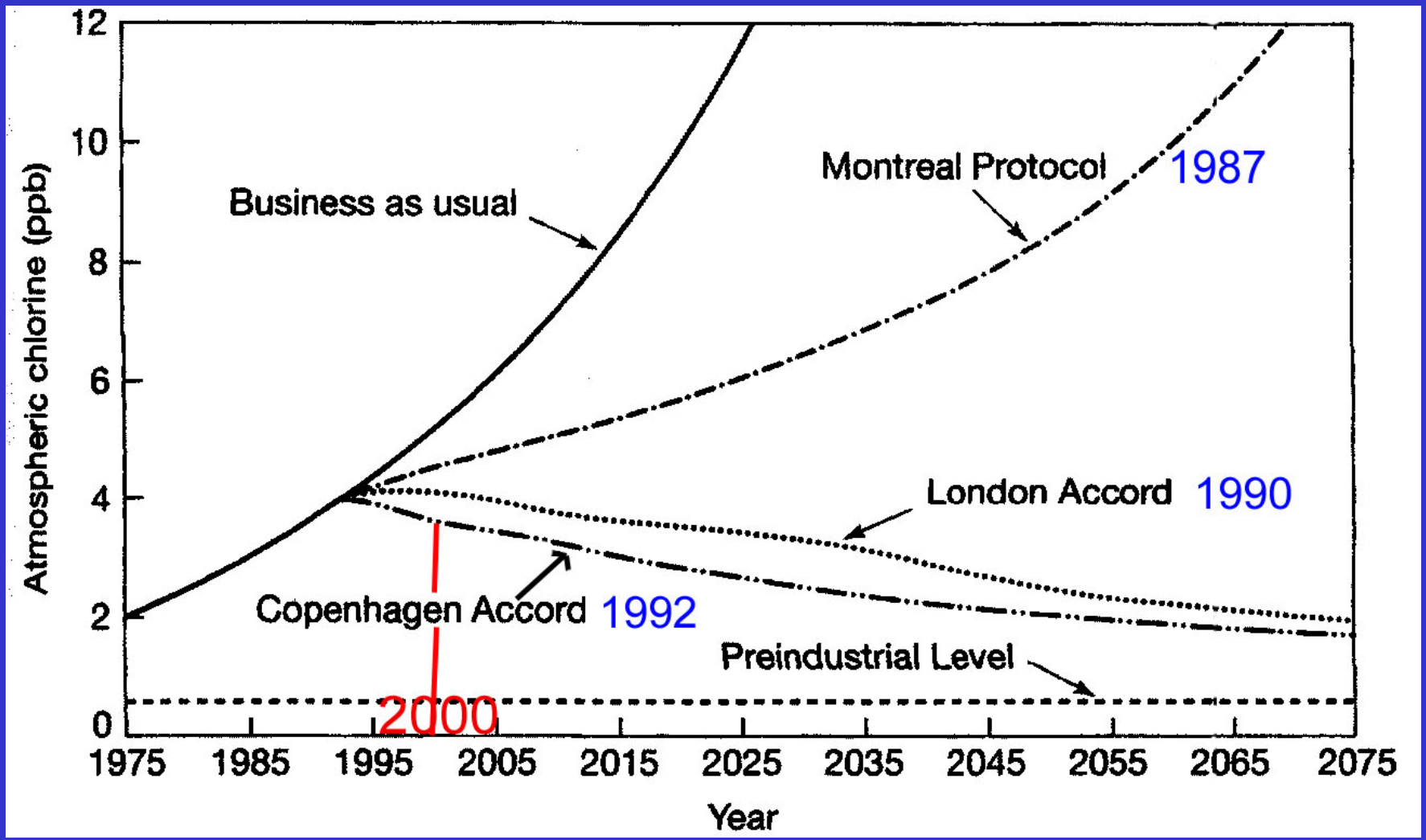


IGC
Fig 1.6

ClO (chlorine monoxide) from the chlorine catalytic cycle = **THE evidence of chemical reactions** occurring in hole region during time of greatest O_3 depletion (in September, spring in Southern Hemisphere)

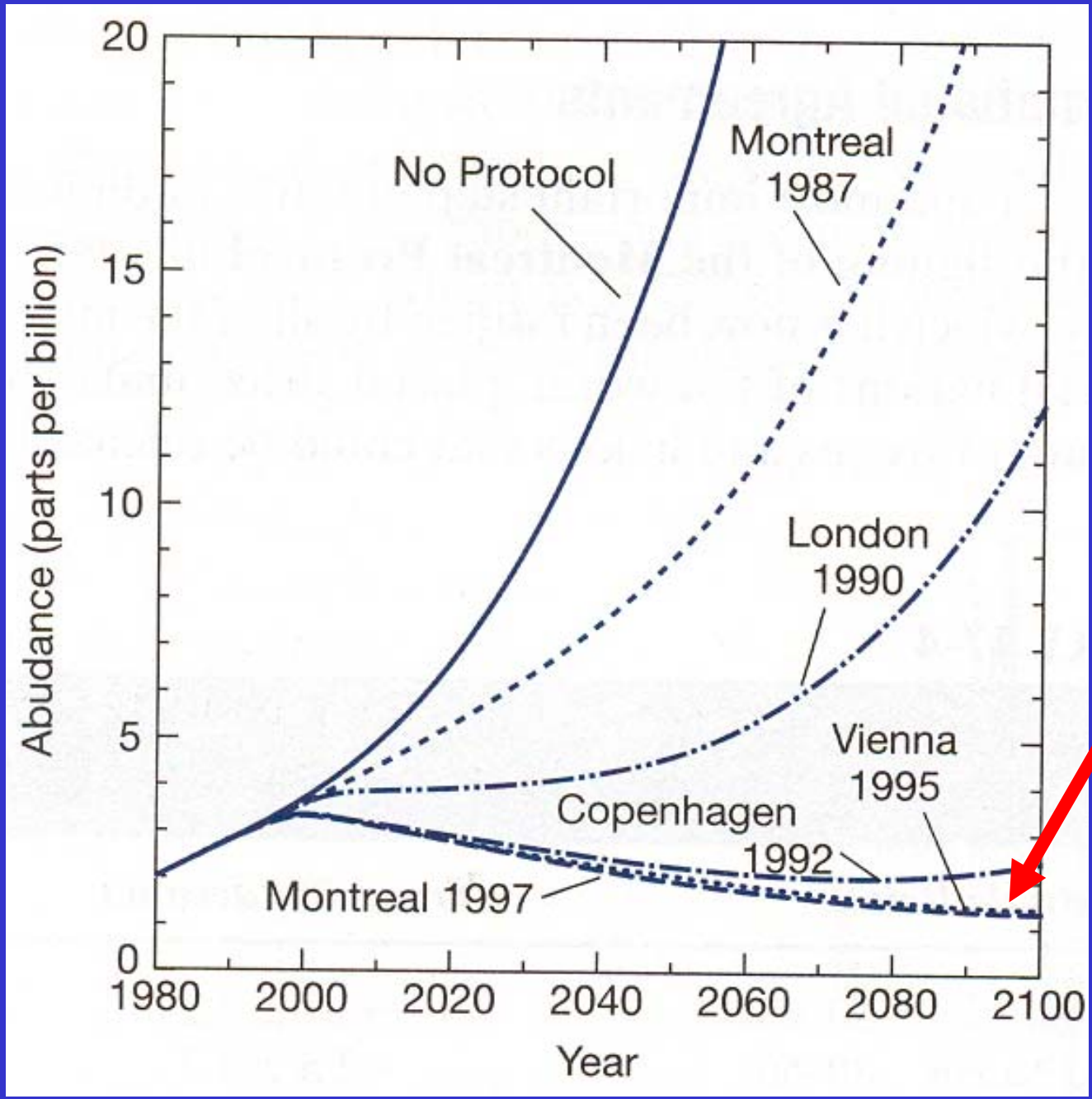
ANTARCTIC LAND MASS

To the South Pole



Very long residence time of CFCs!

(like IGC Fig 17-14)



Model results based on more recent agreements:

Vienna 1995 & Montreal *(again)* 1997

The world is "making do" with freon substitutes, but some concern over long-term effects of substitutes remains . . .

Yolo and the hole in the sky

Methyl bromide is a pesticide used on tomatoes, once used often in the county. Now, the rest of the world is making sure the U.S. lets the chemical go.

By The Associated Press and Daily Democrat staff

Nations working to save the earth's protective ozone layer agreed Friday to let the United States use thousands of tons of the pest-killing chemical methyl bromide. They modestly pared the Bush administration's requested allotment of the powerful fumigant, which is banned for all but the most critical uses.

"Under the Montreal Protocol, (methyl bromide) was to be fazed out in stages," said Thomas Gordon, a professor of plant pathology and department chair at UC Davis. "It was scheduled to be fazedout completely, but there have been exemptions granted."
The United States since has received annual exemptions allowing methyl bromide's continued use on specific crops in California, Florida and other heavily agricultural states. Other nations have received far smaller exemptions.

U.S. gets more methyl bromide approval

Officials secure additional exceptions for banned pesticide

By RITA BEAMISH Associated Press Writer Nov 10, 2006

http://www.capitalpress.info/main.asp?SectionID=67&SubSectionID=616&ArticleID=28527&TM=168.238

SAN MATEO (AP) - The Bush administration won international approval for U.S. farmers to use thousands of tons of a potent pesticide without having to dip substantially into large stockpiles that were recently revealed.

The pesticide, methyl bromide, was banned under an international treaty nearly two years ago except for uses deemed critical because it is believed to harm the earth's ozone layer. U.S. officials have secured exemptions to the ban so that growers can use it to kill soil pests for tomatoes, strawberries and other crops in agricultural states like California and Florida.

Jay Vroom, president of the pesticide association CropLife America, said the action in New Delhi reflected appropriate compromise and underscores the need for methyl bromide in America's diverse agriculture.

The decision brought strong criticism from environmental advocates attending the session.

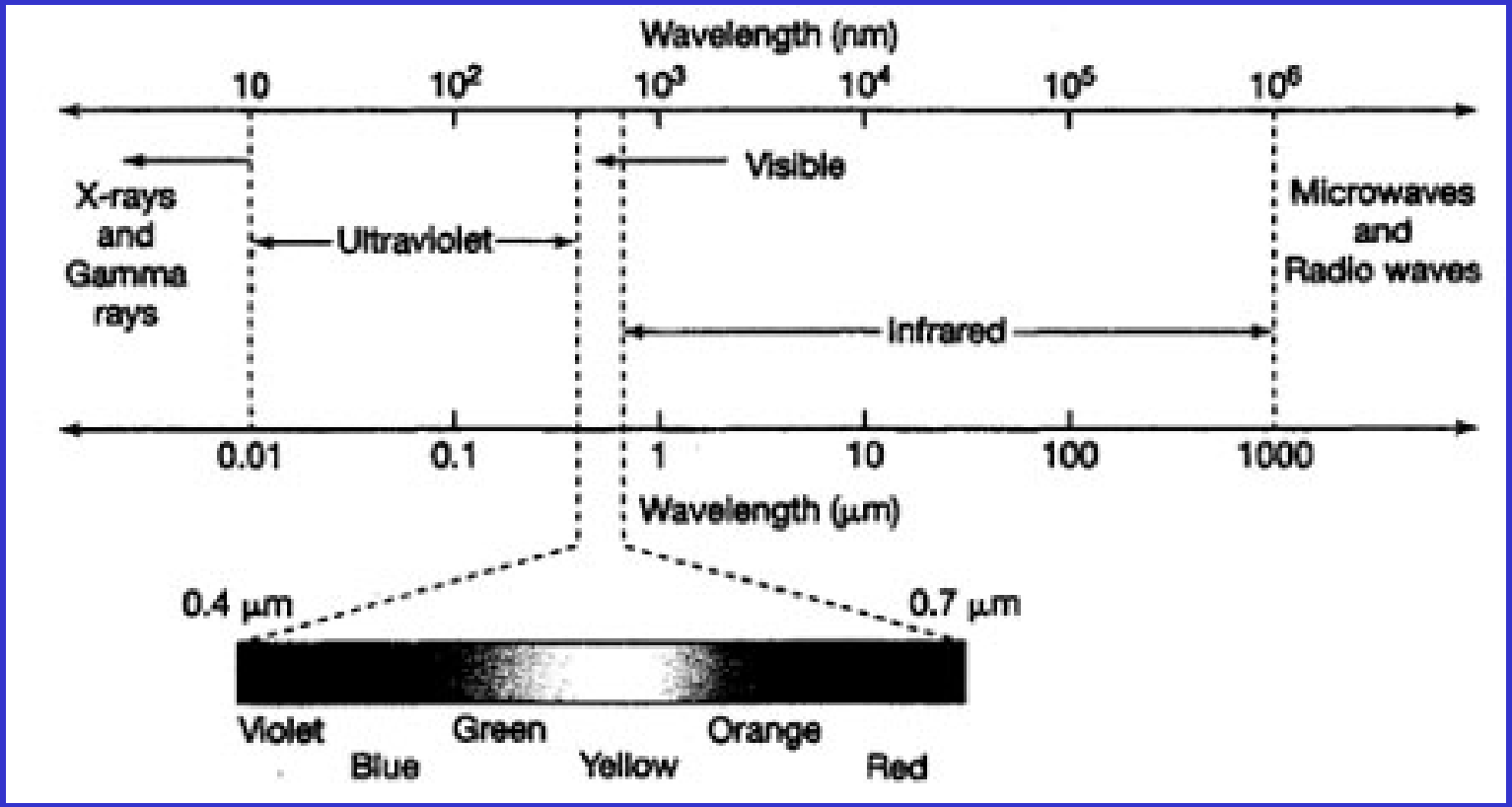
"It's extremely disappointing that now that the U.S. has finally confirmed its enormous stockpile, it continues to fight tooth and nail to get special treatment in the world to use a gas that will cause increased skin cancer and a host of other environmental effects," said Sascha Von Bismarck of the Environmental Investigation Agency. The ozone layer protects life on earth from harmful ultraviolet radiation. Scientists reported recently that the hole in the ozone layer over Antarctica is the largest on record.

The Bush administration contends that the stockpiles existed before the 2005 ban and thus are not subject to a treaty rule allowing new production only if existing, available stockpiles cannot cover the need.

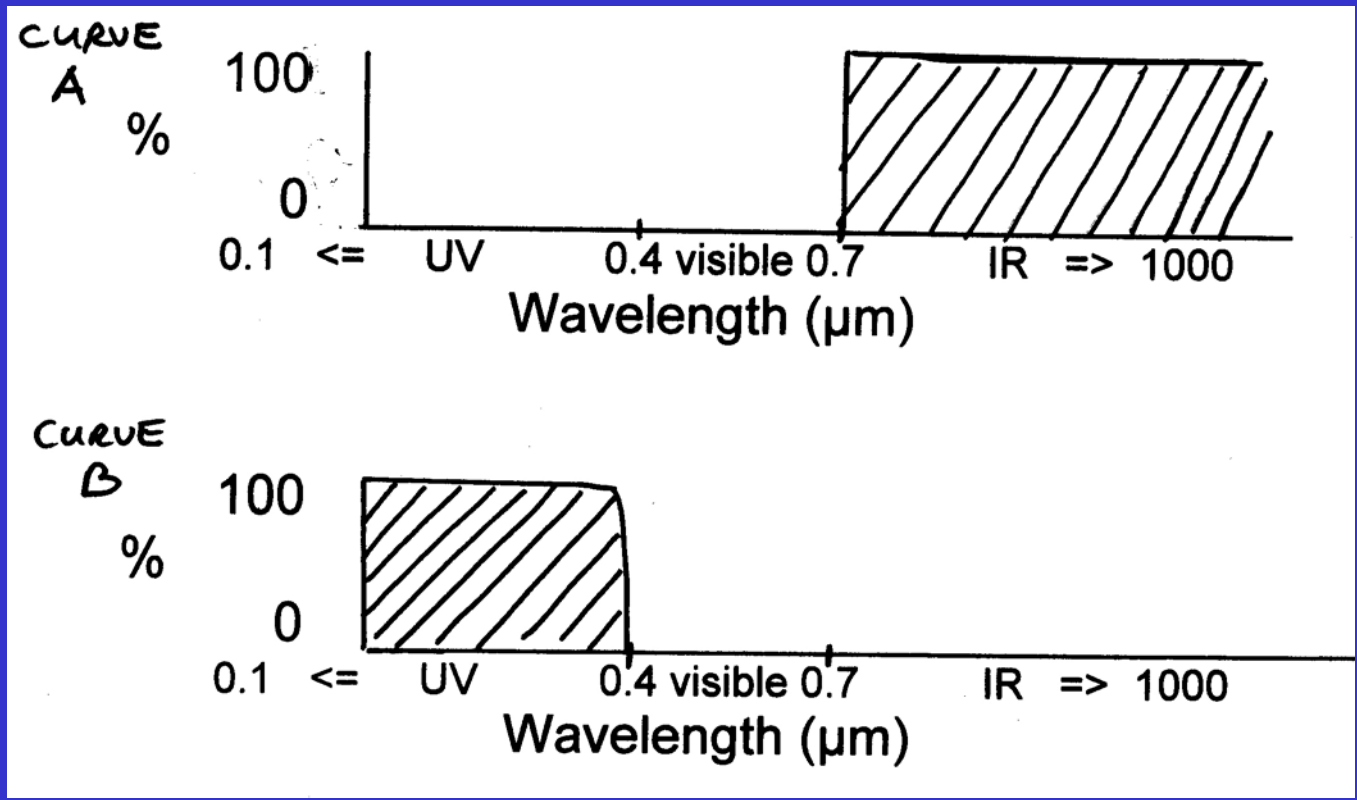
THE OZONE DEPLETION STORY TIES TOGETHER MANY OF THE CONCEPTS YOU'VE LEARNED IN THE COURSE THUS FAR:

- the nature of matter, e.g., chemical reactions and photon interaction with atoms

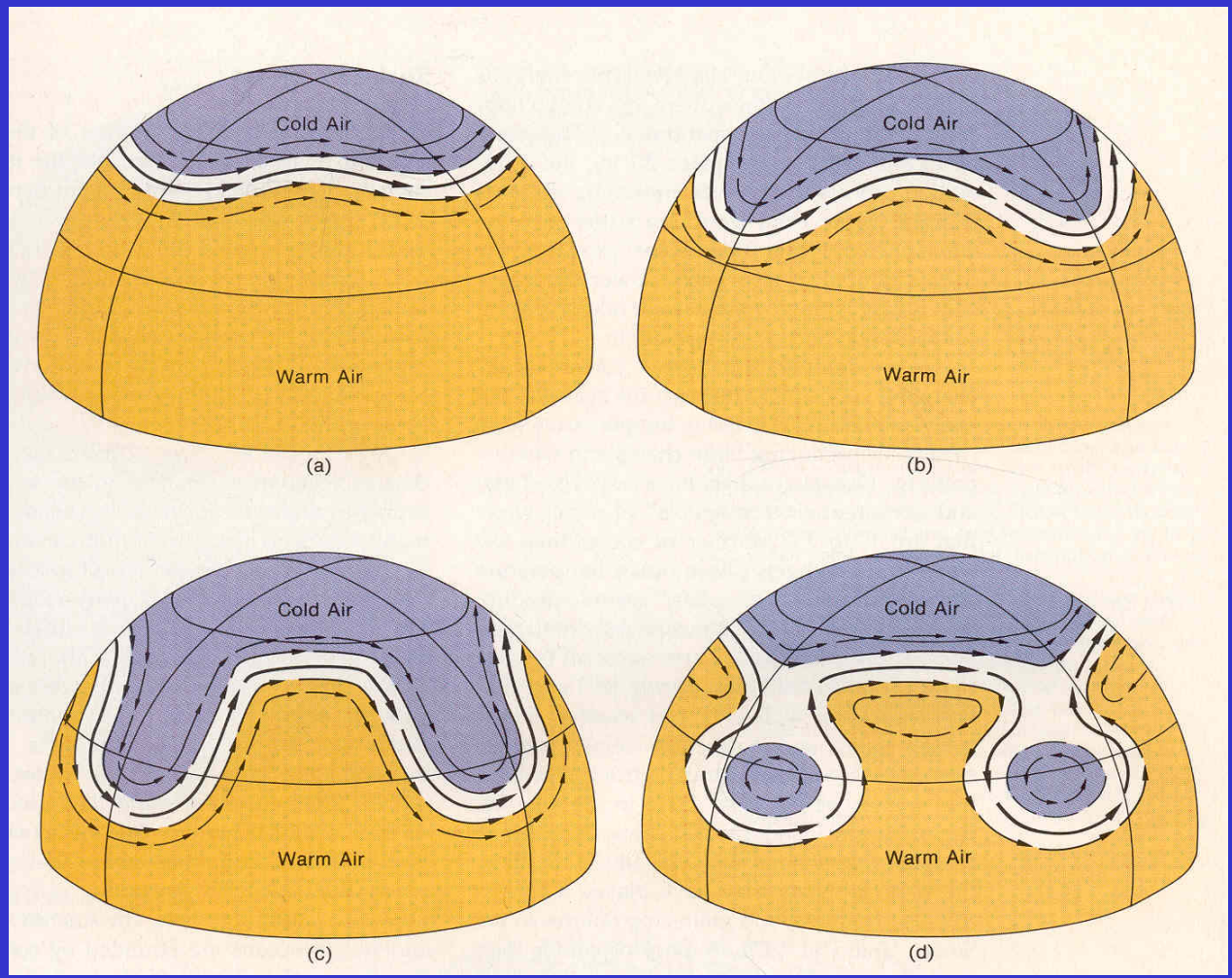
> the electromagnetic spectrum --especially the wavelengths of UV radiation



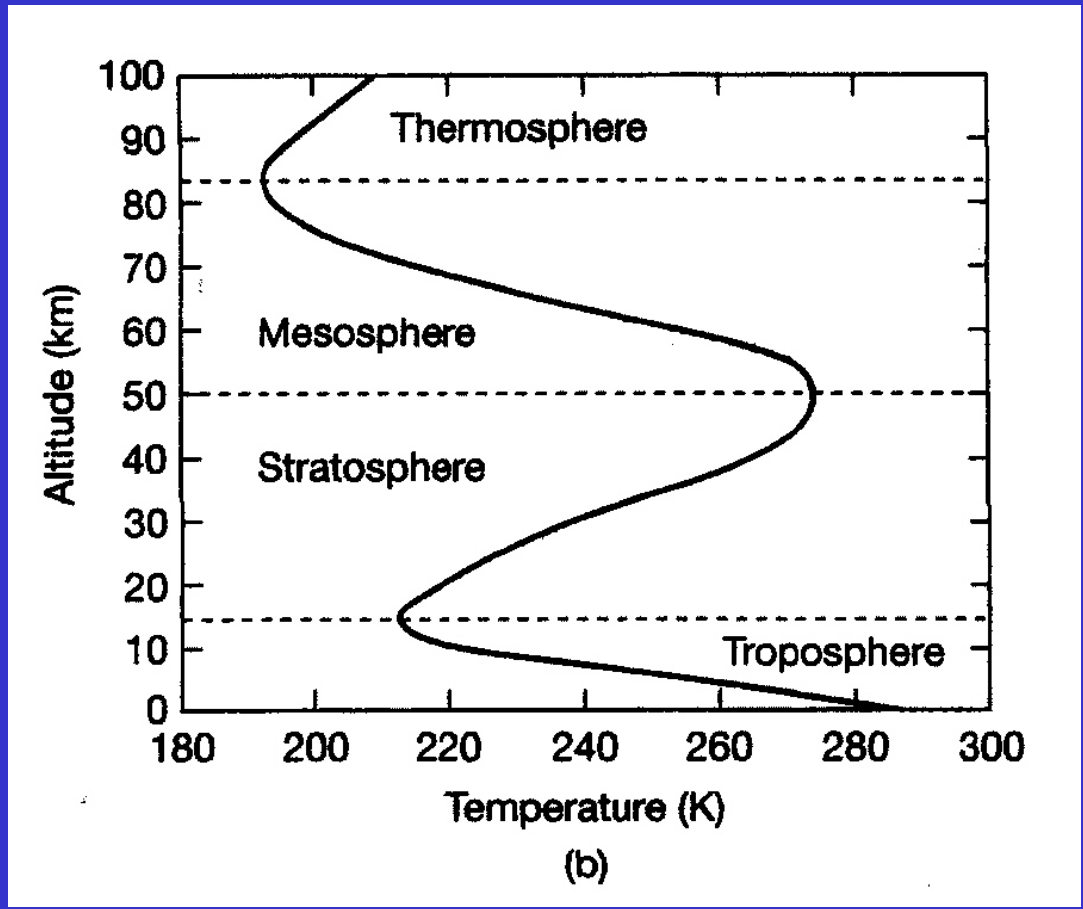
> absorption curves, especially the absorption curve for ozone

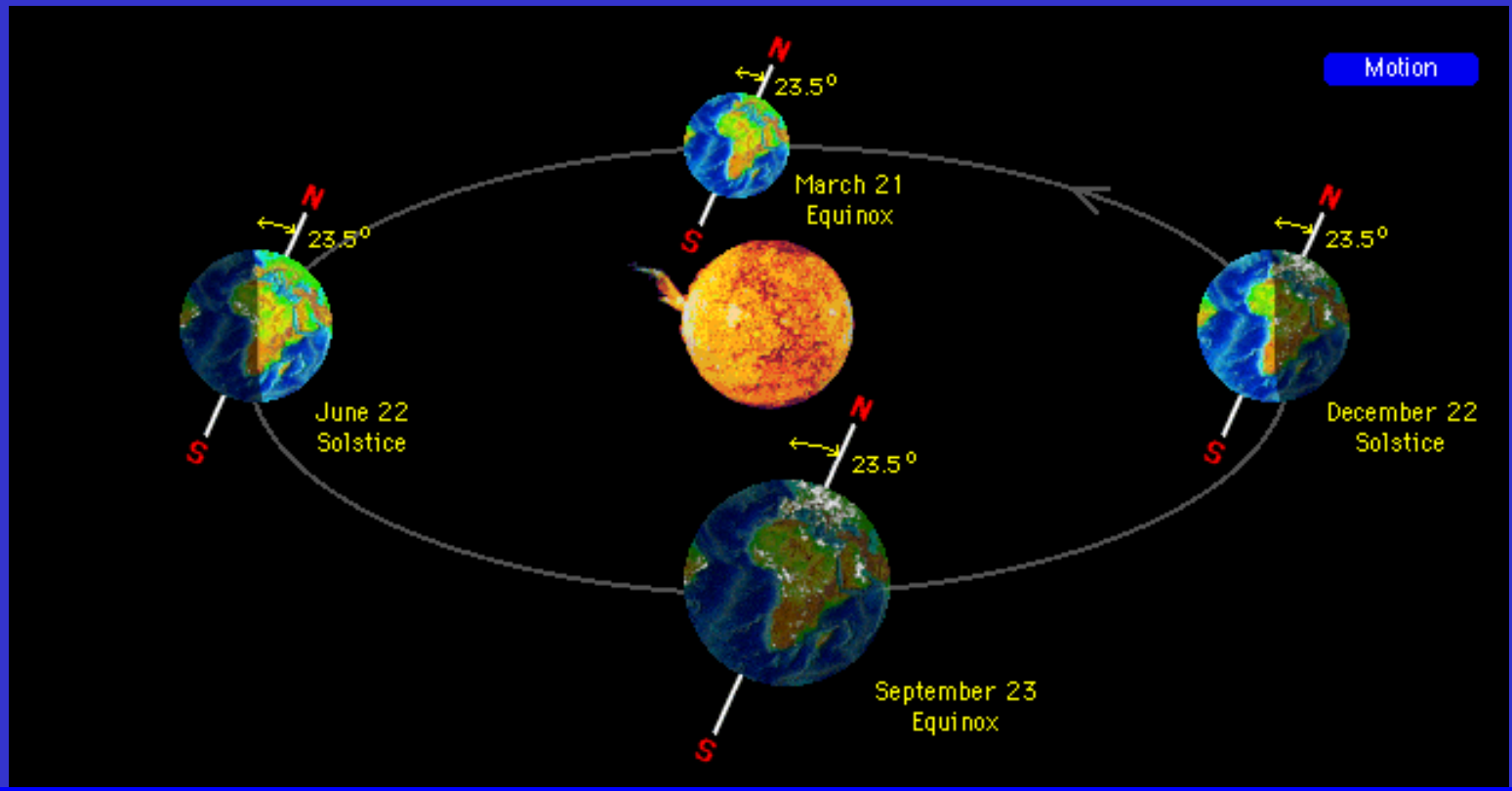


> Atmospheric circulation (in this case stratospheric circulation & the South Pole circumpolar vortex)



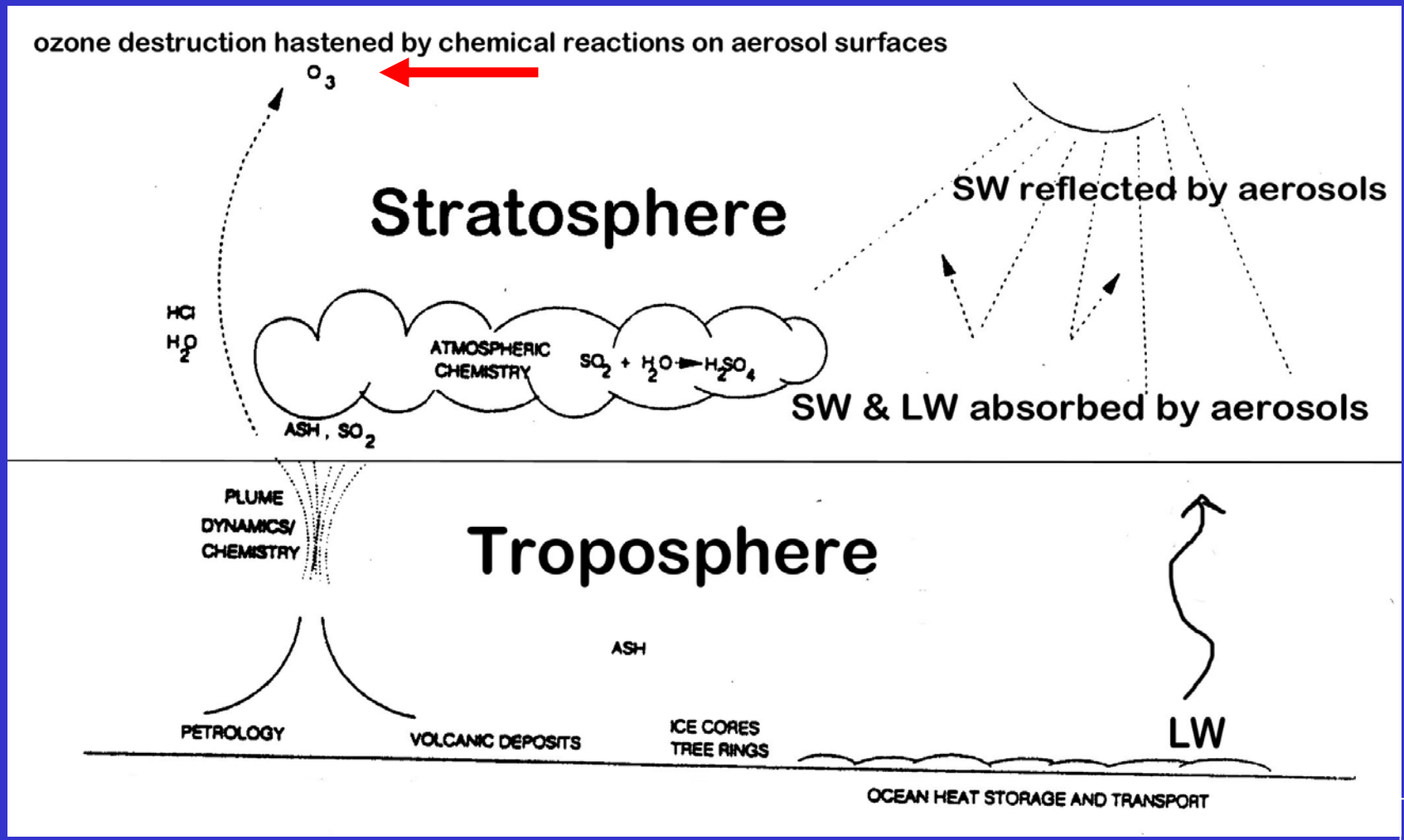
> the vertical structure of the atmosphere (troposphere, stratosphere)





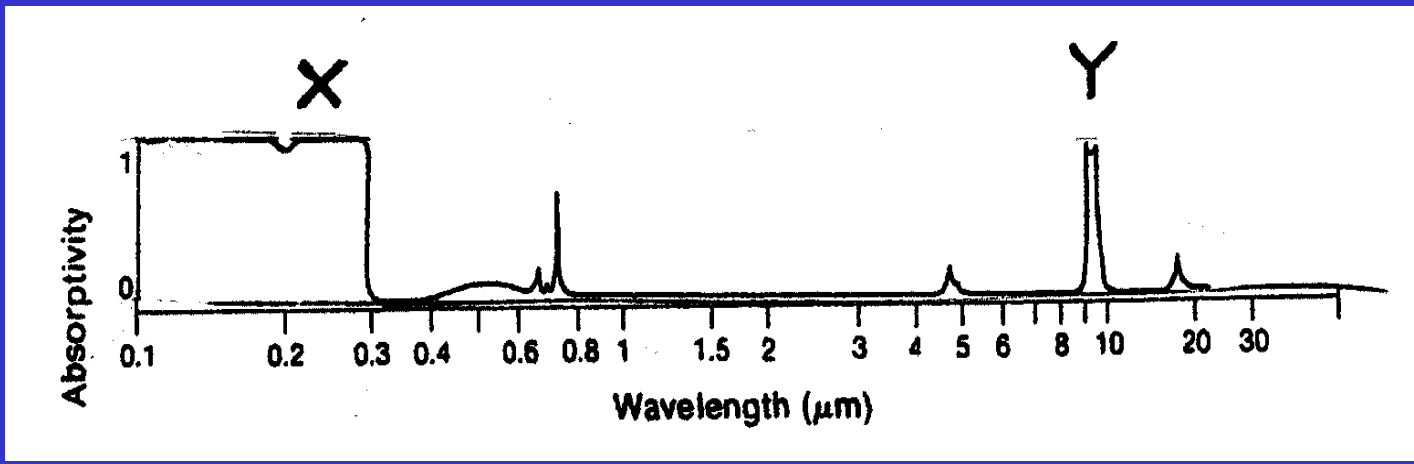
> Earth-sun relationships, the seasons, solar angle, etc.

> Volcanic eruptions (HCl from eruptions can be source of stratospheric chlorine; but most tends to rain out)



> Effect of clouds -- in this case the importance of Polar Stratospheric Clouds (PSCs)

> Greenhouse gases (ozone is also a greenhouse gas but this affects IR radiation, not UV radiation)

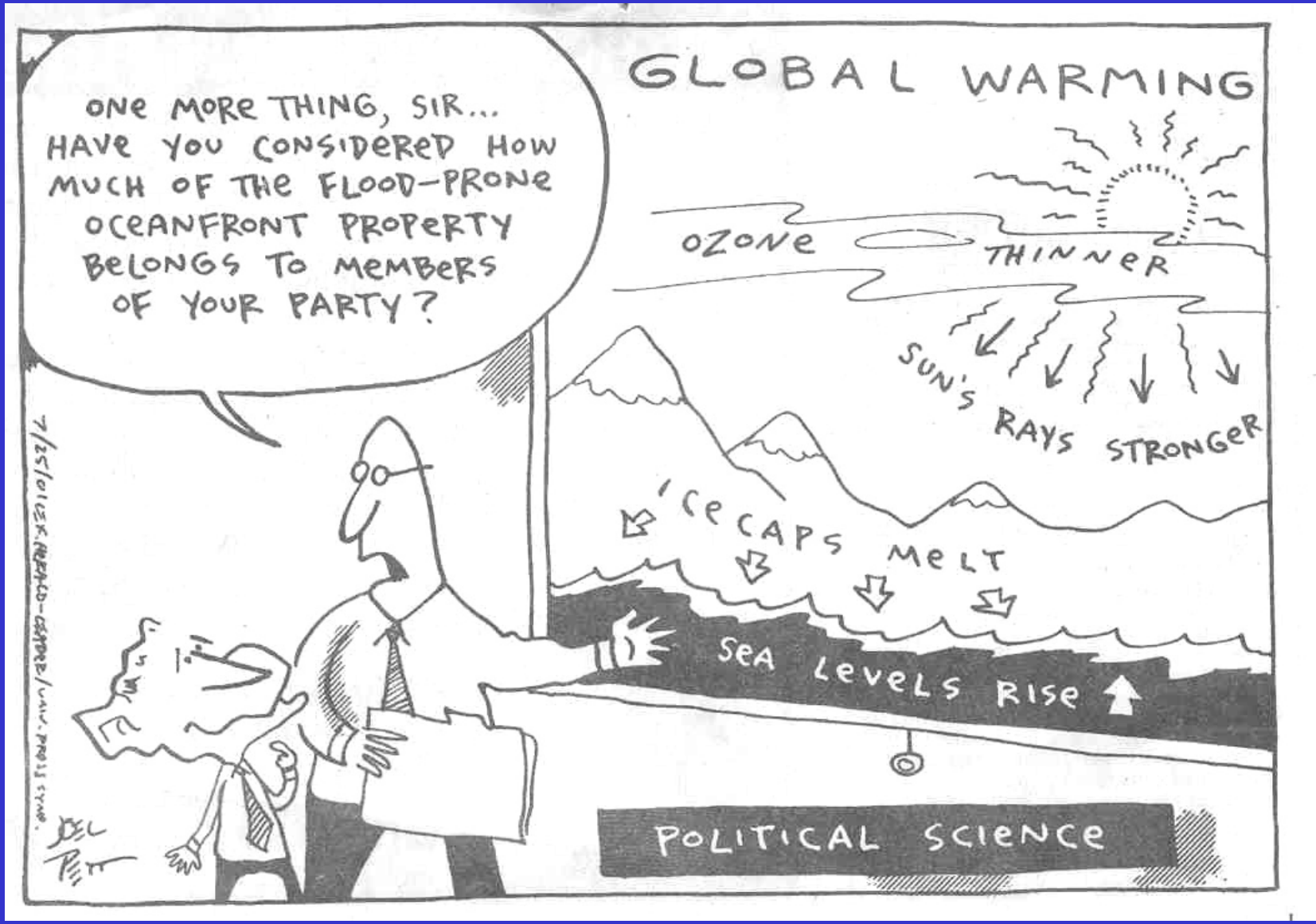


> the ever-changing nature of science; early theory right for wrong reason

> Preconceived ideas influencing one's observations

. . . and the surprise of discovery!

Finally, we leave you with two inhabitants with strong cause for concern about the Antarctic ozone hole...



What – if anything -- is scientifically inaccurate in this cartoon?