

**Thursday Nov 13th SIT WITH YOUR GROUP TODAY**

**Topic # 12 Anthropogenic Forcing:  
STRATOSPHERIC OZONE DEPLETION**

**ANNOUNCEMENTS**

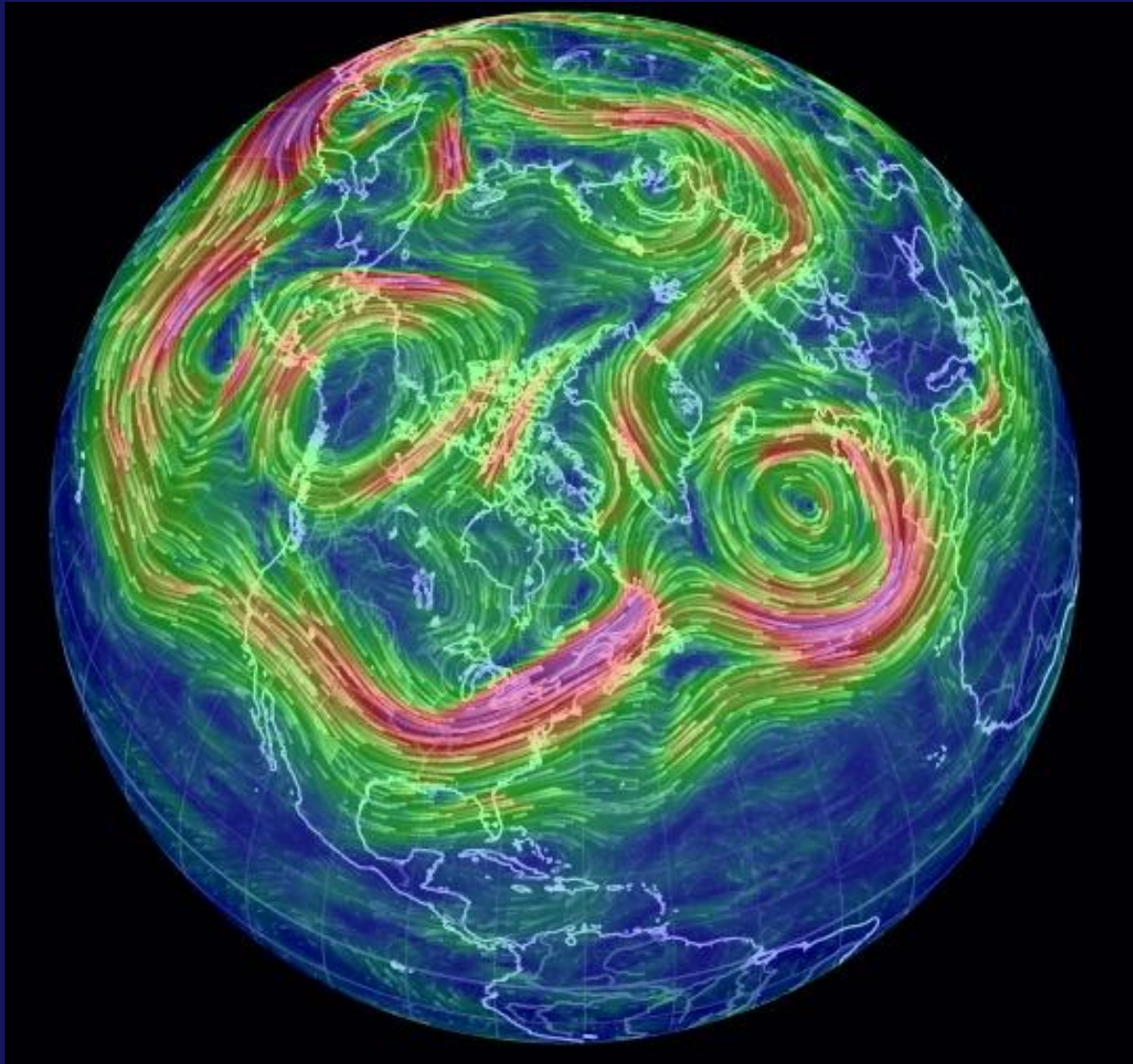
- **I-3 “Lesson 3 on “Observable Changes”  
is due TONIGHT !**
- **RQ-7 on Stratospheric Ozone Depletion  
was due Veteran’s Day ! Missed it? FAQ #22**
- **The G-4 Tree-Ring Wood Kit Assignment ended yesterday**
- **Midterm Recovery Points have been added to your score  
– pick up your exam at Group Time**
- **Linking-to-Life Part A is available to begin, Parts B & C  
will be posted tonight!**

*These announcements  
were not made in class:*

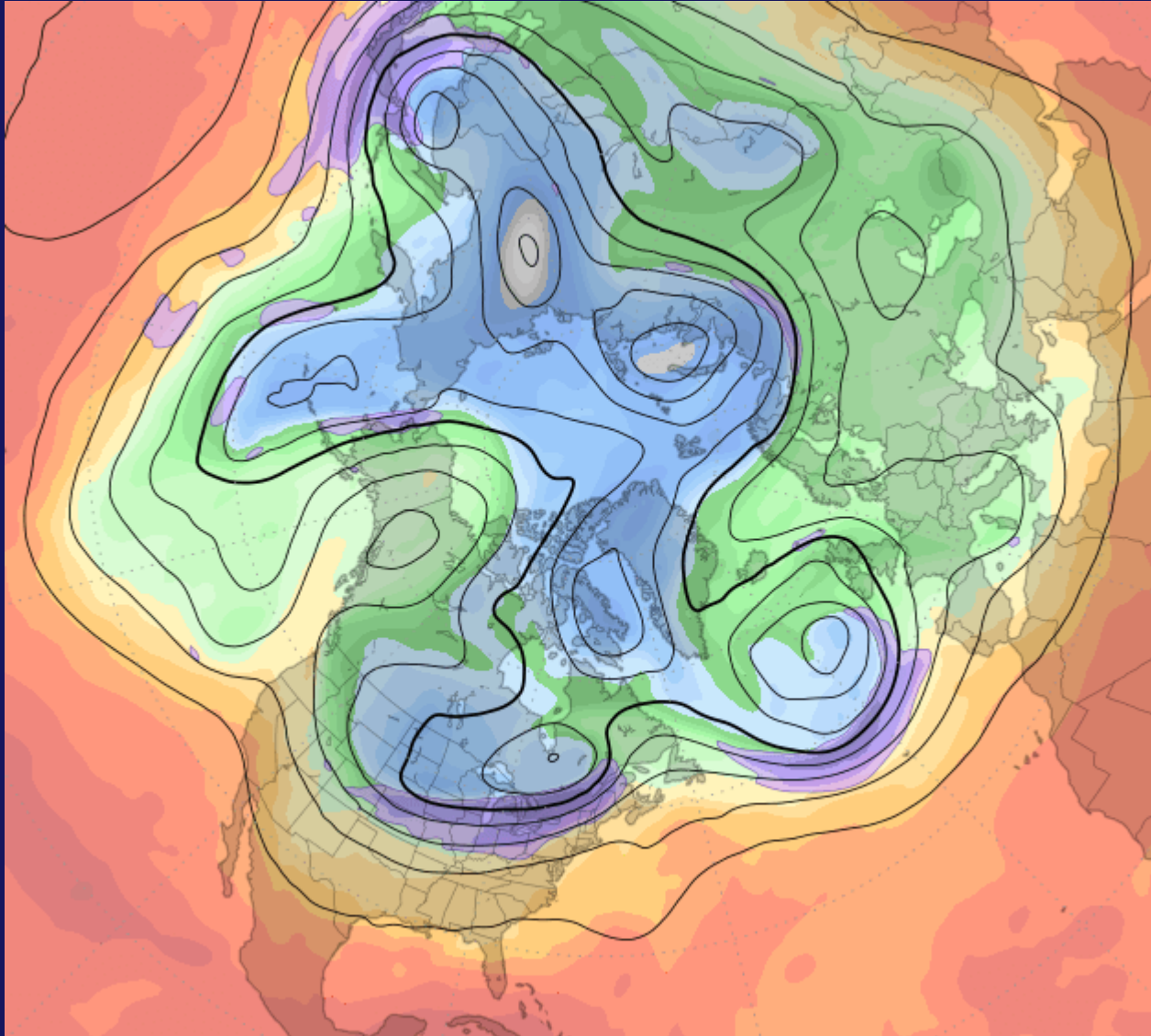
2 ADDITIONAL ANNOUNCEMENTS:

- **RQ-8 on Global Warming is due**  
**NEXT TUESDAY Nov 18<sup>th</sup> @ 30 minutes before class!**
- If you missed the **G-4 Tree-Ring Wood Kit Assignment** and would like an opportunity for a make up (for partial credit) there will be **one last session** tomorrow:  
**Friday Nov 14<sup>th</sup> from 3:0 – 4:00 pm**

# What's going on with the Circumpolar Vortex? and Jet stream now?



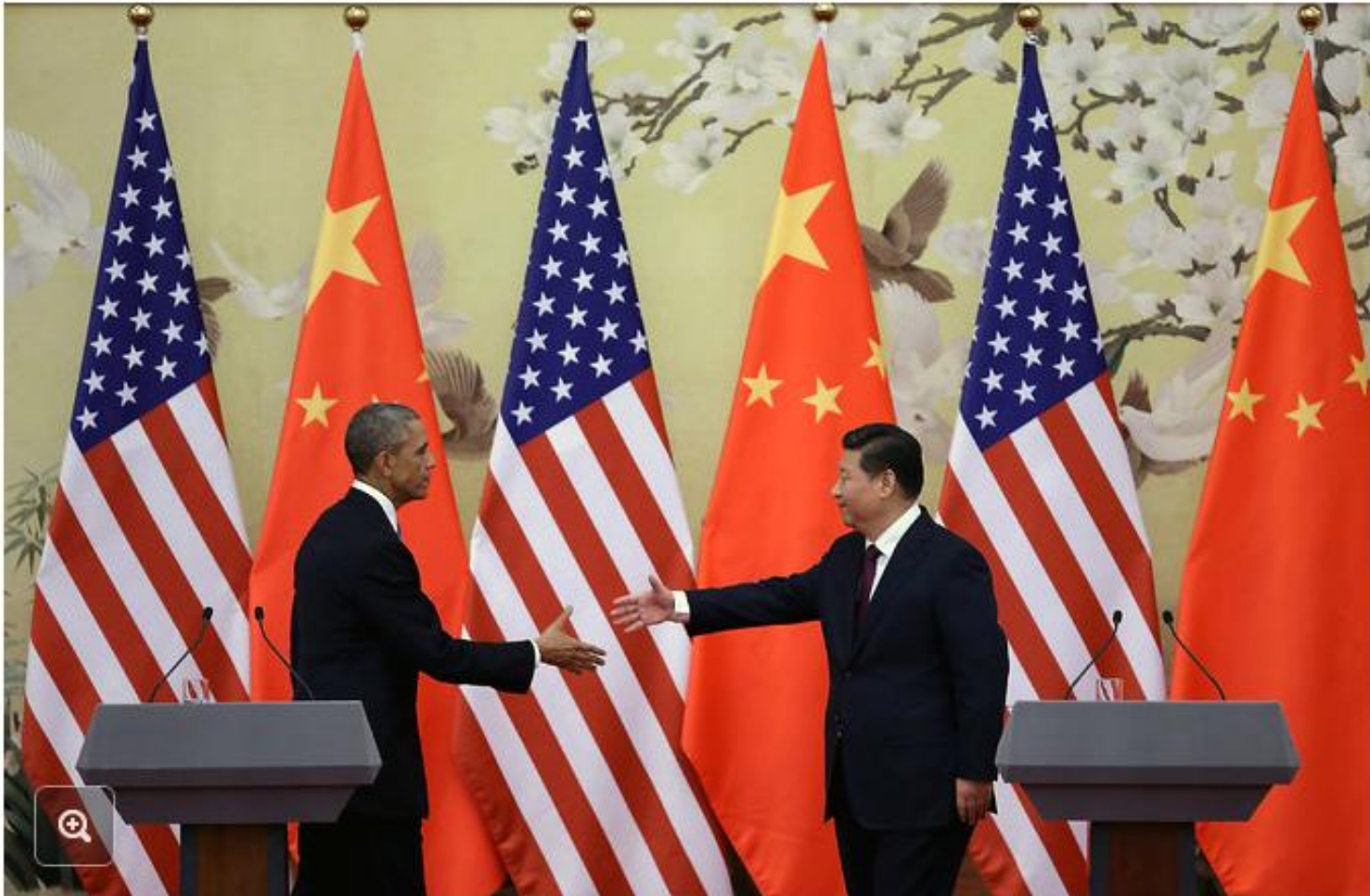
# What's the forecast for the Circumpolar Vortex? and Jet stream for the next 2 weeks?



<http://wxmaps.org/pix/NHanim.html>

# A Major Breakthrough on Climate Change

By THE EDITORIAL BOARD NOV. 12, 2014



President Obama and President Xi Jinping of China on Wednesday at a joint news conference. Feng Li/Getty Images

<http://www.nytimes.com/interactive/2014/11/12/world/asia/climate-goals-pledged-by-us-and-china-2.html>



HOLY DISAPPEARING SMOKE!

## New U.S.-China climate deal is a game changer

**Is it really a game changer???**

Next week during Topic 13 we will look at it more closely and examine it critically from a science perspective . . .

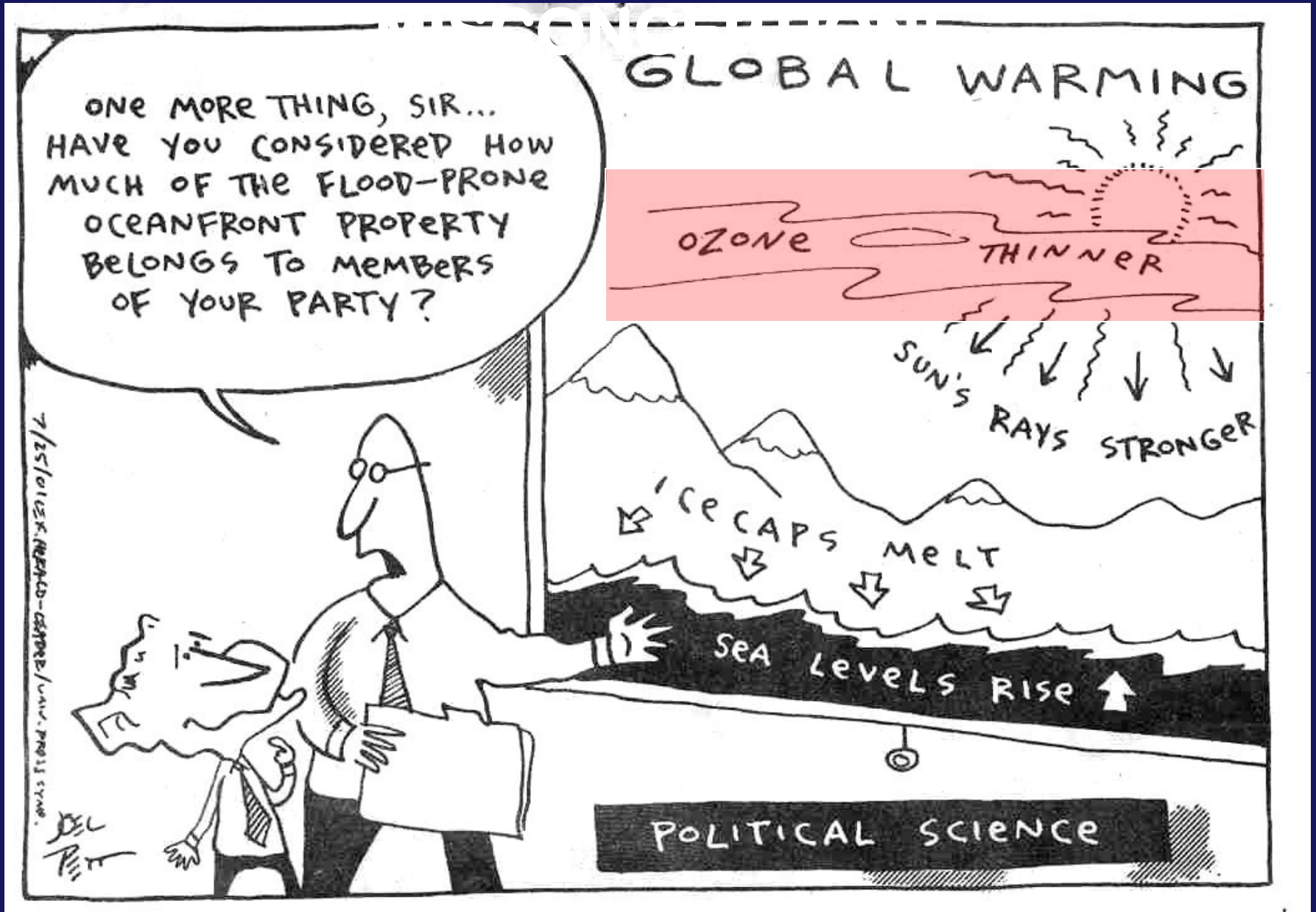
# Topic # 12

## OZONE DEPLETION IN THE STRATOSPHERE

A Story of Anthropogenic  
Disruption of a Natural  
Steady State

p 79 in Class Notes

# An OZONE-RELATED CARTOON:





# Clicker Q1:

Is the depletion of STRATOSPHERIC OZONE  
(in the OZONE HOLE and elsewhere)  
an important CAUSE  
of GLOBAL WARMING?

1 – YES

2 -- NO

I will ask this again when we complete Topic 12!

**“[ 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**

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

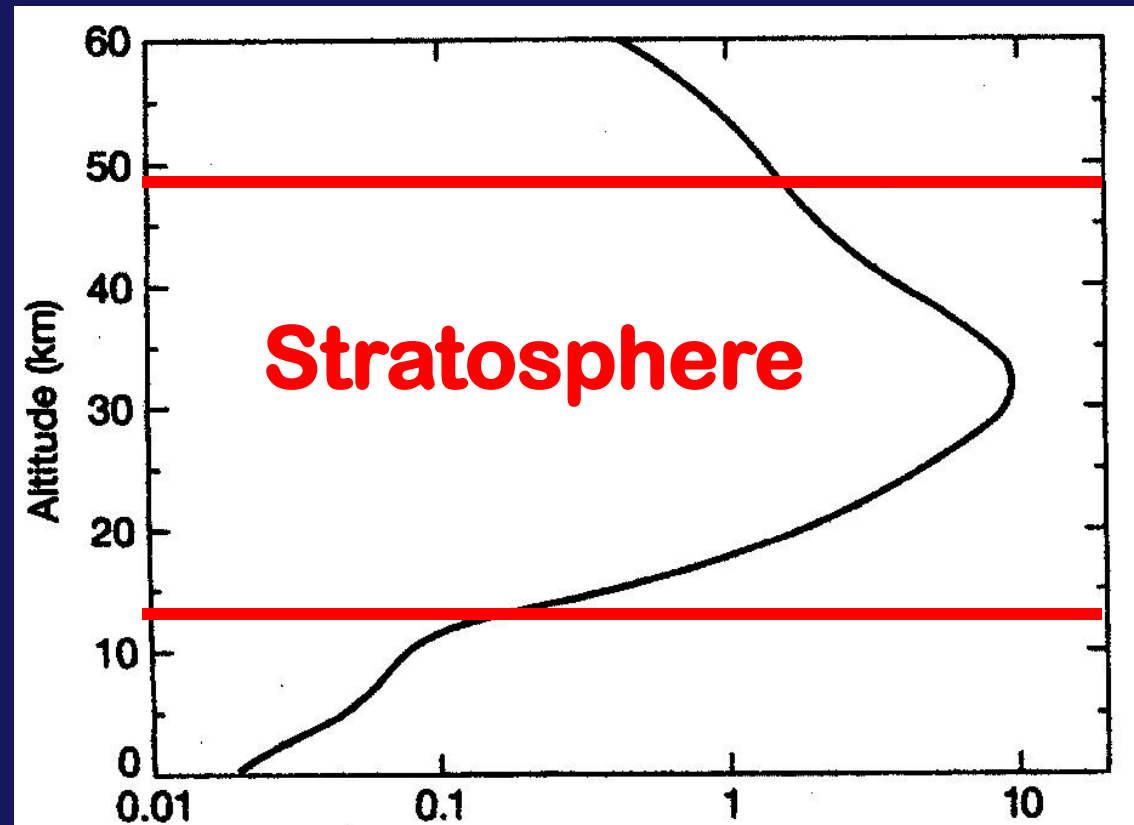
The **THEORY** that the ozone layer in the stratosphere might be damaged by human intervention **PRECEDED** the actual **OBSERVATION** of the ozone hole.

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 . . . . .**

# REVIEW: WHERE IS THE OZONE LAYER?

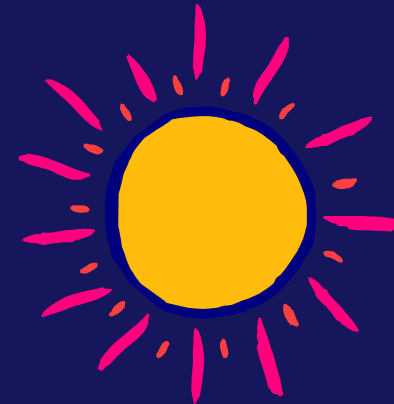
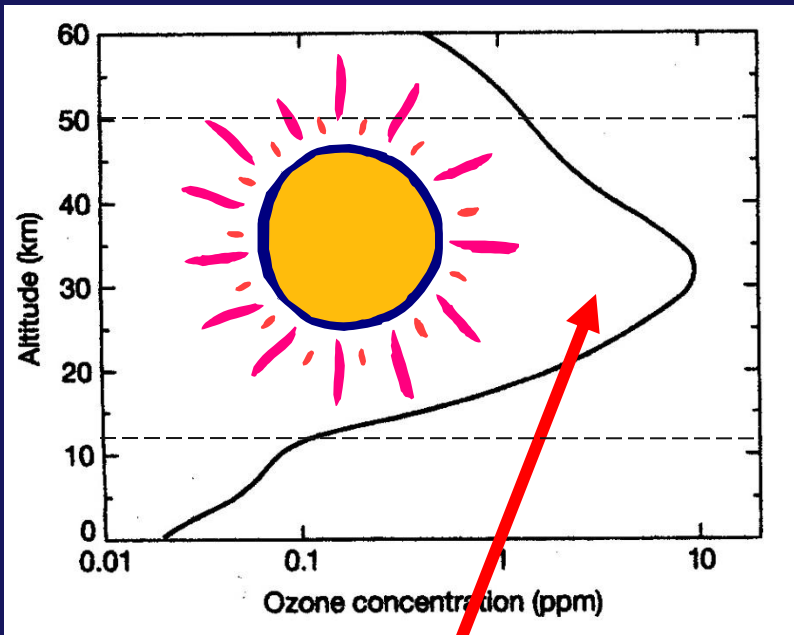
SGC  
E-Text  
Fig. 3-11



Ozone Concentration (ppm)



# OZONE: Sources



Ozone is produced naturally in **photochemical reactions** in the stratospheric ozone layer --“**good ozone**” -- is decreasing!



However, ozone has increased in **troposphere** due to photochemical smog reactions -- “**bad ozone**”

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

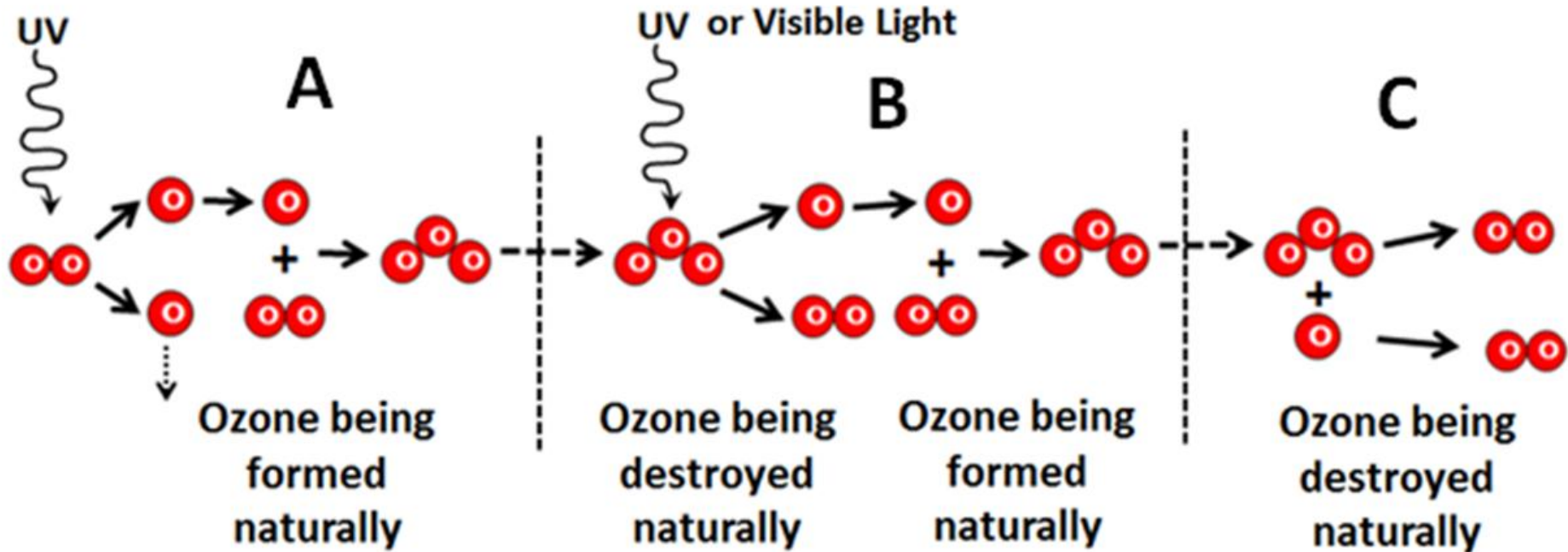
Due to: the natural  
“Chapman Mechanism”  
**(a series of photochemical reactions)**

# 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** ( $O_3$ ).

# The Chapman Mechanism

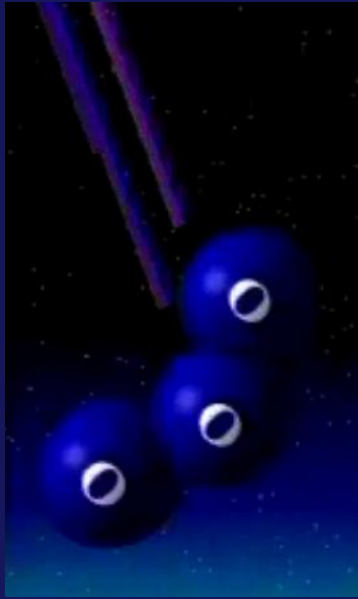


*(See explanation in box on top of p 79)*

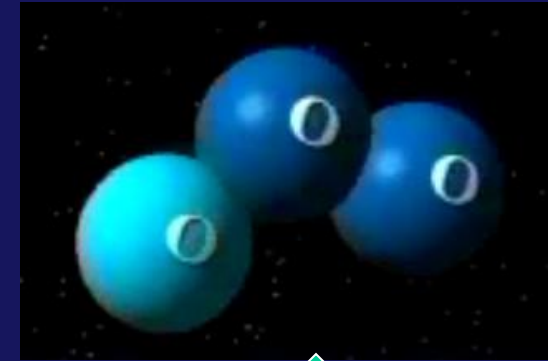
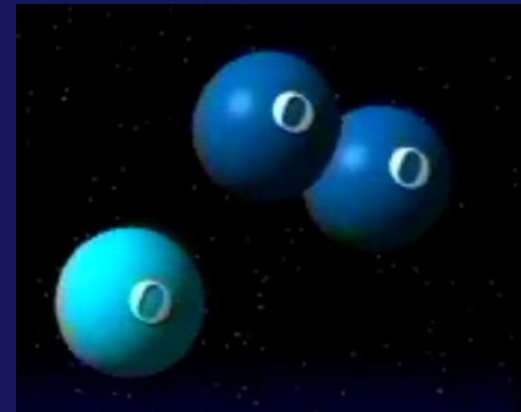
[Go to movie clip]



# The Natural Chapman Mechanism in the Stratosphere Breaks down & re-forms ozone naturally



High  
energy UV  
splits  
apart O<sub>3</sub>



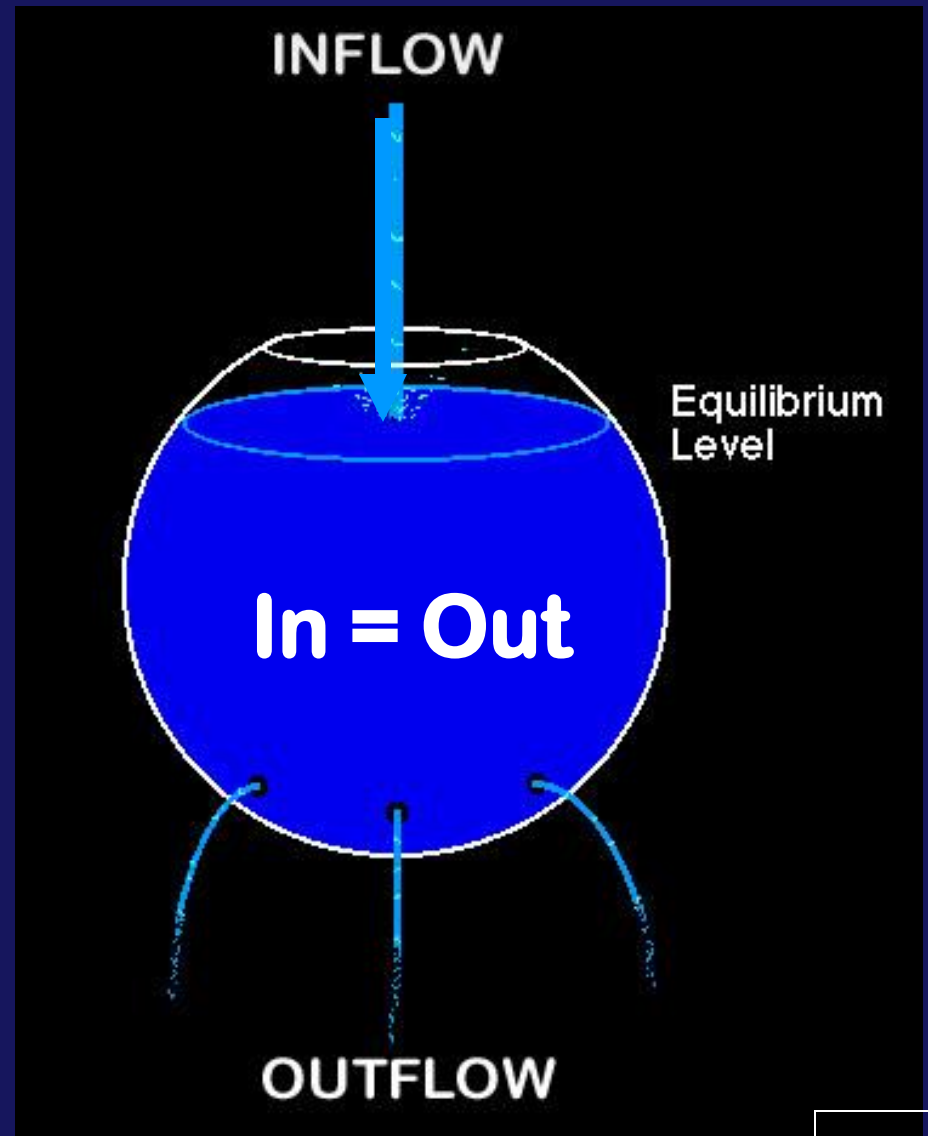
single O molecule  
bonds with O<sub>2</sub> to  
produce new O<sub>3</sub>

**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”**

**STEADY STATE =**  
a condition in which  
the **STATE** of a  
system component  
(e.g. reservoir)  
is **CONSTANT**  
over time.

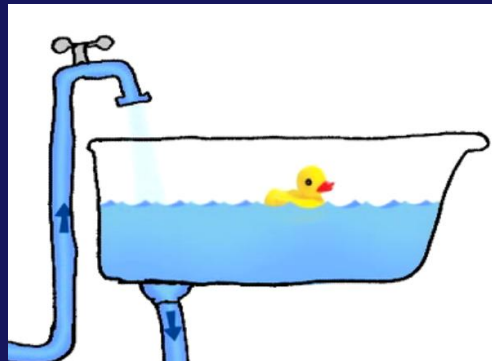


# FLOW DIAGRAM OF A STEADY STATE



Where have we seen something like this before?

I-1 Lesson 1  
Carbon Dioxide in  
the Atmosphere

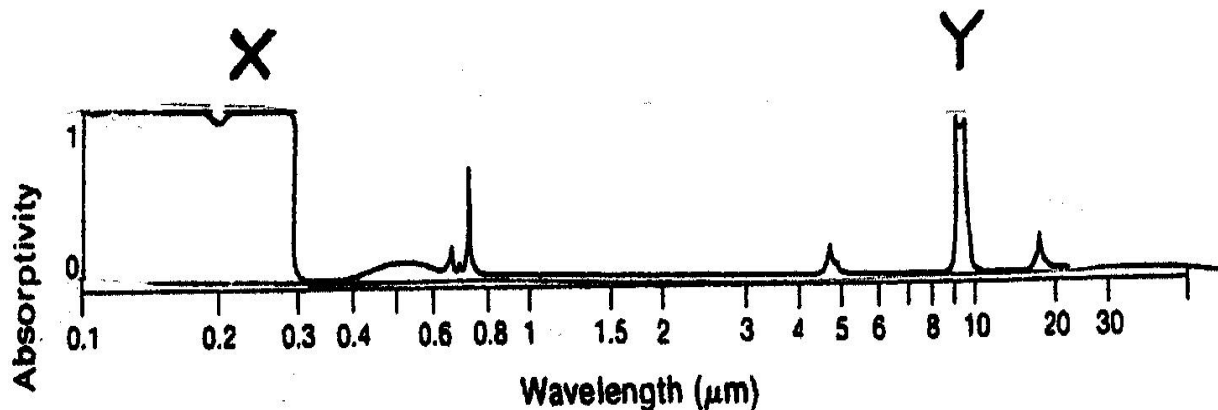
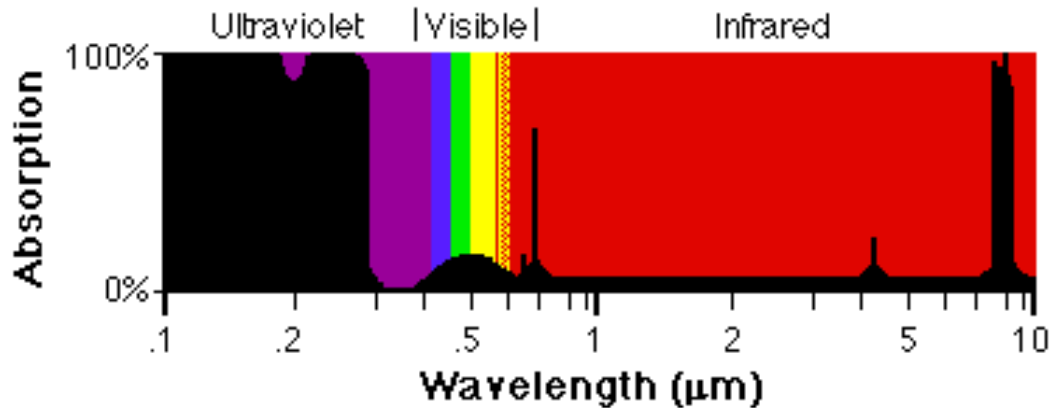


The **NATURAL**  
**Carbon Cycle**  
is in balance!



# Review: Why stratospheric ozone is “Good”:

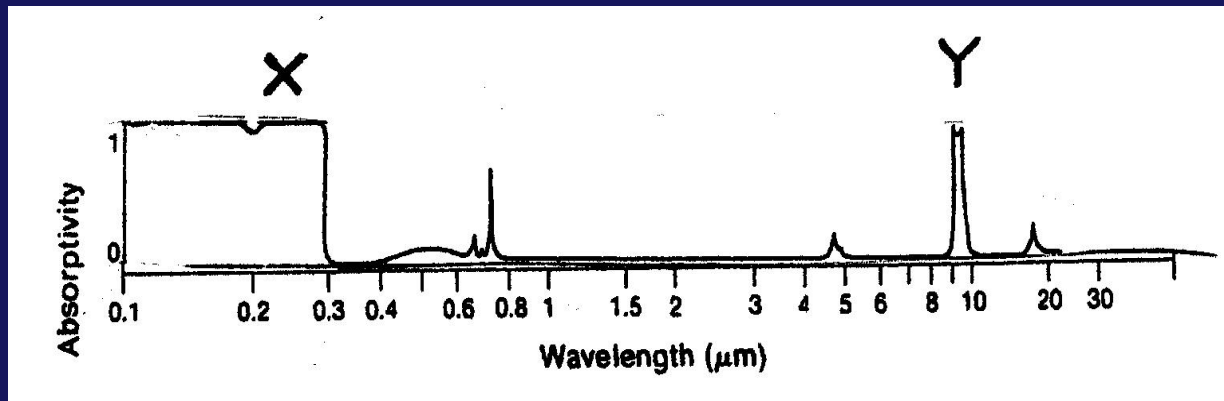
Black areas = radiation absorbed



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

←remember this absorption curve?

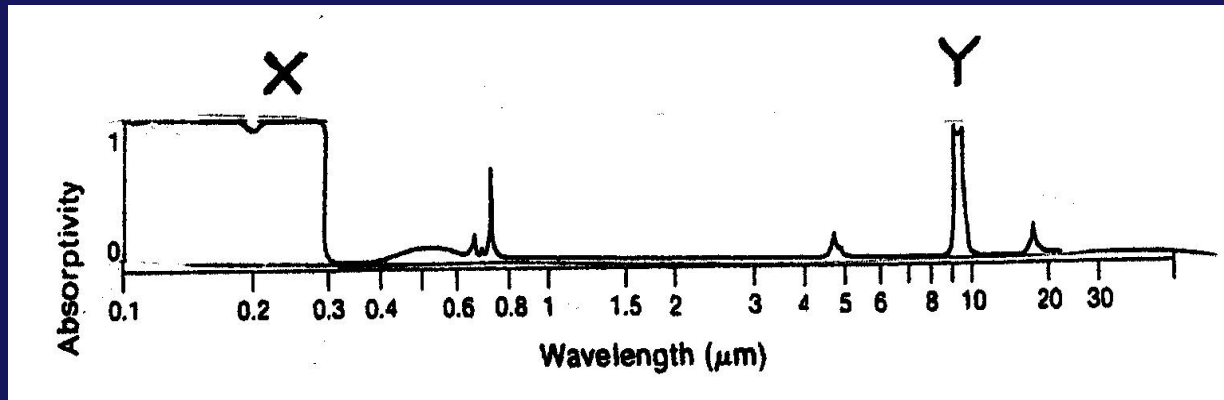
←**CLICKER Q** coming up!



**Clicker Q2:** What is 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 \_\_\_\_.

(1) **X** or (2) **Y**

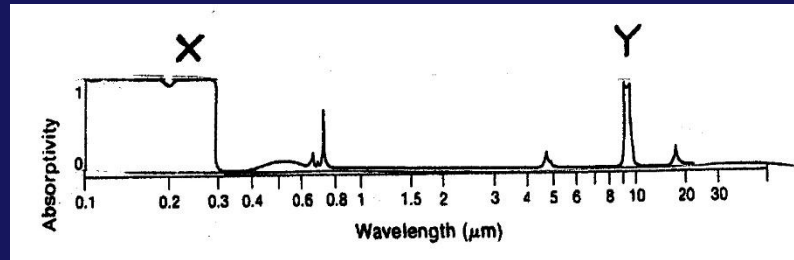


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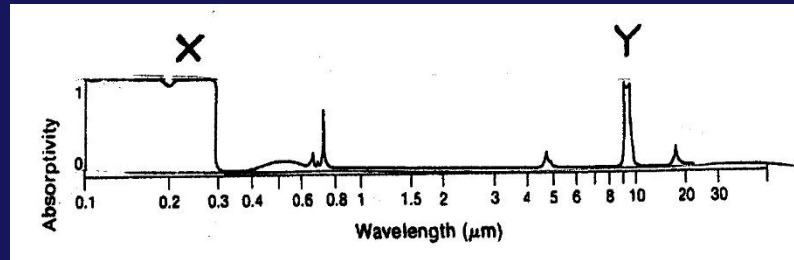
# Clicker Q3: Ok, X is right, but Why?



1. . . . because X represents **UV** radiation being absorbed -- hence **if ozone is depleted, MORE ultraviolet** radiation will **reach the Earth's surface**.
2. . . . because X represents **terrestrial longwave** radiation being absorbed -- and hence serves as a catalyst in the Chapman mechanism.
3. . . . because X 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.



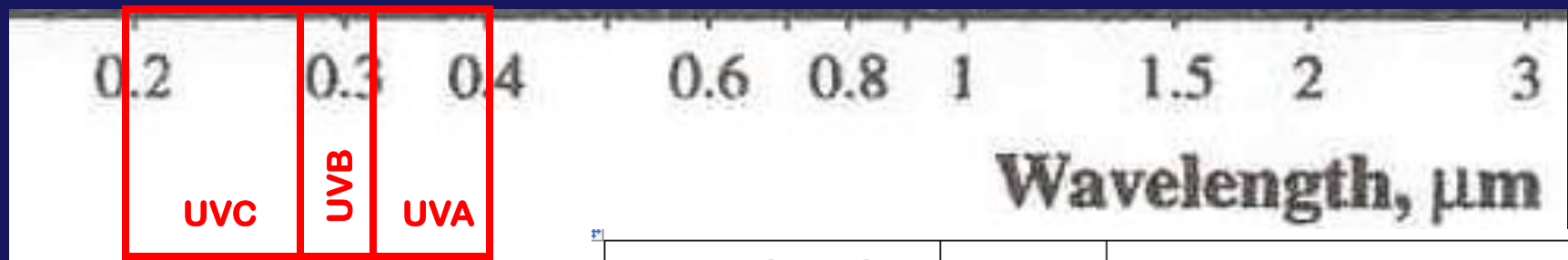
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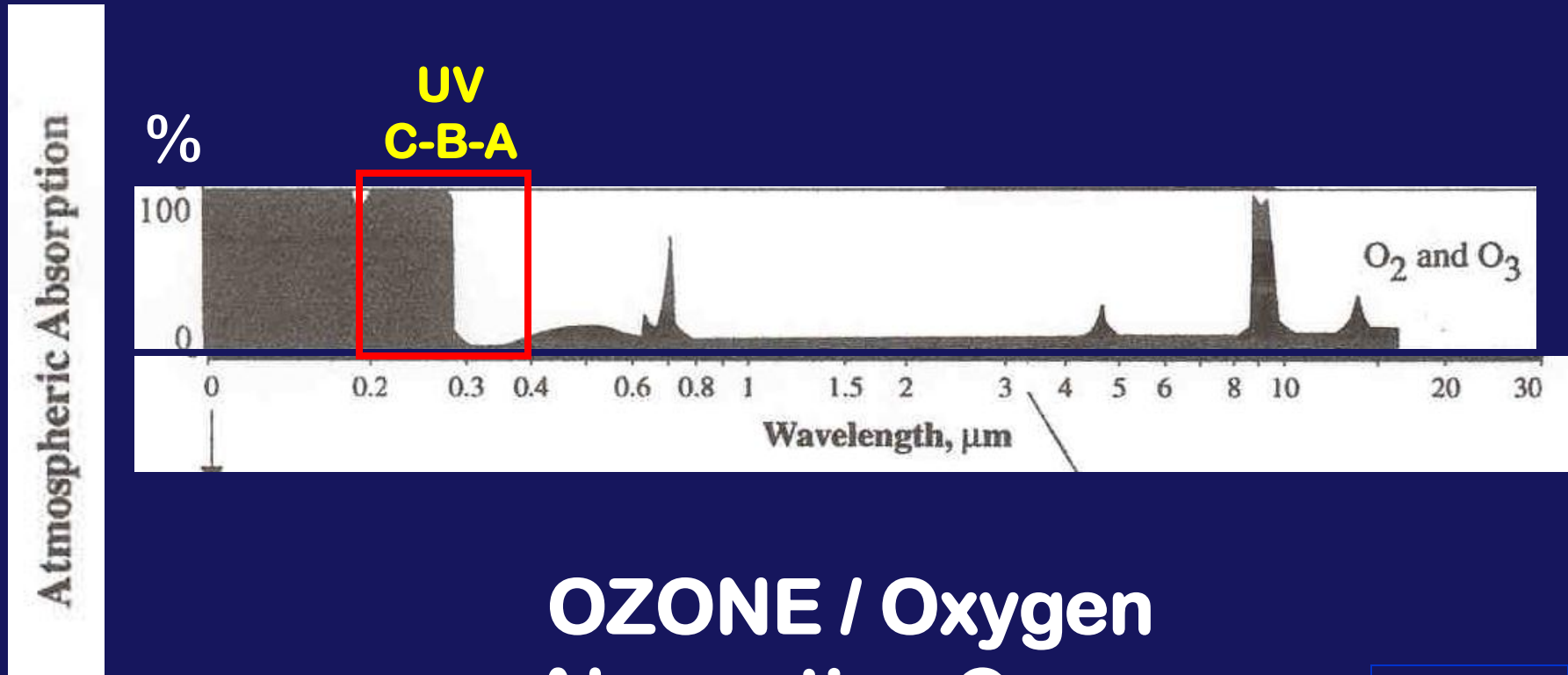
**ANOTHER LINK TO  
EVERYDAY LIFE:**

**SUN SAFETY!**



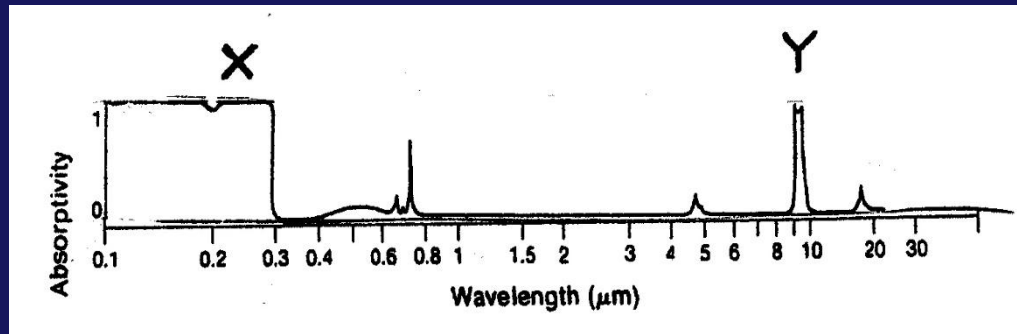
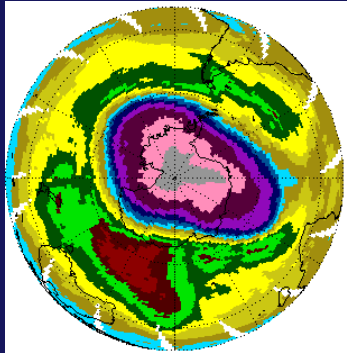
Wavelength Range	Name	Biological Effect
.32 to .4 $\mu\text{m}$ (320-400 nm)	UVA	once thought to be relatively harmless, <b>BUT causes wrinkles, premature aging</b> and associated sun-related skin damage; <b>new research indicates possible skin cancer link</b>
29 to .32 $\mu\text{m}$ (290-320 nm)	UVB	<b>harmful</b> , causes sunburn, skin cancer, and other disorders
.20 to .29 $\mu\text{m}$ (200 - 290 nm)	UVC	<b>extremely harmful, damages DNA</b> -- but almost completely absorbed by ozone

# FULL SPECTRUM PROTECTION NEEDED!!



OZONE / Oxygen  
Absorption Curve

# OZONE'S DUAL PERSONALITY!

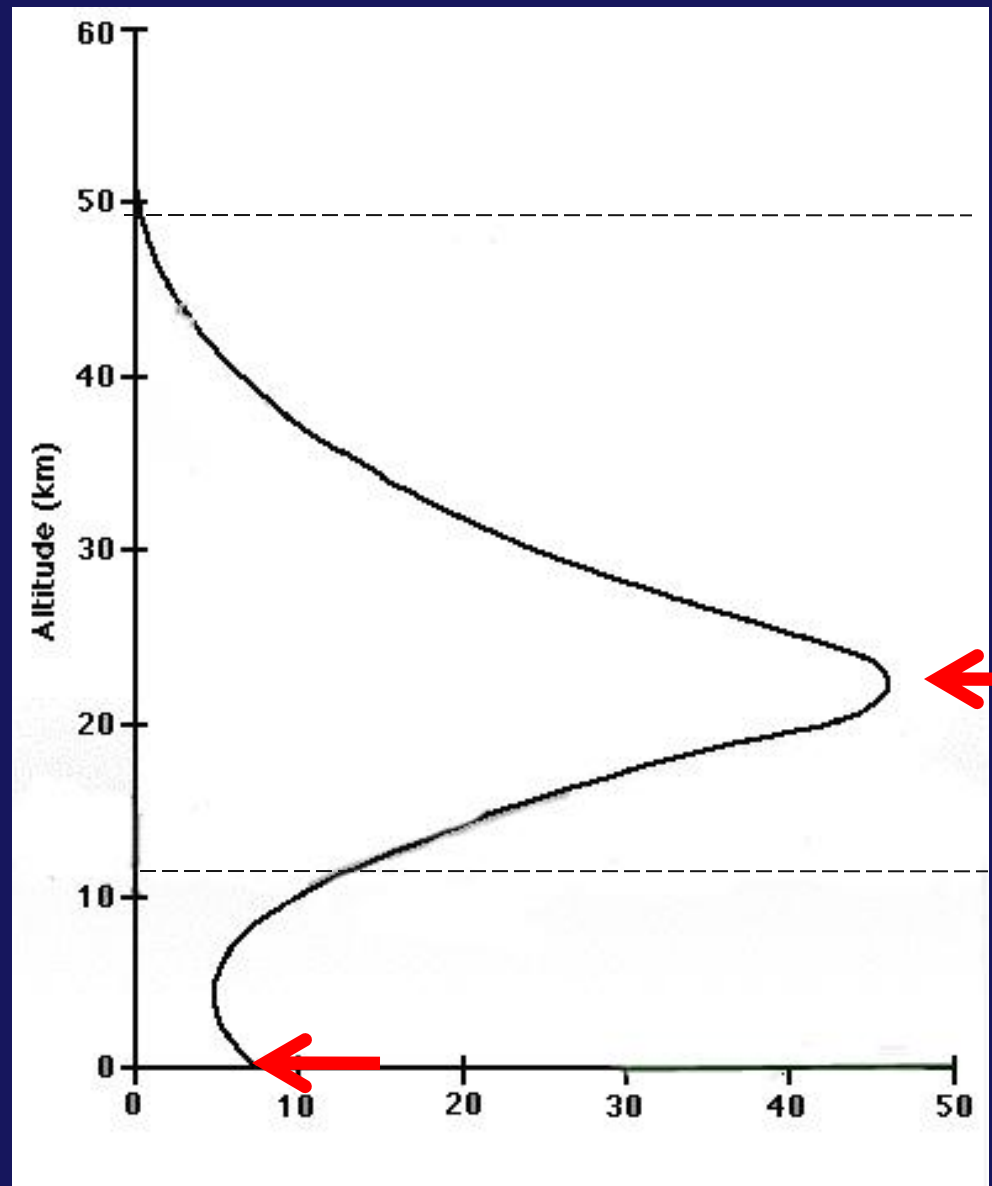


Important as an  
absorber of  
harmful UV  
in the  
**STRATOSPHERE**

Important as a  
GH Gas =  
absorber of IR  
in the  
**TROPOSPHERE**

Here's a different version of the figure →

Shows 2 peaks, a major peak in O<sub>3</sub> density in the **stratosphere**, a smaller secondary peak in the **lower troposphere**

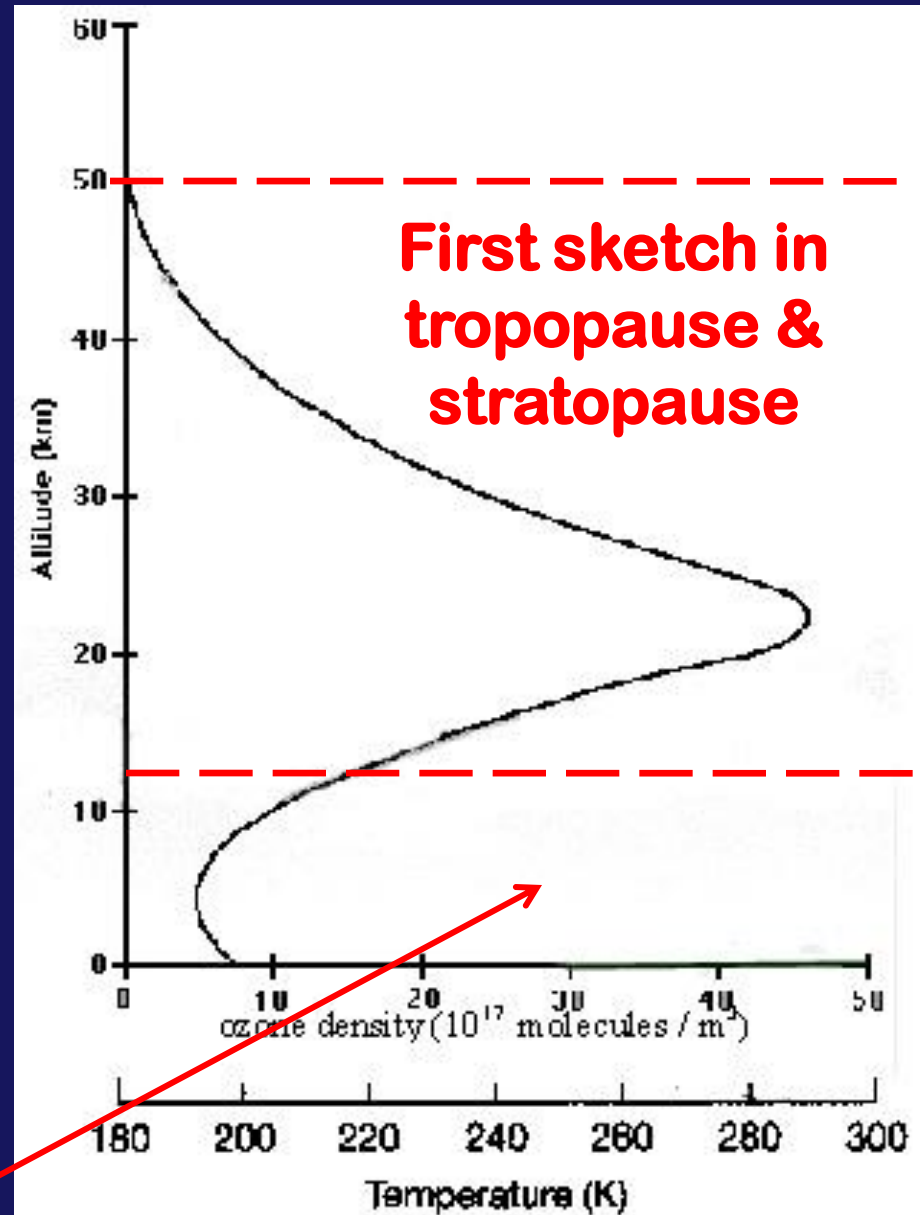
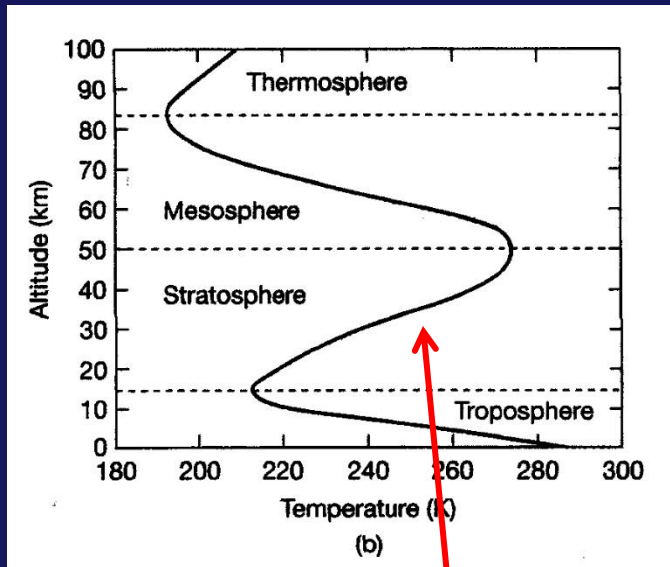


Ozone Density  
( $10^{17}$  molecules / m<sup>3</sup>)

Hands on – sketch this in on p 80:

## Ozone Density graph

## Temperature graph



First sketch in tropopause & stratopause

Now roughly sketch the temperature line from this graph onto the ozone graph

Fill in the Q on p 80:

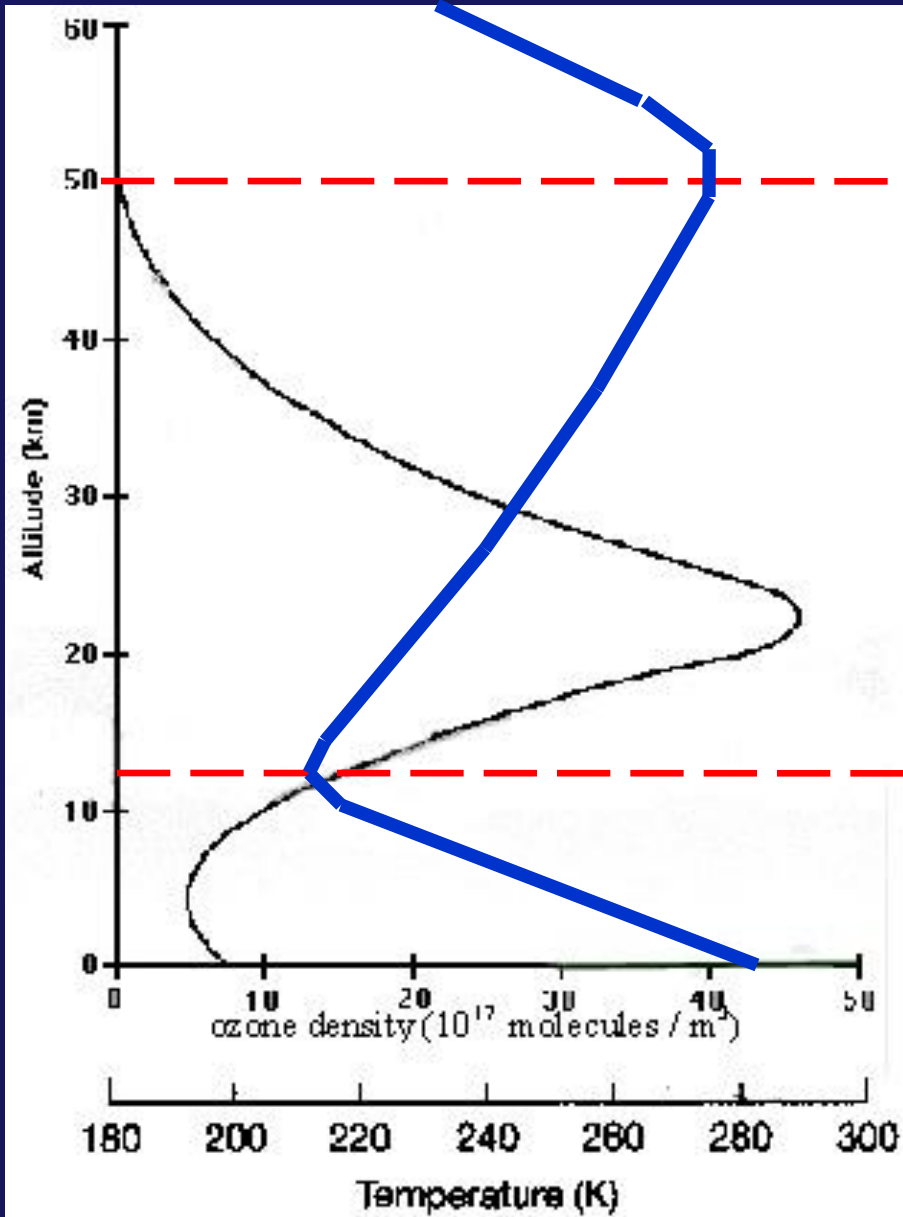
Q. Does the temperature of the atmosphere **INCREASE** or **DECREASE** with increasing altitude in the Stratosphere?

**TEMPERATURE**

[ increases / decreases ]

with increasing altitude in the stratosphere

**WHY???**





# Clicker Q4. Why is there an increase in temperature with altitude in the STRATOSPHERE?

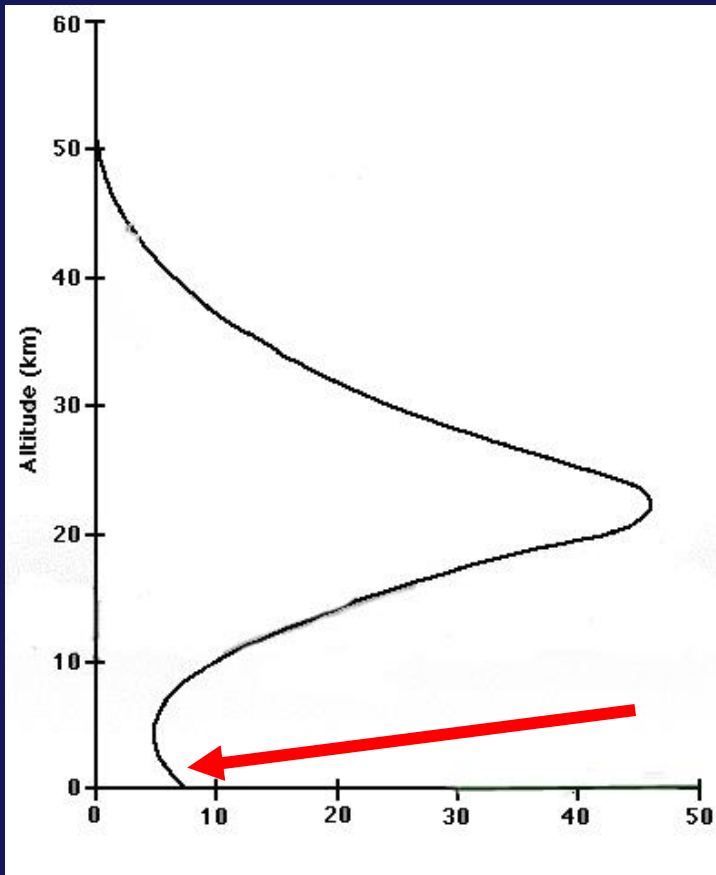
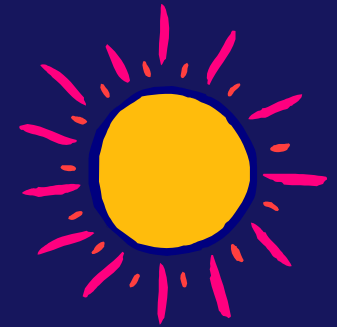


1. It is the closest layer to the sun, hence it is closest to the solar “heat source.”
2. It receives **large amounts of UV radiation** from the sun PLUS it has a **high concentration of ozone** to absorb this UV.
3. It is the layer which **contains most of the GH gases** that absorb IR radiation emitted by the Earth’s surface.

## Clicker Q4. Why is there an increase in temperature with altitude in the STRATOSPHERE?

1. It is the closest layer to the sun, hence it is 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.

# What about the “BAD” ozone located in the troposphere?



Ozone has increased in troposphere due to photochemical smog reactions → “bad ozone”



# HEALTH AND ENVIRONMENTAL EFFECTS OF GROUND-LEVEL OZONE

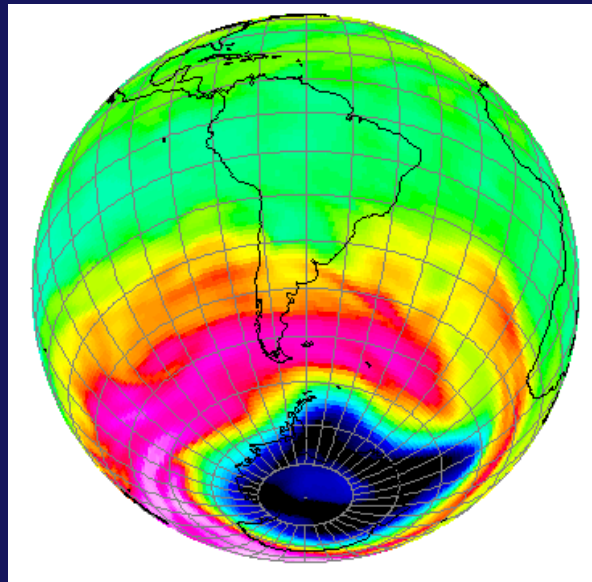
Why are We Concerned  
about Ground-Level Ozone?

→ Ozone is the prime ingredient  
of smog in our cities and  
other areas of the country.

Phoenix  
smog →



# THE DESTRUCTION OF STRATOSPHERIC OZONE



# The ozone hole is:

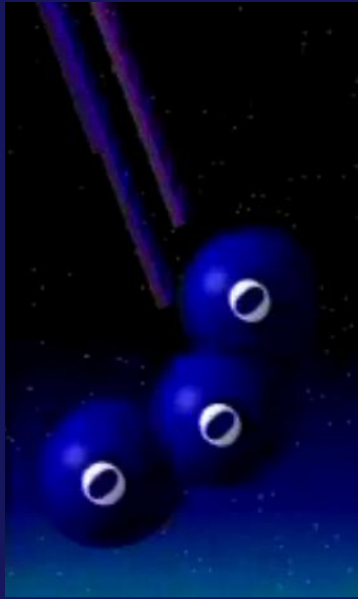
-- a depletion of ozone in the lower stratosphere

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

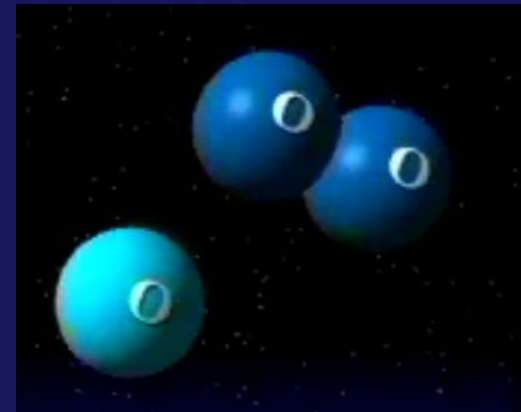
NOTE: this and other “bullet” items from today’s lecture are in the box on p 81

# The Natural Chapman Mechanism in the Stratosphere

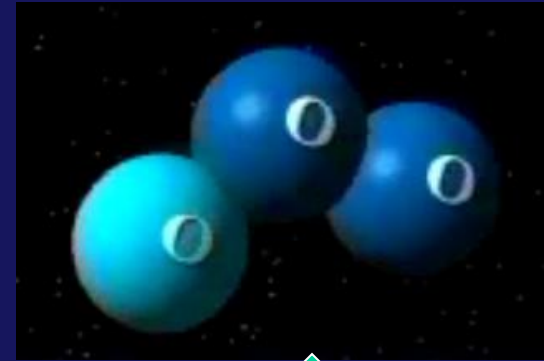
Breaks down & re-forms  
ozone naturally in a  
steady state



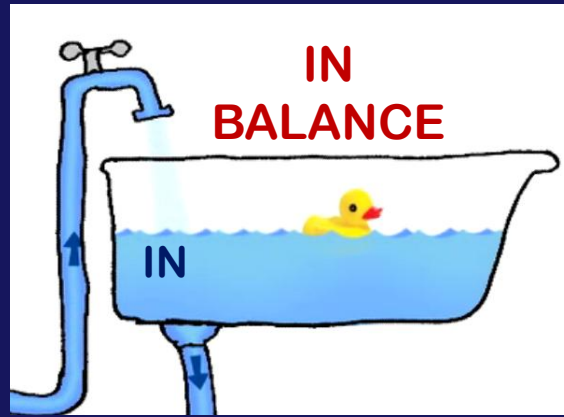
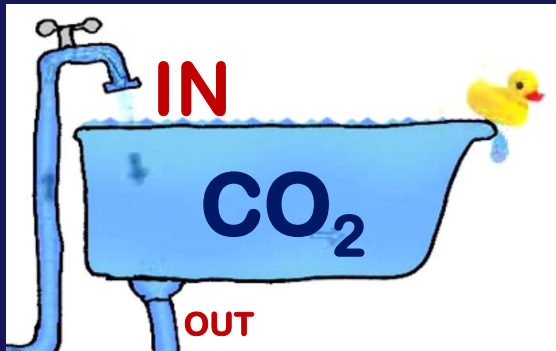
High  
energy UV  
splits  
apart  $O_3$



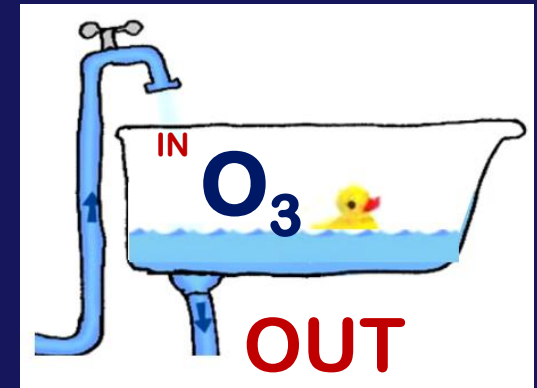
single O molecule  
bonds with  $O_2$  to  
produce new  $O_3$



# FLOW DIAGRAM OF A STEADY STATE



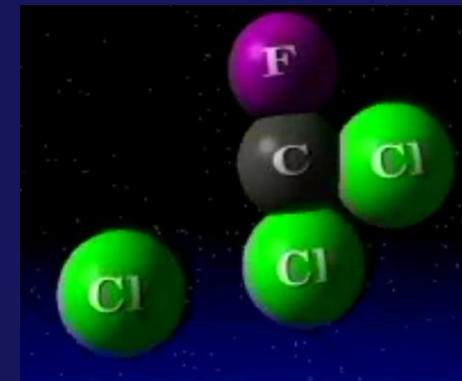
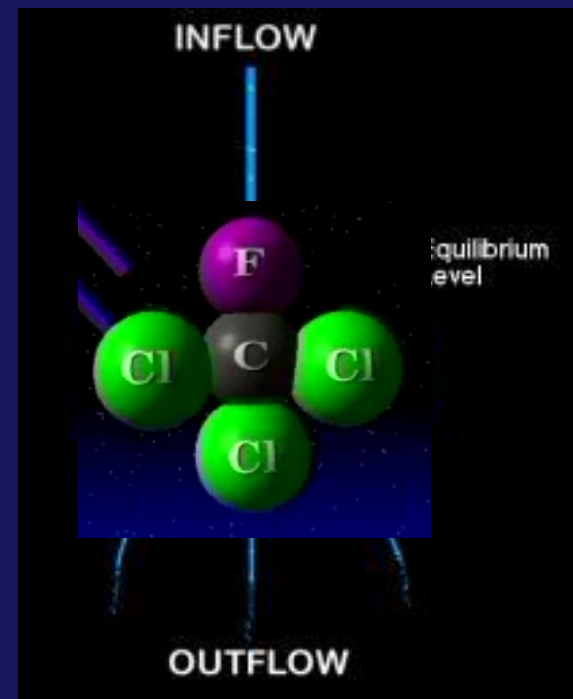
← 2 ways to get  
out of balance →





The Chapman Mechanism “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 ray
- > **Chlorine** → acts as **catalyst** in ozone loss reactions



# CATALYST =

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

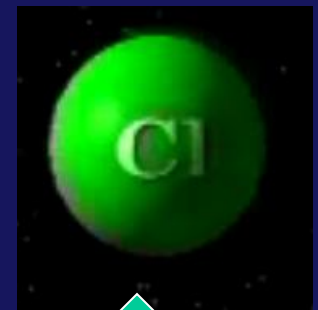
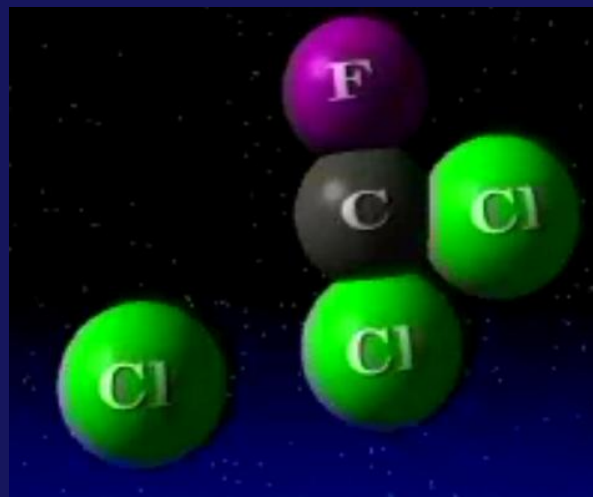
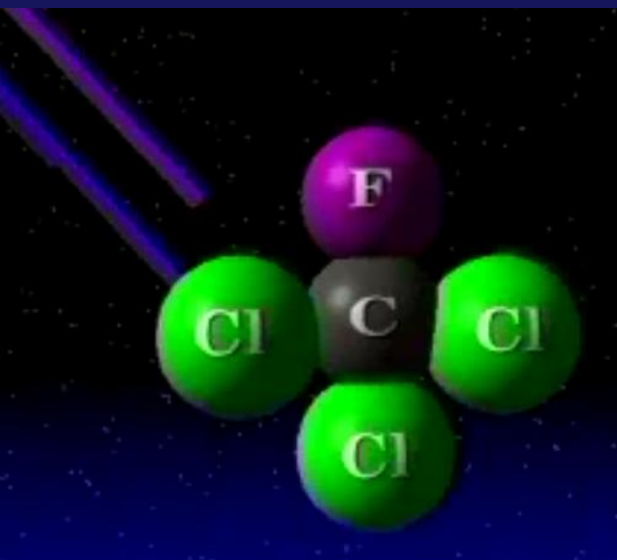
*Through chemical reactions:*

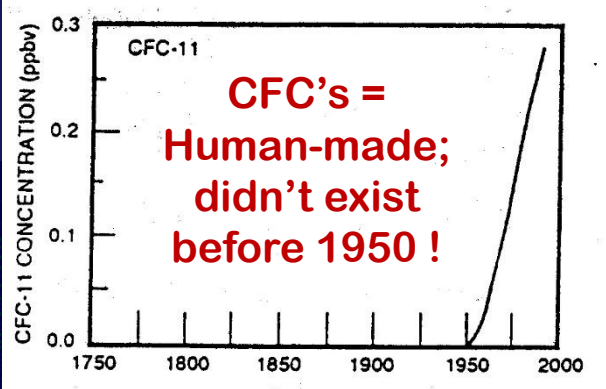
- **the chlorine removes ozone from the stratosphere**
- **and also frees more chlorine atoms to begin the process all over again**

**[Go to movie clip]**

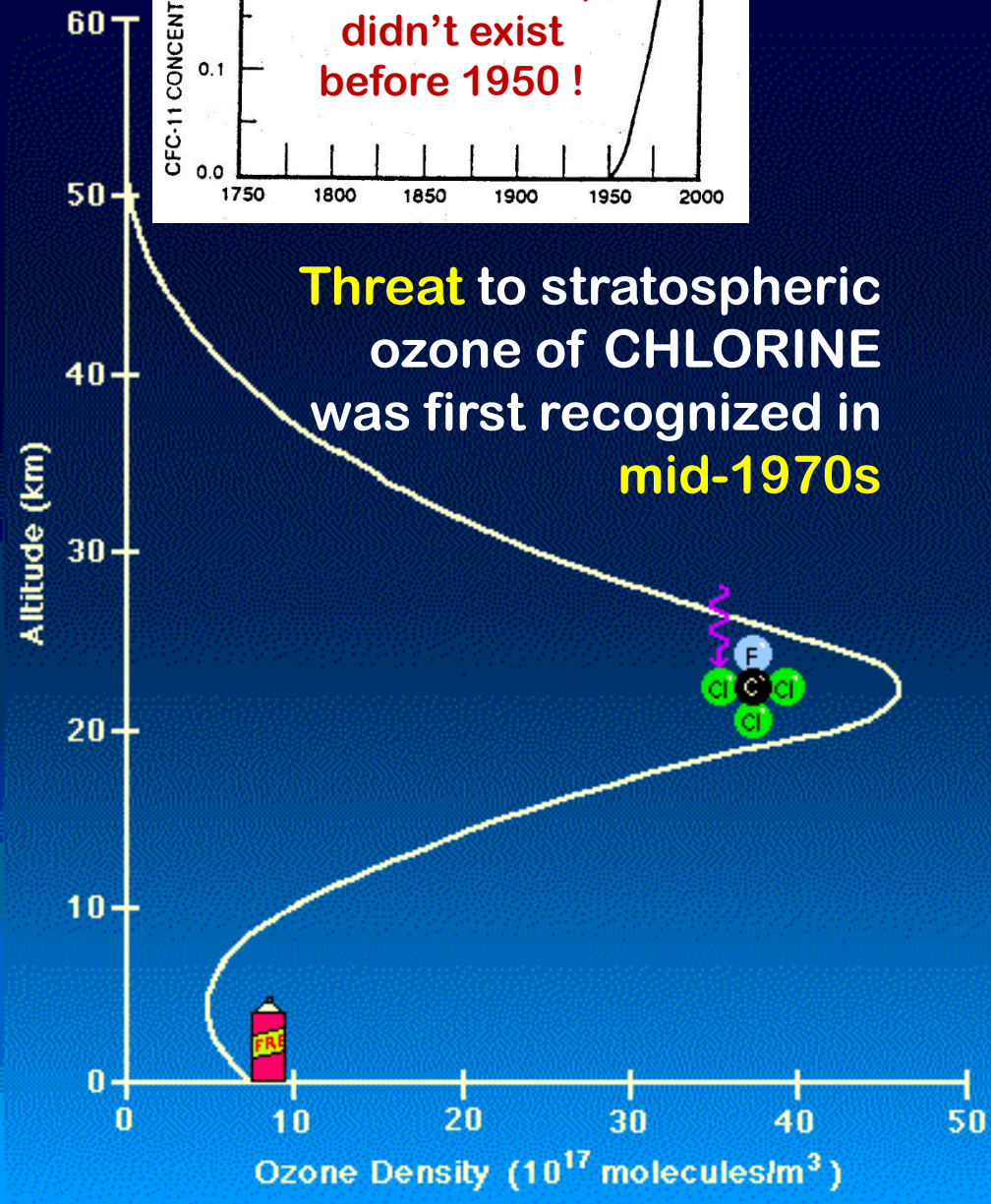
# DESTRUCTION OF OZONE BY CFC's & CHLORINE CATALYST

A single Cl atom destroys 100,000s of  $O_3$  but is not itself destroyed





**Threat** to stratospheric ozone of CHLORINE was first recognized in **mid-1970s**

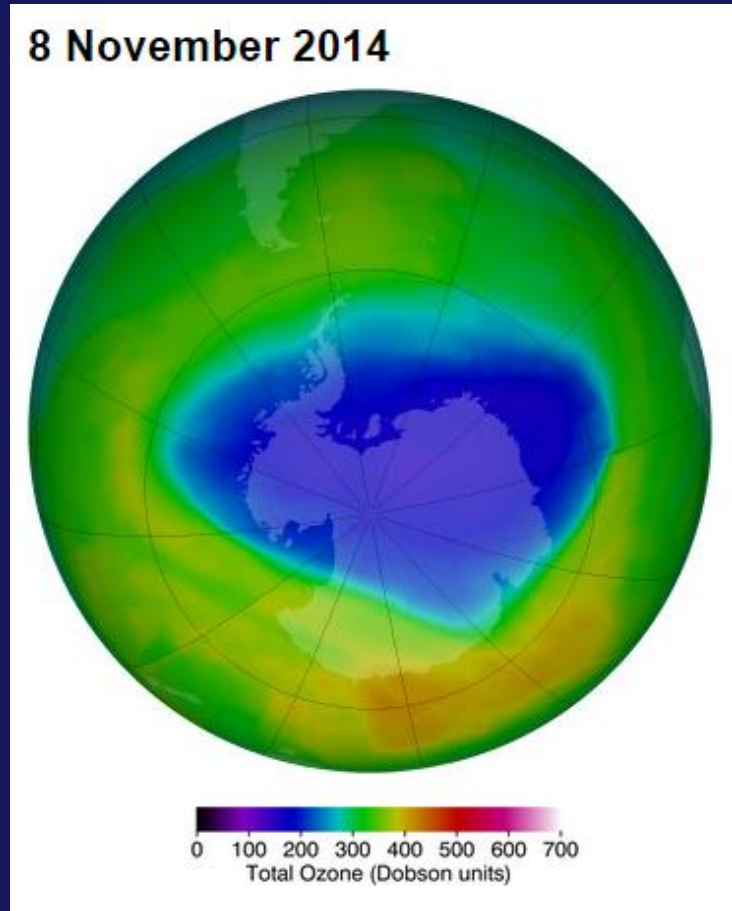
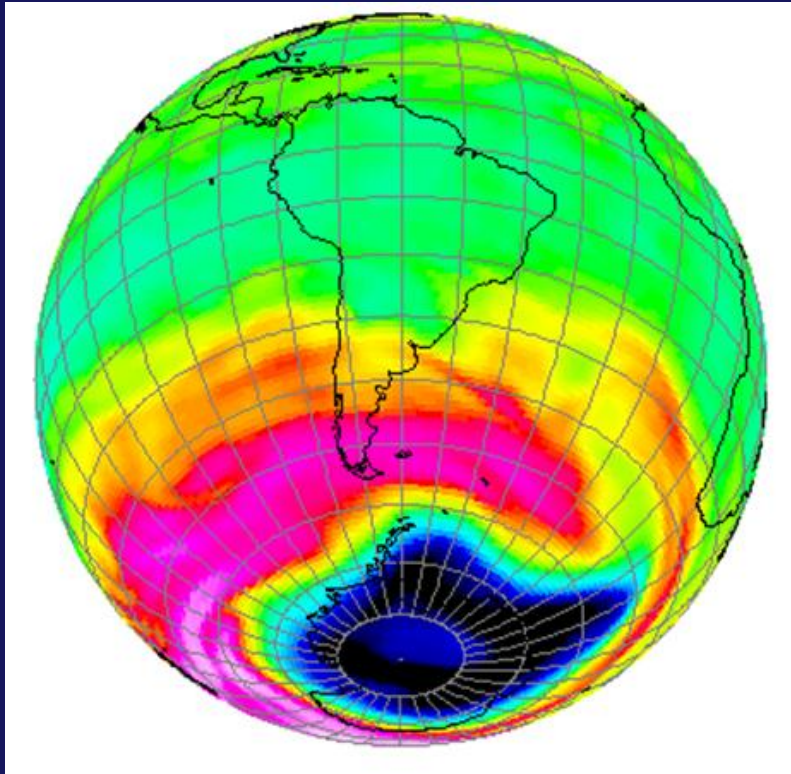


# CFC compounds: Chlorofluorocarbons

are unreactive at Earth's surface, but if they get into the stratosphere . . .

they can be **broken down** by high energy UV → highly reactive **CHLORINE atoms (Cl)**

# THE ANTARCTIC OZONE HOLE



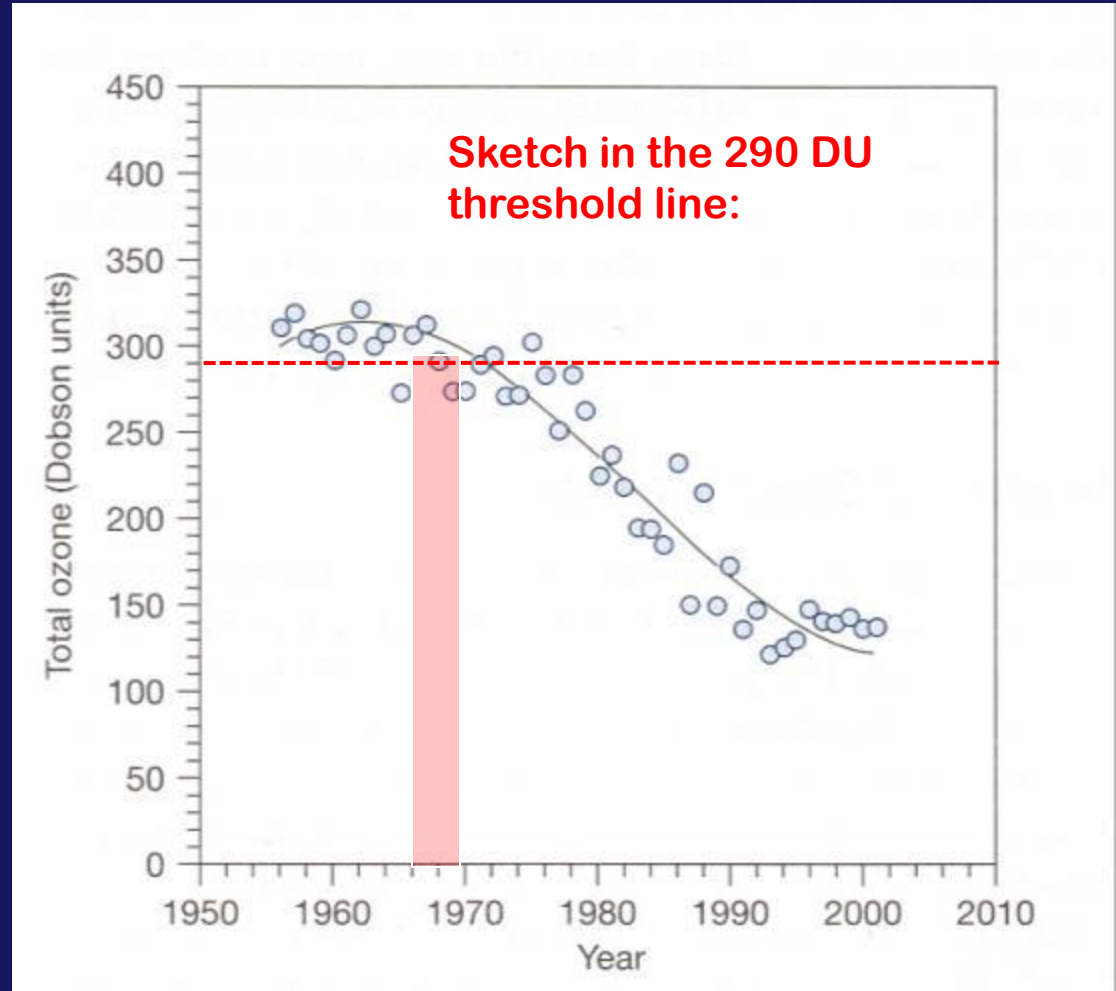
<http://ozonewatch.gsfc.nasa.gov/>

# RATE OF OZONE DEPLETION

in DOBSON UNITS (DU)

When did the Hole  
begin forming?

Hole generally  
defined as  
< 290 DU

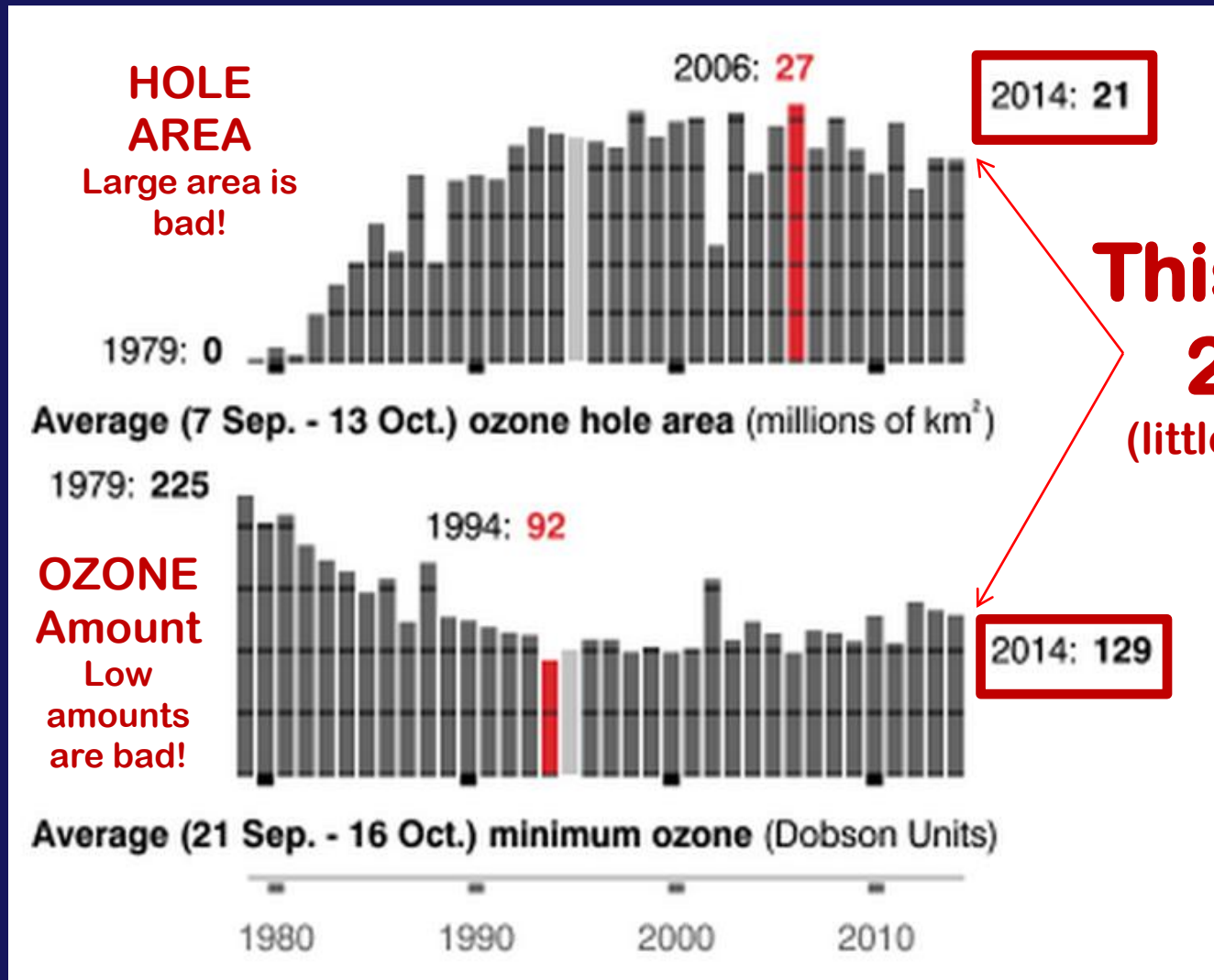


~ 1969 to 1970



OZONE HOLE WATCH  
images, data, and information; updated daily

# Annual Ozone Hole Variations (since 1979)



**This year:  
2014**  
(little change!)

# RECIPE FOR THE OZONE HOLE

<http://www.youtube.com/watch?v=qUfVMogldr8>



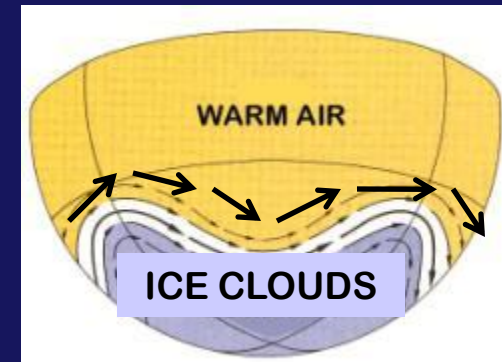
# WHY ANTARCTICA?

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)

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 a 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.

Key Concept



**POLAR  
STRATOSPHERIC  
CLOUDS OVER  
ANTARCTICA**

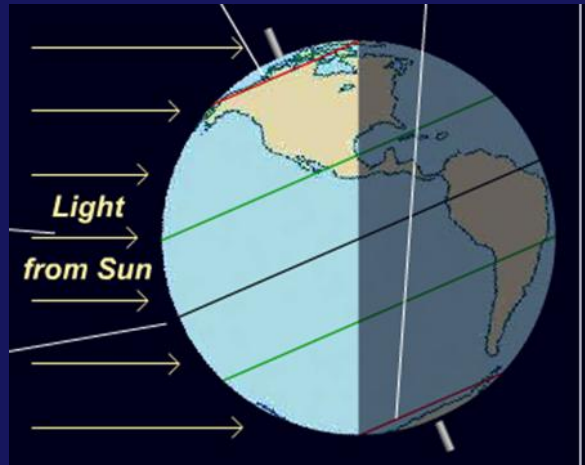
[\[Go to movie clip\]](#)



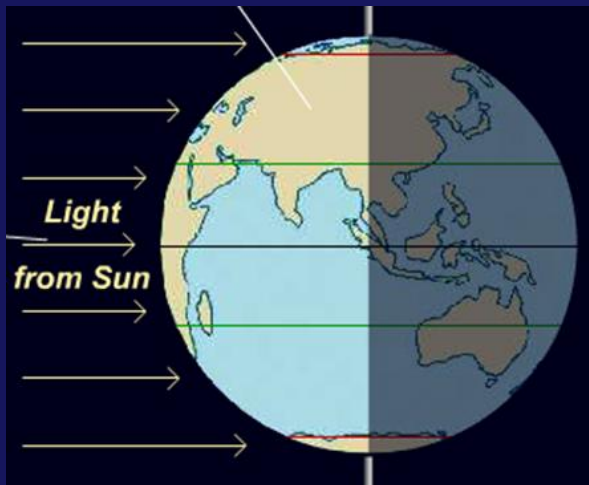
# LAST INGREDIENT:

## SUNLIGHT + UV PHOTONS

June



Sept



Only after well after the June Solstice and esp. the September Equinox, does the South Pole & Antarctic Circle receive sufficient sunlight!

# HOW DEEP DOES THE HOLE GET?

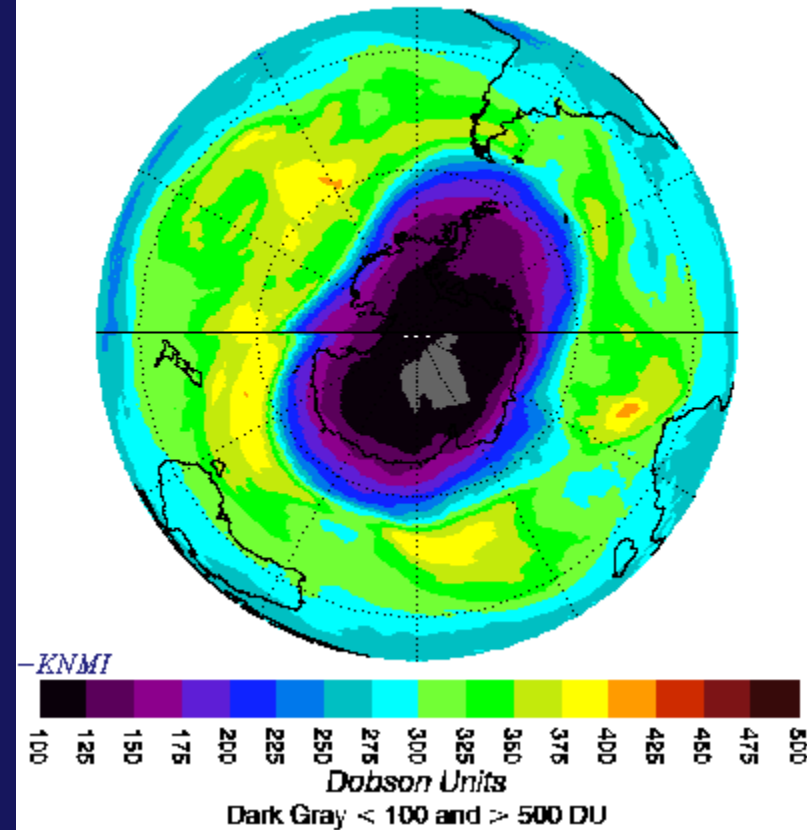
The intensity of ozone depletion varies from year to year.

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

**Nearly ALL** of the ozone in the layer 8-13 miles above the Earth's surface was destroyed!

In this critical layer, the instrument measured a record low of only **1.2 DU!**

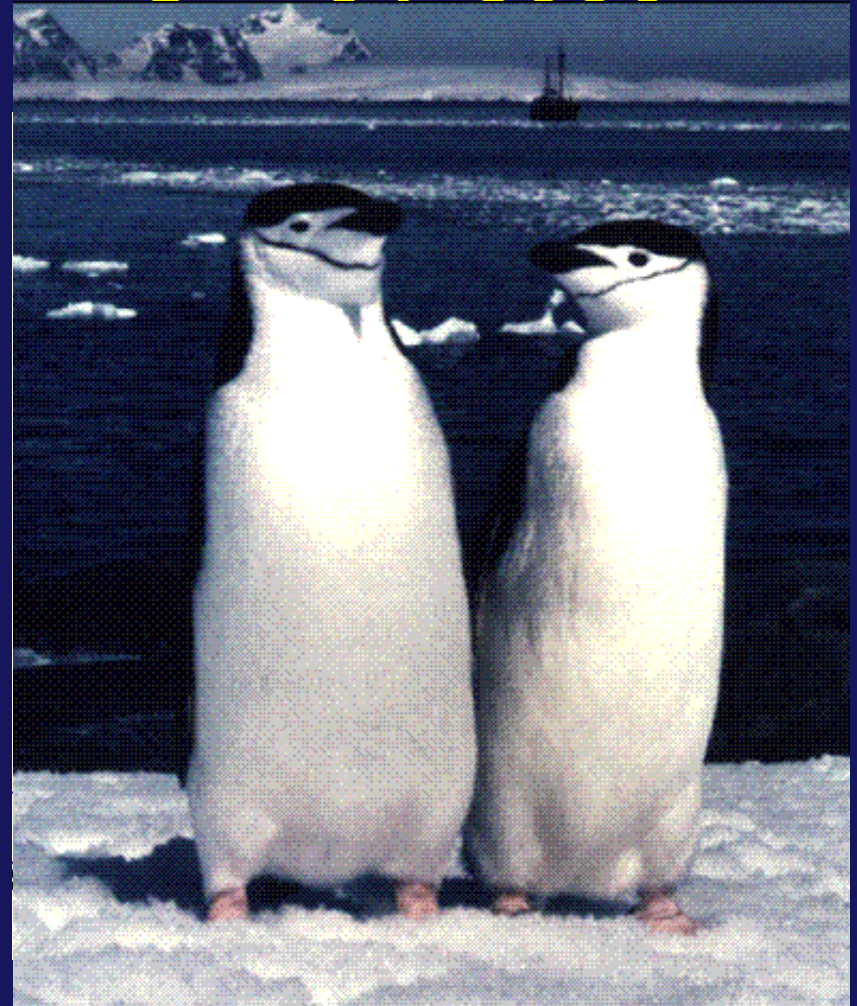
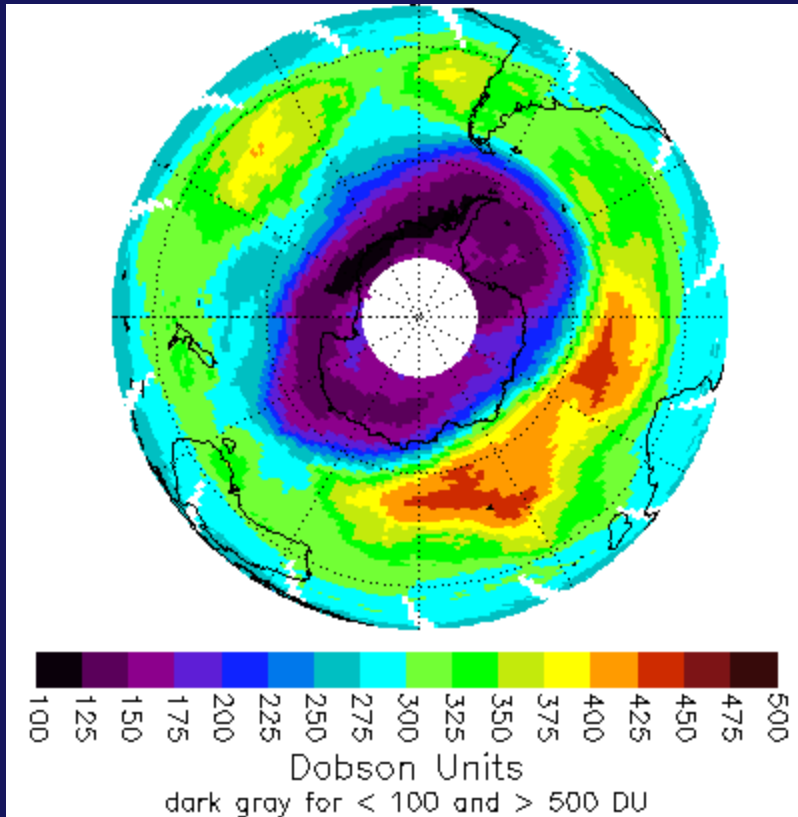
OMI Total Ozone for Oct 8, 2006



**2006** also saw the second **LARGEST** sustained ozone hole.



Sep 9, 2000



Here are some inhabitants with strong cause for concern about the Ozone Hole!  
**But what about the rest of us?**



# 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. . . .

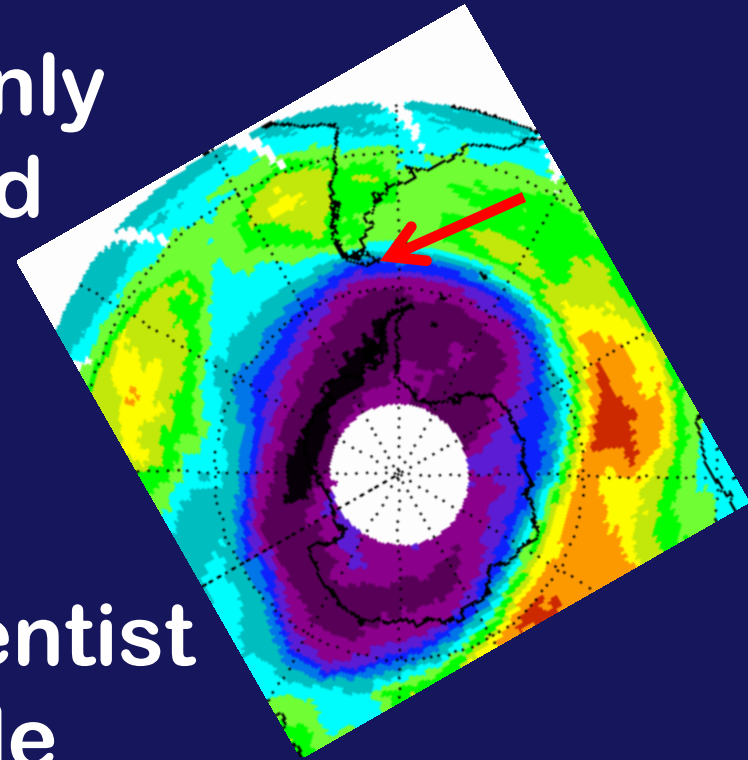


In an Upside-Down World, Sunshine Is Shunned  
(New York Times 12-27-2002)



“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.







A "solar stoplight" in Punta Arenas announces an orange alert, the second highest of four levels, and warns people to limit their exposure to the sun between noon and 3 p.m. to a maximum of 21 minutes.



a woman and her child are bundled up against the sun

“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.”

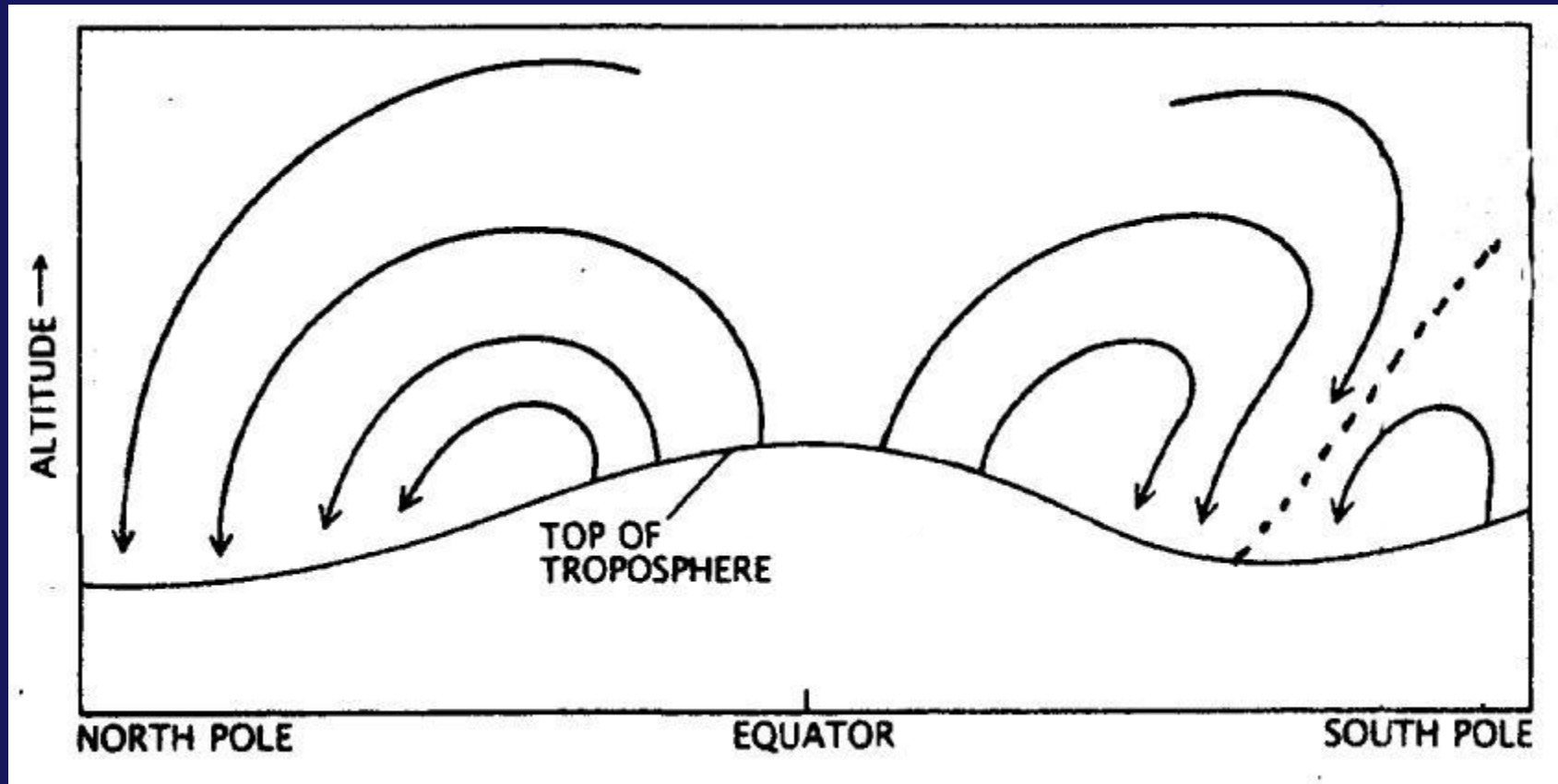


# What about other parts of the globe?

- > Decreases have been observed in nearly all latitude zones:  
(1.1 - 9% in S.H. & 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.

<http://www.theozonehole.com/arcticozone.htm>

# Stratospheric Atmospheric Circulation Determines this Distribution



**Ozone production is highest in tropics  
but stratospheric circulation  
distributes it poleward**



# GROUP CHALLENGE QUESTION:

**Q: Why do you think ozone production in the stratosphere is highest over the TROPICS?**

**Hint: Chapman Mechanism**

**Time to finish up:**

**G-5 ACTIVITY ON  
VOLCANISM & CLIMATE**



**GO CATS!**