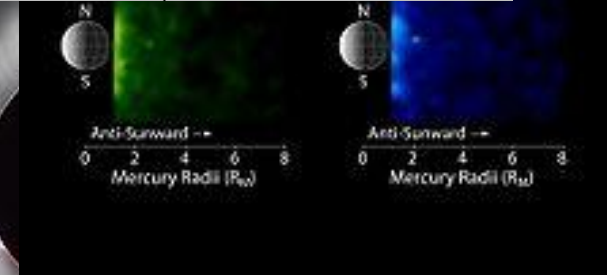
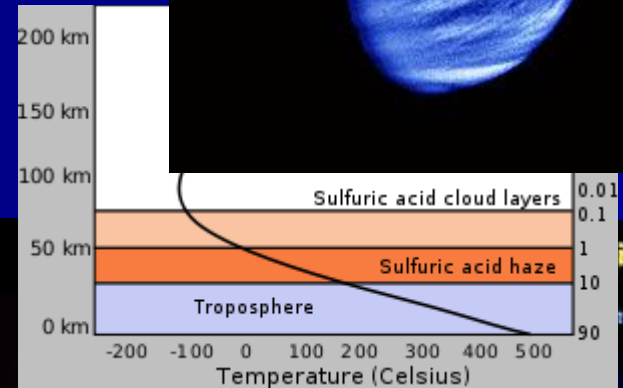
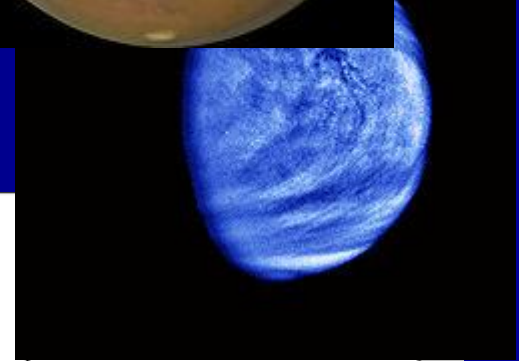
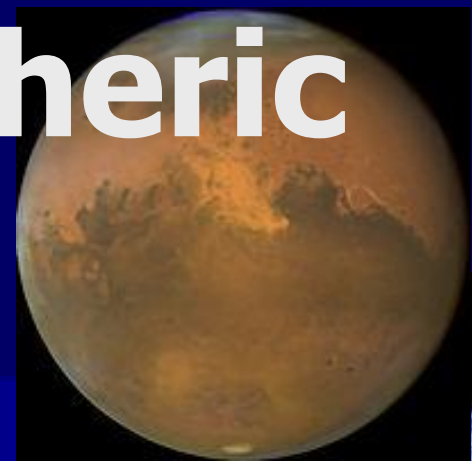
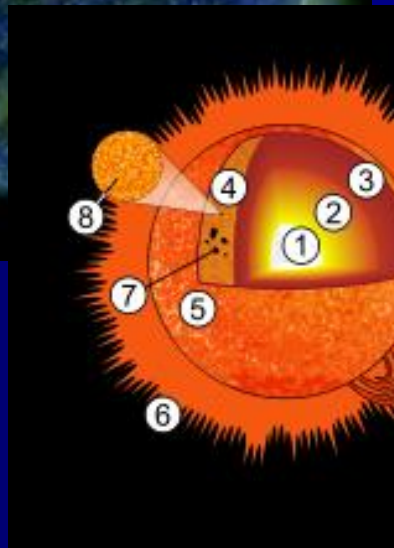
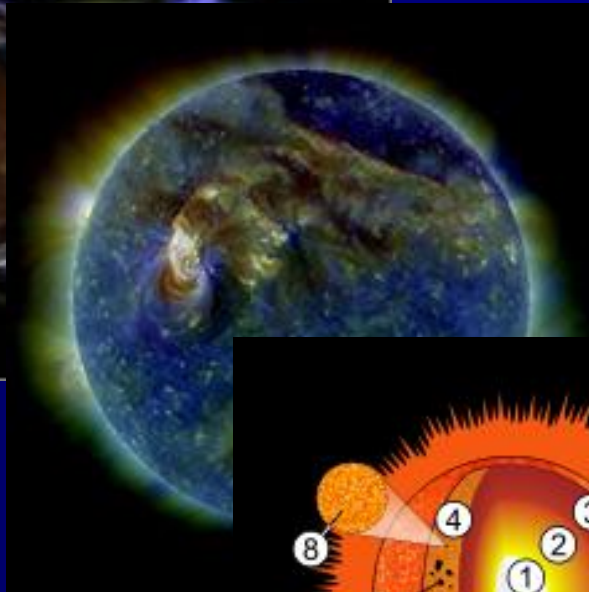
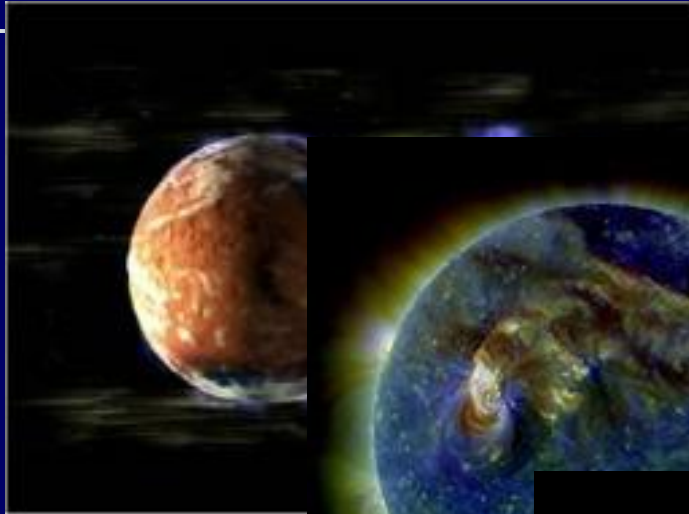


# Space & Atmospheric Physics

# Space & Atmospheric Physics



Lecture – 06

# Earth Atmosphere

Retaining of Gases in the Earth

Major / Minor constituents

Barometric Equation

Scale Height

Atmospheric Regions

**Temperature Profiles**

Retaining of Gases

Number Density Profiles

# Temperature Profile of the Earth

The temperature of the atmosphere of the Earth varies with the **distance from the equator (latitude)** and **height above the surface (altitude)**. It also changes in **time, varying from season to season, from day to night and irregularly due to passing weather systems**. If these variations are averaged out on a global basis, a pattern of average temperatures emerges for the atmosphere.

# Temperature Profile of the Earth

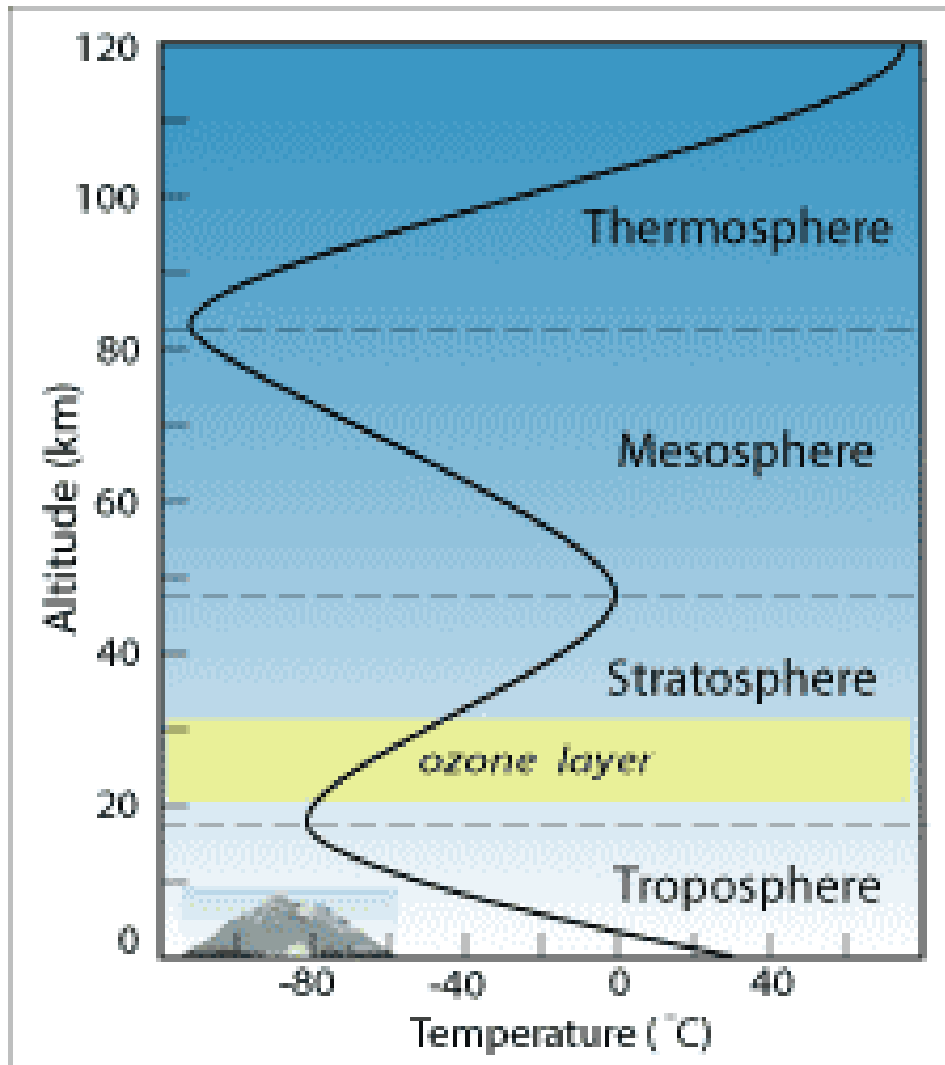
**The vertical temperature profile** (the way temperature changes with height) divides the atmosphere into four layers:

- The troposphere,**
- The stratosphere,**
- The mesosphere,**
- The thermosphere.**

The boundaries between these regions / layers are called tropopause, stratopause and mesopause.

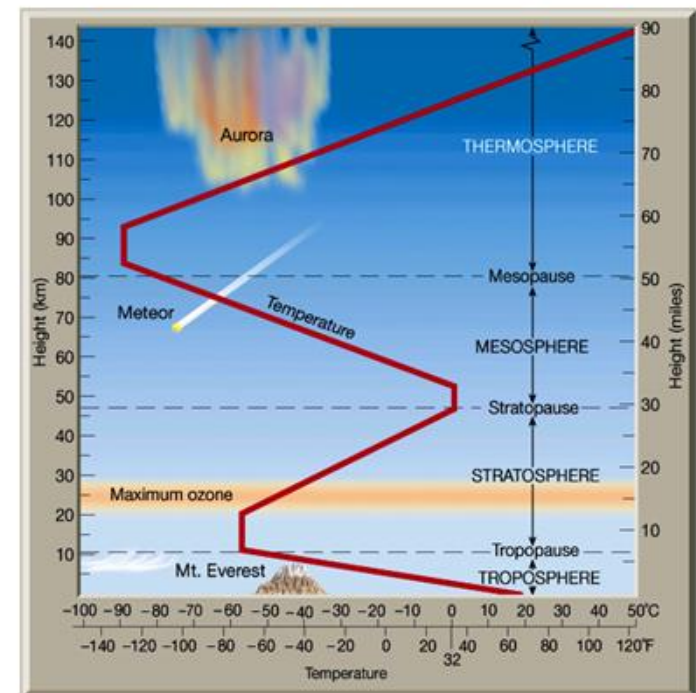
# Temperature Profile



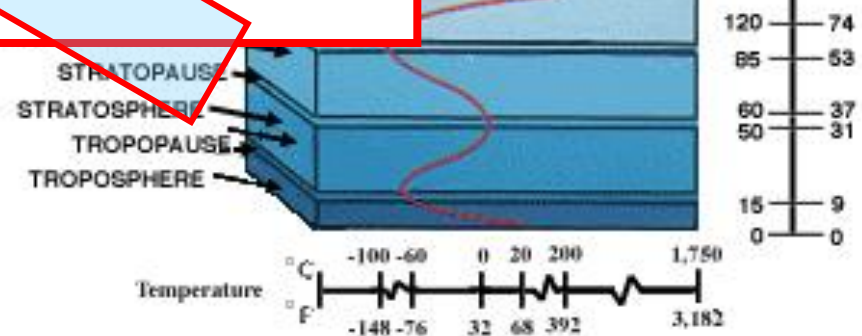
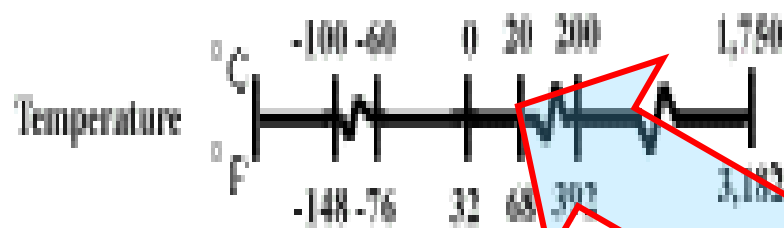
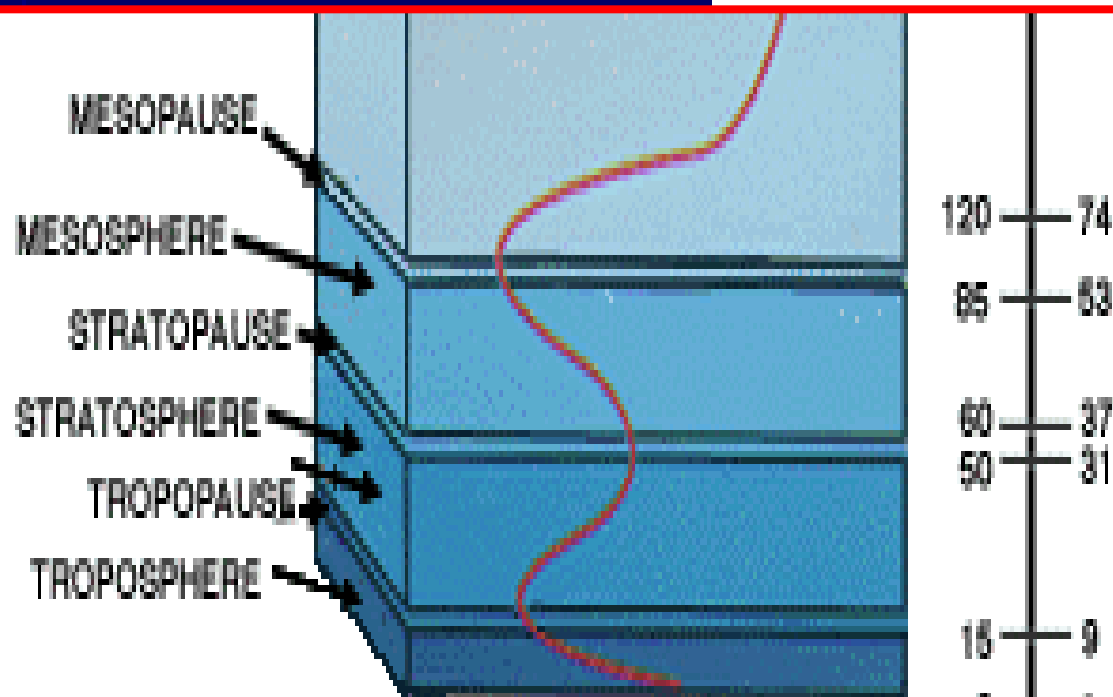


This graph shows how temperature varies with altitude in earth's atmosphere.

### Vertical structure of the atmosphere



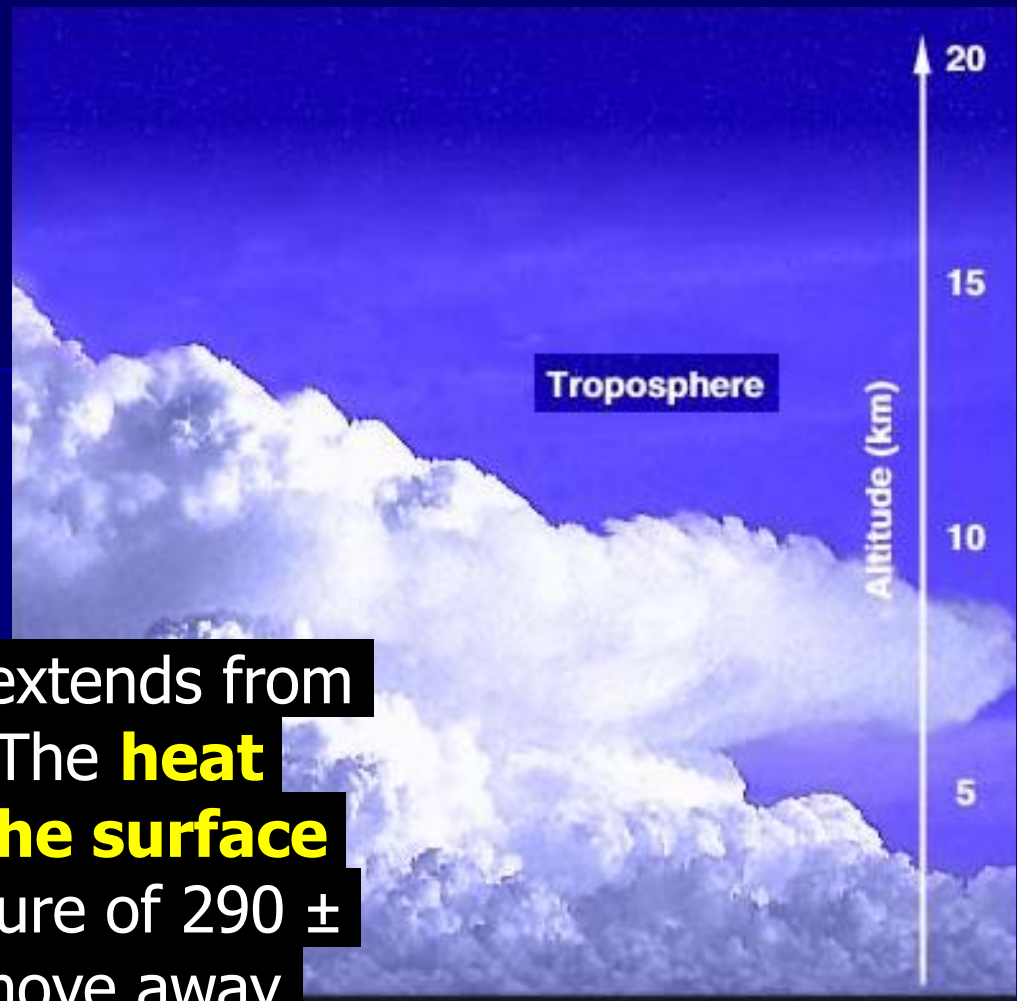






## Troposphere

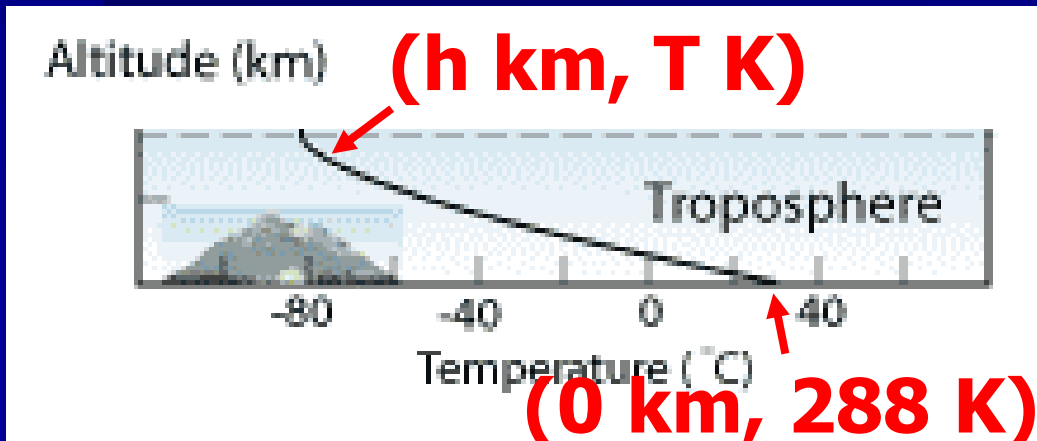
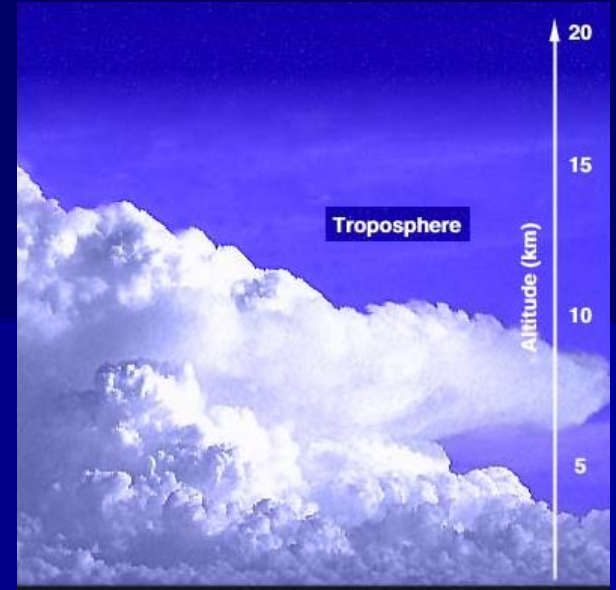
This is the lowest layer and extends from the ground to about 13 km. The **heat source for this region is the surface of the Earth**, at a temperature of  $290 \pm 20$  K and, therefore, as we move away from the ground, the temperature decreases at a rate of reaching a minimum of  $210 \pm 20$  K at the tropopause.



# Troposphere

This level, is just above the cruising altitude of large commercial jet aircraft.

The drop of temperature with height is called the lapse rate, is nearly steady throughout the troposphere at  $6.5^{\circ}\text{C}/\text{km}$ .



The drop of Temperature with height :

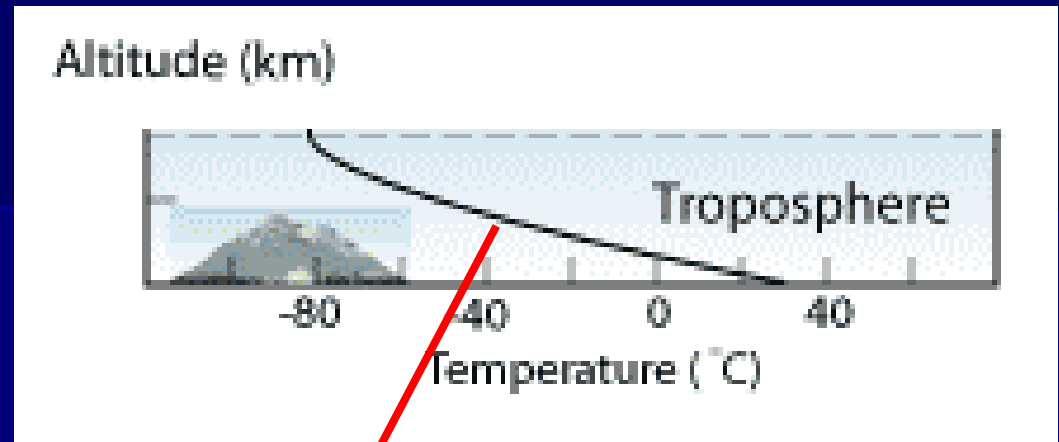
**Lapse Rate :  $6.5^{\circ}\text{C}/\text{km}$**

```
In[1]:= h1 = 0;  
h2 = h;  
rate = -6.5;  
thita1 = 15 + 273;  
thita2 = T;  
Solve[  
  ((thita2 - thita1) / (h2 - h1)) ==  
  rate, T]
```

$$\text{Out[6]} = \left\{ \left\{ T \rightarrow \left( -6.5 + \frac{288.}{h} \right) h \right\} \right\}$$

# Troposphere

Altitude (km)	Temperature (K)
0	288
2	275
4	262
6	249
8	236
10	223
12	210



**Lapse Rate : 6.5  
°C / km**

## Tropopause:

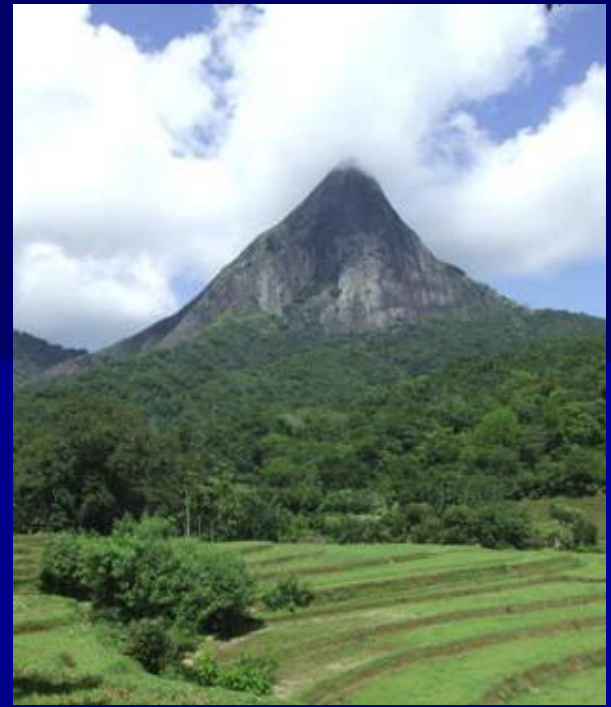
The upper boundary of the troposphere occurring at an altitude of  $13 \pm 5$  km.

$$T(h) = -6.5 h + 288$$

(K)      (km)      (K)

**1 °C = 1 K**      (K)

**Pidurutalagala**, or Mount Pedro in English, is an ultra prominent peak, and the tallest mountain in Sri Lanka, at **2,524 m**. Find the temperature at the top of the mountain. **Answer : 10.5 °C**

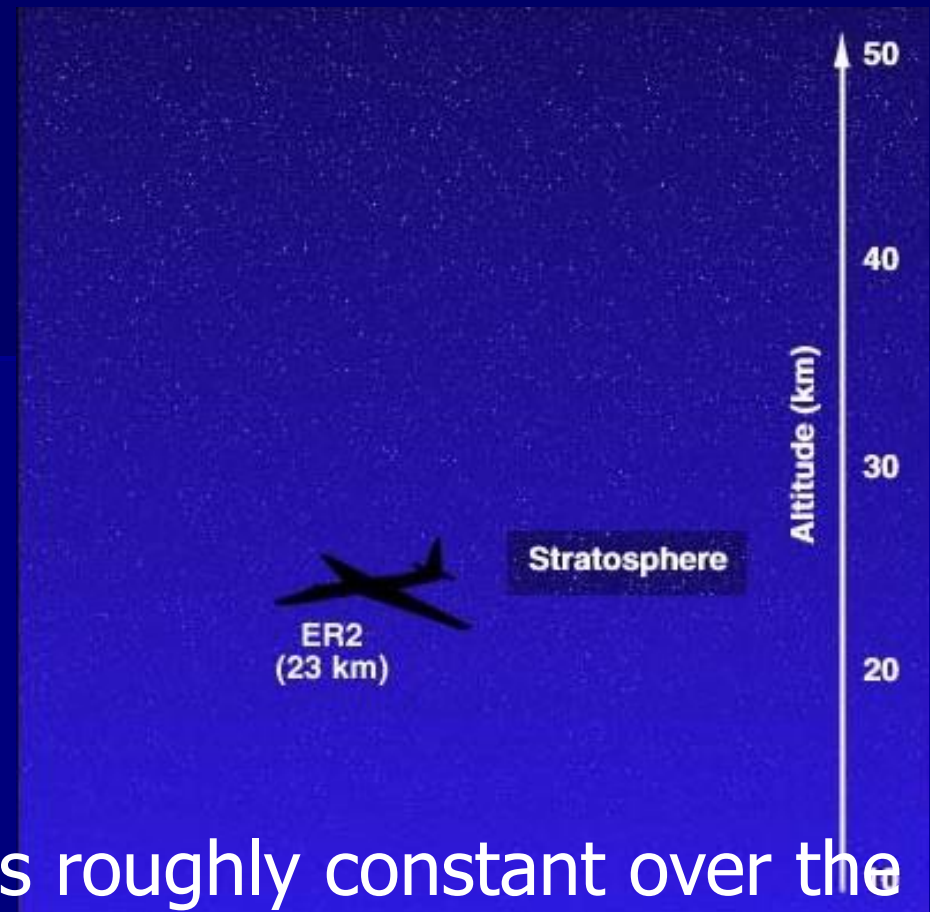


**Mount Everest**, is Earth's highest mountain. Its peak is **8,848 meters** above sea level. Find the temperature at the top of the mountain.

**Answer : - 30.5 °C**

## Stratosphere:

The stratosphere is situated directly above the troposphere and just below the mesosphere.



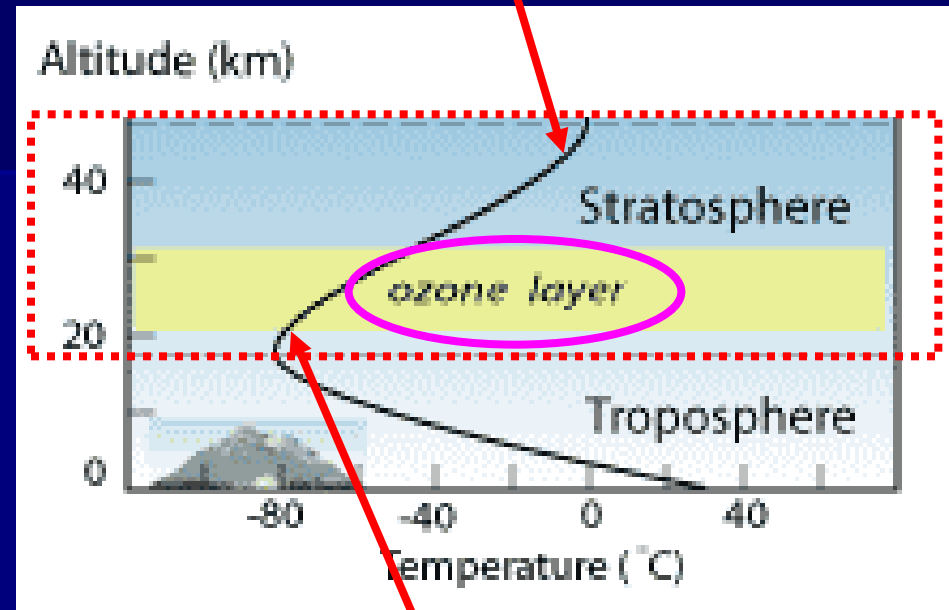
Atmospheric temperature is roughly constant over the next 20 km and then begins to rise with increasing altitude up to about 50 km. This region of increasing temperatures is the stratosphere. At the top of the layer, called the stratopause, temperatures are nearly as warm as the surface values.



# Stratosphere:

The temperature begins to rise in this region reaching a maximum of  $270 \pm 20$  K at the stratopause.

**The heating of the stratosphere is due to the absorption of the ultraviolet radiation in the 2000 Å - 3000 Å range by the Ozone in the ozonosphere.**



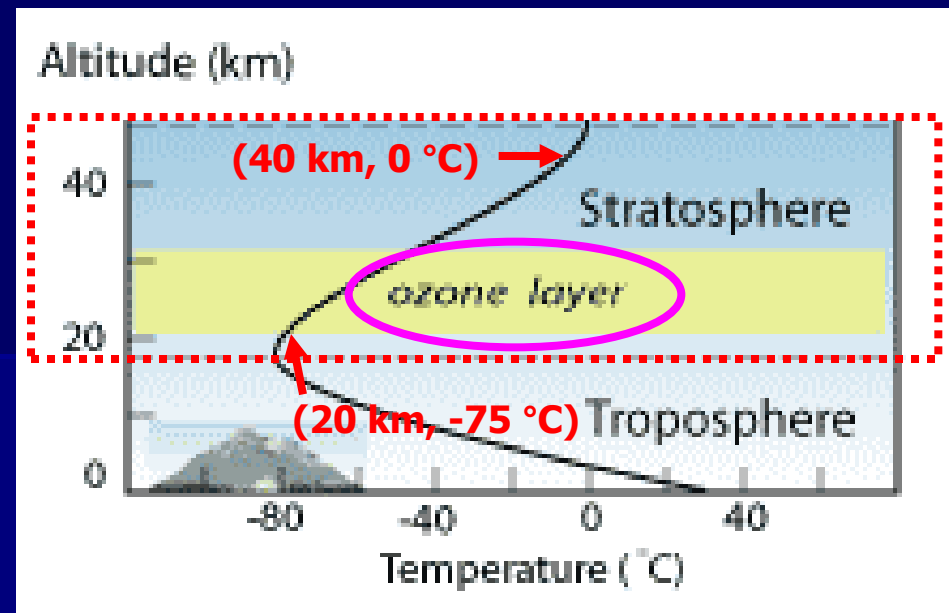
(40 km, 0 °C)

(20 km, -75 °C)



## Stratosphere:

The upper layers of the stratosphere are heated by the presence of an ozone layer that absorbs **ultraviolet (UV) radiation from the Sun** that would otherwise be harmful to living organisms on Earth. The **Ozone layer reaches a maximum concentration around 20 – 25 km.**



## Stratopause:

The upper boundary of the stratosphere occurring at an altitude of  $50 \pm 5$  km.

```
In[62]:= h1 = 20;  
h2 = 40;  
thita1 = -75 + 273;  
thita2 = 0 + 273;  
Solve[ ((T - thita1) / (h - h1)) ==  
        ((thita2 - thita1) / (h2 - h1)),  
        T]
```

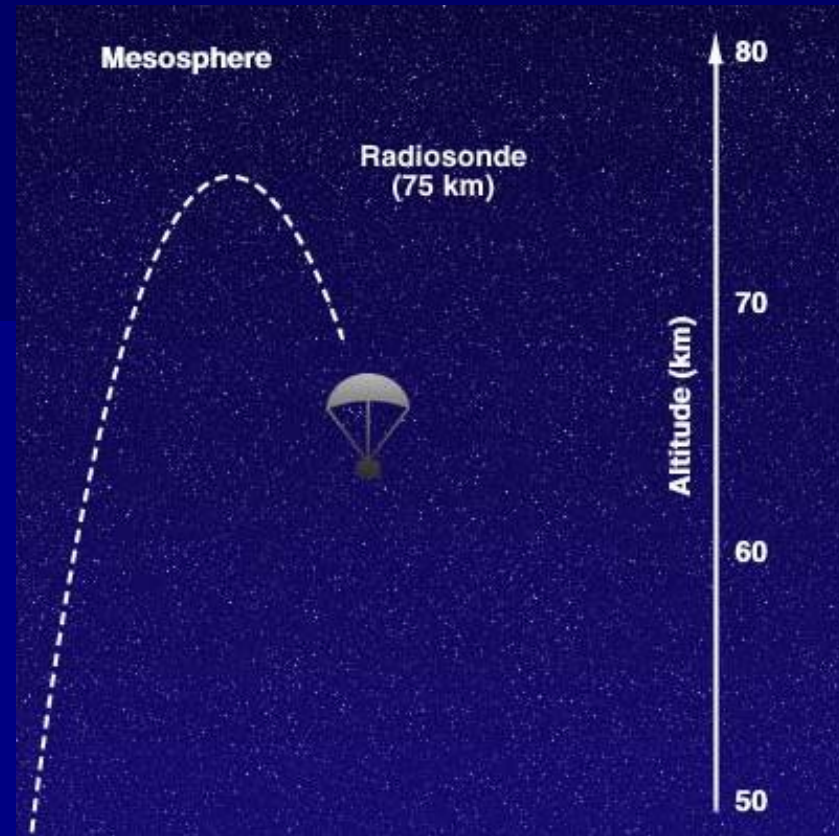
```
Out[66]= { { T -> 3/4 (164 + 5 h) } }
```

$$T(h) = 3.75 h + 123$$

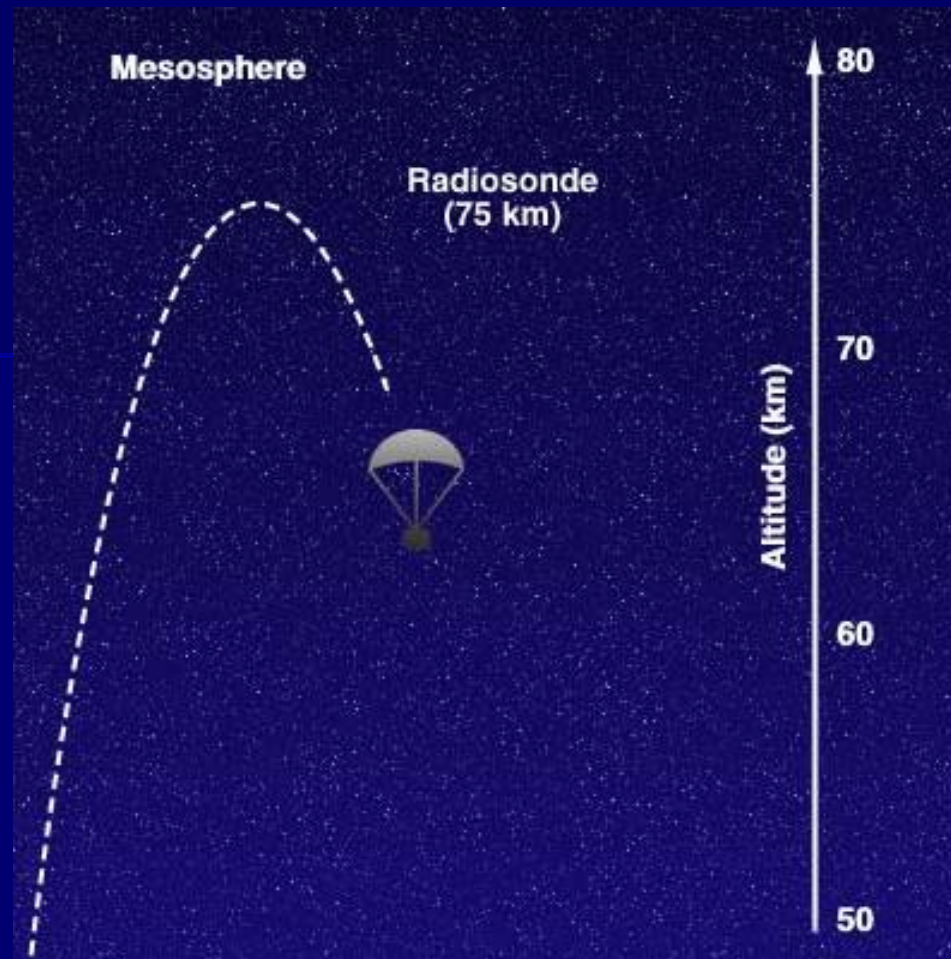
# Mesosphere:

It is sandwiched between the stratosphere and the thermosphere.

Between about 50–80 km lies the mesosphere, where atmospheric temperature resumes its drop with altitude and reaches a very cold minimum of 180K ( $-93^{\circ}\text{C}$ ) at the top of the layer (the mesopause), around 80 km.



# Mesosphere:

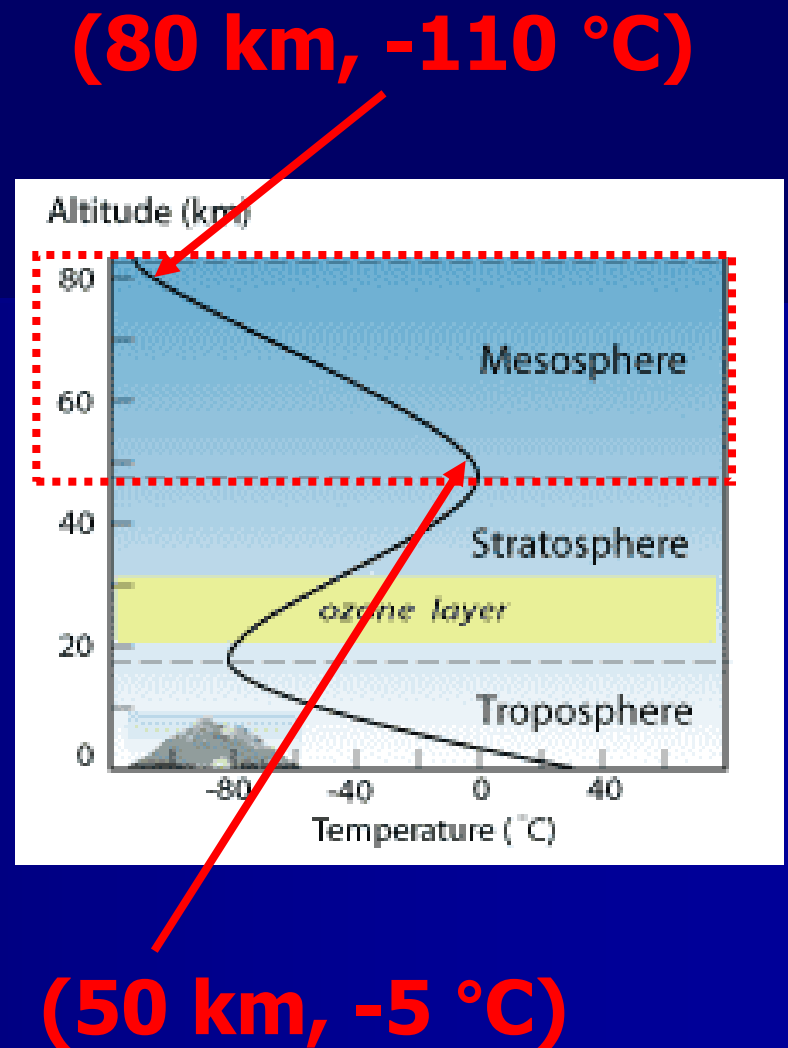


**Millions of meteors burn up daily** in the mesosphere, as a result of collisions with the gas particles contained there, leading to a high concentration of iron and other metal atoms.

## Mesosphere:

The temperature starts decreasing with height in the region due to an **energy sink provided by the CO<sub>2</sub> and Oxygen emission in the far infrared**. It reaches a minimum of  $180 \pm 20$  K at the mesopause.

**Mesopause:** The upper boundary of the mesosphere occurring at an altitude of  $85 \pm 5$  km.



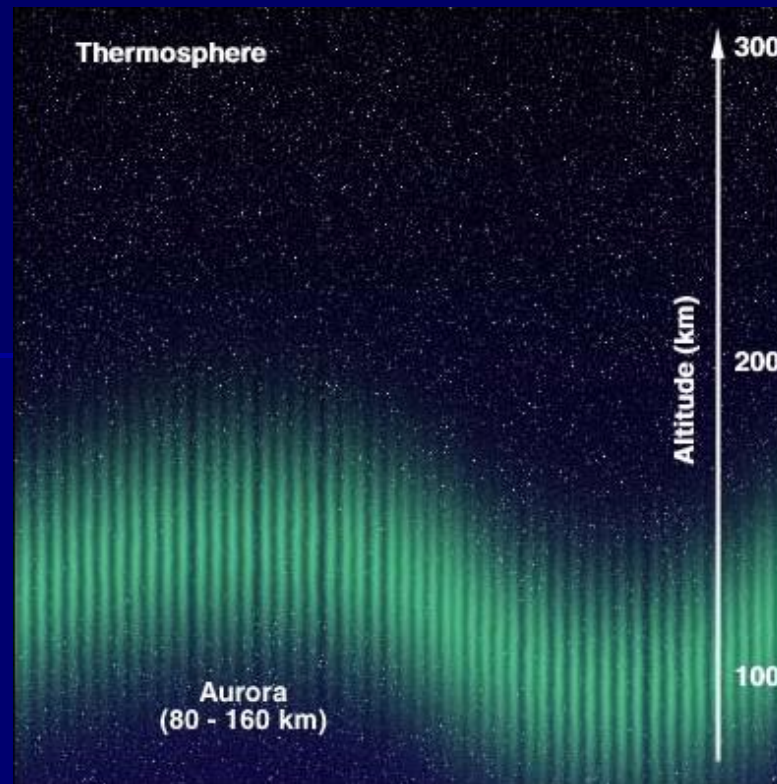


```
In[57]:= h1 = 50;  
h2 = 80;  
thita1 = -5 + 273;  
thita2 = -110 + 273;  
Solve[ ((T - thita1) / (h - h1)) ==  
        ((thita2 - thita1) / (h2 - h1)),  
        T]
```

```
Out[61]= { { T -> 1/2 (886 - 7 h) } }
```

$$T(h) = -3.5 h + 443$$

# Thermosphere:



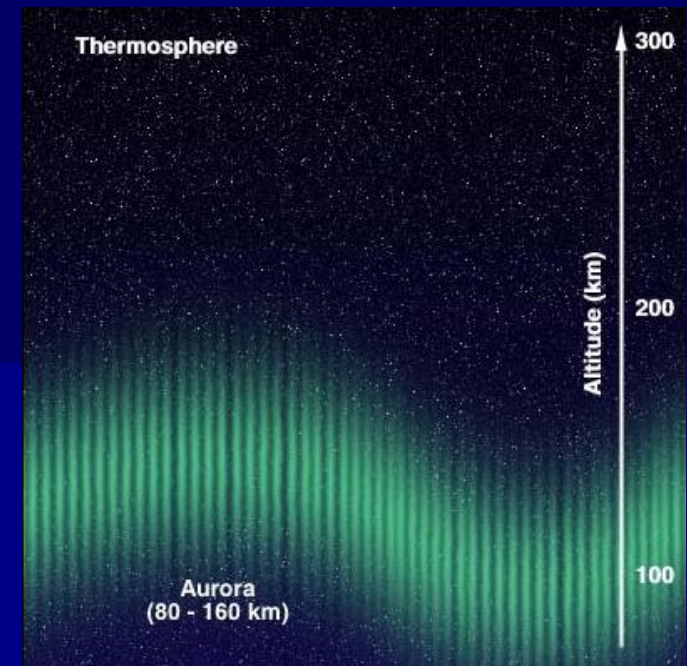
Above the mesopause is the thermosphere, which as its name implies is a zone of high gas temperatures. In the very high thermosphere (about 500 km above Earth's surface) gas temperatures can reach from 500 K – 2,000K (227°C – 1,727°C), depending on how active the sun is.



## Thermosphere:

However, **these figures are somewhat misleading.**

Temperature is a measure of the energy of the gas molecules' motion. Although they have high energies, the molecules in the thermosphere are present in very low numbers, less than one millionth of the amount present on average at Earth's surface. **If a person were in the thermosphere, it would feel to them much more like the icy cold of space because such a small number of energetic gas molecules would be unable to transfer much of their heat energy.**



## Thermosphere:



The aurora (the Southern and Northern Lights) primarily occur in the thermosphere. Charged particles (electrons, protons, and other ions) from space collide with atoms and molecules in the thermosphere at high latitudes, exciting them into higher energy states. Those atoms and molecules shed this excess energy by emitting photons of light, which we see as colorful auroral displays.

## Thermosphere:

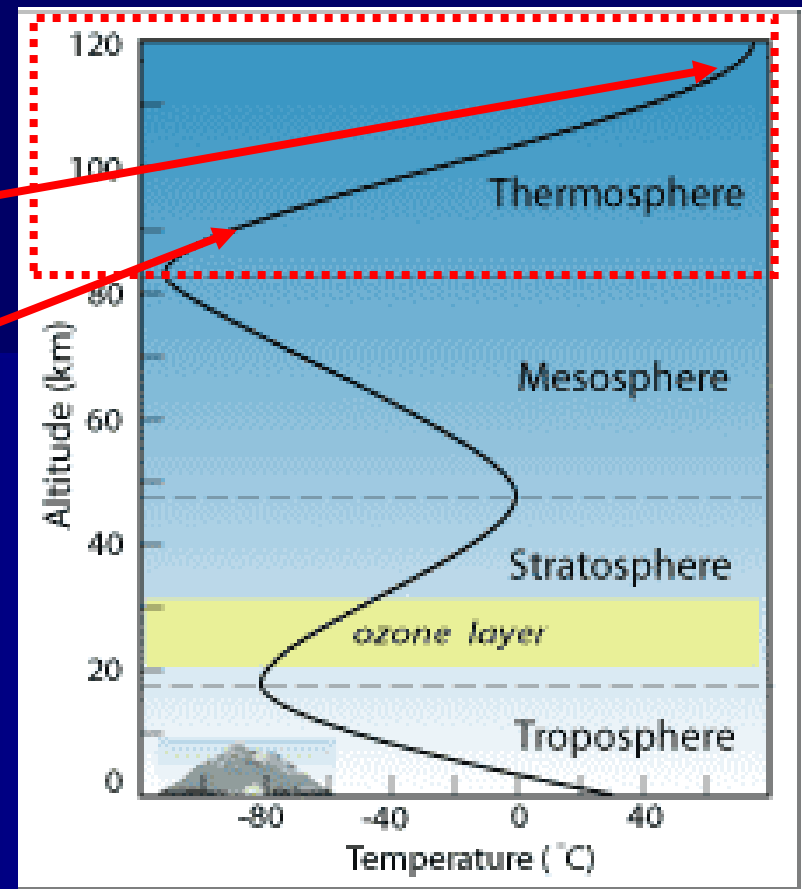


**The aurora :** the aurora is formed when protons and electrons from the Sun travel along the Earth's magnetic field lines. The lights of the aurora come in different colours. **Oxygen atoms** give off green light and sometimes red. **Nitrogen** molecules glow red, blue, and purple.

# Thermosphere:

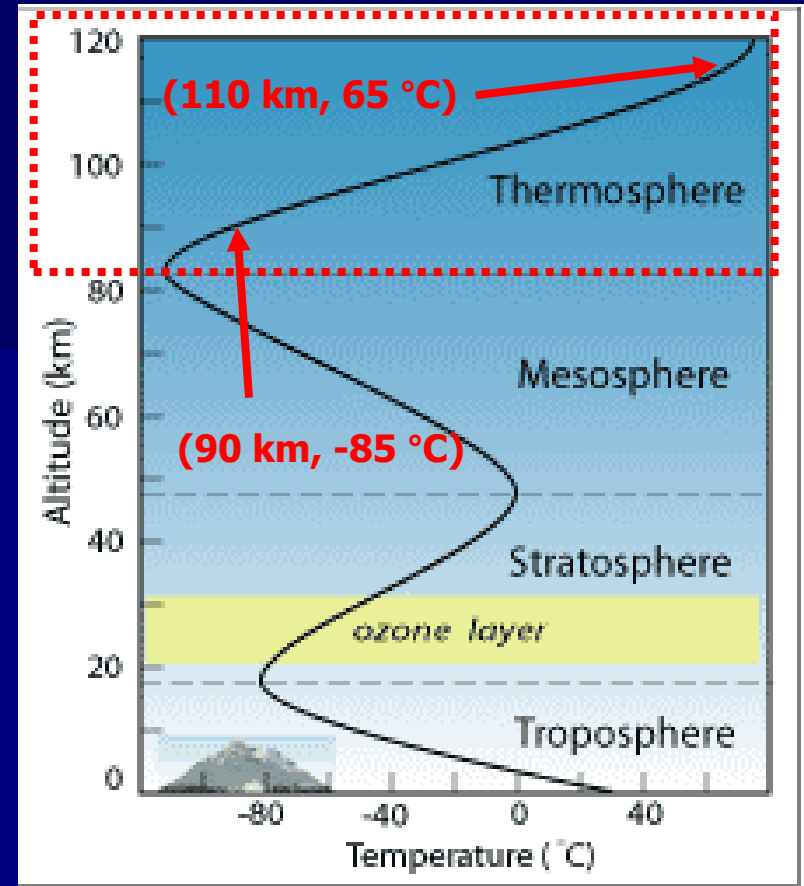
(110 km, 65 °C)

(90 km, -85 °C)



The temperature increases steeply with height in this region reaching its peak value of  $1500 \pm 500$  K at the thermopause. The very effective **heating source of this layer is the far ultra-violet ( $100 \text{ \AA} - 2000 \text{ \AA}$ ) radiation from the Sun which is absorbed....**

# Thermosphere:



..... which is absorbed in this region causing the photodissociation and photoionization of the atmospheric constituents. Solar particles and meteors also make a small contribution to the heating process.

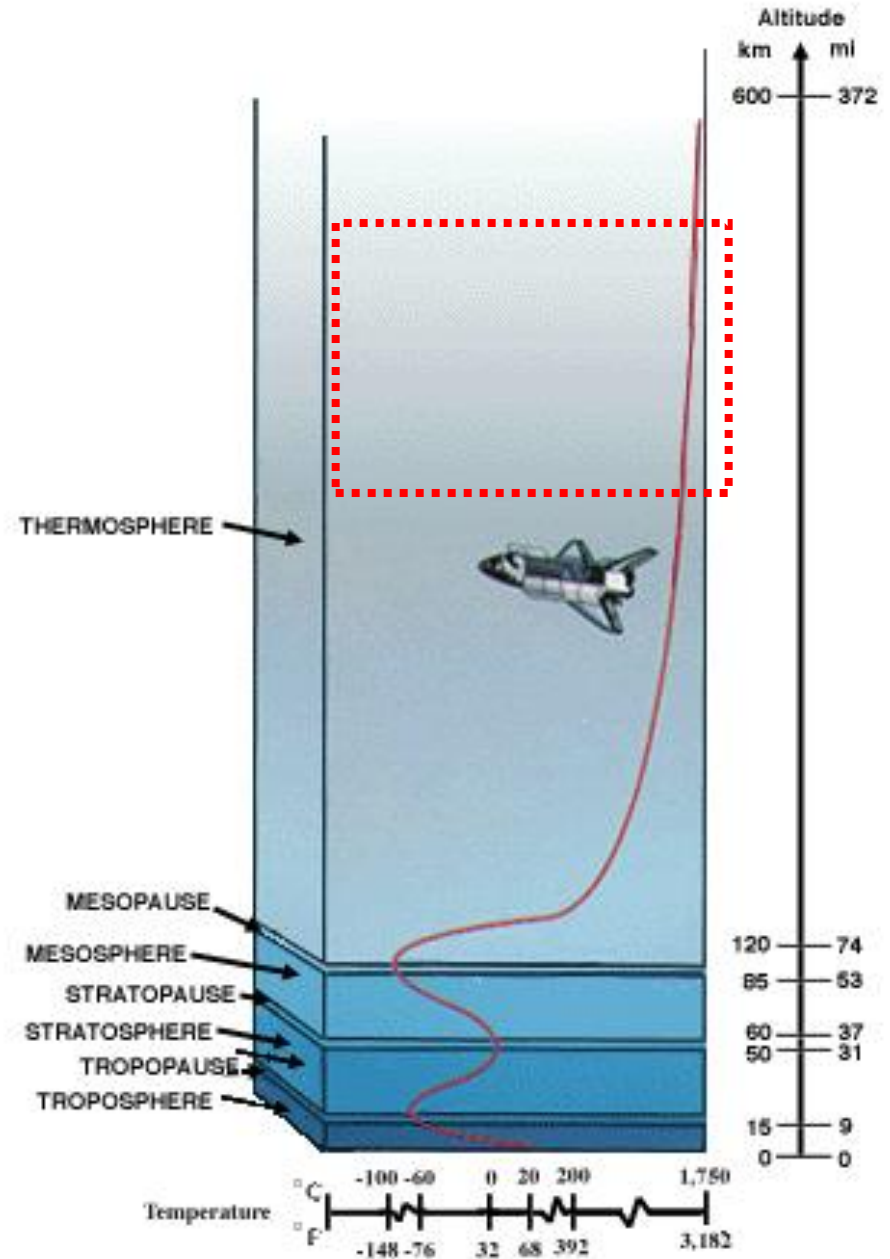
```
In[75]:= h1 = 90;  
h2 = 110;  
thita1 = -85 + 273;  
thita2 = 65 + 273;  
Solve[ ((T - thita1) / (h - h1)) ==  
        ((thita2 - thita1) / (h2 - h1)),  
        T]
```

```
Out[79]= { { T -> 1/2 (-974 + 15 h) } }
```

$$T(h) = 7.5 h - 487$$

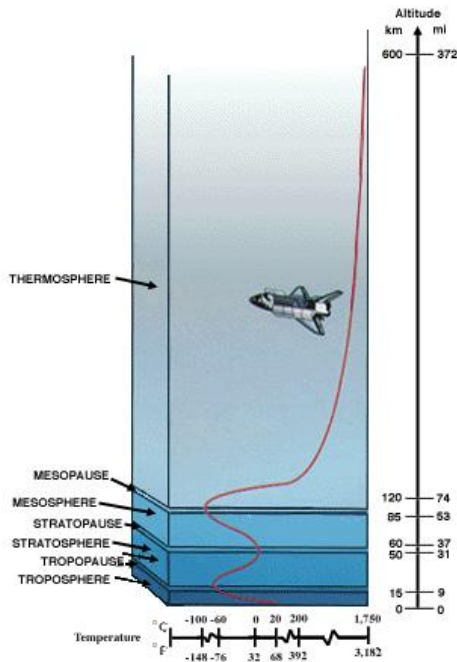
# Thermopause:

The upper boundary of the thermosphere occurring at an altitude of  $350 \pm 100$  km. Above this height the atmosphere, due to its high thermal conductivity, maintains the same high temperature which it first reached at the thermopause.





# Summary :



**T (h)**

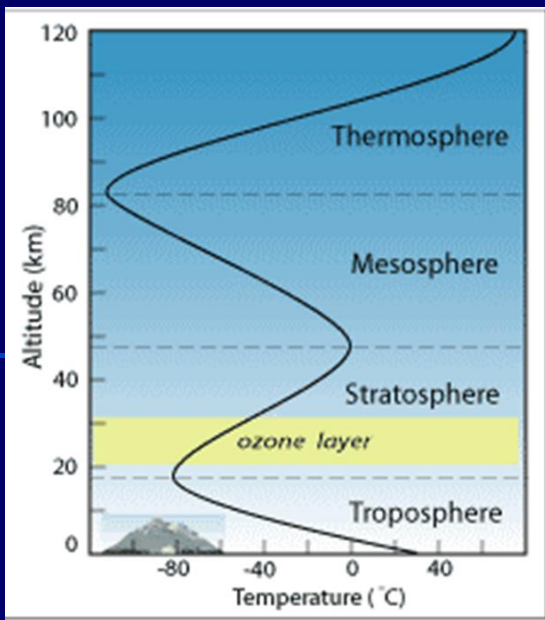
$$- 6.5 h + 288 \quad ; \quad 0 \leq h < 20 \text{ km}$$

$$3.75 h + 123 \quad ; \quad 20 \leq h < 40 \text{ km}$$

$$- 3.5 h + 443 \quad ; \quad 50 \leq h < 80 \text{ km}$$

$$7.5 h - 487 \quad ; \quad 90 \leq h < 110 \text{ km}$$

# Ozone Layer

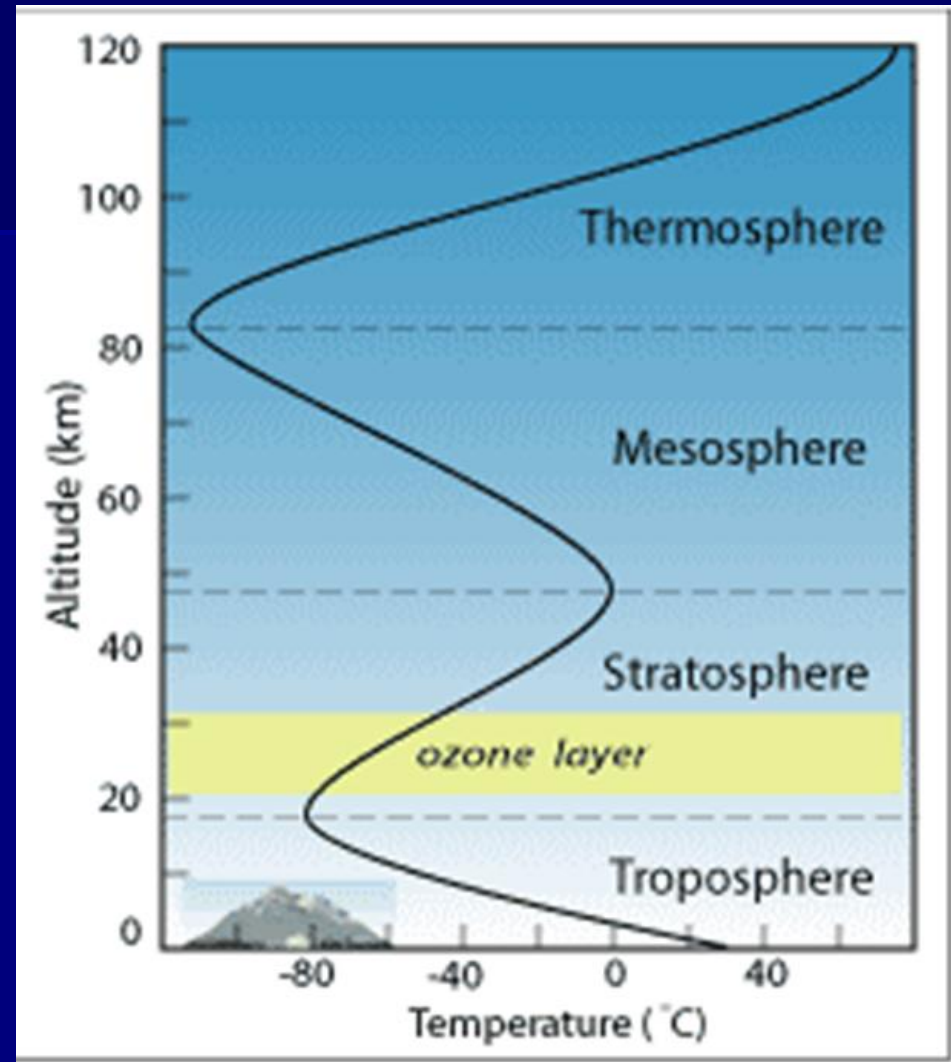


## Ozone Layer :

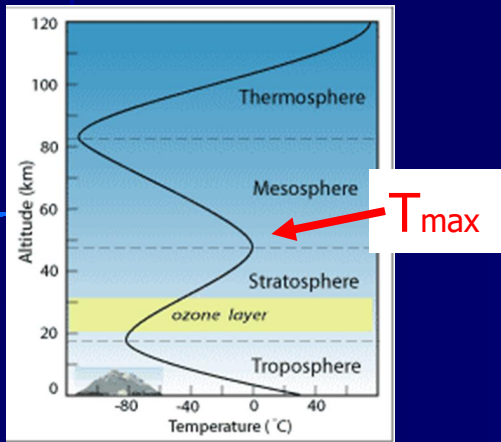
The variation of the middle of the graph is due to the Ozone Layer. Because the UV (ultra violet) radiation from the Sun is absorbed by the Ozone Layer. As a result the UV reacts with the atoms of the O<sub>3</sub> layer increases.

In a planet, the temperature decreases as the distance surface of the planet increases. But after certain distance, due to the effect of the Sun, the temperature increases again.

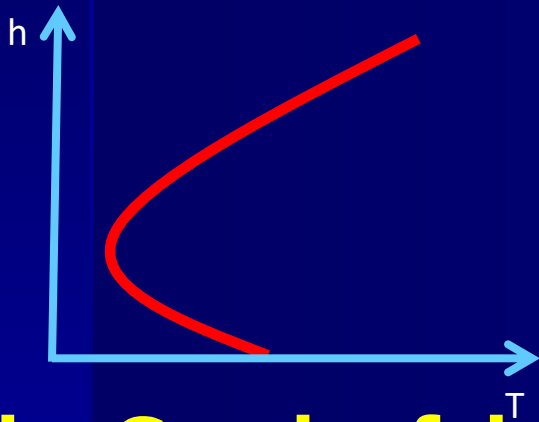
But the Earth behaves slightly different from the normal planet. That is when the distance from the surface of the Earth increases, initially the temperature decreases, then the temperature increases, again after a certain distance the temperature decreases and finally the temperature increases continuously !



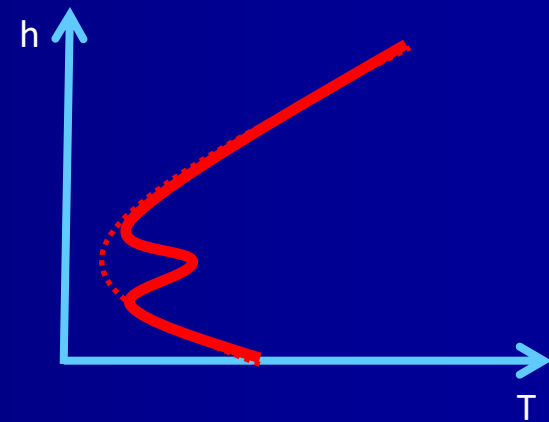
# Ozone Layer :



This  $T_{max}$  of the middle of the graph, is **depend on the number of O<sub>3</sub> exist in the Ozone Layer**. If we study the graph of **Height vs Temperature** of any planet, we can get an idea whether it has an Ozone Layer or Not !



**The Graph of h vs T of a planet which does not consist an Ozone Layer**

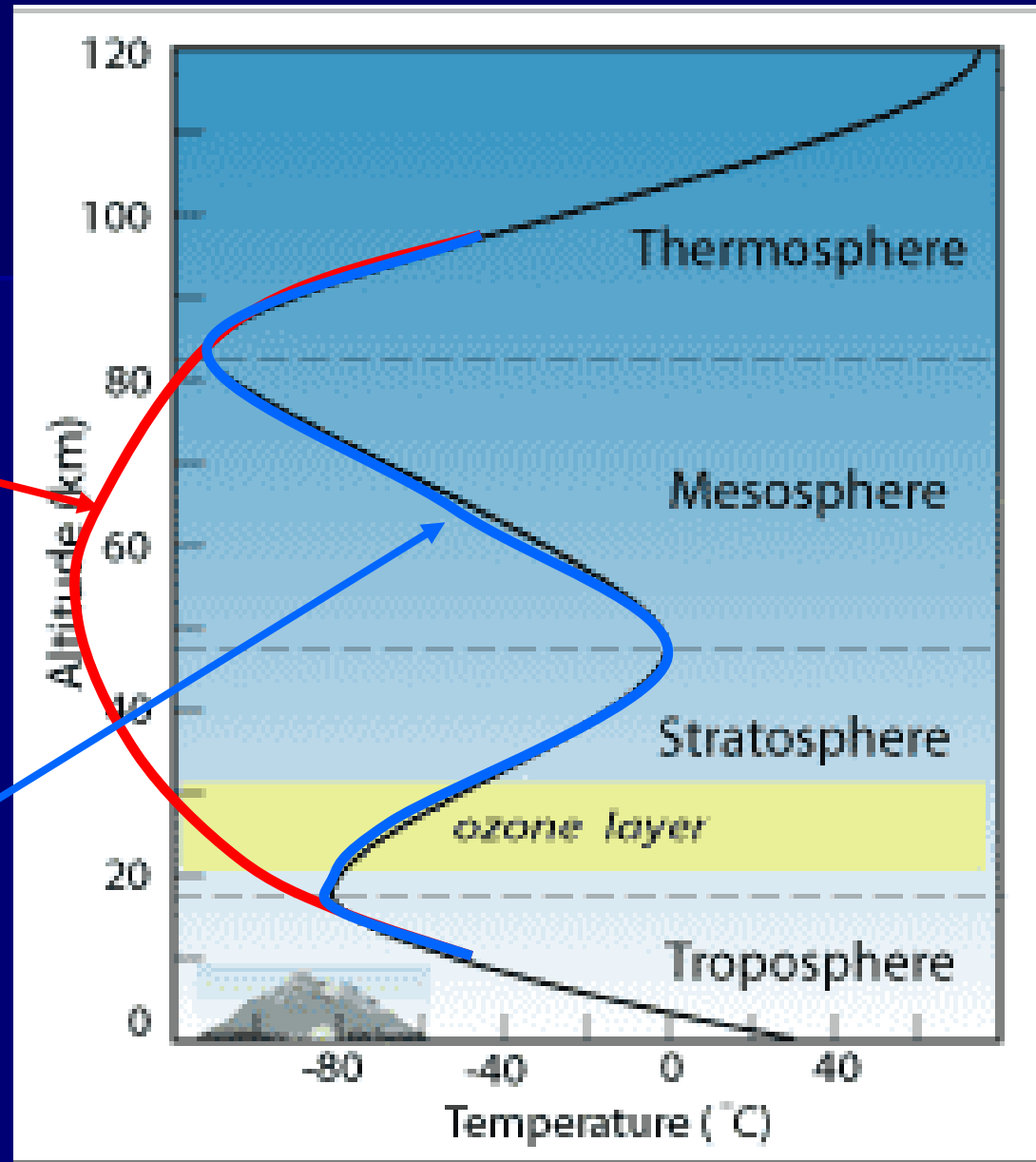


**The Graph of h vs T of a planet which consist an Ozone Layer**

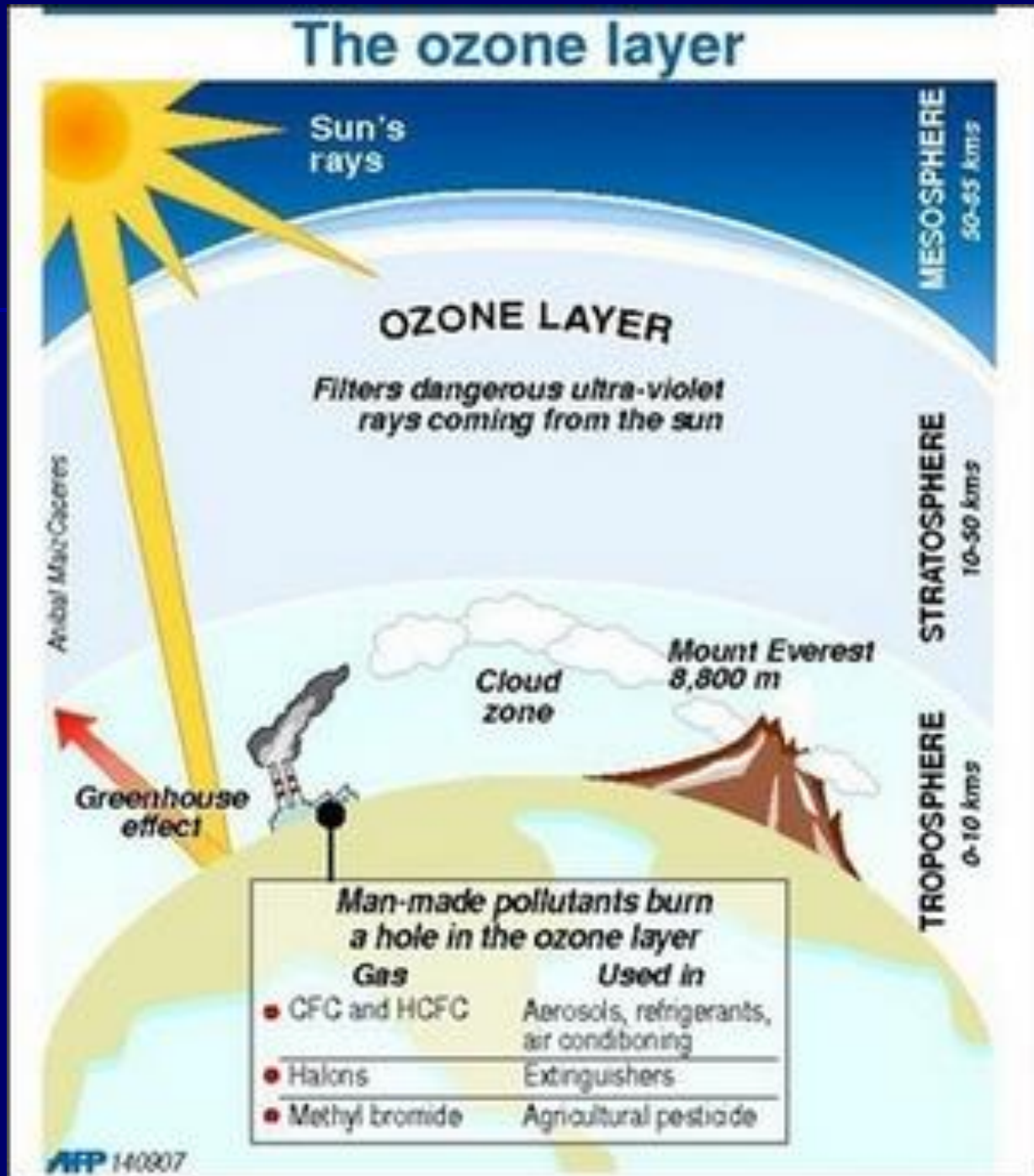
# Altitude vs Temperature Graph of a Planet :

A planet which does not consist an Ozone Layer

A planet which consists an Ozone Layer



# OZONE LAYER





# Ozone layer

The **ozone layer** is a layer in **Earth's Atmosphere** **which contains relatively high concentrations of ozone** ( $O_3$ ).

This layer absorbs 97–99% of the Sun's high frequency ultraviolet light, which is damaging to life on Earth. It is mainly located in the lower portion of the stratosphere from approximately **13 to 40 kilometres above Earth**, though the **thickness varies seasonally and geographically**.

# Ozone layer

The ozone layer was discovered in **1913 by the French physicists Charles Fabry and Henri Buisson.**



**Henri Buisson**



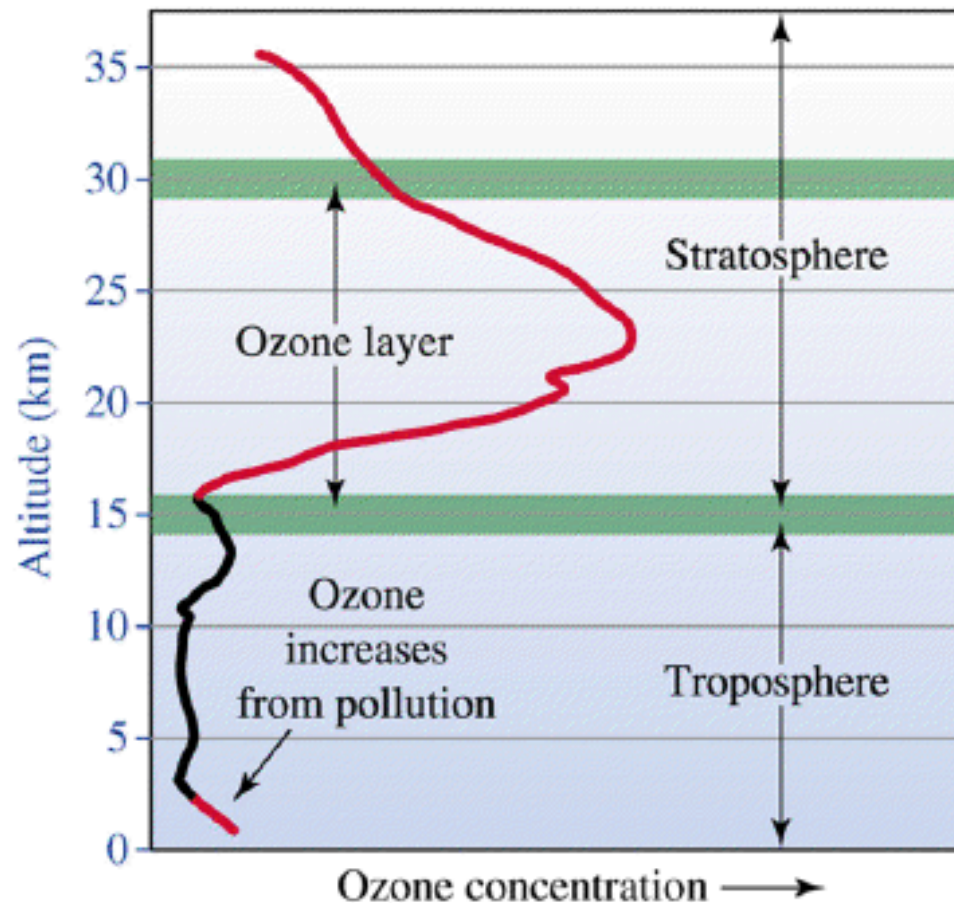
**Charles Fabry**

# Ozone layer

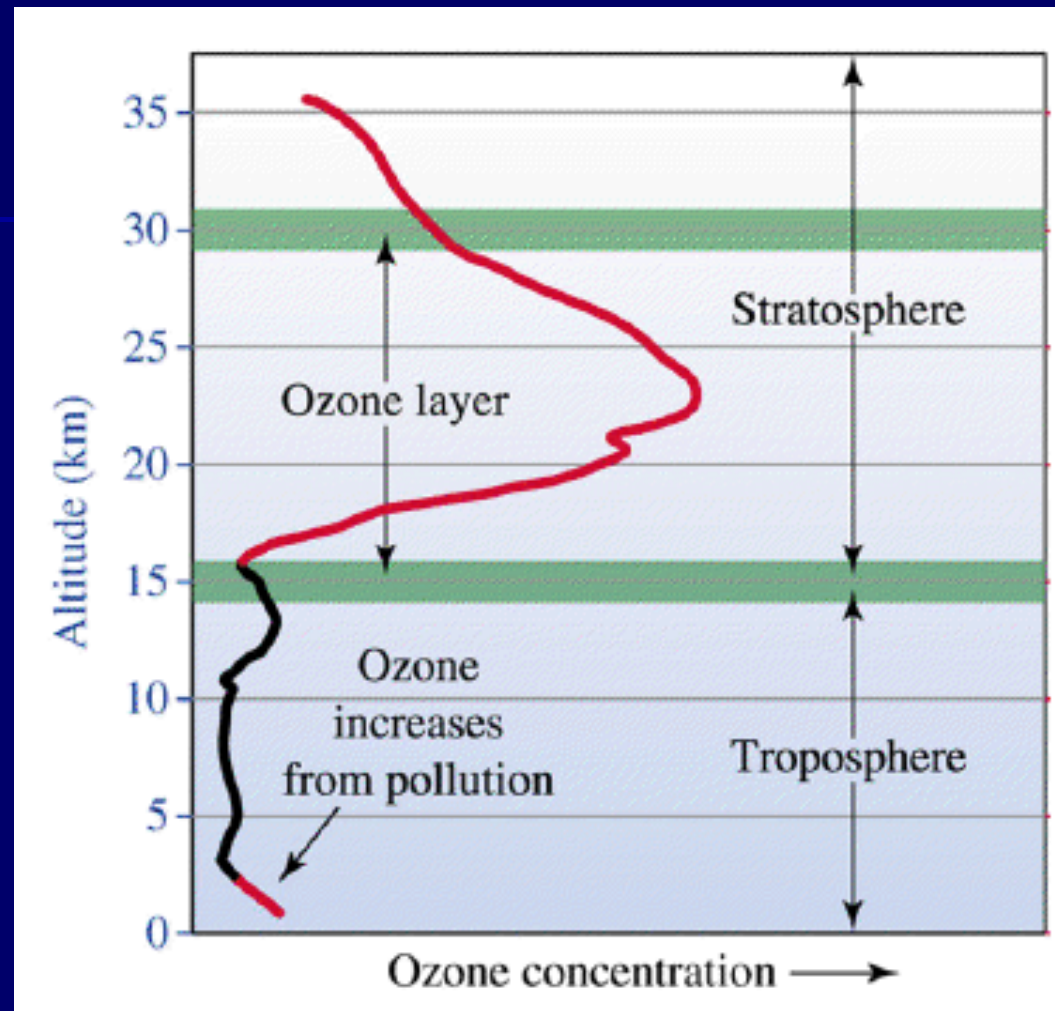


Its properties were explored in detail by the British meteorologist G. M. B. Dobson, who developed a simple spectrophotometer (the Dobson meter) that could be used to measure stratospheric ozone from the ground. Between 1928 and 1958 Dobson established a worldwide network of ozone monitoring stations, which continue to operate to this day. The "**Dobson Unit**", a convenient measure of the **columnar density of ozone overhead**, is named in his honour.

# The Ozone Layer



# What is the maximum concentration of ozone in the ozone layer?

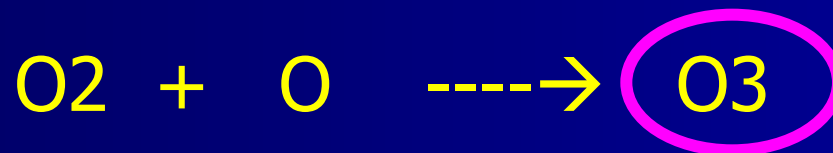


- Maximum of absolute conc about 23 km (up to  $10^{13}$  molecules/mL)
- Maximum of relative conc about 35 km (up to 10 ppm)

# Origin of ozone

The photochemical mechanisms that give rise to the ozone layer were discovered by the British physicist Sidney Chapman in 1930.

Ozone in the Earth's stratosphere is created by ultraviolet light striking oxygen molecules containing two oxygen atoms (O<sub>2</sub>), splitting them into individual oxygen atoms (atomic oxygen); the atomic oxygen then combines with unbroken O<sub>2</sub> to create ozone, O<sub>3</sub>.



# Origin of ozone

The ozone molecule is also unstable (although, in the stratosphere, long-lived) and when ultraviolet light hits ozone it splits into a molecule of O<sub>2</sub> and an atom of atomic oxygen, a continuing process called the ozone oxygen cycle, thus creating an ozone layer in the stratosphere, the region from about 10 to 50 kilometres above Earth's surface.



For this reaction, wave length of the UV radiation should be less than 3100 Å



# Origin of ozone



**$10^6$  O<sub>2</sub> molecules are required to absorb the same amount of radiation that is absorbed by a single O<sub>3</sub> molecule. This is the importance of O<sub>3</sub>!**

After O<sub>3</sub> reacting with UV radiation from the Sun, it produces O<sub>2</sub> and O atoms and energy and again O<sub>2</sub> and O atoms recombine naturally in the Ozone layer to reproduce O<sub>3</sub>.

# Origin of ozone



**$10^6$  O<sub>2</sub> molecules are required to absorb the same amount of radiation that is absorbed by a single O<sub>3</sub> molecule. This is the importance of O<sub>3</sub>!**

After O<sub>3</sub> reacting with UV radiation from the Sun, it produces O<sub>2</sub> and O atoms and energy and again O<sub>2</sub> and O atoms recombine naturally in the Ozone layer to reproduce O<sub>3</sub>.

About 90% of the ozone in our atmosphere is contained in the stratosphere. Ozone concentrations are greatest between about 20 and 40 kilometres, where they range from about 2 to 8 parts per million. **If all of the ozone were compressed to the pressure of the air at sea level, it would be only a few milli-meters thick.**

# Origin of ozone

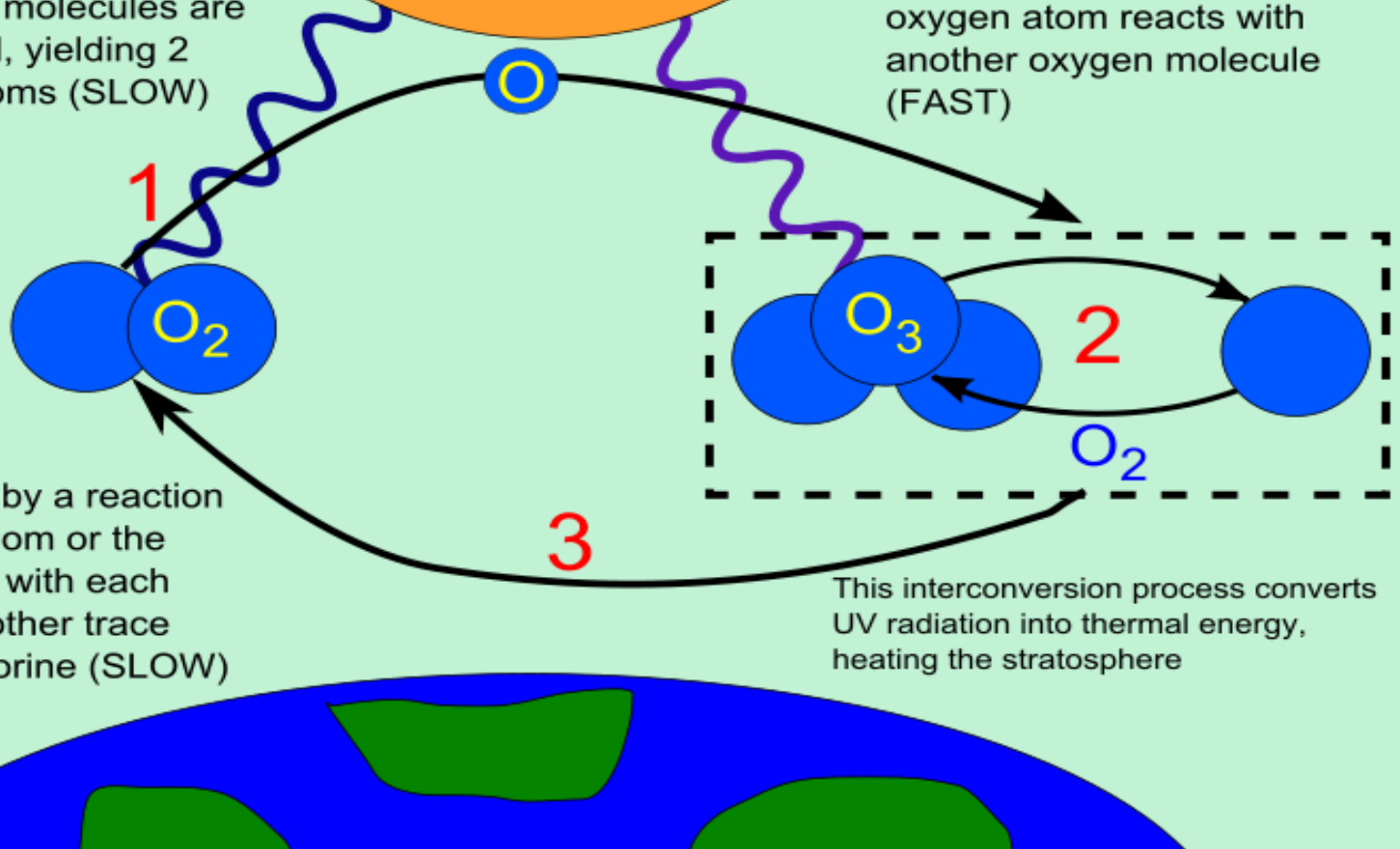
SUN

1. Oxygen molecules are photolyzed, yielding 2 oxygen atoms (SLOW)

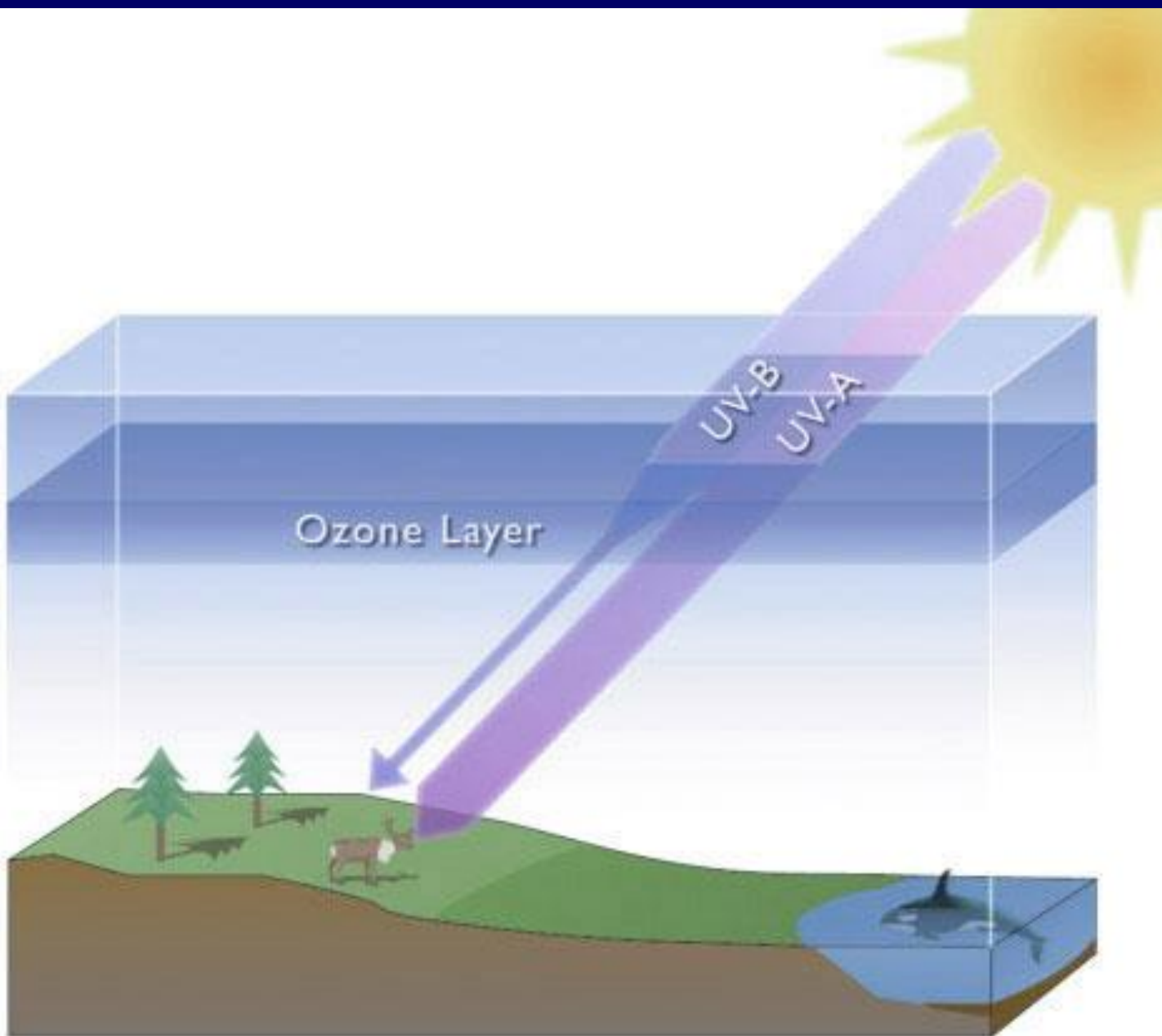
2. Ozone and oxygen atoms are continuously being interconverted as solar UV breaks ozone and the oxygen atom reacts with another oxygen molecule (FAST)

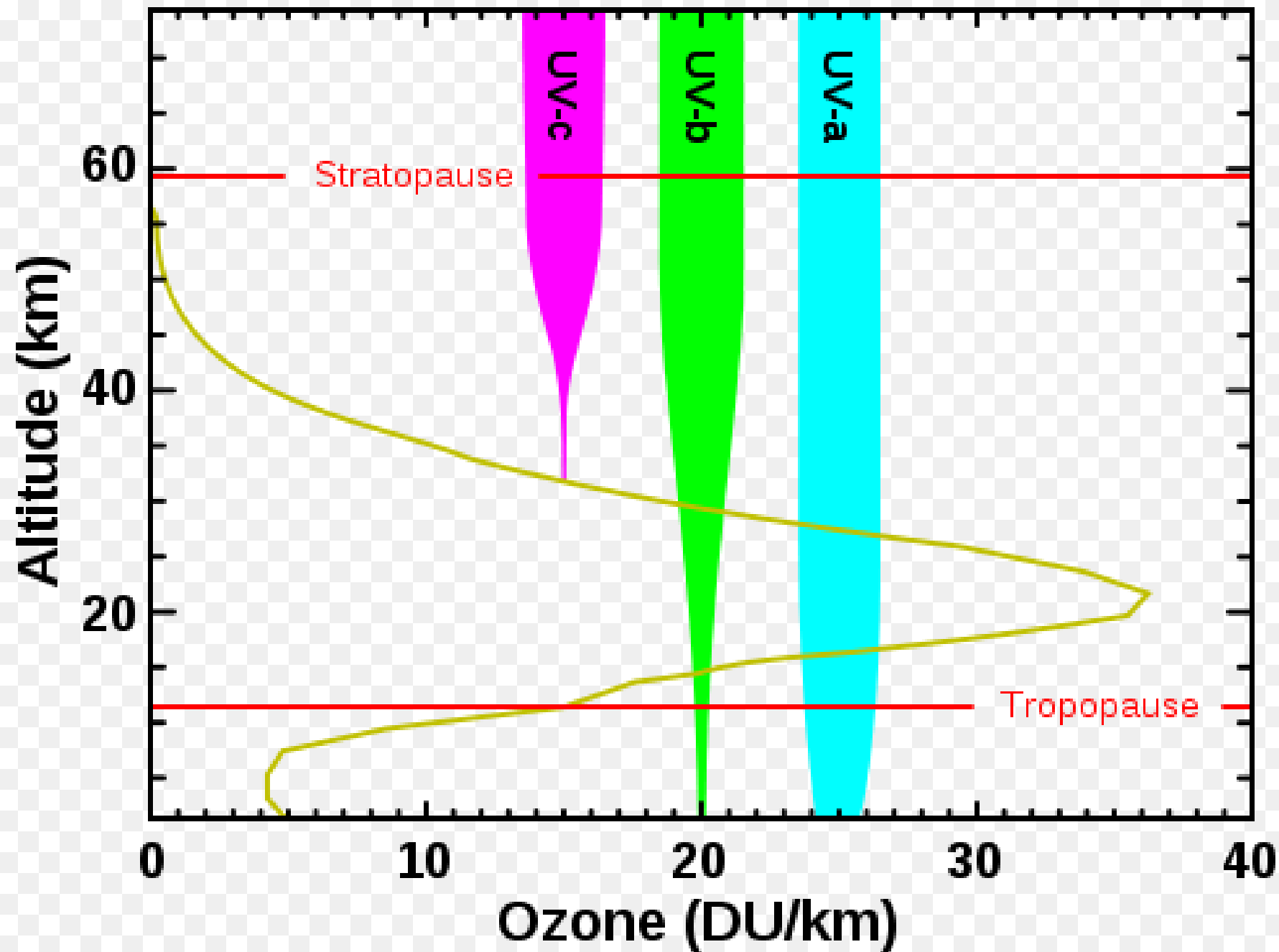
3. Ozone is lost by a reaction of the oxygen atom or the ozone molecule with each other, or some other trace gas such as chlorine (SLOW)

This interconversion process converts UV radiation into thermal energy, heating the stratosphere



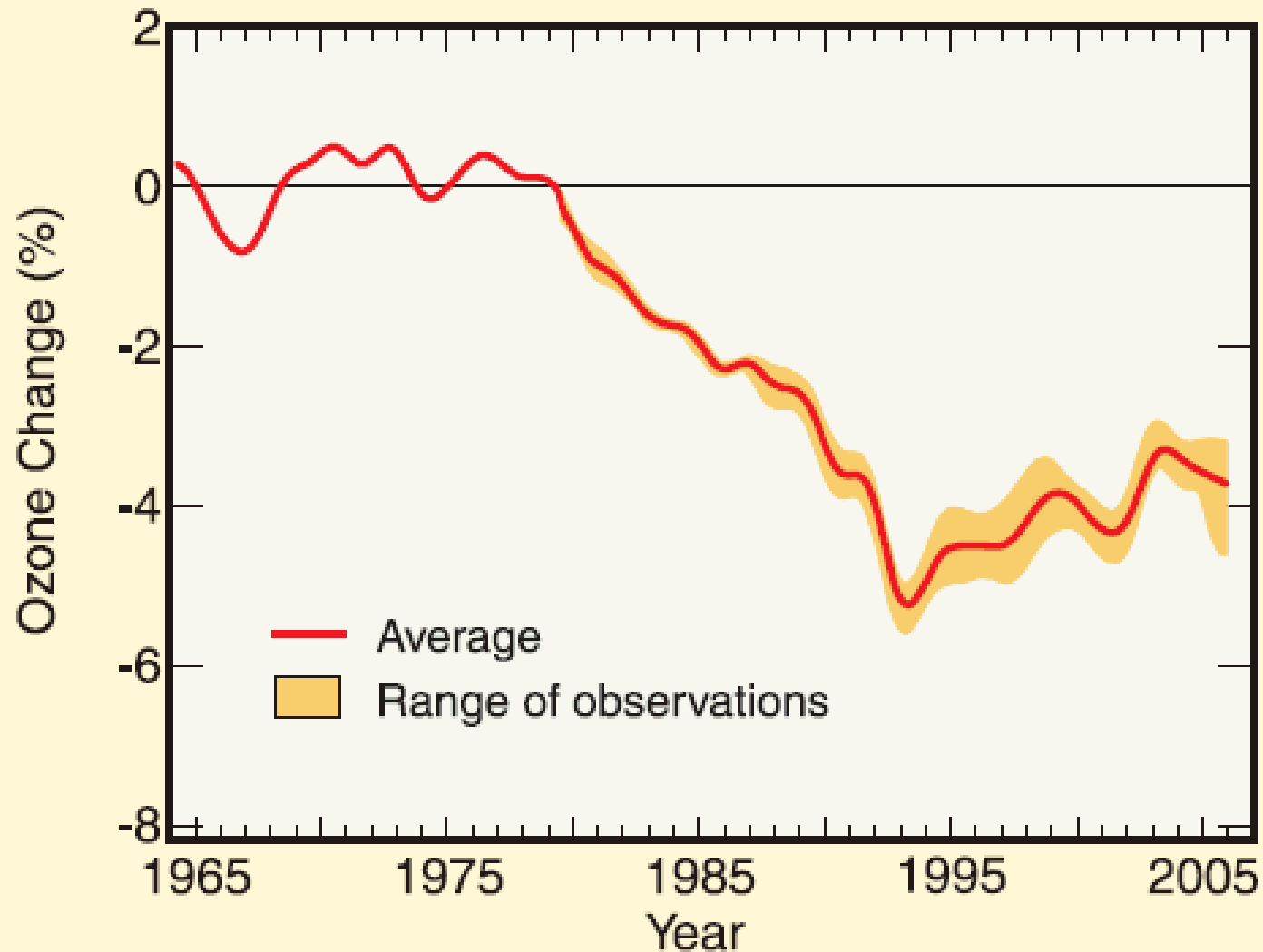
About 90% of the ozone in our atmosphere is contained in the stratosphere. Ozone concentrations are greatest between about 20 and 40 kilometres, where they range from about 2 to 8 parts per million. If all of the ozone were compressed to the pressure of the air at sea level, it would be only a few millimeters thick.



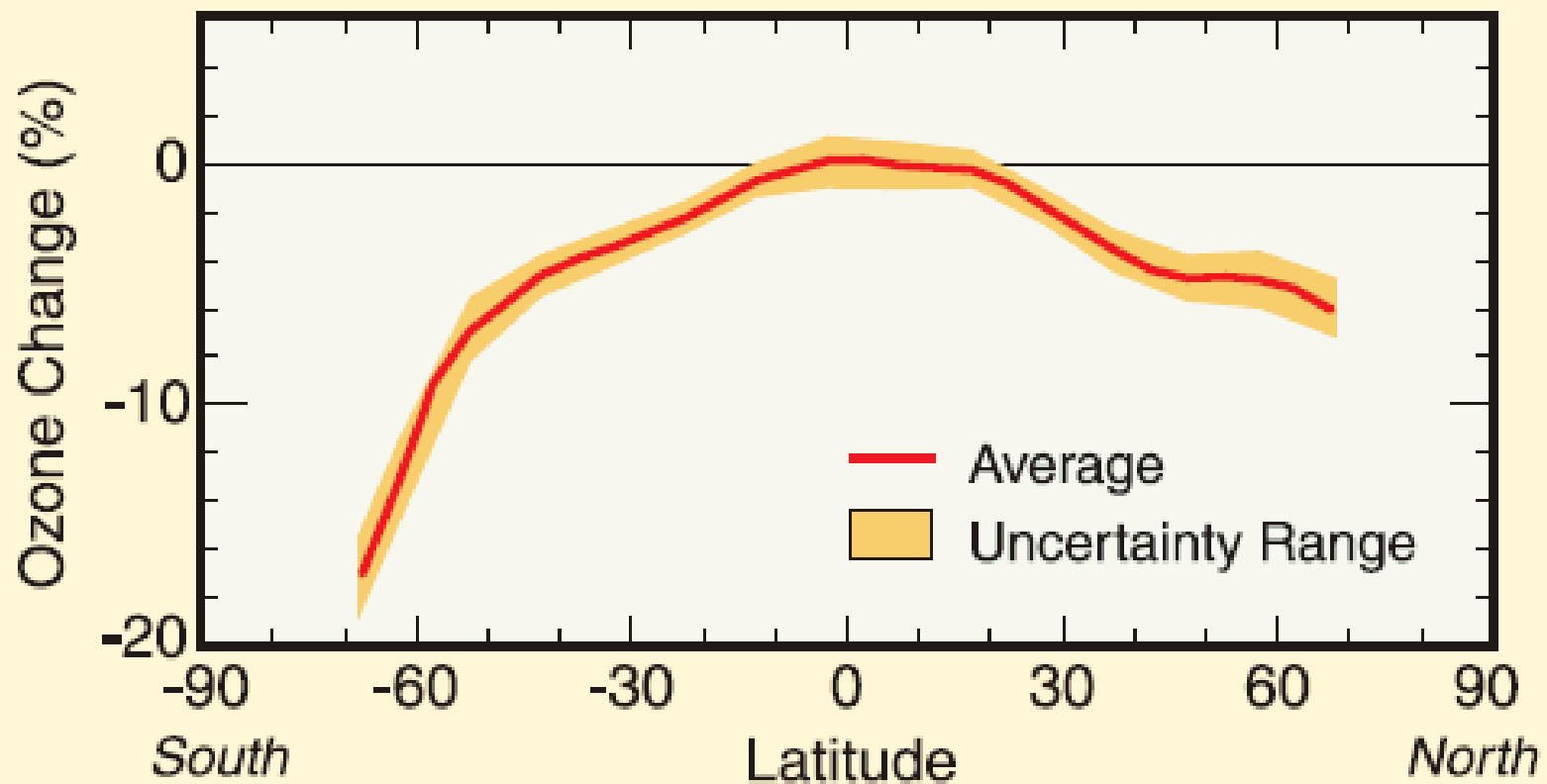


# Global Total Ozone Change

Changes from 1964-1980 average



## Changes between 1980-2004





# Ozone depletion

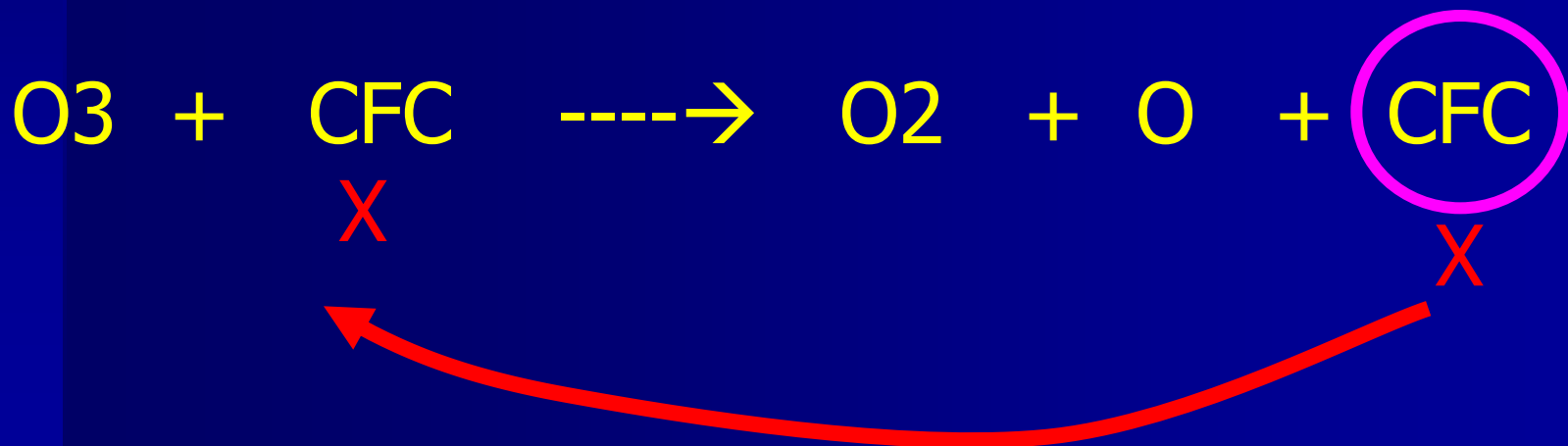
The ozone layer can be depleted by **free radical catalysts, including nitric oxide** (NO), **nitrous oxide** (N<sub>2</sub>O), **hydroxyl** (OH), **atomic chlorine** (Cl), and **atomic bromine** (Br).

While there are natural sources for all of these species, the concentrations of chlorine and bromine have increased markedly in recent years due to the release of large quantities of man-made **organohalogen compounds**, especially **chlorofluorocarbons** (CFCs) and **bromofluorocarbons**.

# Ozone depletion

The ozone layer can be depleted by **free radical catalysts**, including **nitric oxide** (NO), **nitrous oxide** (N<sub>2</sub>O), **hydroxyl** (OH), **atomic chlorine** (Cl), and **atomic bromine** (Br).

While there are natural sources for all of these species, the concentrations of chlorine and bromine have increased markedly in recent years due to the release of large quantities of man-made **organohalogen compounds**, especially **chlorofluorocarbons** (CFCs) and **bromofluorocarbons**.



# Ozone depletion



CFC (**chlorofluorocarbons**) molecules reacts with O<sub>3</sub> and it produces O<sub>2</sub> and O atoms and again CFC. This released CFC again break O<sub>3</sub> and this process repeated continuously. As a result a small number of CFC molecules can break a large number of O<sub>3</sub> molecules to O<sub>2</sub> and O atoms. The Cl in CFC molecules is the main cause to break O<sub>3</sub> molecules.

**Because of this reason usage of an electrical items which contain CFC was prohibited !**

# Ozone depletion



**Because of this reason  
usage of an electrical items  
which contain CFC was  
prohibited !**



As mentioned earlier, from the graph of  $h$  vs  $T$  of a planet, we can conclude whether the planet contains an Ozone Layer or not. If a planet contains Ozone Layer, there is a high possibility for the Living Organisms to exist in the planet !

In our planetary system, if we analyze the graph of  $h$  vs  $T$  of the planets and other natural satellites (moons), in any of these an Ozone Layer does not exist except the Earth !

**Form the above statement we can conclude that any living organisms can not exist in any planets than the Earth !**

Using this logic argument we can interpret whether a living organism can exist in another planetary system. The closest planetary system is situated 4.2 light years (Alpha-Centauri) far away from our planetary system.



**Form the above statement we can conclude that any living organisms can not exist in any planets than the Earth !**

We can not 100% confirm conclude whether there exist any living organism, by using the another planetary system, by using the above interpretation. But this is the way which is usually done in Science





# 5 PRODUCTS THAT CAUSE OZONE DEPLETION

## 1. Inhalers



## 2. Fire extinguishers



## 3. Aerosol hairsprays



## 4. Wasp (ବେଢ଼ିରା) and hornets (ବଢ଼ିରା) sprays



## 5. Foam insulation product



# Ozone depletion

These highly stable compounds are capable of surviving the rise to the stratosphere, where Cl and Br radicals are liberated by the action of ultraviolet light. Each radical is then free to initiate and catalyze a chain reaction capable of breaking down over 100,000 ozone molecules. The breakdown of ozone in the stratosphere results in the ozone molecules being unable to absorb ultraviolet radiation. Consequently, unabsorbed and dangerous ultraviolet-B radiation is able to reach the Earth's surface.

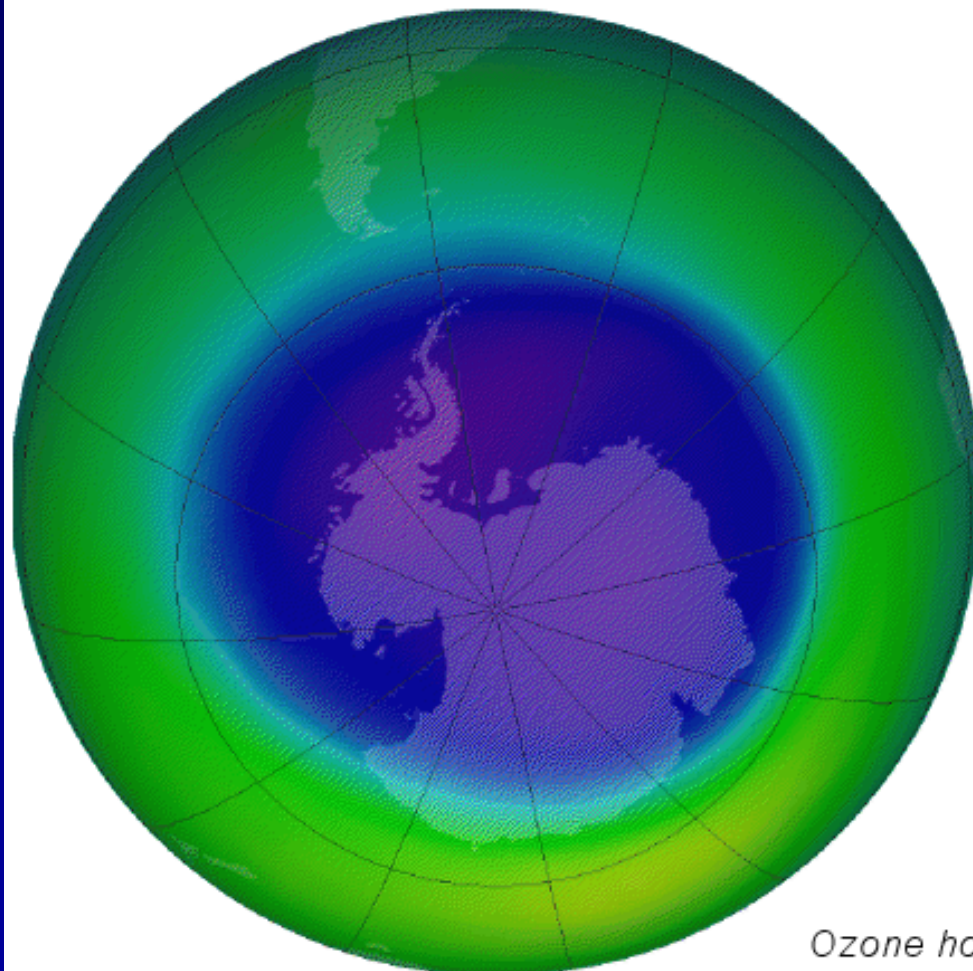
# Ozone depletion

Ozone levels, over the northern hemisphere, have been dropping by 4% per decade. Over approximately 5% of the Earth's surface, around the north and south poles, much larger (but seasonal) declines have been seen; these are the ozone holes.

**In 2009, nitrous oxide (N<sub>2</sub>O) was the largest ozone-depleting substance emitted through human activities.**

# The “Ozone Hole”

- What is the “ozone hole?” When did it first appear? How does it form?

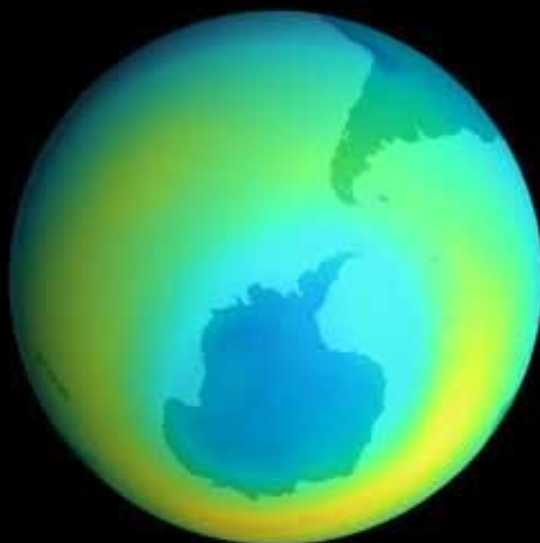


**Total Ozone (Dobson Units)**

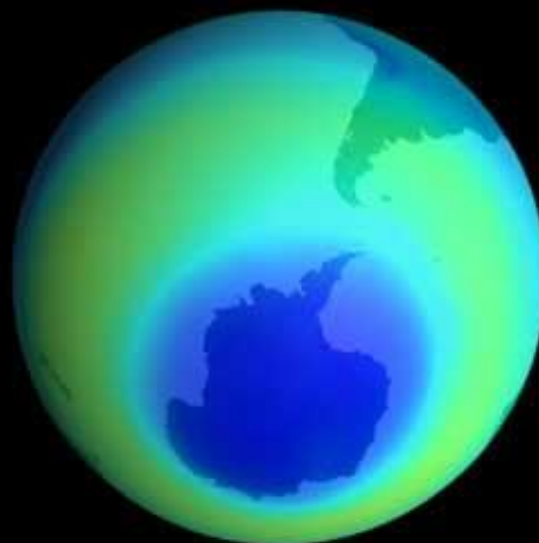
110 220 330 440 550

The ozone hole is the region over Antarctica with total ozone 220 Dobson Units or lower. (The avg total column ozone in the atmosphere is about 300 DU.)

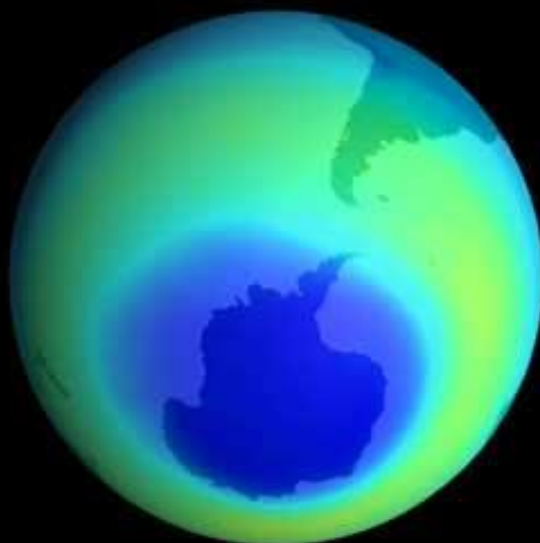
*Ozone hole in Sept 2005. Source: NASA*



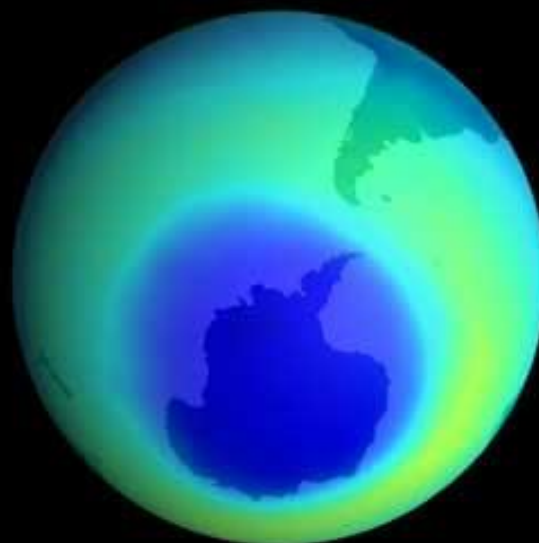
September 1981



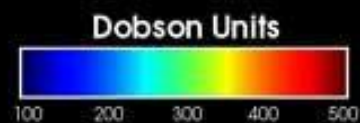
September 1987



September 1993



September 1999





# Regulation

In 1978, the United States, Canada and Norway enacted bans on CFC-containing aerosol sprays that are thought to damage the ozone layer. The European Community rejected an analogous proposal to do the same.

**In the U.S., chlorofluorocarbons continued to be used in other applications, such as refrigeration and industrial cleaning, until after the discovery of the Antarctic ozone hole in 1985.**

# Regulation

After negotiation of an international **treaty** (**The Montreal Protocol**), CFC production was sharply limited beginning in 1987 and phased out completely by 1996.

Since that time, the **treaty** has been amended to ban CFC production **after 1995 in the developed countries, and later in developing. Today, over 160 countries have signed the treaty.**

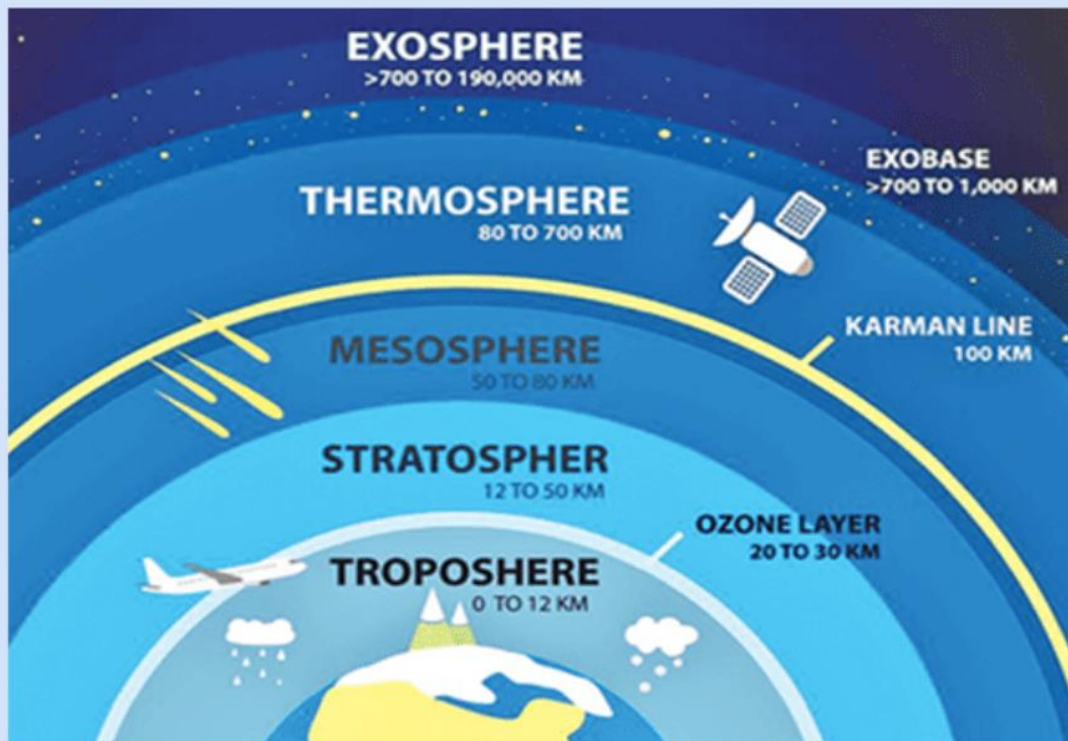


# The Montreal Protocol

The Montreal Protocol is a global agreement, signed in 1987, to protect the stratospheric ozone layer by phasing out the production and consumption of ozone-depleting substances (ODS). It has proven to be a successful environmental treaty and has achieved universal ratification. Under the agreement, countries are obligated to reduce and ultimately eliminate substances like chlorofluorocarbons (CFCs), which were commonly used in products like refrigerators and aerosols. More recently, an amendment to the protocol has also addressed hydrofluorocarbons (HFCs), potent greenhouse gases that, while not depleting the ozone layer, contribute to climate change.

# The Montreal Protocol

## OZONE LAYER:



Ozone ( $O_3$ ) naturally exists in the Earth's stratospheric layer.

Serving as a protective layer against harmful ultraviolet (UV) rays from the sun.

The increase in UV radiation due to the depletion of the ozone layer can elevate the risk of skin cancer and cataracts, weaken the human immune system, reduce agricultural productivity, and have negative effects on aquatic organisms and sensitive ecosystems.

# The Montreal Protocol

OZONE-DEPLETING SUBSTANCES CAN BE FOUND IN THESE PRODUCTS:



Refrigerator



Fire extinguisher



Air-conditioning



Solvent



Foam Insulation



Aerosol

# The Montreal Protocol

## Chronology of the Montreal Protocol in Malaysia:



# The Montreal Protocol



Vienna  
Convention was  
signed.  
**1985**

Montreal Protocol  
was signed  
**1987**

**1989**  
Malaysia ratified the  
Vienna Convention  
Montreal Protocol.

London  
Amendment  
**1990**  
Multilateral Fund (MLF)  
financial assistance for  
the implementation of  
Ozone Depleting  
Substance (ODS)  
reduction approved.

Copenhagen  
Amendment  
**1992**

**1993**  
Malaysia ratified the  
London Amendment  
and Copenhagen  
Amendment

Montreal  
Amendment  
**1997**

# The Montreal Protocol





# The Montreal Protocol

**Main goal:** To protect the stratospheric ozone layer, which shields Earth from harmful ultraviolet radiation.

**How it works:** By phasing out the production and consumption of ozone-depleting substances (ODS).

**Key actions:**

Banned chemicals like CFCs, which were widely used in everyday products.

The Kigali Amendment (2016) added the phase-down of hydrofluorocarbons (HFCs), powerful greenhouse gases used as substitutes for ODS.



# The Montreal Protocol

**Impact:** It has successfully halted the damage to the ozone layer, which is expected to be repaired by the middle of the century. It also contributes to the battle against climate change.

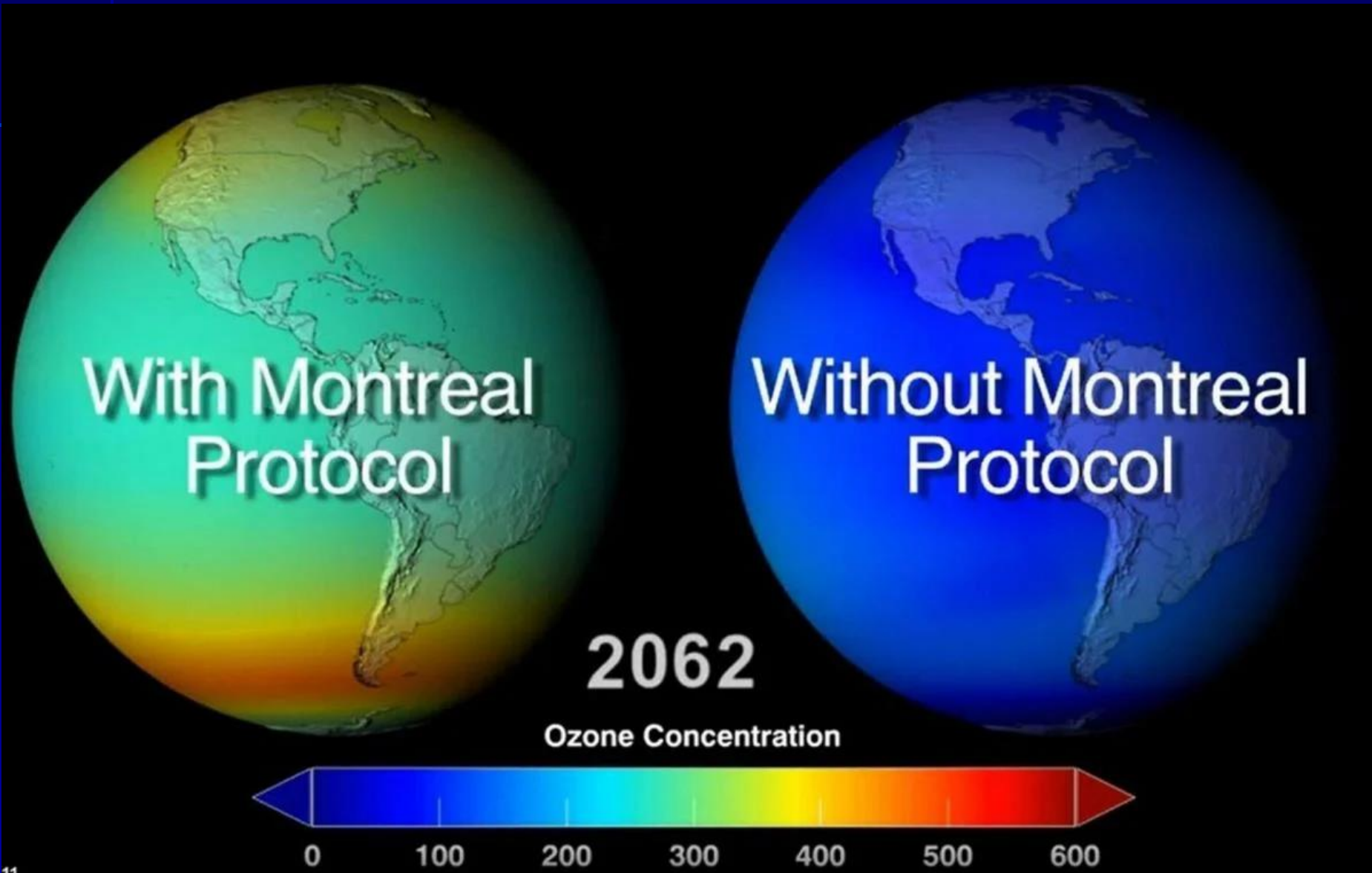
## **Key features:**

Achieved universal ratification, meaning every country in the world has agreed to its terms.

Provides a framework for international cooperation with provisions like financial assistance for developing countries.

Has been amended six times to adapt to new scientific and technical information.

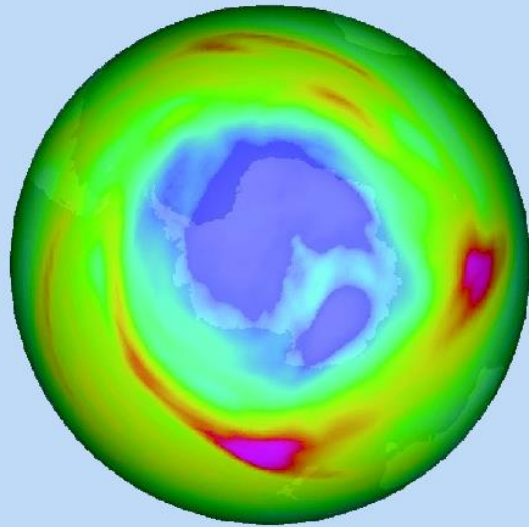
# The Montreal Protocol



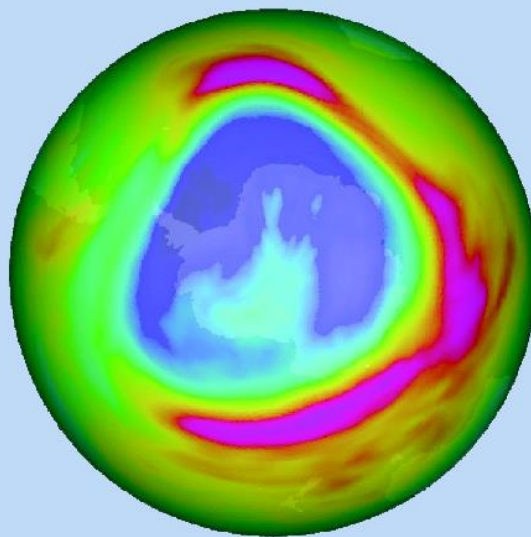
# **NASA Observations Confirm Expected Ozone Layer Recovery**

NASA satellite observations have provided the first evidence the rate of ozone depletion in the Earth's upper atmosphere is decreasing. This may indicate the first stage of ozone layer recovery.

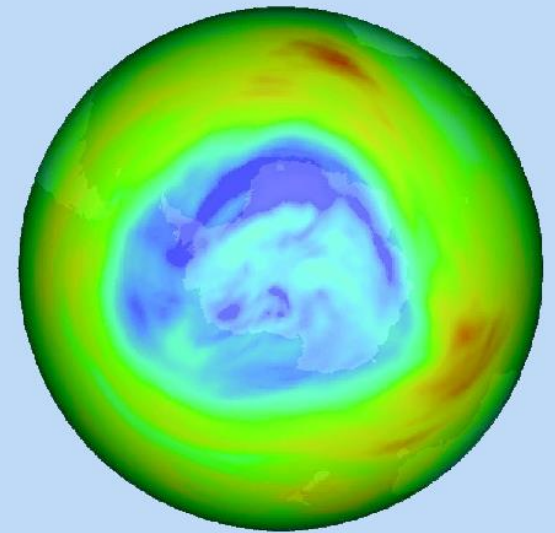
9 September 2006



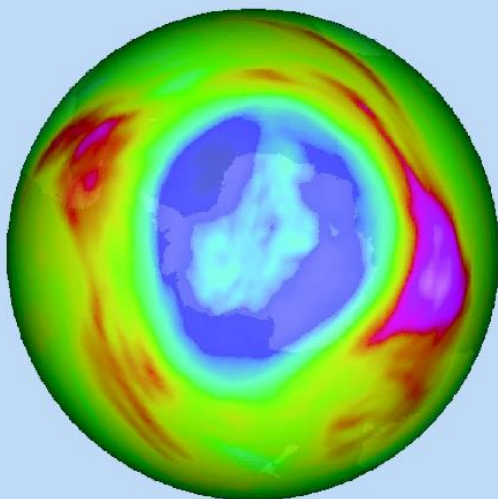
9 September 2007



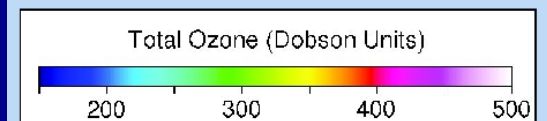
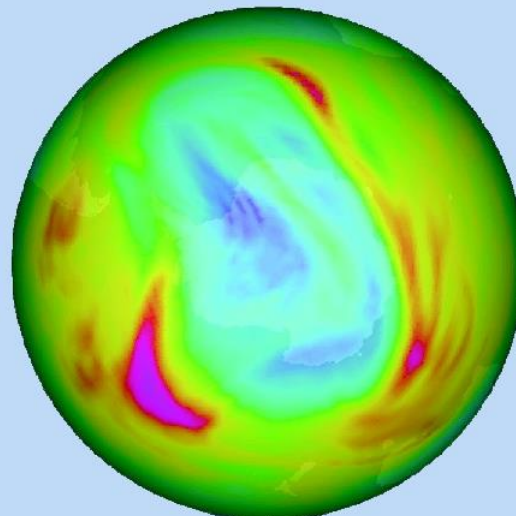
9 September 2008



9 September 2009



9 September 2010





# Global Warming



# Global Warming

**Global warming** is the rise in the average temperature of Earth's atmosphere and oceans since the late 19th century and its projected continuation.

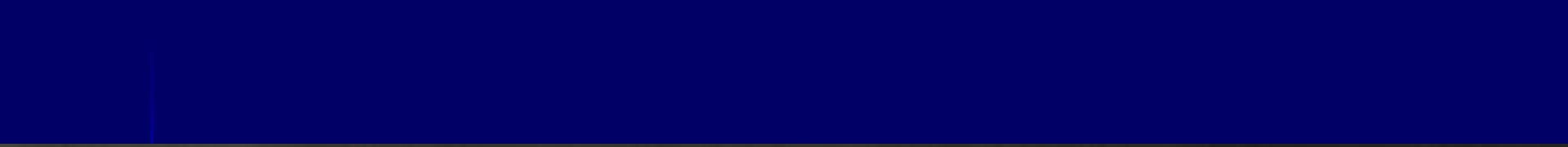


# Global Warming

Since the early 20th century, Earth's mean surface temperature has increased by about  $0.8^{\circ}\text{C}$ , with about two-thirds of the increase occurring since 1980.







Thank You !