Air Pollution and Control
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Lecture 37
Global and Regional Environmental Issues - Ozone Layer Depletion

Hello friends, welcome back. So, you may recall that we have discussed so many issues related to air quality air pollution, like Air Quality Management, assessment, monitoring, modeling, indoor outdoor air quality, so many issues. So, today onwards we will discuss about environmental issues of global and regional scale. And first of all let us start with ozone layer depletion, because this is one issue which is affecting across the world and very important because of its serious nature as, it can affect all kinds of ecosystems and humans or all kinds of species. So, we will discuss first of all introduction, then how ozone layer is formed basically.

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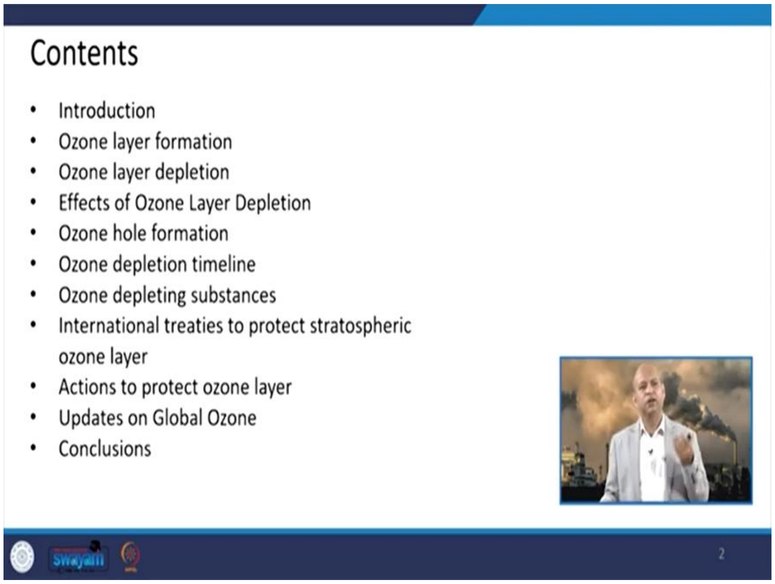

Then what is the depletion of ozone layer what is the science behind it and the effects of ozone layer depletion. If ozone layer is destroyed, then what kind of negative impacts we can foresee and then what is the, mechanism of formation of so, called ozone hole. First of all we will discuss whether it is a really hole or something else, why this ozone hole terminology came into existence.

Then we will see the timeline of this ozone depletion how it is started, what is its stage and what are the substances which are responsible for depletion of ozone layer. And then international treaties, which were necessary for protecting the stratospheric ozone layer. And then we will see actions several actions which have been used to protect the ozone layer and what are their impacts like updates on the global ozone scenario and after all we will conclude.

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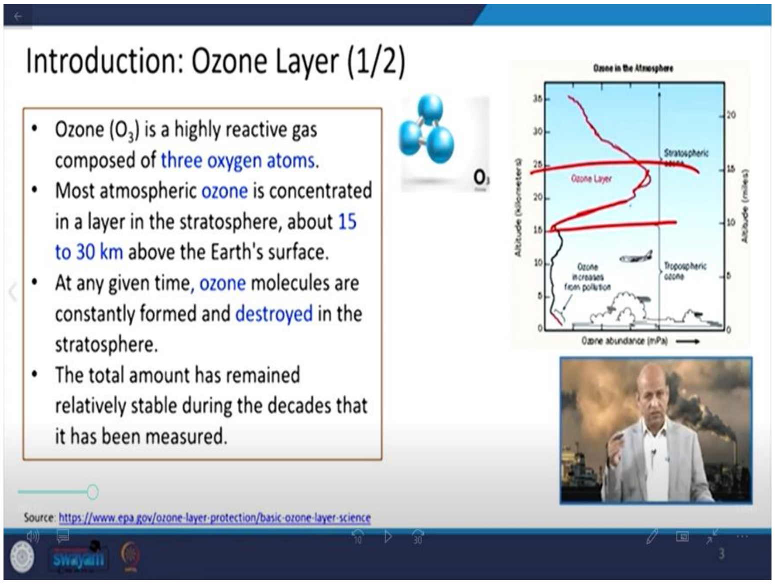

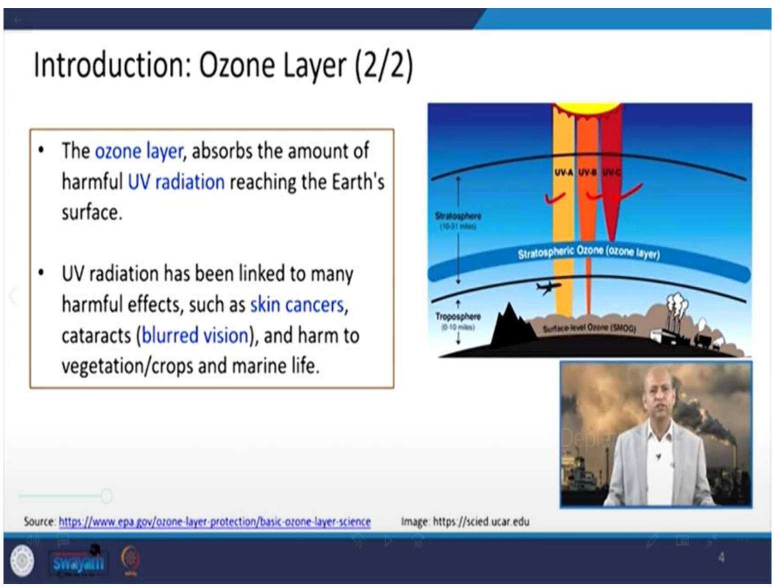

So, when we look into this ozone layer case basically, ozone is nothing but a very reactive gas with the three atoms of oxygen (O_3). And in the atmosphere basically, it is present in the stratosphere though it is formed in troposphere also means mainly it is in the stratosphere where this layer is there and it protects us from ultraviolet rays. But in troposphere it is produced as a secondary pollutants, so, that that also we will see. You can see here like up to this troposphere is there and when this about this troposphere.

So, this ozone layer means ozone concentration increases ozone abundance you can see here as we go up in the altitude and it goes up to like 15 miles or so, then again it is start to decrease. But up to this means around five miles or so, it is quite thick layer in terms of that concentration of the ozone which we see as a layer in the stratosphere.

And this layer basically absorbs the amount of harmful ultraviolet rays and the ultraviolet rays can be of A, B or C that kind of different spectrum. Well this radiation has linked too many harmful effects such as skin cancers or cataracts this blurred vision and it can also damage the crops and vegetation and marine life. So, that is very important aspect that this ultraviolet rays protection through ozone layer is something which is kind of building block of our life on the Earth's surface.

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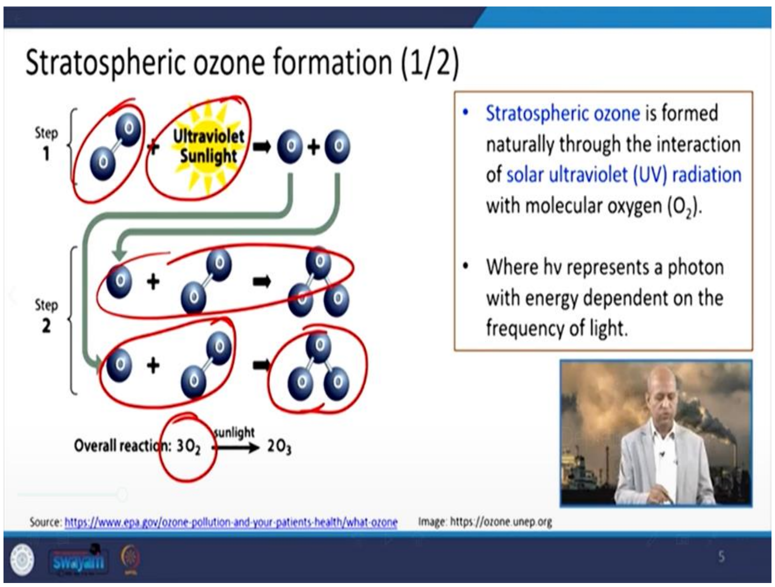

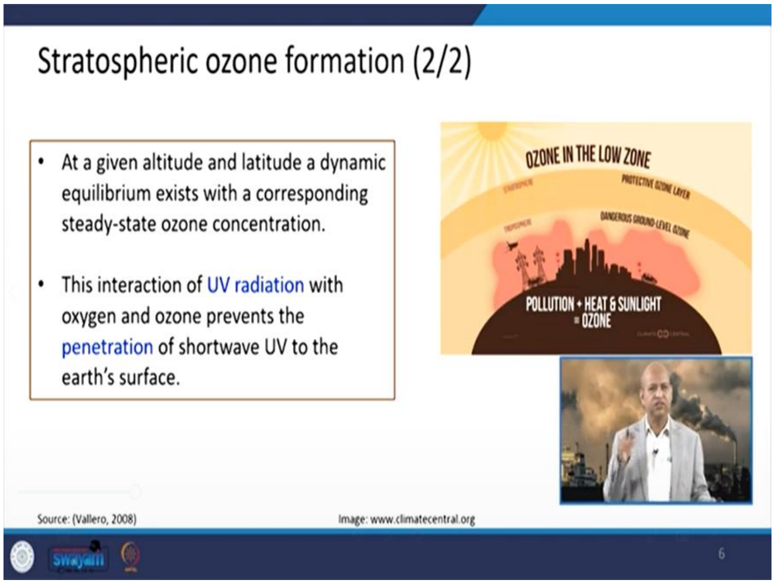

Well when we see this mechanism how this ozone is produced in the stratosphere. So, you can see this oxygen is there 2 atoms of oxygen, because of this ultraviolet sunlight, it dissociates into two atoms, one atom gets attached to one molecule and then one molecule of oxygen and this molecule of ozone is produced similarly, happens here also. So, you can say that, three molecules of oxygen basically produce two molecules of ozone. So, from oxygen to ozone products and this kind of reaction occurs in the presence of sunlight or ultraviolet rays basically.

And you can see here at a given altitude and latitude this is a dynamic equilibrium, because it says cyclic reaction ozone is produced then it is destroyed. And then again ozone is produced that kind of thing happened. And this particular interaction of ultraviolet radiation with oxygen and ozone prevents the penetration of this shortwave ultraviolet to the Earth's surface. So, that is wonderful mechanism in the nature which protects us from the ultraviolet rays. Because, in this process this ozone is formed because of oxygen dissociation into oxygen atoms and then association with oxygen molecules and creation of ozone molecules.

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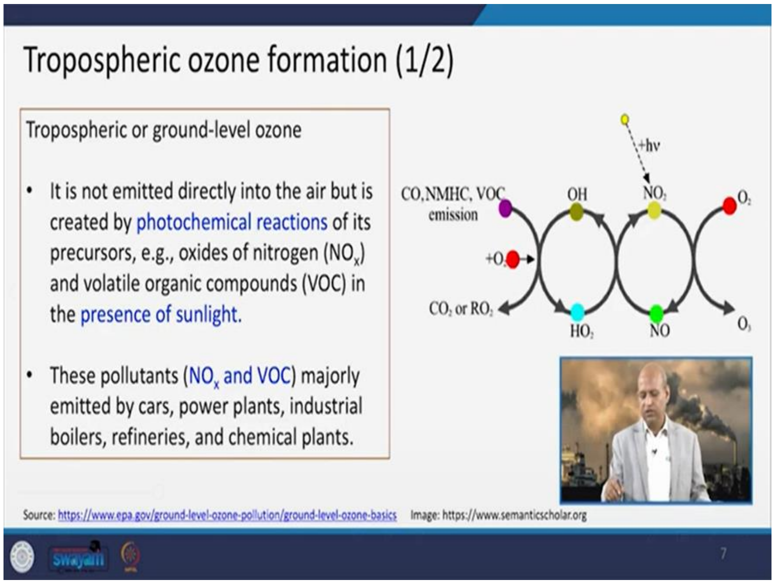

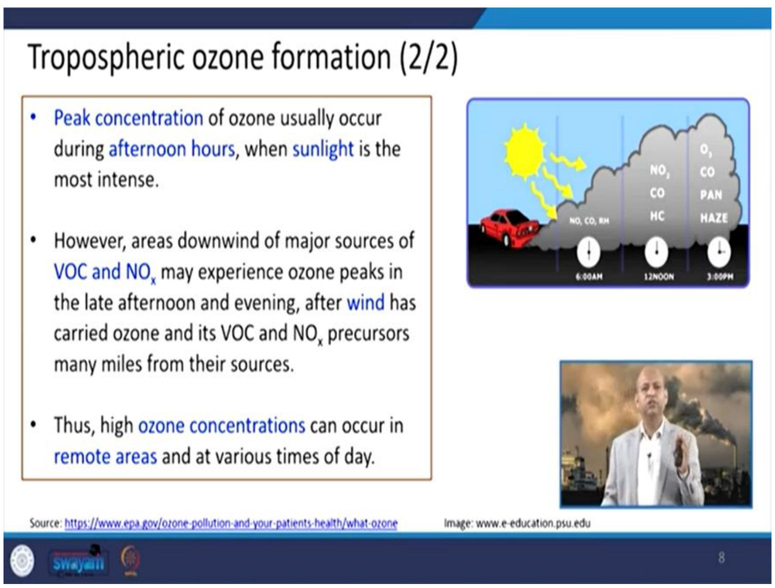

You can see tropospheric ozone formation is a little bit different because it needs some precursors. Precursors are those kind of compounds chemical compounds or air pollutants, you can say which again in the presence of sunlight, because of these photochemical reactions, they produce ozone. That is why we call them precursors like carbon monoxide or VOCs (volatile organic compounds) or non-methane hydrocarbons, VOCs and in all those kind of pollutants, they are precursors of the ozone.

And in the presence of these OH radicals or hydroxyl radicals, HO_2 and then these ultraviolet sorry sunlight, the photochemical reactions, and then again this ozone production is there. So, we will see the reactions, how does it occur later on.

But, basically you can see that because it is dependent on solar radiation. So basically, the variation happens from morning to evening in the troposphere, I am talking now of the tropospheric ozone, troposphere means where we are living troposphere is the first layer of the atmosphere just near to the Earth's surface after that stratosphere there.

And this ozone layer is basically in stratosphere, but just for your knowledge, we are discussing about this tropospheric ozone formation also because sometimes we get confused why it is bad ozone, when sometimes it is present in the atmosphere in troposphere, because it is harmful for us. But in the stratosphere it is very good, it is our friend in the stratosphere.

So, ozone layer is good in the stratosphere, but ozone products and in troposphere is very bad because it is having several negative impacts on our life on our property on ecosystem etc. Anyway, this is a photochemical reaction, it happens in the presence of sunlight. So, there is the diurnal variation in the daytime.

So, ozone production becomes at peak in the afternoon or when sunlight is quite bright at the noon time or so, because precursors are there then ozone production is there. And then, but in the downwind directions because like in city centers, there may be many emissions of these NOx and precursors of ozone like VOCs etc.

But, ozone production titration also happens with the this chemical reaction of ozone, because they get like this NO, get converted into NO_2 in the presence of ozone, but NO_2 get, transported in the downwind direction, and there it acts as the precursor and produces ozone again.

So, you can say that the cities, urban areas, sometimes in city centers, you will not find, so much ozone which is at the regions of downwind direction like countryside region or rural areas and there is no source of those precursors. But these precursors come with the wind from the cities. So, these cities which are polluting or emitting lot of air pollutants, they also harm the nearby areas like rural areas, etc.

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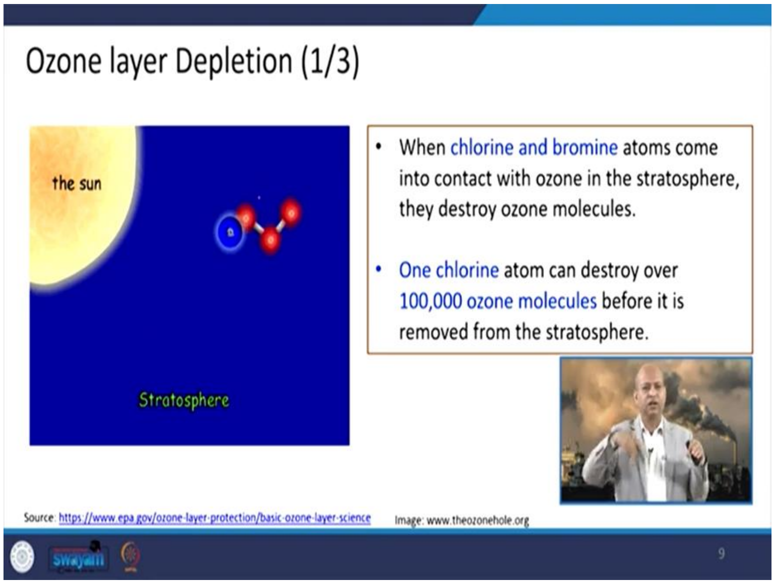

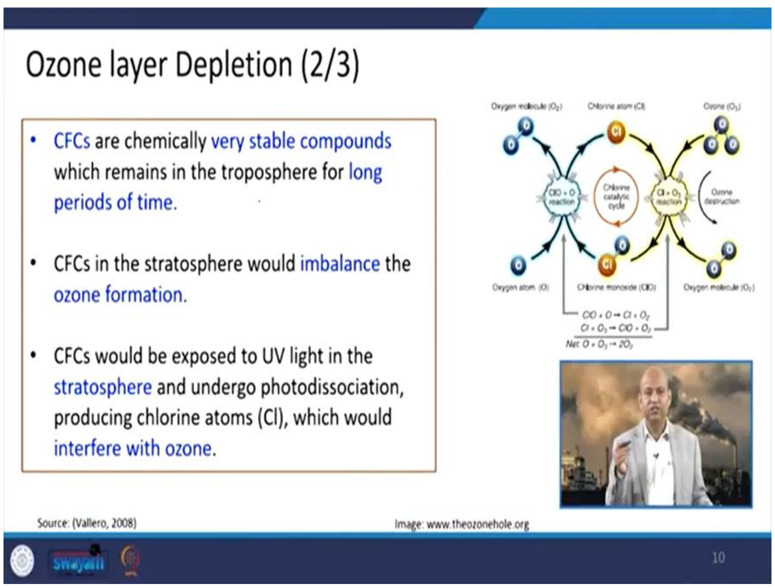

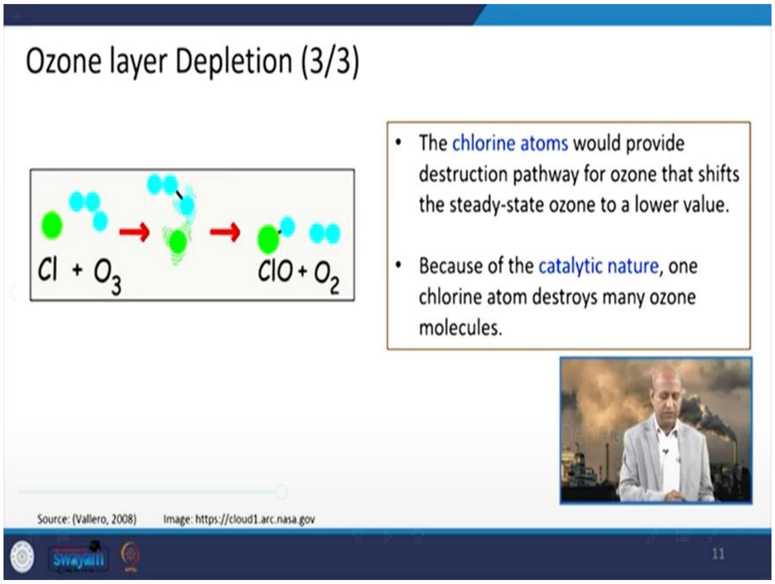

Well, so now, if we come to the process of ozone layer depletion, how does it happens? So, you can see this animation, how this, like chlorine or bromine atom is there. So, it takes away this one atom of the oxygen from the ozone because ozone has three atoms of oxygen one atom it takes, it has very fast affinity, and then it removed you can see. And one atom of chlorine or bromine can remove thousands of hundreds or thousands of ozone molecules it can destroy basically.

So, that is why this chain reaction happens. And in wintertime it is very severe and it can destroy so, many molecules of ozone that it happens like ozone layer depletion phenomena, starts to take place because this layer becomes very thin and that is why we call it, although we call it ozone hole, but it is not a hole. You can say this ozone layer is there, surrounding this complete our atmosphere surrounding the earth and this layer wherever it is thin. So it is kind of hole you can see like if there is a thin cloth and you can this sunlight passes very thoroughly, but if thick cloth is there or dark cloth is there then it is difficult.

So, that way you can visualize that the thin layer of the ozone basically is because of depletion of ozone in that layer of stratospheric ozone layer. Well, why it happens where this chlorine and bromine etc come there, they are because of like CFCs, these chlorofluorocarbons etc.

They have this chlorine atom and they are very persistent pollutants basically, and they are like robust, you can say or they do not disintegrate very easily. So, in several years, they go up to the stratospheric layer because of this convection phenomena, it goes up and slowly they reach to the stratosphere. Nobody imagined when in fact CFCs were invented people were very happy this is wonder chemical it is so inert it can be used in industrial applications and it is nontoxic is a very good chemical that was a great discovery at that time. But nobody imagined that this a CFC can really harm the ozone layer in the stratosphere.

And when scientists derived these relationships several kind of theories came into existence to debunk that maybe it is because of some aliens they are sprinkling some chemical to destroy the human race. So, many stories came like conspiracy theories etc, but ultimately, it was proved that this CFCs and like N_2O nitrous oxide etc which reaches up to the layer of the stratosphere, they are the responsible for creating a cyclic chain reaction to destroy the ozone molecules or ozone layer. So, basically these chlorine etc they are part of this CFCs etc, and they go to the stratosphere by this convection phenomenon.

Well, you can see again, the same thing, that is chlorine takes away this atom of the oxygen from ozone and oxygen is produced that way, ozone is destroyed. This is a catalytic kind of nature of the reaction and it happens in a chain reaction for means one atom can destroy hundreds and thousands of the molecules.

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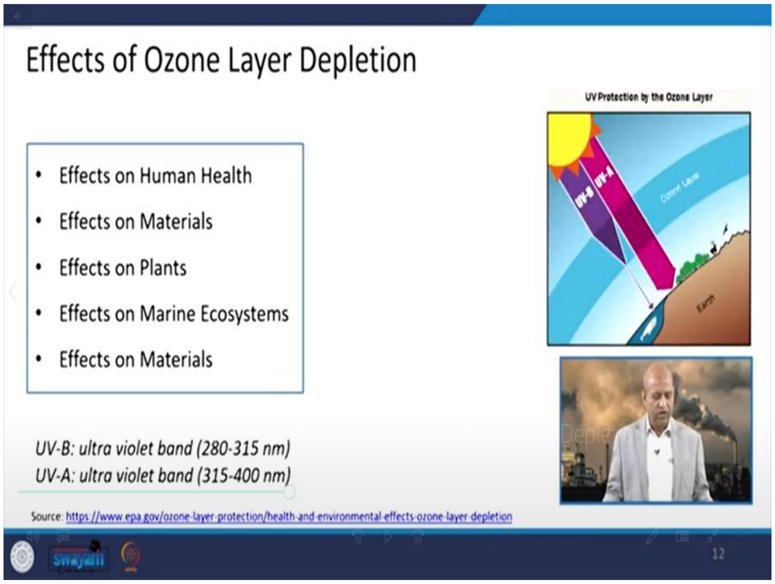

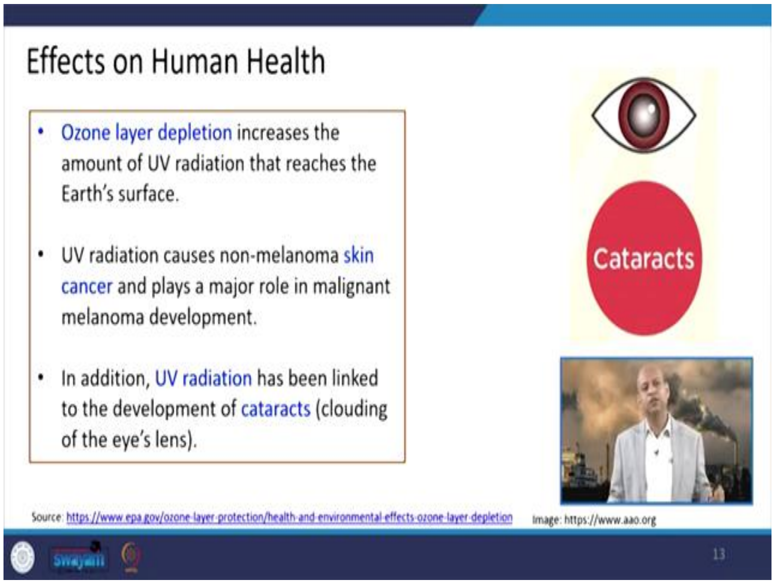

Well, if we see what is the problem, if ozone layer depletes. So, we have to see the impact or the effects, so, there are the effects on human health because this ultraviolet rays will come. If there is no ozone layer, then ultraviolet rays will directly reach to the surface of the earth and they will have very harmful impacts on human health, materials, plants, crops, vegetation, marine ecosystem material etc, what kind of effect they can have, you can see here like it can increase skin cancer related problems. And it can also cause cataracts as I discussed earlier also.

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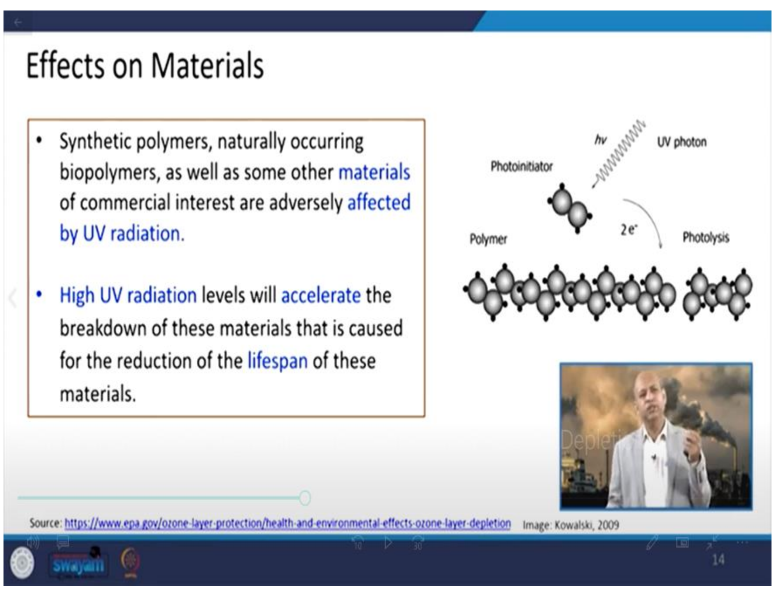

In case of, materials like polymers, bio polymers or synthetic polymers, rubber etc, because it is very kind of reactive, so, this has energy these UV photons. So, they destroy these kinds of bonds of the polymers and these kind of metal can be destroyed in the presence of these ultraviolet photons.

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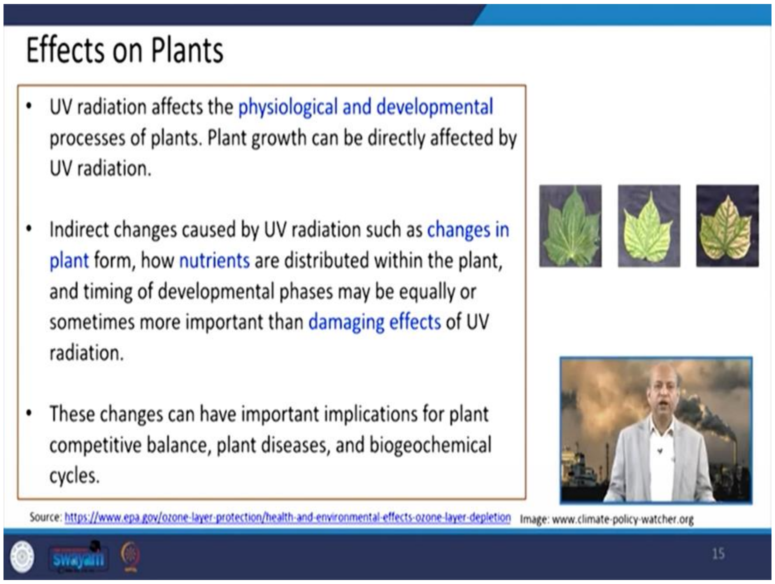

Well on plants, if we see the effects again, they can destroy the green color and photosynthesis is affected very badly. So, the physiological effect is there and the nutrient value does not reach to the plant properly and ultimately the crop yield is reduced significantly as well as plant live vegetation etc, are affected negatively.

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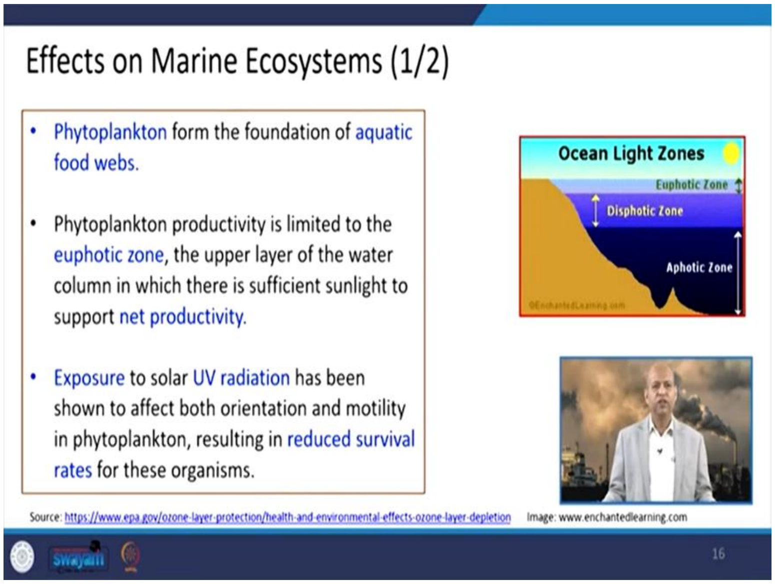

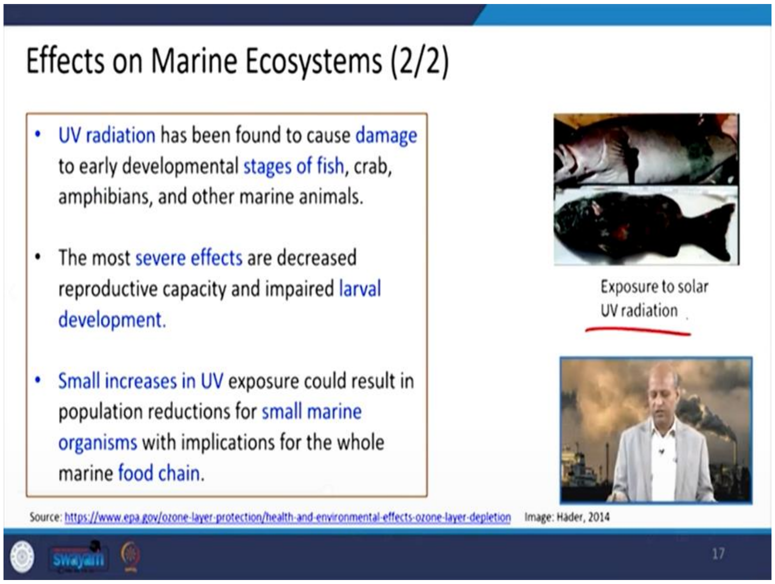

If you talk about like marine **s**ystem or eco system of the marine environment, again like phytoplankton, etc, which are the basic thing for very low form of life like small fish, etc. So, they are destroyed and they are productivities severely affected and when the food is not available for small fish, then the whole food chain can get affected you can see.

So, this exposure to solar ultraviolet radiation is also the damage into the marine life you can see different these developmental stages of fish can be affected. And then it can affect the reproductive capacity also, at the larva development stage. Then a small increase in ultraviolet rays exposure, it could result in population reduction of small marine organisms with implications of the disturbance of the marine whole marine food chain as I said earlier also. So, that way a lot of negative impacts are there.

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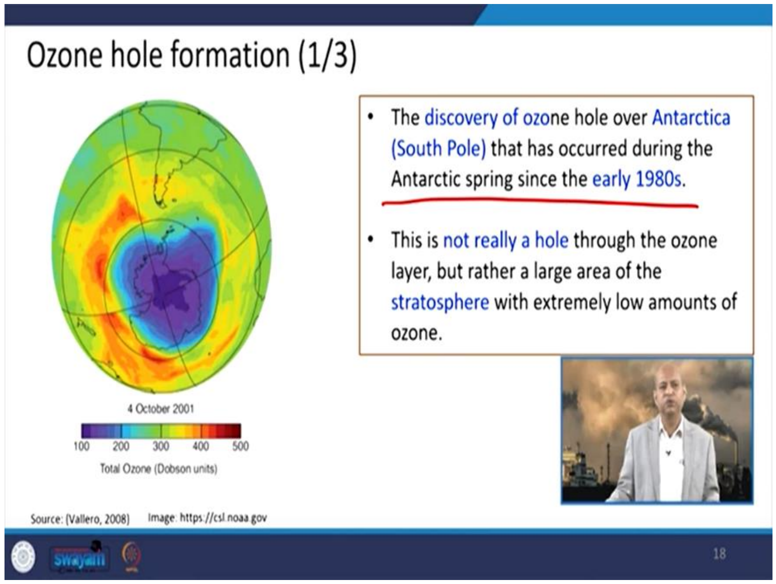

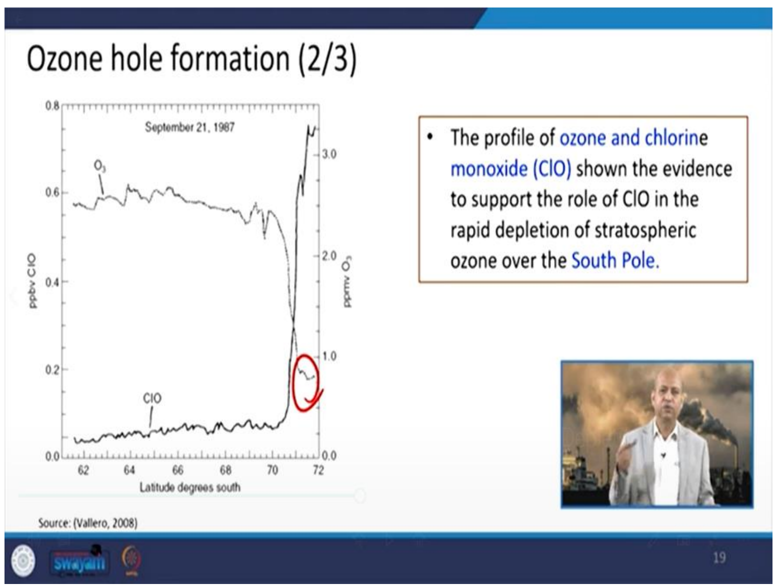

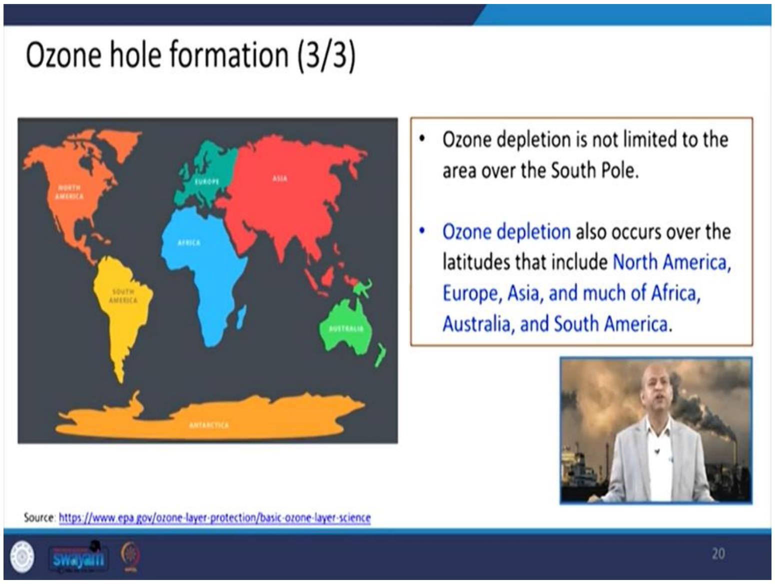

Now, if you want to see how this ozone hole formation took place. So, as I said, this ozone hole is not a hole basically, it is the thin layer means wherever this ozone concentration becomes very thin we call it ozone hole. And at South Pole It was first discovered that this layer of the ozone has become very thin ozone has been destroyed you can see 1980s this was in an Antarctic spring this was discovered that this the layer of the thickness of the ozone layer is very thin with respect to earlier readings.

And you can see here are the concentration of the ozone and this concentration of chlorine monoxide, this was observed. So, when it increased the ozone concentration decreased. So, this also again proves this reaction validation of the reaction of that this presence of these kind of chlorine related compounds can destroy the ozone layer.

Well, when we talk about like, where it is limited, whether it is at a particular place, it is basically has been observed this thin layer of the ozone has been observed at several places. It is not only the South Pole, but other places also like other continents like Africa, South America, Australia, Asia, everywhere it has been observed that there are patches where ozone layer is thin. Of course, at South Pole it is very predominant the reason is in very low temperature, this reaction of chlorine that cyclic reaction is very intense and winters that is why this ozone layer depletes very significantly and this ozone hole is absorbed in that sense.

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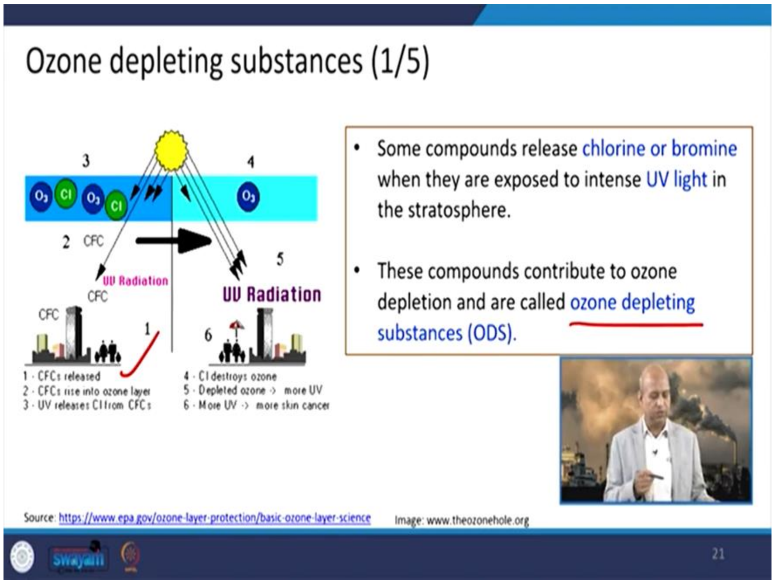
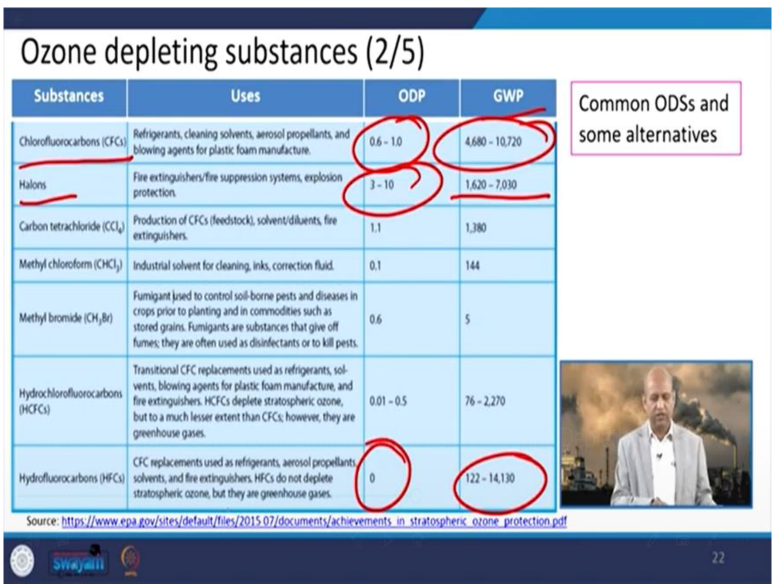
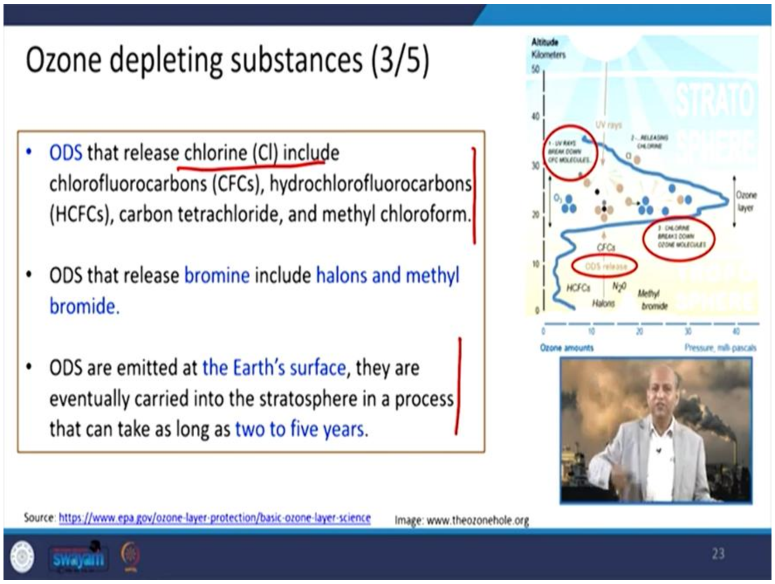




Substances	Uses	ODP	GWP
Chlorofluorocarbons (CFCs)	Refrigerants, cleaning solvents, aerosol propellants, and blowing agents for plastic foam manufacture.	0.6 – 1.0	4,680 – 10,720
Halons	Fire extinguishers/fire suppression systems, explosion protection.	3 – 10	1,620 – 7,030
Carbon tetrachloride (CCl_4)	Production of CFCs (feedstock), solvent/diluents, fire extinguishers.	1.1	1,380
Methyl chloroform ($CHCl_3$)	Industrial solvent for cleaning, inks, correction fluid.	0.1	144
Methyl bromide (CH_3Br)	Fumigant used to control soil-borne pests and diseases in crops prior to planting and in commodities such as stored grains. Fumigants are substances that give off fumes; they are often used as disinfectants or to kill pests.	0.6	5
Hydrochlorofluorocarbons (HCFCs)	Transitional CFC replacements used as refrigerants, solvents, blowing agents for plastic foam manufacture, and fire extinguishers. HCFCs deplete stratospheric ozone, but to a much lesser extent than CFCs; however, they are greenhouse gases.	0.01 – 0.5	76 – 2,270
Hydrofluorocarbons (HFCs)	CFC replacements used as refrigerants, aerosol propellants, solvents, and fire extinguishers. HFCs do not deplete stratospheric ozone, but they are greenhouse gases.	0	122 – 14,130



Well, what are the substances which are responsible for this ozone hole depletion. So, you can see these chlorine or bromine related compounds are there which we call Ozone Depleting Substances. So, they are like CFCs and other compounds are also there, but basically whosoever chemical is having chlorine and bromine related things, they are responsible for this kind of depletion of ozone at the stratosphere.

Well, you can see these the list of the substances and this oxygen depletion potential and global warming potential. Interestingly, these ozone depleting substances or also greenhouse gas related gases you can say or compounds. So, this chlorofluorocarbons it has around 0.6 to 1 ozone depletion potential in respect of that, but global warming potentiality it has very high in like if CO_2 has 1 it has around 5000 to 11,000 times of the CO_2 you can see. Then these halons these are like 3 to 10 times oxygen depleting potential these chlorine etc, ClO and those kinds of things. And around 1600 or 7000 times of the global warming potential.

So, you can see different kinds of chemicals which are methyl bromide and all those although these hydro fluorocarbons which replaced these chlorofluorocarbons like they are having 0 ozone depletion potential. But still they are having significant these global warming potential, but because their quantity is very less so that way that has been recommended as the replacement for the CFCs.

Well, when these ozone depletion substances they release chlorine. So, they include, as I said earlier chlorofluorocarbons or hydrofluorocarbons or carbon tetrachloride or methyl chloroform these are basically these ODS or ozone depleting substances. So, they can release bromine and they can include these halons or methyl bromide also.

And then you can see like in the stratosphere, they can take around 2 to 5 years. Eventually, they go to the in the stratosphere, although how do they come into the stratosphere, this is so far they are released at the earth surface, but because of this atmospheric circulation, so this convection, when things go up in advection, horizontal movement, and vertical movement we call convection.

So through convection, slowly it goes up, and ultimately, it can reach, much part of it can reach to the stratosphere within 2 to 5 years, and then they start to do this damaging job.

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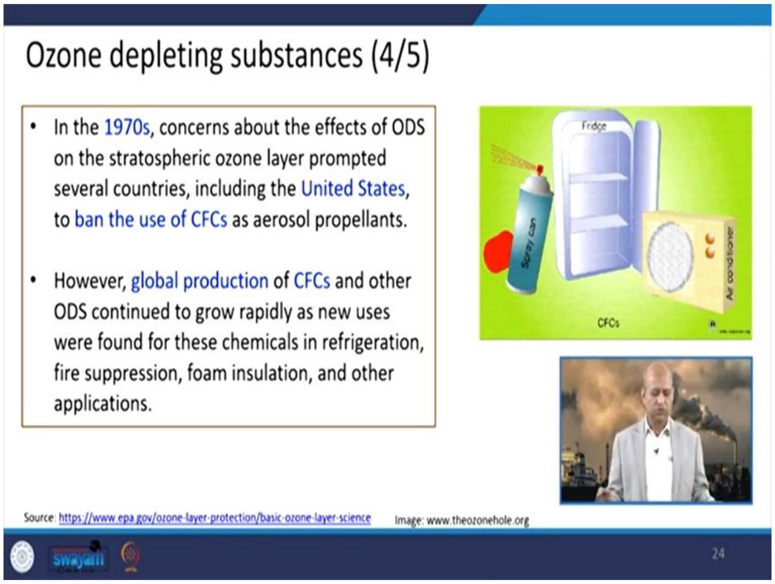

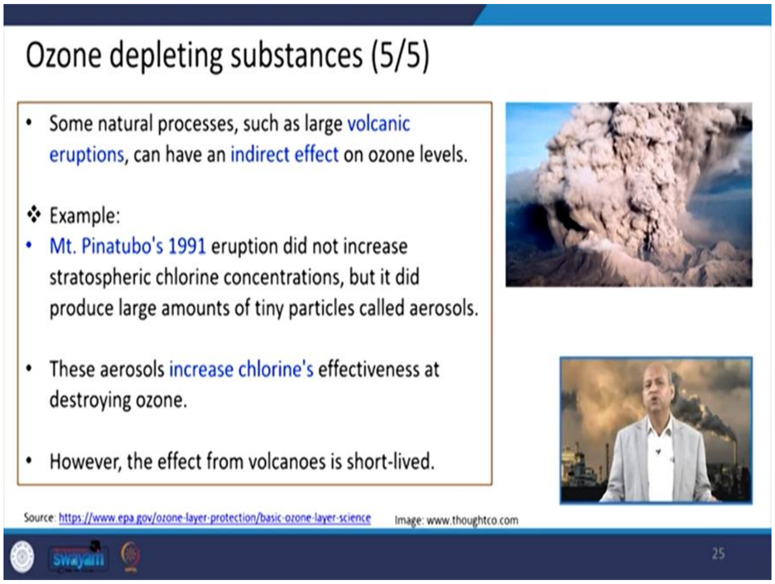

So in 1970s, basically, lot of concerns about the effects of ozone depleting substances on the stratospheric ozone layer. And in several countries, it was concerned were taken into account, like including United States, and there were demand of banning these CFCs, but at the time people did not come with such a force that it could be banned.

And later on, you can see like global production of CFCs and other these ozone depleting substances continued to grow rapidly as new usage of these chemicals into refrigeration or fire suppression or foam insulation or other applications got into practice. So, their utility their application real world application in a beneficial manner they push their production in large quantity. So, you could say this kind of debate took into the back burner.

But later on means, people continued to talk about and prove that these are the responsible and then we will see in the timeline that Montreal protocol happened to ban these kinds of chemicals. And not only these anthropogenic chemicals, but some natural processes, such as large volcanic eruptions can have indirect effect on the ozone levels. Like in 1991, there was this eruption of Mount Pinatubo eruption and this did not increase the stratospheric chlorine concentration. But it did produce large amount of tiny particles called aerosols.

And these aerosols basically, increased Chlorine’s effectiveness at the destroy ozone, because temperature reduction or this reaction speed or reaction kinetics it increased. And the effect of volcanoes is short lived in comparison to those chemicals, which are responsible for reduction of ozone layer.

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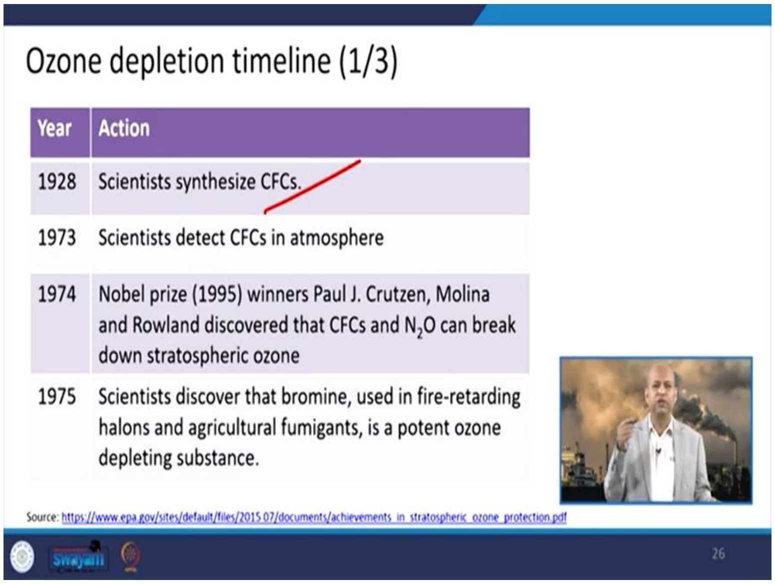

Well, if we talk about ozone depletion timeline, so in 1928 scientists synthesize CFCs chlorofluorocarbons, and it was a wonder chemical, as I said, people, industries welcomed it, because it was so inert, nontoxic, and that way, wonderful chemical. But in 1973, scientists detected that CFCs are present in atmosphere. So that was a kind of worry some thing, because otherwise people assumed that they will be only near and because they are inert, so, they would not harm any in any way.

In 1974, basically, when researchers were publishing their results like Molina, Mario Molina or this Rowland Sherwood, so they took these modeling efforts based on their lab reactions, lab based reactions. And they found that these CFCs can reach to the stratosphere and they can destroy the ozone layer.

At the same time in Max Planck Institute for chemistry professor Paul Crutzen, they also came to conclusion like nitrous oxide also can reach to the, at the stratosphere, they can also cause the depletion of ozone. So ultimately 1995 these three scientists were given Nobel Prize for their great discovery but up to that there was great struggle to convince the community scientific community, rather policymakers that these CFCs are responsible and we should stop their production and usage in the industries.

So in 1975 scientist discovered that bromine used in fire retarding Halons or agriculture fumigants is also a potent, potent ozone depleting substance. So that way these chlorine, bromine and other kind of chemicals were found to be responsible for depletion of the ozone.

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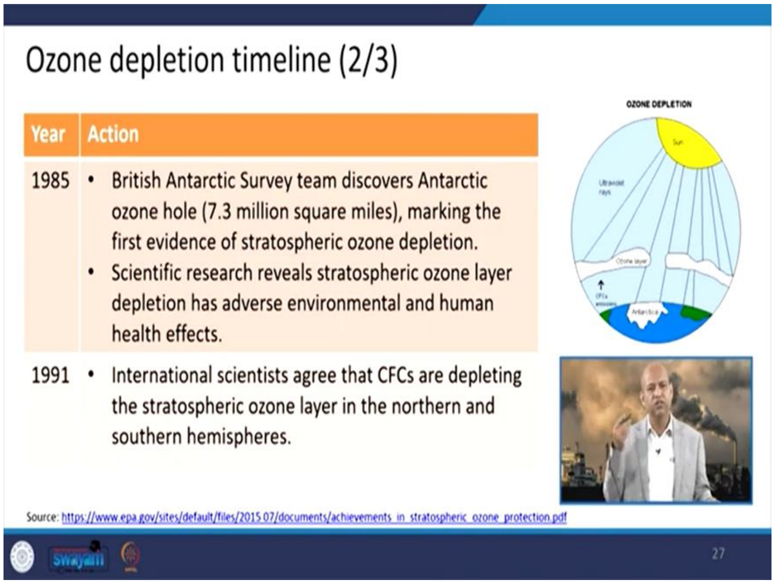

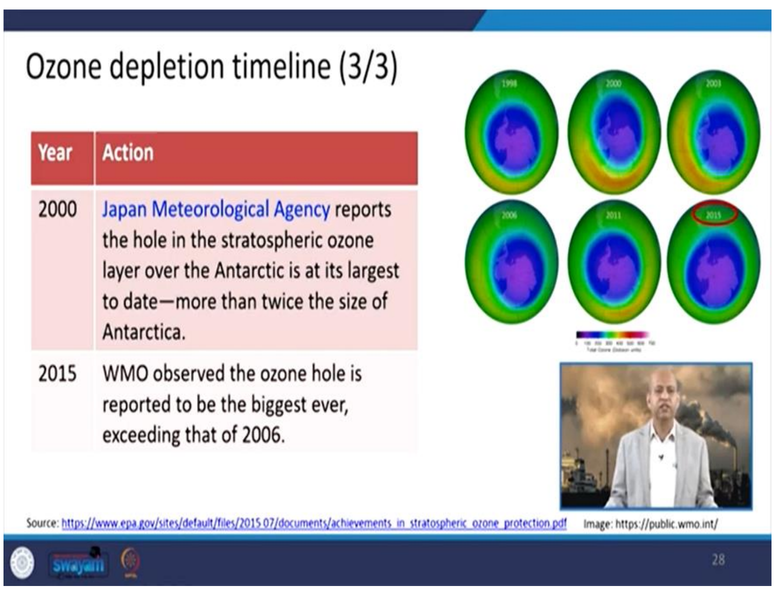

In 1985 there was like this British Antarctic Survey team, they discovered Antarctic ozone hole in 7.3 million square miles, means thin layer marking the first evidence of the stratospheric ozone depletion. And the scientific research revealed that the stratospheric ozone layer depletion has adverse environmental mental and human health effects, which was correlated with those kinds of effects, which were observed in those years, basically.

In 1991, then international scientists agreed that CFCs are depleting the stratospheric ozone layer in the northern and southern hemisphere. So that was kind of consensus, because of the scientific research and publications scientific community got agreement on this particular issue.

In 2000, then Japan metrological agency reported that hole in the stratospheric ozone layer over the Antarctic is at the largest to date in 2000 it was found it was the biggest one, more than twice the size of Antarctica. So, that was a big kind of story in that sense, because if it goes on then the life on Earth can be completely at the jeopardy. In 2015 this World Meteorological Organization observed that ozone only hole is reported to be the biggest ever exceeding that of 2006. So, that way it was increasing because there was no kind of control on emissions of those ozone depleting substances.

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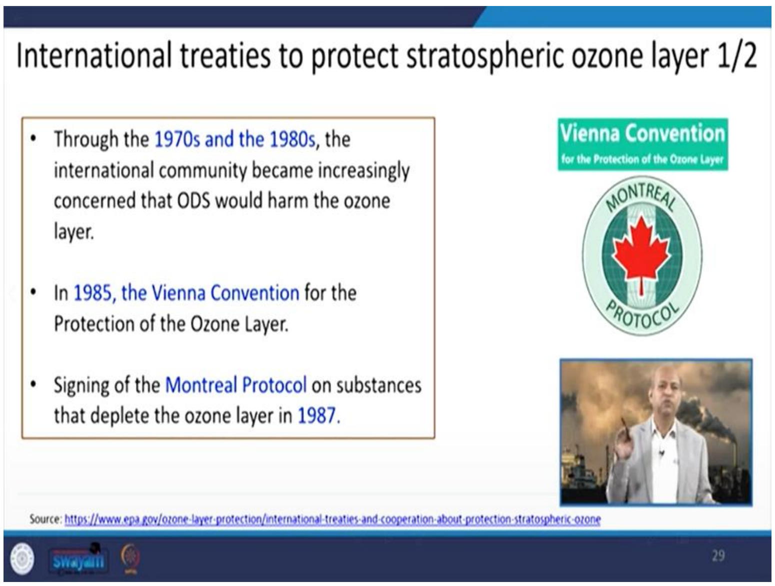

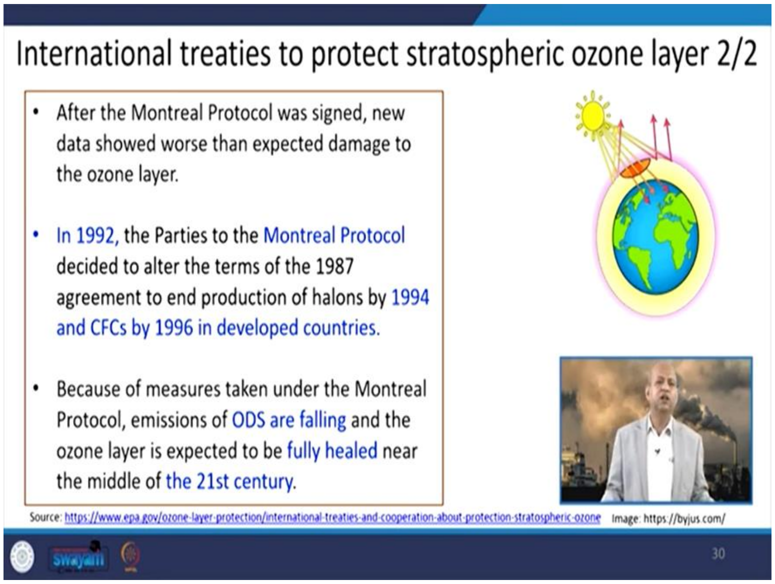

So, you can see through 1970s to 1980s, the international community became increasingly very concerned about ozone depleting substances and their harmful effects on the ozone layer. In 1985 in parallel means in time story, the Vienna Convention for the Protection of ozone layer occurred was held and then this Montréal protocol was signed in 1987 to kind of stop the production of ozone depletion substances.

So, after the Montreal protocol was signed, new data showed worse than expected damage to the ozone layer. So because these ozone depleting substances keep on working, it is not that you are stopping today and the ozone, ozone depletion stops it is not.

Because as I said, this chemical reaction, which is a chain reaction nature, it goes and goes and one molecule of that particular ozone depleting substance can destroy hundreds and thousands of molecules of the ozone. And for years, together, it goes on as their life is managed more.

So, in 1992, the parties to the Montreal protocol decided to alter the terms of 1987 agreement to end productions of Halons by 1994 and CFCs by 1996 in developed countries, so, that was a big achievement in that direction. And because of measures taken under the Montreal protocol, emissions of these ozone depleting substances, it started to fall and the ozone layer, it started to regain its thickness.

And it is assumed that because it is having the time lag and even if the products and an emissions of those ozone depleting substances are not there, but whatever chemicals are present in the stratosphere, they will take time to stop their reaction. Because their lifespan is much more at that particular level and one molecule destroys hundreds and thousands of molecules of ozone, because of this chain reaction. So, it is assumed that ultimately by mid-21st century it will be fully recovered that thickness will be fully recovered.

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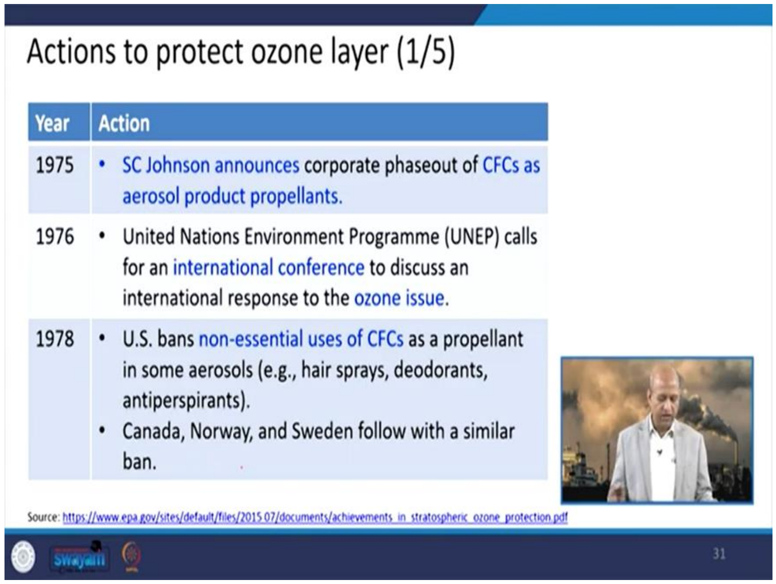

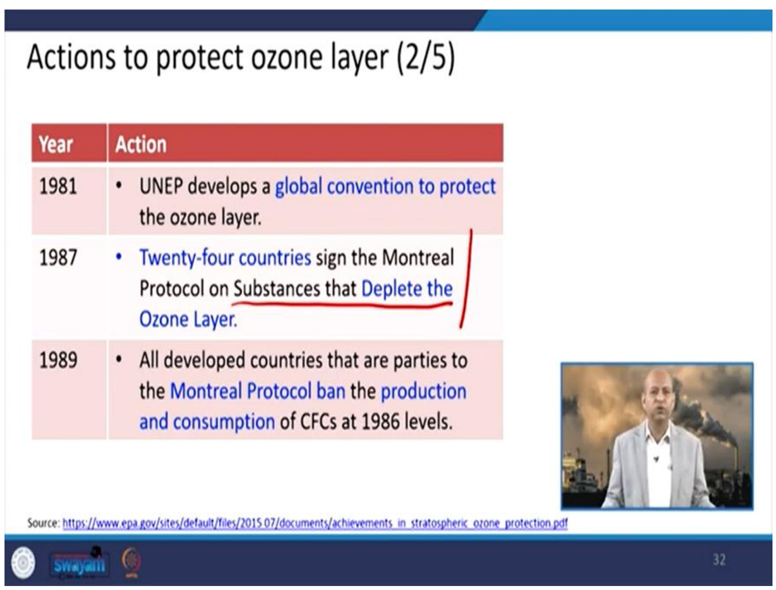

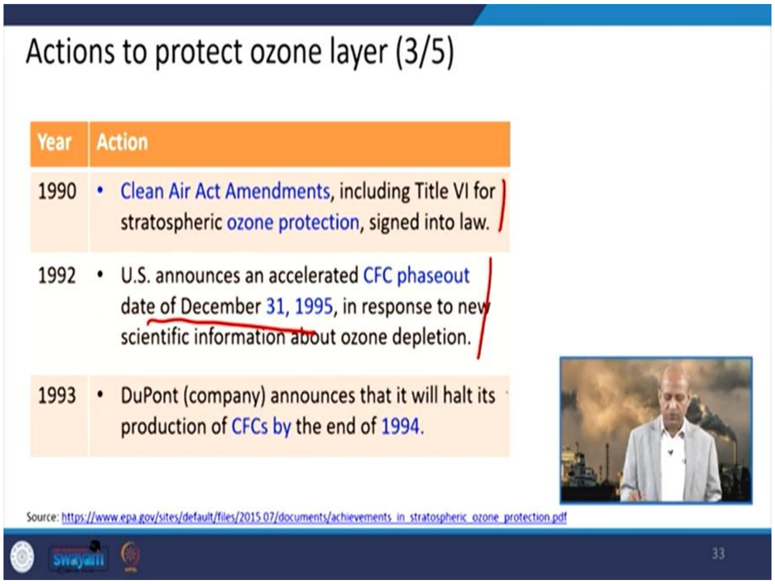

Now, you can see these actions to protect ozone layer in terms of timeline. So, in 1975, this SC Johnson announces corporate phase out of CFCs as aerosol product, these propellants, so, that was a good action in that sense. We will now see the action related timeline earlier we just have discussed like a policy related timeline or means how this was discovered observed in terms of observation and what kind of protocol happened.

In 1976, these United Nations Environmental Program (UNEP) called for this international conference to discuss international response to the ozone issue. In 78 US banned non-essential usage of CFCs as a propellant in some aerosols, like hair spray, Deodorant, Antiperspirants. Canada, Norway and Sweden followed similar ban.

Then in 1981 UNEP developed a global convention to product the ozone layer. And 1987 this Montreal protocol as we just saw, so, that was basically in 1987, 24 countries signed this Montreal protocol. So, in the history of this protecting in ozone layer, this Montreal protocol is very important. So, protocol on substance that deplete the ozone layer. In 1989, these developed countries, which were Parties to the Montreal Protocol to ban the production and consumption of CFCs at 1986 levels. So, those kind of incremental progress was there.

In 1990, Clean Air Act amendments, including the title Six for stratospheric ozone production signed into law so those were the progress. In 1992 US announced these accelerated CFC phase out program on 31st December 1995. And in response to new scientific information about ozone depletion. So that was decided that up to this particular program will be taken shape. In 1993 you can see these announcements so halt production of CFCs by the end of 1994.

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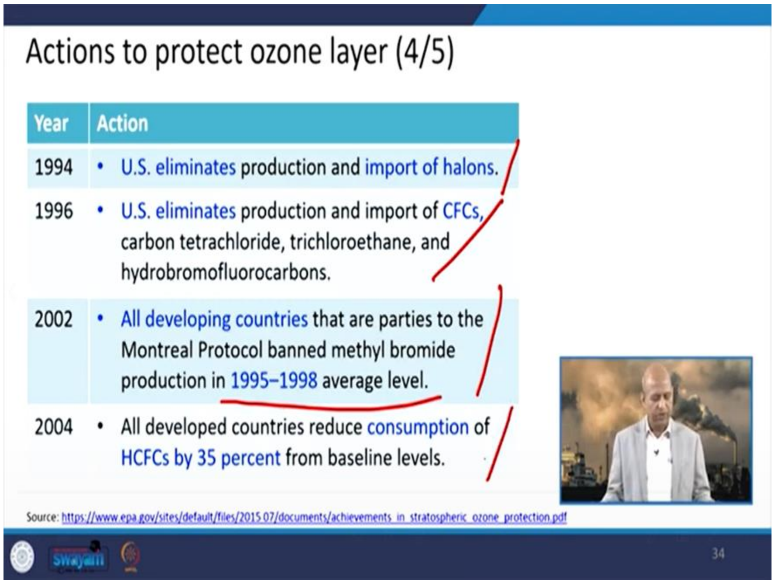

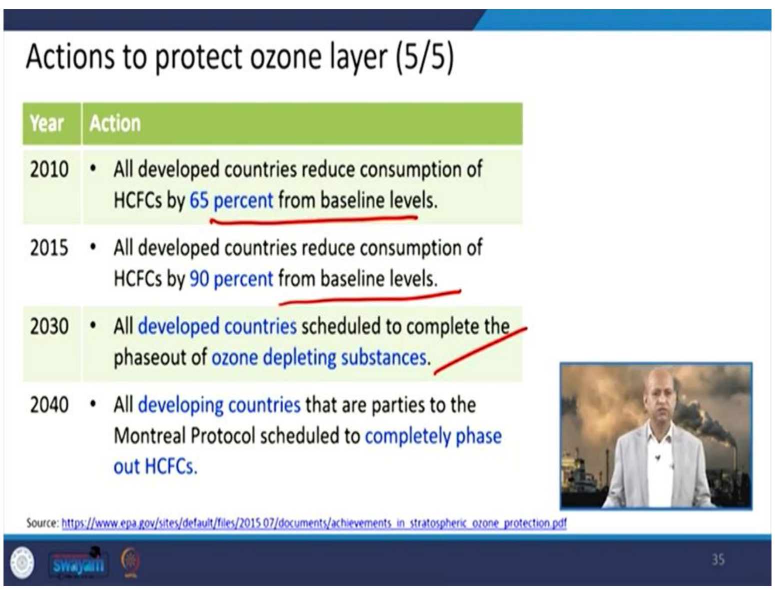

Then in 1994, you can see US eliminates products and an import of the halons, so that was a big, big milestone in that program. In 1996, US eliminated production and imports of CFCs carbon tetrachloride, then try chloromethane and hydrobromo fluorocarbons. In 2002 all developing countries that are Parties to the Montreal Protocol banned methyl bromide production. In 1995 to 1998 average levels, they were the benchmark kind of thing baseline data. In 2004 all developed countries reduced consumption of these SCFCs by 30 percent from the baseline levels.

In 2010 all developed countries reduce consumption of HCFCs by 65 percent with respect to the baseline data. In 2015, all developed countries reduce consumption of HCFCs by 90 percent from the baseline levels so that was big progress. So, this is as per the timeline, it is assumed that by 2030 all developed countries schedule the complete phase out of the ozone depleting substances. So, means much progress has been taken place already. In 2040 all developing countries that are Parties to the Montreal Protocol, they will be able to completely phased out at HSFC's. So, that way this is the timeline to protect the ozone layer.

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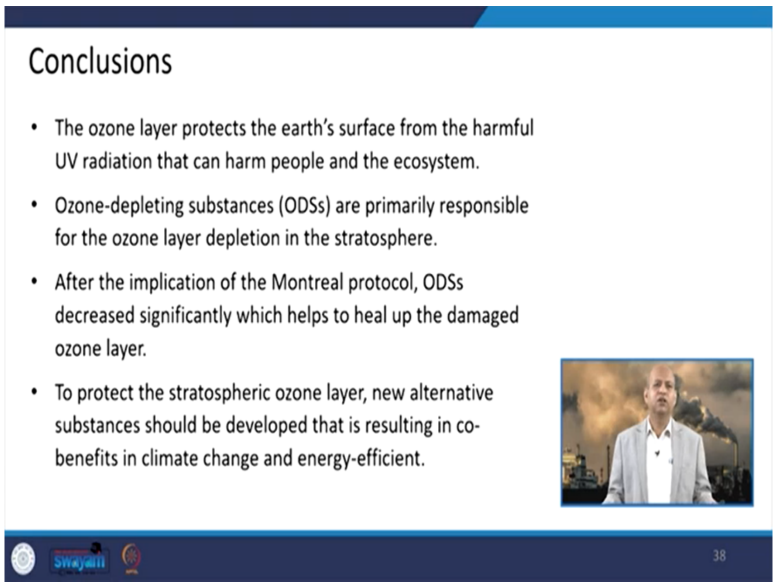

So, there have been lot of efforts to protect the ozone layer or to recover the thickness original thickness of this ozone layer in the stratosphere. And good signs are there that because of ban on the production and usage of those ozone depleting substances. Now, the regaining or recovering of the ozone layer is going on in a very nice way in a very encouraging way.

So, in conclusion, we can say that this ozone layer is very important for our life. And because it protects the complete Earth planet with the ultra violet rays, otherwise these ultraviolet rays will reach to the surface and it will destroy the complete life forms of the earth or it will cripple it will have so many negative impacts and harmful impacts.

These ozone depleting substances which were primarily responsible for destruction of ozone layer they have been now banned because of through international treaties etc. And we can see the implications of those treaties like Montreal protocol that the production and uses of these ozone depleting substances have reduced significantly. And now it is helping us to recover the ozone layer.

To protect the stratospheric ozone layer now new alternate substances should be developed and they are being developed in fact which can result in co benefits in climate change and energy efficient manner because which is, this is the need of the hour so that these chemicals are not harmful they are useful for our daily life but they are not harmful in any sense to this ozone layer or any other kind of climate change related issues they may produce as a side effect.

So we need to be careful about those kind of emissions, which are harmful we have to reduce them and we have to get into those kind of energy sources or chemicals which are harmless.

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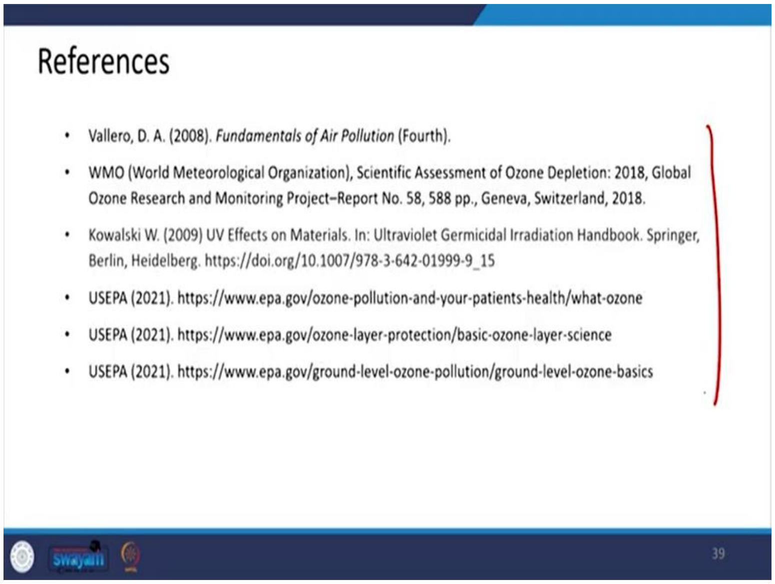

So this is all for today and these are the references for additional information. And thank you for your kind attention see you again in the next lecture. Thanks again.