Agri Mirror: Future India
Vol 1 Issue 7: November 2020
ISSN: 2582-6980

Understanding of Stratospheric Ozone

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Article ID: 107
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Introduction

Stratospheric ozone is naturally formed in chemical reactions involving ultraviolet sunlight and oxygen molecules, which make up 21% of the atmosphere. In the first step, sunlight breaks apart one oxygen molecule (O_2) to produce two oxygen atoms (2O) In the second step, each atom combines with an oxygen molecule to produce an ozone molecule (O_3). These reactions occur continually wherever ultraviolet sunlight is present in the stratosphere. As a result, the greatest ozone production occurs in the tropical stratosphere. The production of stratospheric ozone is balanced by its destruction in chemical reactions. Ozone reacts continually with a wide variety of natural and human produced chemicals in the stratosphere. In each reaction, an ozone molecule is lost and other chemical compounds are produced. Important reactive gases that destroy ozone are those containing chlorine and bromine. Some stratospheric ozone is transported down into the troposphere and can influence ozone amounts at Earth's surface, particularly in remote unpolluted regions of the globe.

Role of good ozone

Stratospheric ozone is considered "good" for humans and other life forms because it absorbs ultraviolet UV-B radiation from the Sun. If not absorbed, UV-B would reach Earth's surface in amounts that are harmful to a variety of life forms. In humans, as their exposure to UV-B increases, so does their risk of skin cancer, cataracts, and a suppressed immune system. The UV-B exposure before adulthood and cumulative exposure are both important factors in the risk. Excessive UV-B exposure also can damage terrestrial plant life, single-cell organisms, and aquatic ecosystems. Other UV radiation, UV-A, which is not absorbed significantly by ozone, causes premature aging of the skin. The absorption of UV-B radiation by ozone is a source of heat in the stratosphere. This helps to maintain the stratosphere as a stable region of the atmosphere with temperatures increasing with altitude. As a result, ozone plays a key role in controlling the temperature structure of Earth's atmosphere.

Protecting good ozone

In the mid-1970s, it was discovered that some human-produced gases could cause stratospheric ozone depletion. Ozone depletion increases harmful UV-B amounts at Earth's surface. Global efforts have been undertaken to protect the ozone layer through the regulation of ozone-depleting gases.

Stratospheric Ozone Depletion

Scientists learn about ozone destruction through a combination of laboratory studies, computer models, and stratospheric observations. In laboratory studies scientists are able to discover and evaluate individual chemical reactions that also occur in the stratosphere. Chemical reactions between two gases follow well-defined physical rules. Some of these reactions occur on the surfaces of particles formed in the stratosphere. Reactions have been studied that involve a wide variety of molecules containing chlorine, bromine, fluorine, and iodine and other atmospheric constituents such as oxygen, nitrogen, and hydrogen. These studies show that there exist several reactions involving chlorine and bromine that can directly or indirectly cause ozone destruction in the atmosphere. With computer models, scientists can examine the overall effect of a large group of known reactions under the chemical and physical conditions found in the stratosphere. These models include winds, air temperatures, and the daily and seasonal changes in sunlight. With such analyses, scientists have shown that chlorine and bromine can react in catalytic cycles in which one chlorine or bromine atom can destroy many ozone molecules. Scientists use model results to compare with past observations as a test of our understanding of the atmosphere and to evaluate the importance of new reactions found in the laboratory.

Computer models also enable scientists to explore the future by changing atmospheric conditions and other model parameters. Scientists make stratospheric observations to find out what gases are present in the stratosphere and at what concentrations. Observations have shown that halogen source gases and reactive halogen gases are present in the stratosphere at expected amounts. Ozone and chlorine monoxide (ClO), for example, have been observed extensively with a variety of instruments. Instruments on the ground and on board satellites, balloons, and aircraft detect ozone and ClO at a distance using optical and microwave signals. High-altitude aircraft and balloon instruments detect both gases directly in the stratosphere. For example, these observations show that ClO is present at elevated amounts in the Antarctic and Arctic stratospheres in the winter/spring season, when the most severe ozone depletion occurs.

The Discovery of the Antarctic Ozone Hole

The first decreases in Antarctic ozone were observed in the early 1980s over research stations located on the Antarctic continent. The observations showed unusually low total overhead ozone during the late winter/early spring months of September, October, and November. Total ozone was lower in these months compared with previous observations made as early as 1957. The early-published reports came from the British Antarctic Survey and the Japan Meteorological Agency. The results became more widely known in the international community after they were published in the journal Nature in 1985 by three scientists from the British Antarctic Survey. Soon after, satellite measurements confirmed the spring ozone depletion and further showed that in each late winter/spring season starting in the early 1980s, the depletion extended over a large region centered near the South Pole. The term "ozone hole" came about from satellite images of total ozone that showed very low values encircling the Antarctic continent each spring. Currently, the formation and severity of the Antarctic "ozone hole" are documented each year by a combination of satellite, ground-based, and balloon observations of ozone.

Replacing the Loss of "Good" Ozone in the Stratosphere

The idea is sometimes put forth that humans could replace the loss of global stratospheric ozone, called "good" ozone, by making ozone and transporting it to the stratosphere. Ozone amounts reflect a balance in the stratosphere between continual production and destruction by mostly naturally occurring reactions. The addition of chlorine and bromine to the stratosphere from human activities has increased ozone destruction and lowered "good" ozone amounts. Adding manufactured ozone to the stratosphere would upset the existing balance. As a consequence, most added ozone would be destroyed in chemical reactions within weeks to months as the balance was restored. So, it is not practical to consider replacing the loss of global stratospheric ozone because the replacement effort would need to continue indefinitely, or as long as increased chlorine and bromine amounts remained. Other practical difficulties in replacing stratospheric ozone are the large amounts of ozone required and the delivery method. The total amount of atmospheric ozone is approximately 3000 megatons (1 megaton = 1 billion kilograms) with most residing in the stratosphere. The replacement of the average global ozone loss of 3% would require 90 megatons of stratospheric ozone to be distributed throughout the layer located many kilometers above Earth's surface. The energy required to produce this amount of ozone would be a significant fraction of the electrical power generated in the United States, which is now approximately 5 trillion kilowatt hours. Processing and storing requirements for ozone, which is explosive and toxic in large quantities, would increase the energy requirement. In addition, methods suitable to deliver and distribute large amounts of ozone to the stratosphere have not been demonstrated yet. Concerns for a global delivery system would include further significant energy use and unforeseen environmental consequences.

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