PROTECTION OF THE ATMOSPHERE, WITH PARTICULAR REFERENCE TO NORTH AMERICA

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Summary

Following several decades of rapid growth in emissions of various air pollutants in the mid twentieth century, politicians and the public in North America became increasingly concerned about the possible impacts of these emissions on local, regional and global air quality. During the 1980s, the federal and state/provincial governments of Canada and the United States developed and implemented a number of mitigative programs aimed at protecting the atmosphere from such continued degradation. These programs have been successful in reducing the risks associated with a number of atmospheric issues. Concentrations of many toxic substances decreased dramatically, while other indicators of local air quality have also improved. Acidic deposition, although still significant, has also decreased throughout the eastern regions of North America. Through collaborative efforts with the international community, the atmospheric concentrations of ozone depleting substances are now decreasing.

Increasing growth in the transportation sector and other socio-economic sectors will require continued efforts to ensure that recent gains in local and regional air quality are sustained and improved upon. The introduction of new chemicals will also demand thorough assessment of possible health and ecological impacts. There are however,

encouraging indications that protection of the atmosphere over North America is improving.

There is, however, one important atmospheric issue—perhaps the most important—that remains unresolved. International efforts to limit the emissions of greenhouse gases, and hence reduce the risks of danger due to climate change, have as yet failed to make any appreciable impact on global emissions. Annual releases of greenhouse gases also continue to grow in both Canada and USA. Hence, this issue will be one of considerable importance in the years to come.

1. Introduction

Our understanding of the universe suggests that Earth's life support characteristics are rare, and perhaps unique. One of the most crucial reasons for these unusual characteristics is its atmosphere. The atmosphere provides the oxygen, nitrogen, water vapor and carbon dioxide needed to sustain the biological processes within its terrestrial ecosystems. It contains a protective high-level ozone layer which screens out lethal ultra-violet radiation from the sun. Moreover, it contains trace quantities of heat absorbing gases, including carbon dioxide, that serve as an insulating blanket around the planet, keeping surface temperatures within the range necessary for the presence of liquid water, and hence life as we know it. The lower atmosphere also contains significant amounts of a highly reactive cleanser known as the hydroxyl radical, which quickly reacts with and neutralizes many of the toxic substances entering the atmosphere. Each of these factors is important to the planet's life support system. Each has been present in the atmosphere for millions of years.

In addition to being a reservoir for some of the primary life support elements needed by living terrestrial organisms, the atmosphere also functions as a transport mechanism for nutrients and moisture from one part of the world to another. It provides the conveyor belt by which water recycles by evaporation from the oceans, lakes and vegetation into the atmosphere, condensation into water droplets and cloud formations, and precipitation back to land ecosystems as rain and snow. The clouds formed as part of this cycle also help regulate heat flow to and from the Earth's surface, much like a thermostat. Winds also transport minerals, metals, plant seeds and pollen, and other substances long distances to receptive ecosystems. They induce ocean currents that transport heat and nutrients for aquatic ecosystems. Furthermore, the atmosphere is a transportation corridor by which birds, bats and insects move and migrate. In effect, it acts as a transient, chemically active holding reservoir that helps exchange essential biochemical ingredients and life forms from one form and one location to another, thus helping to maintain dynamic, diverse and healthy life communities around the world.

Despite the common human perception of the atmosphere as a virtually limitless ocean of gaseous substances, these atmospheric life support characteristics are contained within a remarkably thin envelope around the planet About 80% of the atmosphere's mass lies within the first ten km above the Earth's surface. This layer, known as the troposphere, contains most of the atmosphere's clouds and water vapor (which can vary in concentrations from 4% in warm, humid regions to almost zero in arid or very cold climates). The troposphere is very dynamic, with convective air currents providing vigorous vertical mixing and global winds interacting with all corners of the earth's land masses, oceans, ice sheets and fresh water bodies. The next forty kilometers of atmosphere is the stratosphere, much colder and thinner than the troposphere and separated from it by a somewhat permeable tropopause. The stratosphere contains another 19% of the atmosphere's mass, but holds very little water vapor (and hence clouds). It is also the region of the atmosphere where the "ozone layer" is formed and maintained. Ozone is a highly reactive form of oxygen, consisting of three atoms rather than the two atoms in the conventional but stable oxygen molecule. It is very effective in absorbing the shortest ultraviolet components of sunlight, thus shielding life at the Earth's surface from these harmful, high energy rays. Ironically, ozone itself is toxic to most living organisms. Hence, its very low natural concentrations near the Earth's surface is also an important aspect of the atmosphere's unique life supporting properties. The remaining 1% of the atmosphere's mass is located in the thermosphere and mesosphere, which extend out to 300 kilometers above the surface.

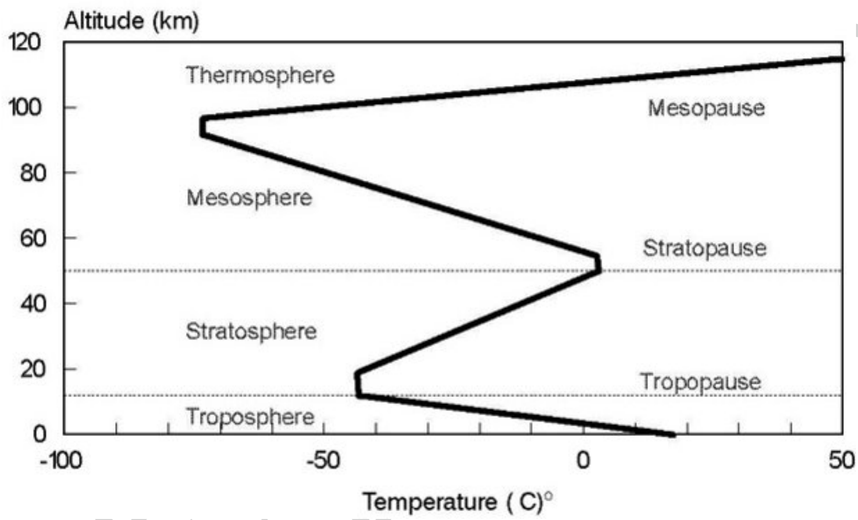

Figure 1. Ninety-nine percent of the mass of the Earth's atmosphere lies within the first 50 km above the surface. The atmosphere's vertical temperature structure is determined by heat absorption by gases and particles, particularly ozone.

Observations from space, unavailable to humans prior to the past few decades, reveal that this envelope of gases that make up the atmosphere is little more than a thin, dark blue, fragile skin stretched around the Earth's ecosphere.

2. Pre-historic changes in atmospheric composition

Although the atmosphere's life-support characteristics noted above have persisted for millions of years, they do vary with time. Instrumental records to monitor these changes have only been available for the very recent past. Hence scientists turn to a rich variety of information sources found within the Earth's surface and oceans, including trees, soils, rocks, ocean and lake sediments and ice sheets, to tease out important clues as to how these properties have varied. Ice sheets on Greenland and Antarctica have been particularly useful in studying the atmosphere's properties over the past several hundred thousand years. These sheets progressively form when the annual amount of snowfall on their surfaces exceed loss through melting and ablation. As these annual layers of net snowfall accumulate over time, they are gradually compressed into hard glacial ice. At a certain point in this process, the air within the snow layers becomes sealed off from the free atmosphere (a process that can take about 100 years) to provide an excellent archive of the composition of the atmosphere at that time. These encapsulated air samples can remain buried within the ice sheets for many thousands of years. Furthermore, the chemical composition of the ice that surrounds these bubbles can provide important clues about the air temperature at the time the snow that formed the ice fell. Because the atmosphere is a dynamic, well mixed system that freely visits all corners of the Earth, these samples become important proxies for not just local atmospheric conditions, but its global status with time.

Research scientists have used special drilling equipment to extract cores of glacial ice from various locations near the top of the Antarctic and Greenland ice sheets, as well as from some mountain glaciers. The ice at the bottom of some of these cores is estimated to be about 400 000 years old. These cores are carefully preserved and analyzed in a number of specially equipped laboratories to piece together important clues about the atmosphere's past. Results from these studies include the following:

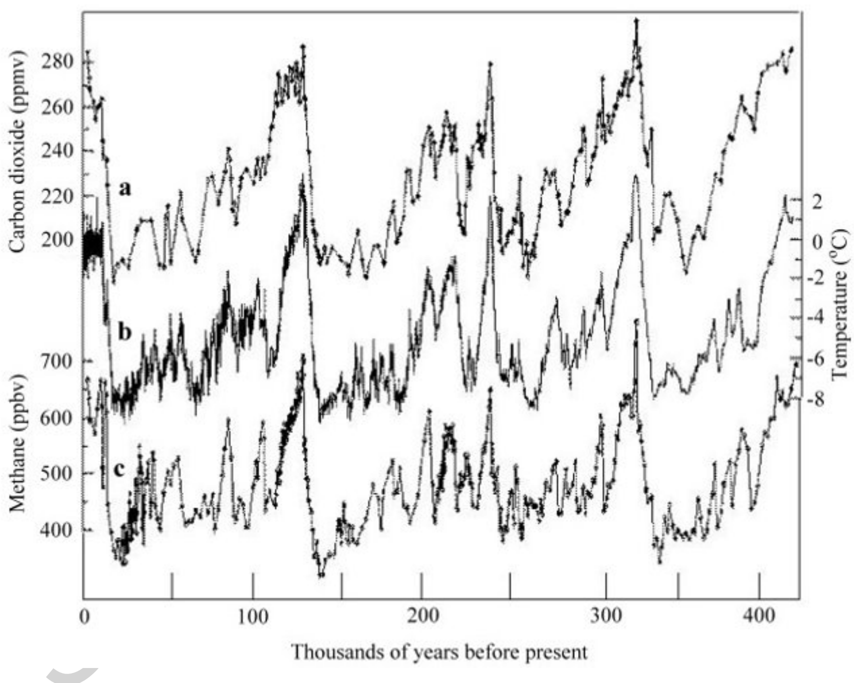

Figure 2. Data collected from Antarctic ice cores show that the large changes in regional temperatures (line b) during the past 400 000 years are closely correlated with changes in atmospheric concentrations of carbon dioxide (line a) and methane (line c).
Source:Adapted from Petit et al. 1999.

- Temperature. The ratios of oxygen and hydrogen isotopes within the ice, which vary according to atmospheric temperatures at the time of snowfall, clearly show the pattern of changes in regional atmospheric temperatures as the Earth's climate vacillated between ice age and interglacial conditions every 100 000 years or so. In Antarctica, for example, local temperatures varied by about ten degrees Celsius during these cycles (see Figure 2). Other data from ocean sediments and land rock formations suggest that most of the rest of the Earth experienced somewhat smaller temperature differences. However, on average, its appears that the Earth was about 4 to 6 °C colder during the peak of the last glacial maximum, some 25 000 years ago, than it has been during the past 10 000 years of the current interglacial.

- Greenhouse gas concentrations. Carbon dioxide concentrations varied between a minimum level of about 200 parts per million of air volume (ppmv), or about 0.02% of the atmosphere, during the glacial maximums to between 280 and 300 ppmv during the interglacial peaks. Smaller variations within this range have occurred on shorter time scales. Likewise, methane concentrations have fluctuated between 400 parts per billion by volume (ppbv) during glacial maxima and 700 ppbv during interglacials. These changes in greenhouse concentrations occur in close step with those of atmospheric temperature. However, the changes in CO_2 appears to lag that of temperature by a thousand years or so during the cooling phases of the temperature cycles. This suggests that the changes in greenhouse gas concentrations were not the initial causes of changes in climate, but an important factor in amplifying the initial temperature changes, perhaps doubling them.

- Dust and other chemicals. The Greenland ice cores show that the amount of dust particles embedded in the ice dropped dramatically at the end of the last glacial period some 12 000 to 15 000 years ago. They also show significant variations in concentrations during the previous 100 000 years. Since the particles were transported long distances by winds passing over the North American continent and Eurasia, they provide useful indications of variations in humidity and vegetation cover on these continents, and in turbidity of the local atmosphere. During cold, dry periods, more dust storms would increase the loading of these particles, including minerals and other important plant nutrients such as iron and zinc, in the overlying atmosphere. Winds would then transport these aerosols to locations far removed from their origin, including the surfaces of the Greenland ice sheet.

These results from analysis of ice core data and other proxy sources of information show that the composition of the Earth's atmosphere is naturally variable. They are also important reminders that these variations occurred within a relatively narrow range that continued to preserve the atmosphere's life support characteristics.

The atmosphere over North America, as part of a dynamic system that knows no geographical boundaries and circulates freely around the entire planet, is inextricably connected to that of other regions of the world. Hence, for gases that remain in the atmosphere for relatively long periods of time (several years or more), changes in the intensity of emissions into the atmosphere, whether from North American sources or elsewhere, affect the composition of the entire global atmosphere. That is, changes in their concentrations in the air over North America are closely linked to variations in global sources, regardless of point of origin. Other substances, however, remain in the atmosphere for relatively short periods of time before they are removed either through gravity or chemical reactions within the atmosphere. For example, mineral dust picked up from soils by surface winds normally remains in the lower atmosphere for only hours to weeks before most of it is removed by gravitational forces or through the cleansing process of rainfall. Likewise, chemically reactive gases such as volatile organic compounds can very quickly interact with other chemicals in the atmosphere and decompose into less reactive substances, producing by-products that likewise can settle out of the atmosphere much like dust. Hence, atmospheric concentrations of such substances are more closely tied to local and regional sources, with only small fractions of the amounts emitted into the atmosphere being transported long distances to other parts of the world. The exception is sulfur gases that are injected directly into the stratosphere through explosive volcanic eruptions. Once in the stratosphere, these quickly interact with other chemicals to form sulfate particles. Because the tropopause somewhat isolates the stratosphere from the lower atmosphere, these particles precipitate out much more slowly (over a period of several years). Hence major volcanic eruptions can affect the concentrations of sulfates throughout the entire global stratosphere.

3. History of human interference with atmospheric properties over North America

While little is known about the influence of early human civilizations prior to the industrial period on the atmosphere over North America, these impacts are likely to have been primarily of a regional nature and relatively short. For example, forest fires started by native Americans will have temporarily increased the volume of particulates in the air, while localized areas of agricultural activity may have increased dust levels from wind erosion. Likewise, irrigated agriculture in the American southwest will have increased local concentrations of water vapor. The arrival of large numbers of European settlers into North American during and after the seventeenth century resulted in increased conversion of forests and grasslands into cultivated land, enhancing these impacts at local scales. In more urban centers with concentrated populations, inefficient combustion of wood for space heating, cooking and other activities also contributed to local degradation of air quality, particularly during cold, calm winter periods. However, on average these changes would have been minor compared to those from natural causes.

The first clear signs of significant changes to local atmospheric conditions over North America began to appear in the late nineteenth and early twentieth century. As the industrial revolution began to alter the fabric of the social infrastructure of North American populations, emissions of particulate matter from the combustion of coal in factories, homes and rail locomotives caused serious local problems with air quality. The first political measures instituted in North America to deal with such pollution were passed in Chicago and Cincinnati in 1881. Further regulations came into place at the county level by the early 1900s. Transborder pollution between Canada and the USA also became an issue in the early twentieth century. Meanwhile, land clearing operations for agricultural development across North America during this period also began to contribute to a rise in global atmospheric concentrations of CO_2. Ice core data from glaciers on Mount Logan, in Canada's Yukon Territory, and Greenland ice sheets indicate that these activities released as much as 2 to 3 billion tonnes of carbon per year directly into the atmosphere during the peak periods of deforestation (see Figure 3).

However, the most dramatic rise in human alterations of the atmosphere over North American began to materialize in the mid twentieth century, as chemical revolutions within industry and agricultural activities began to combine with continued growth in economic activities (fueled by the use of energy from the combustion of coal, oil, and eventually natural gas) to create an exponential growth in emissions into the atmosphere.

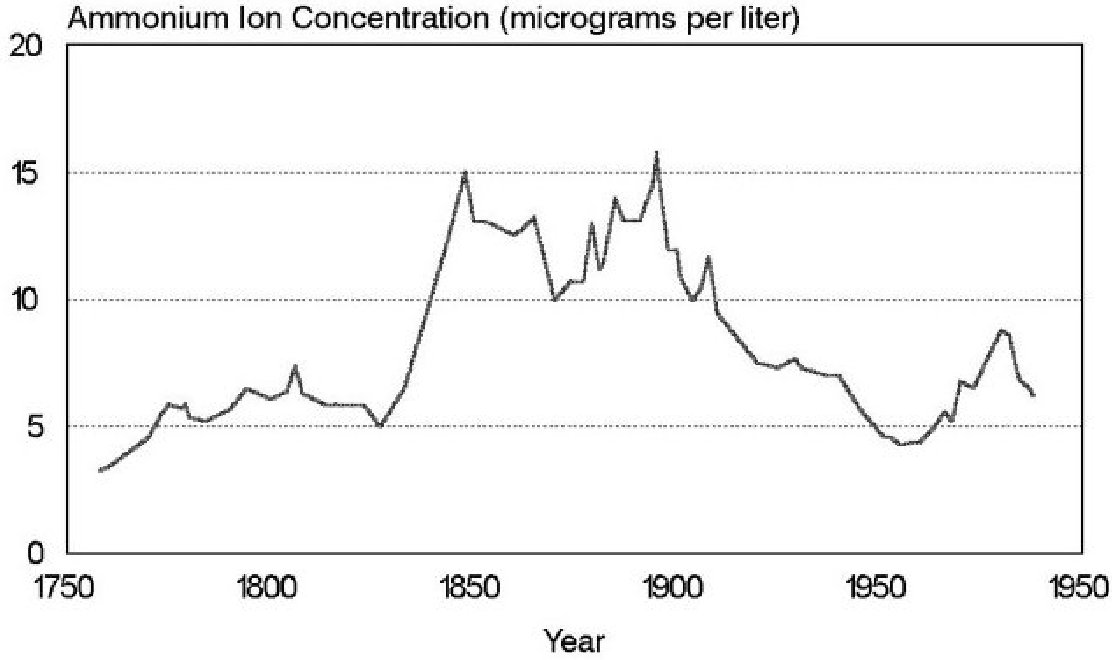

Figure 3. Greenland ice core data provide evidence of a significant increase in the concentrations of ammonium ions (a by-product of biomass burning) in the late nineteenth century. This increase appears to be linked to land clearing for agriculture in North America. Source: Holdsworth et al. 1996.

Over the subsequent decades, local, regional and global air quality issues have emerged as serious political issues, many of which require multi-national policy response to address effectively.

Scientific investigations and political response to a degrading atmosphere over North America are commonly divided into three types of issues—local, regional and global. Local issues, such as smog, particulate matters and toxic chemicals within the atmosphere, can often be resolved through actions taken within regional political jurisdictions, although they may also require cross jurisdictional accords. Regional issues (e.g. acid rain and arctic haze) involve the transport of air pollutants over longer distances, and hence regional and bi-national or multi-national agreements are needed to resolve them. Global issues, primarily that of stratospheric ozone depletion and climate change, deal with well-mixed substances that affect the composition of the global atmosphere, and hence demand international collaboration and cooperation to develop effective responsive action. Collectively, these different atmospheric issues all deal with a dynamic atmosphere that is common to all humanity and all surface ecosystems. They also have important common causes, and are further inter-linked through atmospheric physical and chemical processes. As well, their impacts on ecosystems and humans share the complexity of ecosystems and living organisms exposed to multiple stresses. Hence, although often dealt with independently, both in scientific investigation and policy response, effective understanding and mitigation necessitates that each issue be addressed within the context of the whole atmosphere and other concurrent changes taking place within it. The following sections attempt to provide such a holistic perspective.

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All Things Arctic, http://www.allthingsarctic.com/ecosystems/index.aspx

[This site is a valuable source of information on the Arctic. The section on Arctic ecosystems presents a quick study on Arctic environments which are susceptible to dramatic change due to global warming.]

Biographical Sketch

Henry Hengeveld is the senior science advisor on climate change with Environment Canada, and is based in Toronto, Ontario. For the past two decades, he has undertaken regular assessments of the state of international understanding of the science of climate change, has written numerous reports and articles on the subject for lay audiences, and has frequently provided advice on climate and atmospheric sciences to policy makers and the public. He has participated as a member of national delegations to international climate change science assessment meetings as well as policy related meetings pertaining to the UN Framework Convention on Climate Change. He also routinely collaborates with colleagues in the atmospheric sciences in better understanding the linkages between climate change and other atmospheric environmental concerns.