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LECTURE NOTE
ON

INTRODUCTION TO CLIMATE CHANGE

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INTRODUCTION TO CLIMATE CHANGE

INTRODUCTION

Climate of a region represents the long-term average of weather (more than thirty years). It is a resultant of extremely complex system consisting of different meteorological variables, which vary with time. Climate in a narrow sense is defined as "average weather", or more rigorously, as the statistical description in terms of mean and variability of relevant quantities of weather parameters over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by WMO. These parameters are most often surface variables such as temperature, precipitation and wind.

The climate change is a very common word in the present day world. The common man, media and scientists all seem to be concerned with this phenomenon. It is generally because the mean global temperature of earth is showing an increasing trend. However, this might not be true in a regional scale, but enough evidences have been gathered showing this increasing trend of temperature. The important evidences include worldwide retreat of glaciers in all latitudes, rising of the mean sea level, breaking of Antarctic ice sheets etc. Such changes may have severe impact on mankind and all other living species. Such scenarios of projection have urged researchers from all over the world and of all fields of science to study the problem in a greater depth.

Climate change refers to a statistically significant variation in either the mean state of the climate or in other statistics (such as standard deviations, the occurrence of extremes, etc.), persisting for an extended period particularly decades or longer. Climate change may be due to natural internal processes or external forcings, or to anthropogenic changes in the composition of the atmosphere or in the land use. Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that of UNFCCC which defines climate change as, "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". Climate change is not only a major global environmental problem, but also an issue of great concern to a developing country like India.

The earth's atmosphere - the layer of air that surrounds the earth - contains many gases. Short-wave radiation from the sun passes through the earth's atmosphere. Partly this radiation is reflected back into space, absorbed by the atmosphere and remainder reaches the earth's surface, where it is either reflected or absorbed. In turn the earth's surface, emits long-wave radiation toward space. The greenhouse gases (GHGs) available in the atmosphere principally include carbon dioxide (CO_2), nitrous oxide (NO_2), methane (CH_4), and chlorofluorocarbons (CFCs) and ozone (O_3). These GHGs absorb some of this long-wave radiation emitted by the Earth's surface and re-radiate it back to the surface. Ever since the industrial revolution began about 150 years ago, human activities have added significant quantities of GHGs to the atmosphere. An increase in the levels of GHGs could lead to greater warming which, in turn, could have major impact on the world's climate, leading to accelerated climate change. Global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased from 280 ppm to 379 ppm, 715 ppb to 1774 ppb and 270 ppb to 319 ppb respectively, between pre-industrial period and 2005 (IPCC, 2007). Thus GHGs modify the heat balance of the Earth by retaining long-wave radiation that would otherwise be dispersed through the Earth's atmosphere to space. This effect is known as the greenhouse effect. Evidently, GHG have an important role in controlling the temperature of the earth and an increase in their concentration in the atmosphere would increase the temperature of the Earth. In addition, presence of excess quantities of CFCs affects the protective ozone layer which deflects the harmful short wave rays.

Global warming arising from the anthropogenic-driven emissions of greenhouse gases has emerged as one of the most important environmental issues ever to confront humanity in last two decades. Concern over global climatic changes caused by growing atmospheric concentrations of carbon dioxide and other trace gases has increased in recent years as our understanding of atmospheric dynamics and global climate systems has improved. Scientists have learnt a great deal in recent decades about the climate and its response to the human activities, particularly emission of the greenhouse gases such as carbon dioxide, methane, nitrous oxide etc. Nevertheless the global climate system is so vast and complex that it is difficult to understand very accurately. Consequently, some uncertainty remains in the outcome of the analysis. There is focus on scientific research along with probable impact on society. This problem is inextricably linked to the process of development and economic growth itself. This concern arises from the fact that our everyday activities may be leading to changes in the earth's atmosphere that have the potential to significantly alter the planet's heat and radiation balance. It could lead to a warmer climate in the next century, which may have adverse effect on the resources and society.

With an economy closely linked to its natural resource base and climatically sensitive sectors such as agriculture, water and forestry, India may face a major threat because of the projected change in climate. With climate change, there would be increasing scarcity of water, reduction in yields of forest biomass, and increased risk to human health. India released its National Action Plan on Climate Change (NAPCC) on 30th June, 2008 to outline its strategy to meet the Climate Change challenge. The National Action Plan advocates a strategy that promotes, firstly, the adaptation to Climate Change and secondly, further enhancement of the ecological sustainability of India's development path. India's National Action Plan stresses that maintaining a high growth rate is essential for increasing the living standards of the vast majority of people of India and reducing their vulnerability to the impacts of climate change. Accordingly, the Action Plan identifies measures that promote the objectives of sustainable development of India while also yielding to benefits for addressing climate change. Eight National Missions, which form the core of the National Action Plan, represent multi-pronged, long term and integrated strategies for achieving key goals in the context of climate change. The focus is on promoting understanding of Climate Change, adaptation and mitigation, energy efficiency and natural resource conservation.

Recent decades have seen record-high average global surface temperatures. Thermometer readings sufficient to provide reliable global averages are available back to 1850. In the past century, global surface temperature increased by about 1.4 °F (Fig. 1). In the past quarter-century, according to satellite measurements, the lower atmosphere warmed by 0.22-0.34 °F per decade, equivalent to 2-3 °F per century (Christy and Spencer 2005; Mears and Wentz 2005). The past 20 years include the 18 warmest years on record (Hadley Centre 2005).

This well-documented warming trend could result from several factors that influence the earth's climate, some of which are natural, such as changes in solar radiation and volcanic activity. Others, particularly the release of certain gases to the atmosphere and land-cover changes, are manmade. This lecture describes recent scientific progress in identifying the causes and has drawn material from Pew (2005).

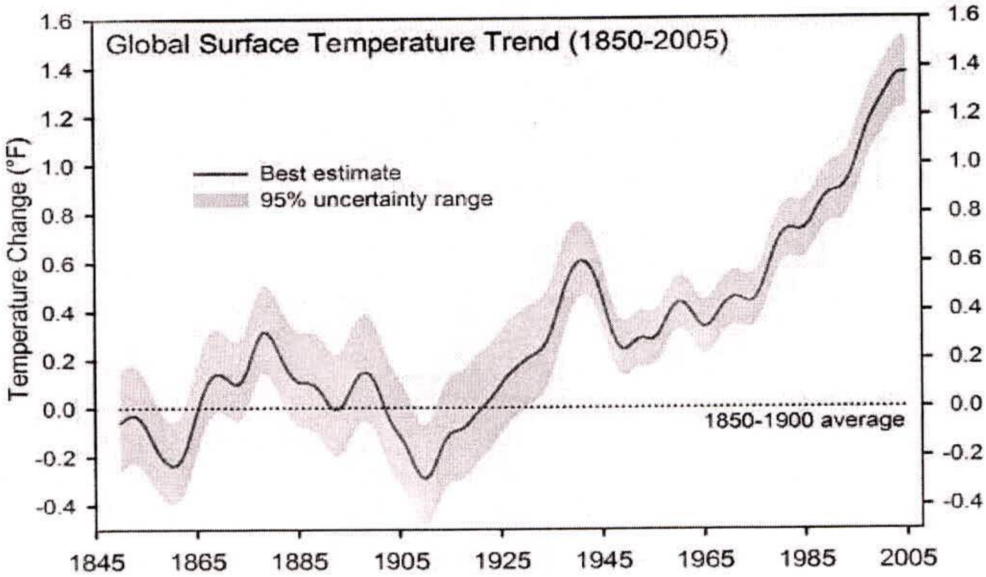

Figure 1. Average global surface temperature based on instrumental measurements (Adapted from Brohan et al. 2006). Temperature rise during the twentieth century is much larger than the uncertainty range.

The **greenhouse effect** is a natural phenomenon whereby certain gases in the earth's atmosphere, known as **greenhouse gases (GHGs)**, absorb heat that would otherwise escape to space. This heat originates from visible sunlight that warms the earth's surface. Subsequently, heat radiates from the surface to the atmosphere, where some of it is absorbed by greenhouse gases and radiated back to the surface (Fig. 2). Recent progress in climate modeling has generated a consensus among climate scientists that GHGs emitted by human activities are likely (66-90% chance) to have caused most of the observed global temperature rise over the past 50 years (Mitchell et al. 2001). The increase in the strength of the greenhouse effect as a result of man-made greenhouse gases is known as the enhanced greenhouse effect.

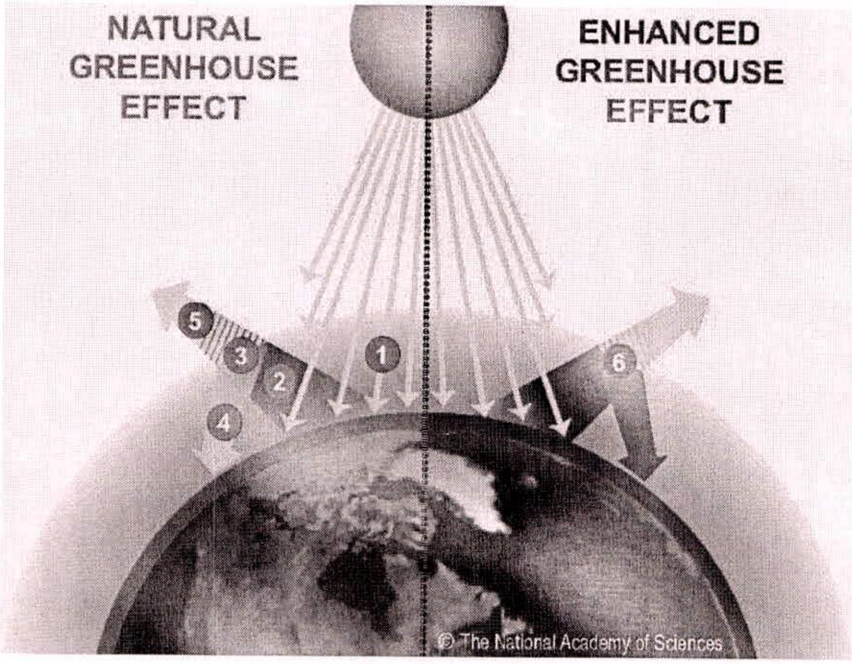

Figure 2. Illustration of the greenhouse effect (Courtesy: National Academy of Sciences). Visible sunlight passes through the atmosphere without being absorbed. Some of the sunlight striking the earth is (1) absorbed and converted to infrared radiation (heat), which warms the surface. The surface (2) emits infrared radiation to the atmosphere, where some of it (3) is absorbed by GHGs and (4) re-emitted toward the surface; some of the infrared radiation is not trapped by GHGs and (5) escapes into space. Human activities that emit additional GHGs to the atmosphere (6) increase the amount of infrared radiation that gets absorbed before escaping to space, thus enhancing the greenhouse effect and amplifying the warming of the earth.

Factors Influencing Global Temperature

Global climate varies over time in response to climate forcings—physical factors external to the climate system that force a net increase (positive forcing) or net decrease (negative forcing) of heat in the climate system as a whole (Hansen, Sato et al. 2005). This type of change is distinct from internal climate variability, in which heat is transported by winds or ocean currents between different components of the climate system with no net change in the total heat within the system. The El Niño–Southern

Oscillation is a well-known example of internal climate variability. Because the observed climate change over the twentieth century results from a net increase of heat in the entire climate system, it can only be explained by external forcing (Hansen, Nazarenko et al. 2005). Hence, the task for climate change scientists is to identify one or more external forcing(s) — natural or manmade — that can explain the observed warming.

Until recent centuries, climate forcings were exclusively natural, such as changes in the amount of sunlight reaching the earth's surface and changes in emissions of dust from volcanoes. During modern times, human activities have introduced a mix of additional forcings, such as increases in atmospheric GHGs that cause warming (positive forcing), and sulfate aerosols, miniscule particles that reflect sunlight and cause cooling (negative forcing). The histories and magnitudes of various forcings are estimated from direct observations, such as satellite measurements of solar radiation in recent decades, or from proxies, such as sunspots for solar radiation in earlier decades (Foukal et al. 2004). The histories of individual forcings (Fig. 3) are then examined for the potential to cause the observed pattern of climate change (Hansen, Sato et al. 2005).

Scientists employ records of various forcings in a "fingerprinting" approach to identify which forcings can account for observed patterns of climate change. A particular forcing imprints itself uniquely on the past climate record based on how the forcing works and how its strength varies over time.

Modeling to Identify Causes of Climate Change

Fingerprint matching between climate forcings and observed climate change is performed using physical climate models that calculate how each forcing should have affected climate over time, based on its history and how the physical mechanisms of each forcing is currently understood. These models are able to reproduce most of the major features of the global climate system, including the pattern of global warming over the past century (e.g., Stott et al. 2000). The models serve as controlled experiments that test alternative hypotheses about the causes of climate change. Each forcing depicted in Fig. 3 represents a hypothesized cause of observed climate change. Entering records of one or more forcings into a model, scientists assess whether the climate scenario generated by the model is similar to the observed climate record; no observed climate data are entered into the model. If the simulated climate matches observed climate, then the forcing(s) represented in the model have correctly explained the observed climate record. If not, the forcing(s) cannot explain the observed climate change. Of course, it is possible that more than one forcing is involved, so it is necessary to test all possible combinations of forcings to see if their combined influence can explain observed climate change (e.g., Meehl et al. 2004). Independent modeling of different components of the climate system demonstrates that man-made GHGs have been the dominant forcing of climate change over the past half century.

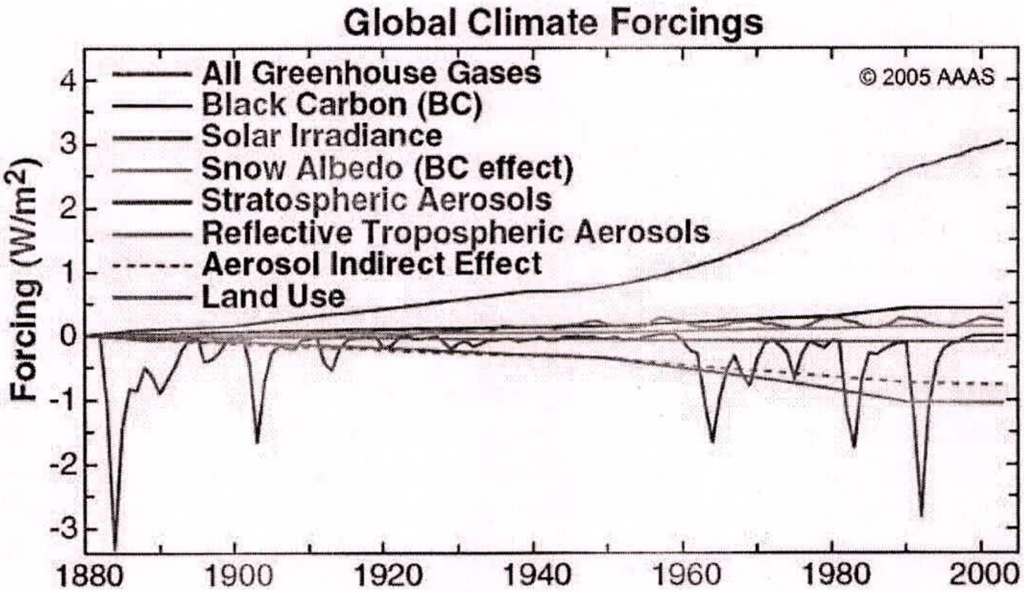

Figure 3. Forcings used to drive global climate simulations (Hansen et al. 2005). Records of forcing history are compiled from a wide variety of direct observations and proxies. Each forcing has a unique historical pattern that serves as its fingerprint of influence on observed climate change. Positive forcings exert a net warming effect (e.g., GHGs, red line), whereas negative forcings exert a net cooling effect (e.g., stratospheric aerosols from volcanic eruptions, dark blue line). GHGs exhibit the largest trend of all forcings shown.

The distinct fingerprint of man-made GHGs has been detected in records of surface temperature, ocean heat content, and the vertical structure of the atmosphere above the earth's surface.

Surface warming The twentieth-century warming trend at the earth's surface progressed in a distinct pattern, with a large warming during 1910-1940, moderate cooling during 1940-1975, and a large warming from 1975 to the present (Fig. 1). Scientists at the National Center for Atmospheric Research (NCAR) looked for fingerprints of various natural (solar radiation, volcanic particles) and man-made (GHGs, sulfate aerosols) forcings in this record of observed climate change (Meehl et al. 2004). The study employed a physical climate model that allowed individual or combinations of forcings to drive the simulated climate. The change in surface temperature calculated by the model for each forcing or combination of forcings was then compared with the observed record of surface temperature change over the twentieth century (Fig. 4).

The best fit of the model results to the observed climate was produced when all of the forcings were included, implicating all of the forcings in producing the overall pattern of change (Fig. 4A). However, different forcings dominated at different times during the century. For instance, the temperature rise in the early part of the century was dominated by natural forcings (Fig. 4B), whereas the warming after 1975 was dominated by man-made GHGs (Fig. 4C). The cooling during the mid-century was consistent with a combination of natural volcanic and man-made aerosols (Nagashima et al. 2006).

The results of this study implicate the enhanced GHG effect as the dominant cause of global warming over the past three decades. If not for the temporary cooling between 1940 and 1975 from volcanic and man-made aerosol emissions, the earth might be even warmer than it is today (Mitchell et al. 2001).

Ocean heat content. Oceans exhibit natural temperature cycles, with some oceans cooling at the same time that others warm. This natural internal variability of climate results from heat transport from one place to another, but it adds no new heat to the ocean as a whole. A major challenge for assigning a cause to temperature changes is distinguishing internal variability from external forcing, which adds new heat to the system. Scientists have demonstrated that the ocean as a whole has been warming for the past five decades (Levitus et al. 2005). The first principles of physics dictate that simultaneous warming of all the world's oceans could only occur through external forcing, as there is no other source of this much energy within the climate system (Hansen, Nazarenko et al. 2005). Using a fingerprinting-modeling approach similar to the one described above, scientists at Scripps Institution of Oceanography, Lawrence Livermore National Lab, NCAR, and the United Kingdom's Hadley Center, published a study showing that the oceans situated along the equator have warmed over the past five decades as a direct result of the enhanced GHG effect (Barnett et al. 2005). Observations show that the oceans have been warming from the surface downward (red dots, Fig. 5), which indicates heat transfer from the atmosphere. The vertical pattern of heat penetration with depth varies from ocean to ocean as a result of internal variability (i.e. currents transporting heat from one ocean to another). This complex pattern of vertical profiles provides a "fingerprint" of climate forcing. Modeling of internal variability alone or internal variability combined with solar and volcanic forcings did not produce temperature profiles that matched this fingerprint (Fig. 5A). However, the combined influence of human-induce forcings, natural forcings, and internal variability reproduced the pattern of heat penetration for each ocean (Fig. 5B). Man-made GHGs strongly dominated the overall forcing.

Vertical structure of the atmosphere. Another fingerprint of the enhanced greenhouse effect has been identified in the observed increase in the height of the **tropopause,** a region of the earth's atmosphere that represents the transition between the lower atmosphere (troposphere) and the upper atmosphere (stratosphere). Factors that either warm the troposphere or cool the stratosphere increase the tropopause elevation (Fig. 6), and climate models have long predicted that the elevation of the tropopause above the earth's surface should increase as a result of the enhanced greenhouse effect (Santer et al. 2003). Although this phenomenon may affect climate behavior, it is discussed here strictly as a tool for identifying causes of observed climate change. Scientists from several American, British, and German research institutions employed a fingerprinting-modeling approach to determine which climate forcings could explain observed changes in the height of the tropopause (Santer et al. 2003; Santer et al. 2004).

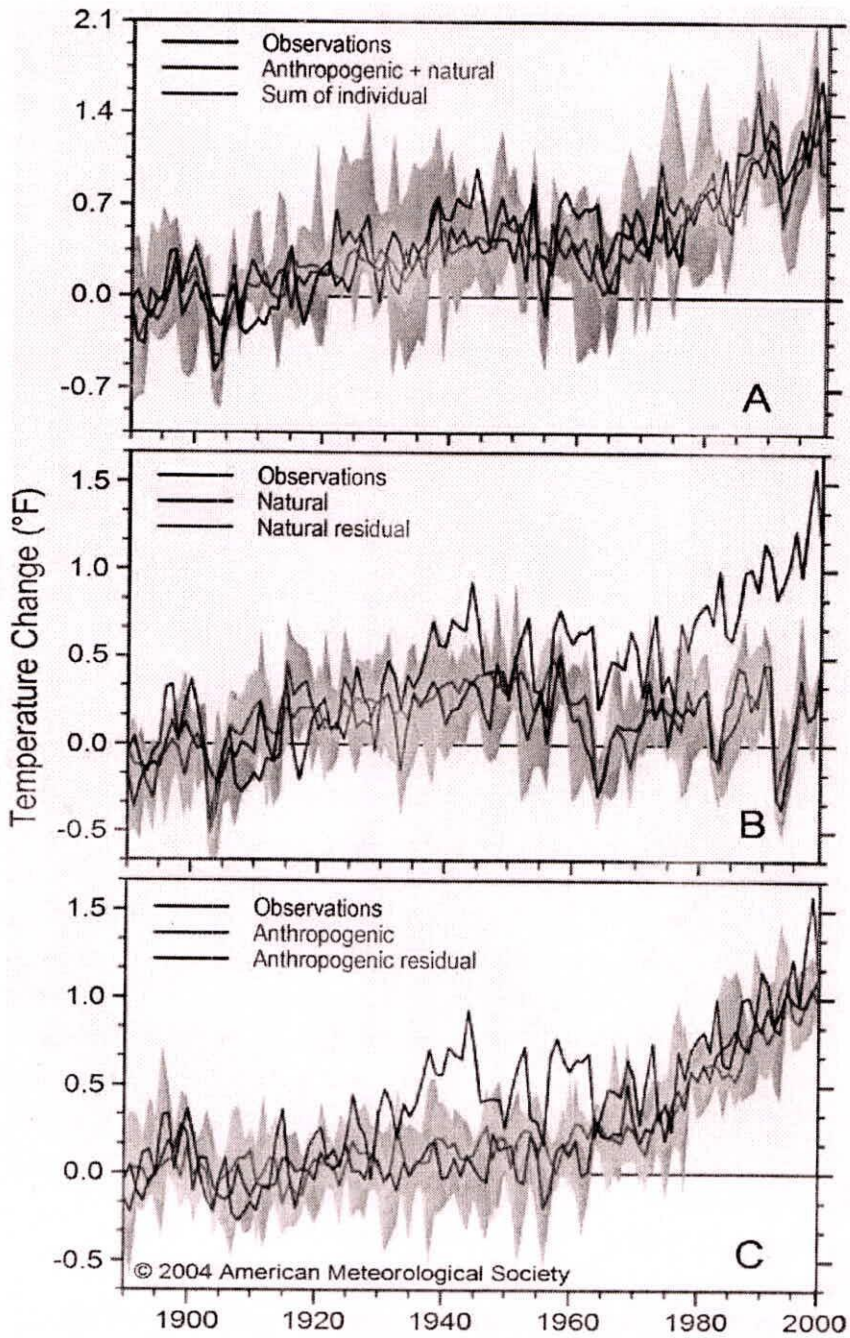

Figure 4. Fingerprint-modeling of global surface temperature change (Adapted from Meehl et al. 2004). (A) Model results with all forcings included. The combined forcings provided the best match to the fingerprint of climate change in the observed record. (B) Natural forcings alone explained much of the temperature change in the first half of the century. (C) Man-made forcings strongly dominated the temperature change after 1975.

Between 1979 and 2001, satellites monitoring the atmosphere recorded a 620-foot rise of the tropopause. In the model simulations forced by both natural and human-induced forcings, the tropopause elevation increased similarly (Fig. 7A). Manmade greenhouse gases, which warmed the troposphere, and stratospheric ozone depletion (by man-made chemicals), which cooled the stratosphere, dominated the forcing. Manmade greenhouse gases caused about 40 percent of the rise (Fig. 7B, green line), whereas ozone depletion caused about 60 percent (Fig. 7B, purple line). Overall, the effect of solar forcing, which contributed slightly (less than 10%) to the rise of the tropopause, was canceled by a small negative forcing (decrease in tropopause height) from volcanoes (Fig. 7B, gray line; note the transitory decreases corresponding to the eruptions of the Agung, El Chichón, and Pinatubo volcanoes).

Thus, human-induced forcings from GHGs and ozone-depleting chemicals provide the best explanation for the observed increase in the elevation of the tropopause over the past few decades.

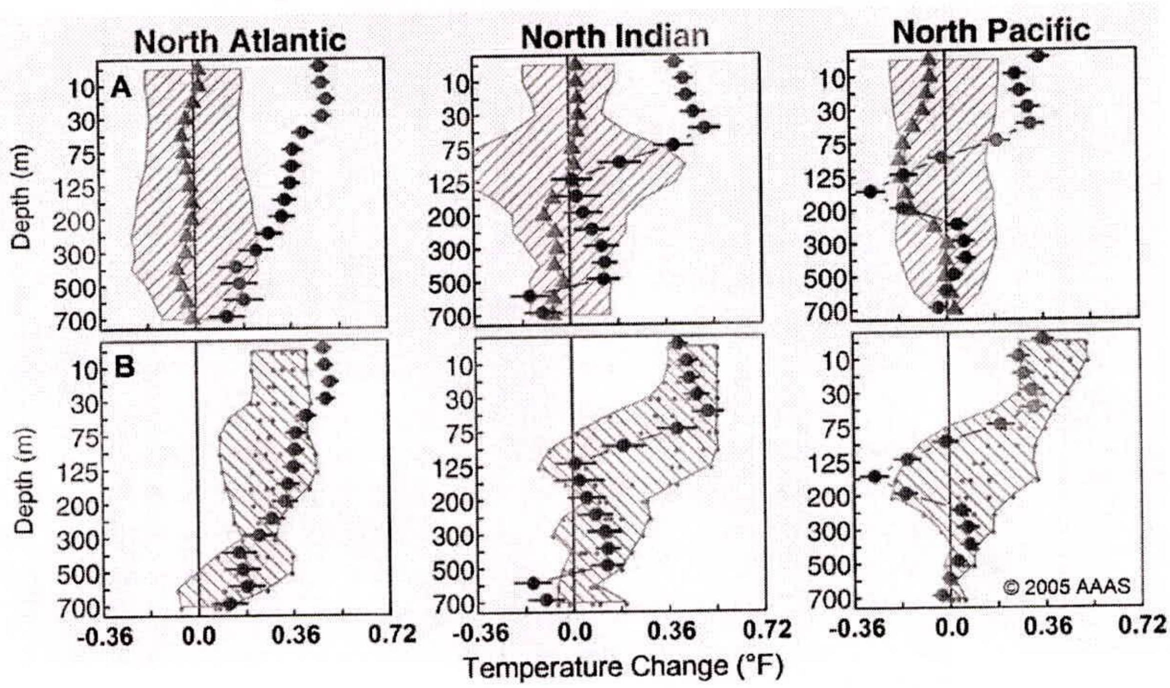

Figure 5. Observed and simulated heat penetration into three ocean basins (Adapted from Barnett et al. 2005; Reprinted with permission from AAAS). (A) The blue hatched region represents the 90% confidence limits of modeled natural internal variability resulting from heat exchange among different ocean basins. The observed record of temperature change (red dots) bears little resemblance to that expected from internal variability. The strength of the warming trend forced by observed solar and volcanic variability (green triangles) shows little agreement with the observed climate trend. (B) The modeled human-induced forcing from greenhouse gases and sulfate aerosols (green hatched region) shows substantial fingerprint matching with the observed heat penetration (red dots).

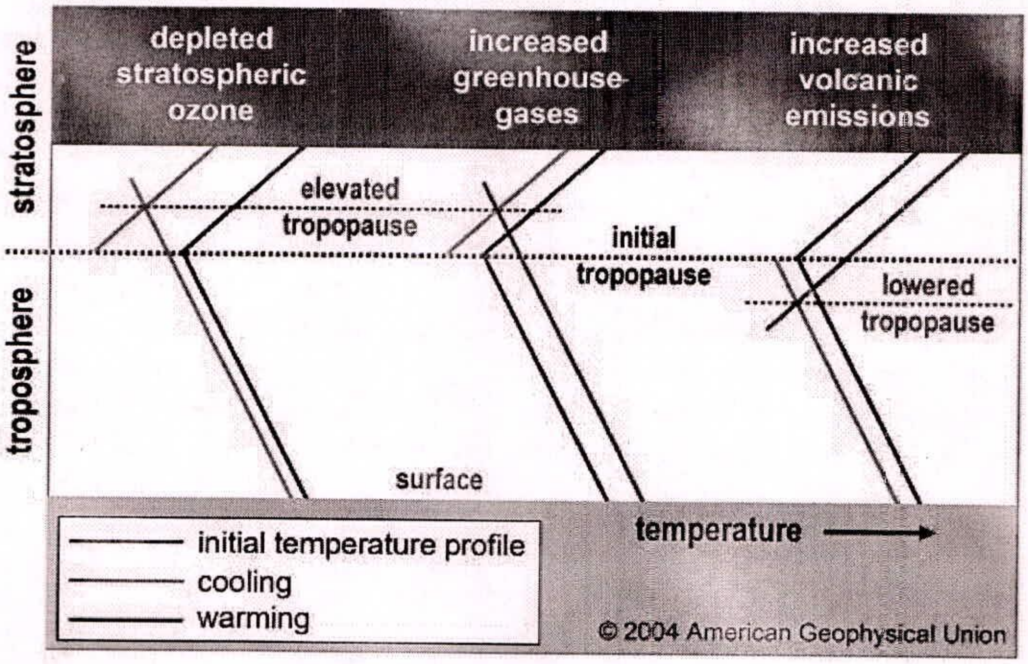

Figure 6. Conceptual model for the effects of three different forcings on tropopause height (Adapted from Santer et al. 2004). The solid black lines are the baseline atmospheric temperature profiles. Forcing by either stratospheric ozone depletion or increases in well-mixed atmospheric greenhouse gases increase tropopause height; volcanic forcing decreases tropopause height.

El Niño–Southern Oscillation (ENSO)

For hundreds of years, South American fishermen noticed the appearance of warm waters in the eastern Pacific Ocean along the coast of Ecuador and Peru. As the phenomenon typically appeared around Christmas time and lasted for several months, the name "El Niño" (El Niño is Spanish for "the little boy"), or the Christ Child was coined. El Niño events usually alternate with the opposite phase of below-normal water temperatures in the eastern & central tropical Pacific. The following description is based on internet resources including Wikipedia.

El Niño is defined by prolonged differences in Pacific Ocean Sea surface temperatures when compared with the average value. The accepted definition is a warming or cooling of at least 0.5 °C averaged over the east-central tropical Pacific Ocean. Typically, this anomaly happens at irregular intervals of 3–7 years and lasts nine months to two years. The average period length is 5 years. When this warming or cooling occurs for only seven to nine months, it is classified as El Niño/La Niña "conditions"; when it occurs for more than that period, it is classified as El Niño/La Niña "episodes".

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