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Climatic Changes During the Past 400,000 Years

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Abstract : Temperature variations, and carbon dioxide and methane concentrations are summarized during the past 400,000 years. Atmospheric temperature varied approximately within 10°C during the past 400,000 years. Most of the time during the past 400,000 years, temperature was lower than today except 410000, 320000, 250000, and 125000 years ago. Temperature was slightly higher or at least similar to today during the time period of 410000, 320000, 250000, and 125000 years ago. The carbon dioxide concentration varied between 180 and 300 ppm, and the methane concentration varied between 400 and 700ppb. The present atmospheric concentration of carbon dioxide is 375ppm and methane is 1750ppb.

Temperature was 5-7°C lower than today during the Last Glacial Maximum(18,000 years ago) and the Younger Dryas(10,000 years ago). Temperature was varied within 1°C during the past 10,000 years. Especially Middle Holocene Climatic Optimum(6,000 years ago), Medieval Warm Period(500-1,000 years ago), and Little Ice Age(100-500 year ago) were global climatic events. In general, mechanism for the Middle Holocene Climatic Optimum, Medieval Warm Period, and Little Ice Age can be explained by the solar insulation changes, however their exact mechanism is not well known.

Carbon dioxide concentration during the past 400,000 years never reached the current value of 375ppm. Furthermore, the current methane concentration never reached during the past 20Ma. However, current temperature value has happened several times during the past 400,000 years. The implication of this is unsolved question so far. This should be challenged in the near future.

Key Words : carbon dioxide, Last Glacial Maximum, Younger Dryas, Middle Climatic Optimum, Medieval Warm Period, Little Ice Age

I. Introduction

Observational record indicates that the global average atmospheric temperature increased approximately 0.6 ± 0.2°C during the past 100 years (Richard, 2001). Intergovernmental Panel on Climate Change (2001) reported that the global average atmospheric temperature will rise approximately 1.4-5.8°C within next 100 years (Fig. 1). This is an abrupt change. IPCC concluded that this abrupt change is caused by using fossil fuels. IPCC is an organization which is established under the WMO (World Meteorological Organization) and UNEP (United Nations Environmental Program) in order to study climate sciences (Washington, 2002). IPCC Report used as guidance in order to keep the Kyoto protocol (Schrope, 2001).

However, IPCC report only used past 100 year's observational record and lacks of data used in the model (Richard, 2001). There is a law saying "the present is the key to the past" in the geology. That is, the past is the key to the future. Therefore, paleoclimatology is very important to understand the present and future climatic conditions.

Three types of climatic change patterns are

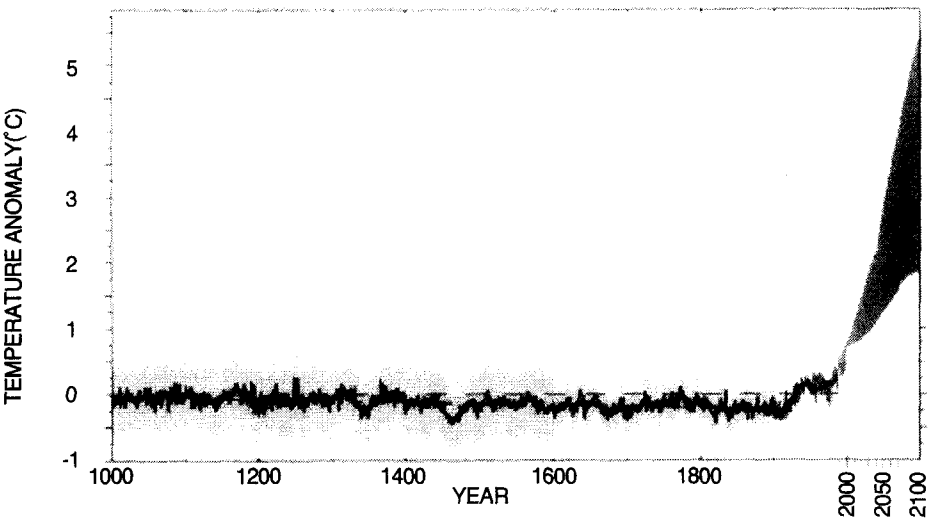

Fig. 1. Climate changes during the past and until 2100 (IPCC, 2001)

known during the paleoclimatic history. These three types are gradual, step-wise, and abrupt climatic changes. Gradual change is a pattern of slow climatic change with time, and does not cause abrupt ecosystem changes. Step-wise climatic change has a pattern of subtle climatic change for certain period and occurs abruptly. Extinctions of species occur selectively in the step-wise patter. Abrupt climatic change is characterized by abrupt climate changes within more or less a few hundred years. In general abrupt climate change is defined by temperature changes of 2-3°C within hundred years.

There are two types of climatic mode during the geologic time. One is Oligotaxic mode and has characteristics of modern day climate. This type is characterized by cold climate, existence of glacier, great temperature differences with latitude, great sea water temperature gradient with water depth, and frequent occurrence of typhoons. This type of Earth is characterized by shortage of food, great competition among plant and animals, frequent extinctions, and reducing global species diversities.

Another type is Polytaxic climatic mode. Polytaxic mode of Earth is characterized by no glaciers and little changes of temperature with latitude, and surface and bottom waters. Ecosystem has fluent foods and this caused mild competition between lives.

The purpose of this paper is to review abrupt climatic changes during the past 400,000 years and try to relate them with the concentrations of carbon dioxide and methane.

II. Climatic Changes During the Past 400,000 Years

Temperature changes, concentrations of carbon dioxide and methane, insulation, and oxygen isotopic ratios have an interrelationship with each other (Petit *et al.*, 1999). Several abrupt climatic changes occurred based on the ice cores collected

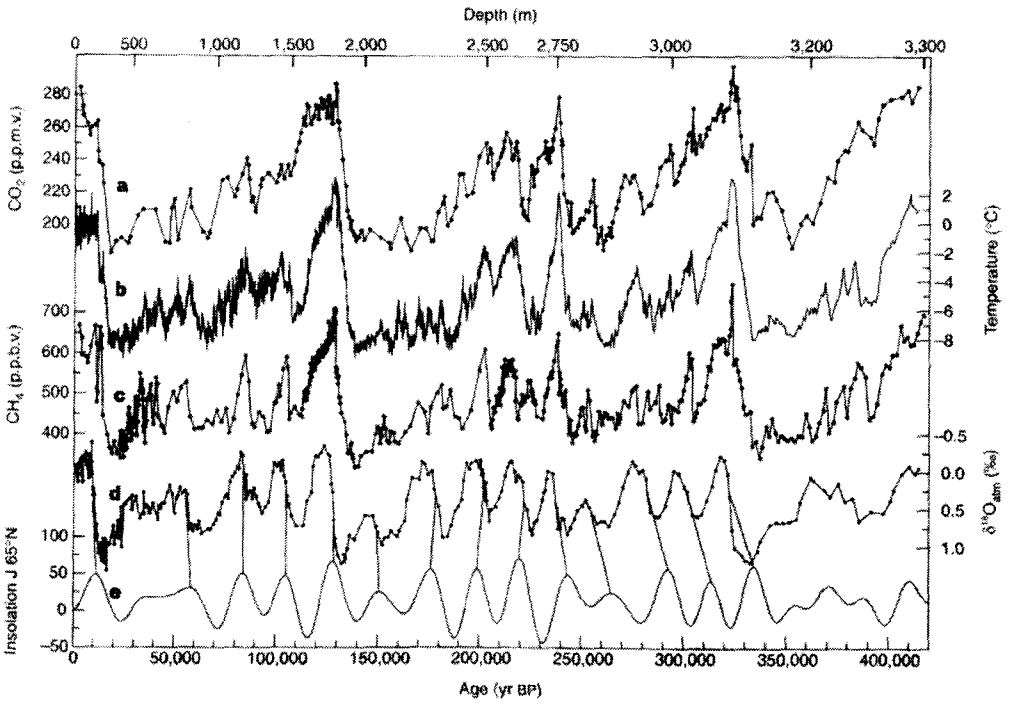

Fig. 2. Variations of temperature, concentrations of carbon dioxide and methane during the past 400,000 years (from Petit et al., 1999).

in the Antarctic. In general, atmospheric average temperature changed within 10°C during the past 400,000 years. Climatic change patterns are characterized by 2-3°C changes for a long period and then abrupt increases or decreases of temperatures. Temperatures similar to today or slightly higher periods are 410,000, 320,000, 250,000, 125,000 years ago (Petit *et al.*, 1999) (Fig. 2).

Climate at 400,000 years ago (oxygen isotope stage 11) is characterized by warm interglacial conditions based on the ice core result (Scherer, 1993). One thousand year cyclic patterns occur based on the paleoclimatic study between 500,000 and 340,000 years ago at the North Atlantic. Sea surface temperature changed within 0.5-1°C during the oxygen isotope stage 11 (Oppo *et al.*, 1998). Three hundred forty thousand years ago (oxygen isotope stage 10) is characterized by cold period and abundant atmospheric dust input (Petit *et al.*, 1997). Based on the study of core sediment at the Pacific, changes in precipitation in Asia and changes in sea surface temperature in Pacific are caused by earth' s rotation axis during the past 350,000 years. Particularly, the intensity of east Asian monsoon precipitation increased during the interglacial and decreased during the glacial (Morley and Heusser, 1997).

Temperature was 2°C higher than today at 125,000 years ago (oxygen isotope stage 5e) (Jouzel *et al.*, 1987; White, 1993) (Fig. 2). West Antarctic ice sheet collapsed at this time (Scherer, 1991). Sea-level was 7.5 ± 1.5 m higher than today

based on the study in the coastal areas of USA (Cronin *et al.*, 1981). Especially climate was very stable during the time period between 118,000 and 127,000 years ago. It shows great climate variability before 127,000 and after 118,000 years ago (Adkins *et al.*, 1997). It took approximately 400 years for climatic transition from stable to unstable conditions based on the study of Th-230 (Adkins *et al.*, 1997).

Climate at 125,000 years ago (oxygen isotope stage 5e) was relatively unstable compared to that of today (Fronval and Jansen, 1997). The volume of ice was similar to Holocene. Oxygen isotope stage 5e started at 130,000 years ago, peaked at 125,000 years ago, ended at 116,000 years ago (Kukla, 2000). However, Rioual (2001) argues that the climate was stable as Holocene. Climate at 125,000 years ago was stable like Holocene based on the analysis of Greenland and Antarctic ice cores (Kukla, 2000). Climatic condition of 127,000-110,000 years ago was similar to Holocene interglacial period (present-12,000 years ago) (Rioual *et al.*, 2001). Vegetation at 127,000-110,000 years ago shows similar to today's vegetation based on pollen data. This indicates that the climate at 127,000-110,000 years ago was similar to today.

Thouveny (1994) suggested that the future climate will be similar to that of the 125,000 years ago climate.

Result from the Antarctic ice cores reveals that the climate abruptly dropped from 125,000 years ago to 100,000 years ago. Then atmospheric temperatures fluctuate approximately 2°C from 100,000 years ago to 18,000 years ago (Last Glacial Maximum). Atmospheric temperature at 18,000 years ago was 10°C lower than 125,000 years ago (Petit, 1999). Last Glacial Maximum (LGM) at eastern equatorial Pacific is characterized by 3-4°C lower sea surface temperature than today, steep thermocline, poorly developed surface water stratification (Patrick and Thunell 1997). This indicates that upwelling was very active during LGM. However, western equatorial Pacific is characterized by well developed mixed layer and deep thermocline (Patrick and Thunell, 1997). Thermocline at Pacific Ocean during LGM was approximately 20 m shallower than today (Andreasen, 1997). Great amount of organics due to the greater surface water productivity is deposited during the LGM (Minagawa and Minagawa 1997). At western equatorial Atlantic, thermocline was deep during the LGM due to the strong trade wind (Ruhlemann *et al.*, 2001).

Based on the oxygen isotope result, deep water (3,000m) temperature of the equatorial Atlantic during LGM was 4°C lower than today (Schrag *et al.*, 1996). Furthermore, sea surface temperature at the equatorial region of South America was 5.4°C lower than today (Stute *et al.*, 1995). The climate during LGM was dry conditions based on the analysis of clay minerals at Amazon basin (Ruhlemann *et al.*, 2001). Atmospheric temperature during the LGM was 5.3°C lower in the Northern Hemisphere and 4.5°C lower in the Southern Hemisphere than today (Gates, 1976). During the LGM, the average snowline was 900m lower than today, and this is equivalent to 5°C atmospheric temperature decrease and 3°C sea surface temperature decrease at the tropical ocean (Broecker, 2001). The sea level was 120m lower than today (Fairbanks, 1989).

Holocene/Pleistocene boundary (12,000 years ago) is marked by abrupt temperature increase

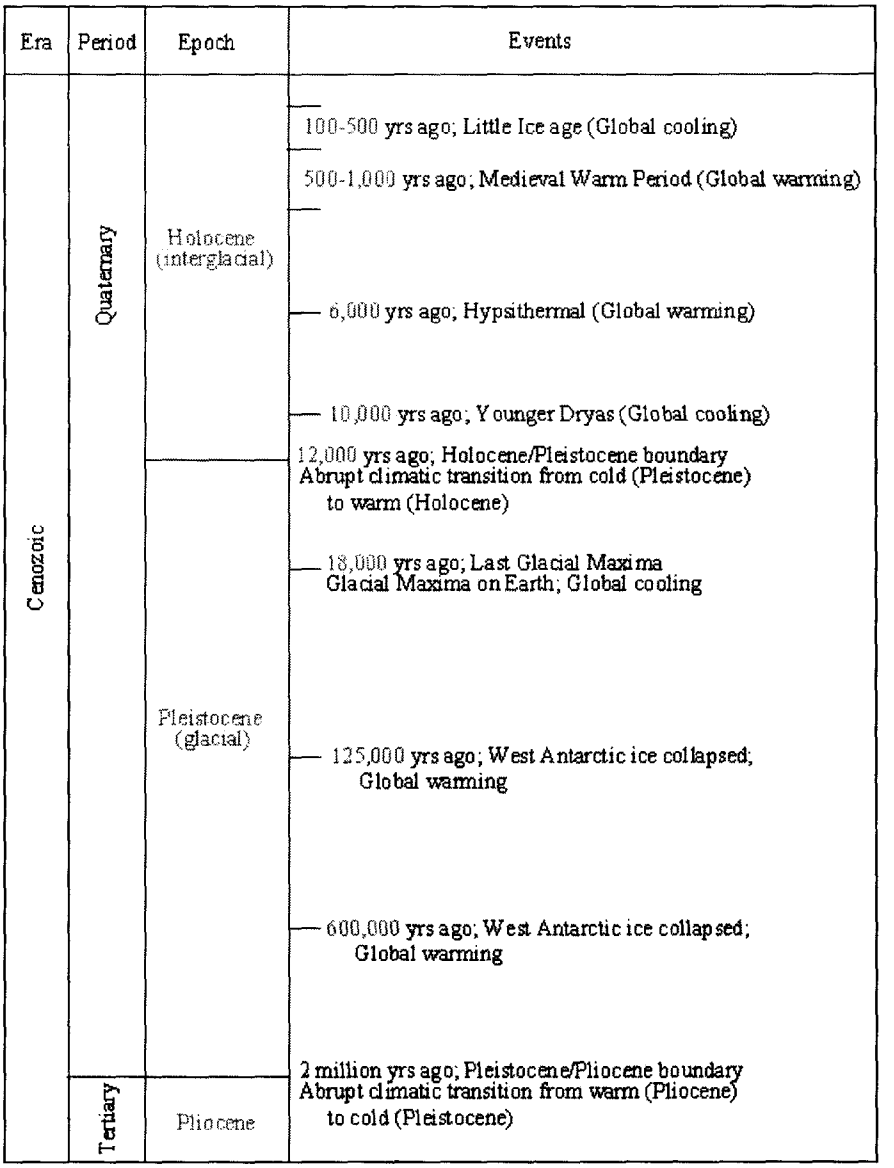

Fig. 3. Summary of the major climatic events during the Quaternary (from Shin et al., 2001)

(Steig *et al.*, 1998). Approximately 12°C temperature rise is at the Greenland (Dansgaard *et al.*, 1989). Ice melted water flowed into the ocean approximately 10,000 years ago (Younger Dryas cooling episode; Fig. 3). This melted water caused slow or completely shut down of thermohaline circulation. Global average temperature dropped 5-7°C during the Younger Dryas cooling period.

There was a global temperature increase at 6,000 years ago (middle Holocene climatic optimum). There was a 2-3°C temperature rise at Switzerland (Deevey *et al.*, 1957). There was

approximately 2°C temperature rise at the high latitude (Foley *et al.*, 1994). Laurentide ice sheet collapsed during the middle Holocene climatic optimum (Halfman *et al.*, 1984). Tropical Atlantic sea surface temperature rise caused atmospheric circulation changes. This change caused the precipitation increase. As a result, there was an increase of 25% precipitation in the Africa (Kutzbach *et al.*, 1997). In general, precipitation increases as temperature increases. There was a 2.5-3 m sea level rise during the middle Holocene climatic optimum (Korotky *et al.*, 2000).

There was a warm period during 500-1,000 years ago. This period is called Medieval Warm Period (Fig. 3). Sea surface temperature was approximately 1°C higher than today. Temperature was approximately 1°C lower than today during 100-500 years ago. This cooling period is called Little Ice Age (Broecker, 2001). Temperature from 100 years ago to now was slightly colder than today.

III. Temperature Change and Carbon Dioxide Concentration During the Past 400,000 Years

Global atmospheric temperature is mainly controlled by carbon dioxide concentrations. However, other factors such as methane concentrations, geomorphic changes of landmasses, circulation changes in the surface and bottom waters, changes in orbital axes, and changes in the brightness of sun are also controls climate changes in other time and other regions of the globe.

Carbon dioxide, methane, water vapor, nitrogen dioxide, Chloro Fluor Carbon, and ozone are greenhouse gases. Among them, concentrations of carbon dioxide and methane are major contributing factors of climate change. Systematic observations of atmospheric carbon dioxide started after 1958. Carbon dioxide concentration was approximately 260 ppm before the influence of human beings. At present, the carbon dioxide concentration is 375 ppm. This value is equivalent to the difference between interglacial and glacial (100 ppm).

Atmospheric temperatures, concentrations of carbon dioxide and methane, and insulations during the past 400,000 years are well studied in the Antarctic ice cores (Fig. 2). Atmospheric carbon dioxide concentrations varied between 180 and 300 ppm and methane concentrations varied between 380 and 700 ppb (Petit *et al.*, 1999).

Let's look at the past carbon dioxide concentrations when there was a climate change. The carbon dioxide concentrations for a few hundred millions years ago were greater than 2,000 ppm. The carbon dioxide concentrations at 125,000 years ago varied between 240 and 290 ppm. During this time the sea surface temperature was 2°C higher than today. Ice volume at 18,000 years ago (Last Glacial Maximum) was twice as compared to today, and the carbon dioxide concentration was 180 ppm which was the lowest value for the last 400,000 years.

The carbon dioxide and methane concentrations at 10,000 years ago (Younger Dryas) were 180-260 ppm, and 700 ppb, respectively. The carbon dioxide and methane concentrations at 6,000 years ago (middle Holocene climatic optimum) were 270 ppm, and 600 ppb, respectively. At 500-1,000 years ago (Medieval Warm Period), the carbon dioxide concentration was 275-285 ppm and

methane concentration was 700 ppb. Retreat of mountain glaciers are globally observed during the Medieval Warm Period.

During the Little Ice Age (100-500 years ago), concentration of carbon dioxide was 270-300 ppm, and concentration of methane was 700 ppb. Aeolian activities were very active during the Little Ice Age. Carbon dioxide and methane concentrations during the past 100 years (AD 1901-2000 year) were 300-340 ppm and 730 ppb, respectively. At present, the concentration of carbon dioxide is 375 ppm and methane is 1750 ppb.

IV. Summary

1. Atmospheric temperature varied within 10°C during the past 400,000 years.
2. Temperatures was slightly higher (or similar) than today during the past 410,000, 320,000, 250,000, and 125,000 years ago.
3. Concentrations of carbon dioxide varied between 180 and 300 ppm during the past 400,000 years.
4. Concentrations of methane varied between 400 and 700 ppb during the past 400,000 years.
5. Present value of carbon dioxide is 375 ppm, and methane is 1750 ppb. These values never have occurred at least for the past a few tens of millions of years.

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