Interrelationship of Global Air Temperature to Atmospheric Carbon Dioxide and Solar Activity

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EXTENDED ABSTRACT

The present study conducted investigations using modern methods of time series analysis to clarify how the increase of atmospheric carbon dioxide is related to the rise in air temperature. The interrelationship of global air temperature to solar activity was also investigated through correlation analysis using time series datasets of them. The results of spectral analysis showed that the variations of air temperature and atmospheric carbon dioxide have an obvious one-year cycle (seasonal cycle), and that the spectral intensity of one- year cycle in air temperature is stronger in the polar regions than in low latitude, while that the spectral in atmospheric carbon dioxide tends to be lower in southward regions. Through coherence analysis, it was found that there are different tendencies between short-term and long-term fluctuations in the interrelationship of air temperature to atmospheric carbon dioxide. The long-term fluctuations in atmospheric carbon dioxide tend to be accompanied by those in air temperature, and vice versa in the short–term fluctuation

As for the comparison with mean deviation air temperature with a solar activity index, the result that compared the chronological order data of global mean deviation air temperature with an index of solar activity is explained. This data is the chronological one which took moving average of ten years. From the result of correlation analysis, correlations with global mean deviation air temperature and the index of solar activity except the length of solar activity are low. However, correlation with the length of period of solar activity and global mean deviation air temperature is high because coefficient of correlation is 0.7 over. In other words, it is a tending that the global mean air temperature rises in the time when an activity period of the sun shortens (Lassen *et al*. 1995). About the mechanism of the relationship solar activity with global air temperature, authors are not able to lead a clean conclusion from correlation analysis, but we want to examine more in future.

In the coherence analysis, about global cases, the coherence between and global air temperature and atmospheric CO_2 concentration exceeds 80% confidence limit in a low frequency domain than 0.01. Likewise, about the Southern Hemisphere, the coherence exceeds 80% confidence limit in a low frequency domain than about 0.004. However, about the Northern Hemisphere, the coherence does not exceed the frequency domain more than 80% confidence.

Here, about the internal variations of air temperature and atmospheric carbon dioxide concentration, mutual relations of both are investigated same as reference (Keeling *et al*. 1989). Both internal variations of air temperature and atmospheric carbon dioxide concentration of long-term change are compared. From this result, the change of air temperature goes ahead than that of carbon dioxide concentration of long-term change.

The followings are possible explanations.

(1) Resolution promotion of soil organic matter by a rise of air temperature.

(2) A fall of production capacity of land level ecosystem by a rise of air temperature and drought.

(3) Increase of forest fire by drying with a rise of air temperature.

(4) And when the surface sea water temperature rises, the solubility of marine carbon dioxide decreases, and burst sizes of carbon dioxide from the ocean to the atmosphere increases.

1. INTRODUCTION

With the onset of industrial revolution, gradual increase of atmospheric CO_2 concentration and of laid rapid increase in CO_2 concentration with increased human activity. In the reason, it is reported that global warming will become serious in future and that it causes various climatic variation (Climate Change 2001, IPCC report. 2002). By the above, the appropriate counter measure to the global warming is urgently being demand. As a research of atmospheric CO_2 concentration, the research to be treated for temporal and spatial variations of atmospheric carbon dioxide has been carried out in great numbers (e.g. Keeling *et al*. 1989, Keeling *et al*. 1995, Hopkins *et al*. 2005). It is considered that recently the consumption of fossil fuel by the human activity may cause the increase of rapid carbon dioxide concentration. According to the research that authors performed by covariance structure analysis (Tominaga *et al*. 2006), it is suggested that solar activity and a long-term change of air temperature not a little influenced to a long-term change of atmospheric CO_2 concentration out of the atmosphere besides the carbon dioxide emissions. In this study, we investigated the interrelationship of global air temperature to atmospheric carbon dioxide concentration and solar activity through spectral analysis and coherence one using time series datasets. Especially, by separating a short-term fluctuation (seasonal change) into a long-term one, that is, the fluctuation of air temperature and atmospheric CO_2 concentration, the causation of both is examined.

2. INTERACTION BETWEEN AIR TEMPERATURE AND SOLAR ACTIVITY

The mean deviation air temperature as reported in the document which Climate Research unit announced is used here.

2.1 Solar Activity Index

About causation with solar activity and climate change on the earth, various arguments made till now, but it is not yet elucidated. Therefore, in this study, we paid attention to five indexes which express relative number of sunspot, sun radiant intensity, quantity of ultraviolet radiation, quantity of earth surface sunlight and period length of solar activity. And correlation between these indexes and global air temperature is examined. The details of the data which we used are explained as follows.

(1) Relative number of sunspot

A sunspot number is general data for index to show an active degree of solar activity that the observation period is long. The data is used the document which National Geophysical Data Centre (NGDC) announced from 1858 to 2002.

(2) Sun radiant intensity

The document of sun radiant intensity by NGDC is used from 1979 to 2005, as emission energy of all wavelength domains that the earth caught from the sun in the atmosphere outside. In addition, this document is a composition data made from the observation value of man-made satellite.

(3) Quantity of ultraviolet radiation

Quantity of change of sun radiant intensity to show emission energy of all wavelength domains equal to or less than 1%, but as for energy of ultraviolet rays domain change 50% around. A quantity of ultraviolet radiation document as the thing which expressed the change is used. This data is a model document by Space Environment Technologies from 1947 to 2001.

(4) Quantity of earth surface sunlight

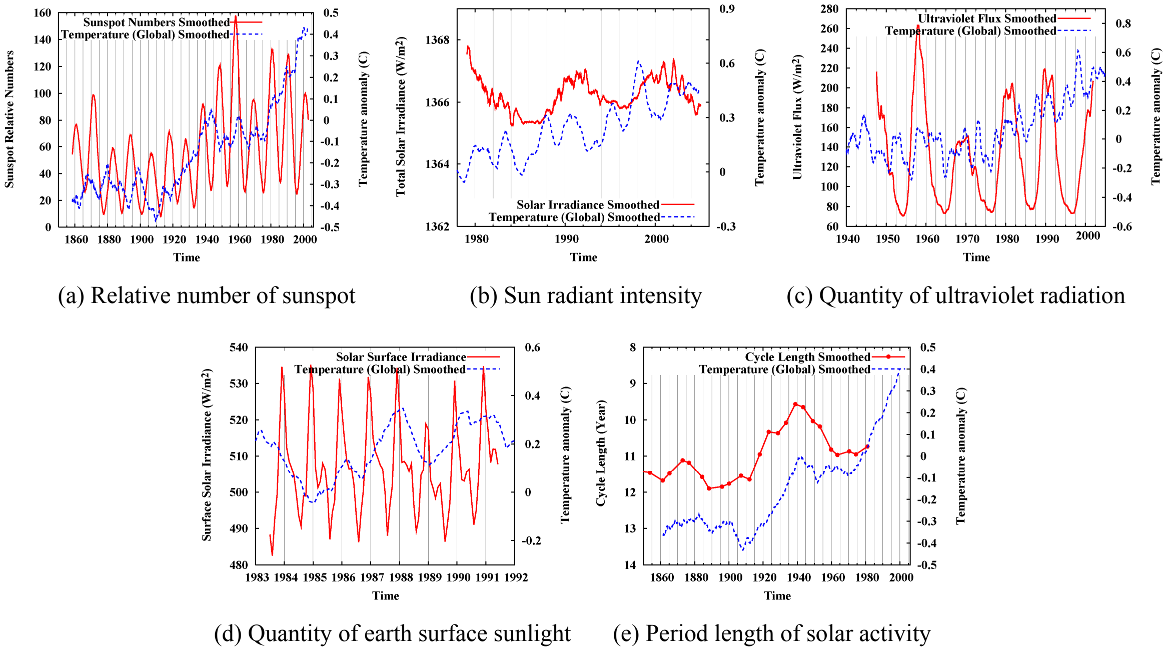
As solar emission energy which arrived at an earth surface after having been affected by dispersion by a cloud, an atmospheric gas molecule and aerosol, the document of quantity of monthly mean average earth surface sunlight by the SeaWiFS (Sea-viewing Wide Field of view Sensor) is used from 1983 to 1991. But because data is short, it is not enough as index to express solar activity to have period of about 10 year.

(5) Period length of solar activity

Generally, period length solar activity has a period of about 10 year, but changes by width range in a period from 9 year to 14 year. And a period tends to shorten for the brisk or active period of solar activity (Baliunas *et al*. 1995). In this study, with a relative numerical chronological data of a sunspot, the length of period from a certain extreme value to the next extreme one is the length in a period of solar activity.

2.2 Comparison with mean deviation air temperature and a solar activity index

The figure which compared chronological order data of global mean deviation air temperature with an index of solar activity is shown in Figure 1. This data is the chronological one which took moving average of ten years. Coefficient of correlation is given by equ. (1),



(a) Relative number of sunspot (b) Sun radiant intensity (c) Quantity of ultraviolet radiation

(d) Quantity of earth surface sunlight (e) Period length of solar activity

Figure 1. Comparison of chronological order data of global mean deviation air temperature with an index of solar activity.

$$Cxy = \frac{\sigma_{xy}}{\sigma_x \sigma_y} \qquad (1)$$

in which σ_x : variance of variable x, σ_y : variance of variable y, σ_{xy} : covariance of x and y..

And coefficient of correlation with global mean deviation air temperature and a solar activity index is shown in Table 1. From these results, correlations with global mean deviation air temperature and the index of solar activity except the length of solar activity are low. However, correlation with the length of period of solar activity and global mean deviation air temperature is high because coefficient of correlation is 0.7 over. In other word, it is a tending that the global mean air temperature rises in the time when an activity period of the sun shortens (Lassen *et al*. 1995). About the mechanism of the relationship solar activity with global air temperature, authors are not able to lead a clean conclusion from correlation analysis, but we want to examine more in future.

Table 1. Coefficient of correlation with global mean deviation air temperature and a solar activity index.

Solar activity index	Period of data	Coefficient of correlation
Relative number of sunspot	1858.5 – 2002.11	0.4109
Sun radiant intensity	1979.2 – 2005.1	0.3392
Quantity of ultraviolet radiation	1947.7 – 2001.12	0.1412
Quantity of earth surface sunlight	1983.7 – 1991.6	0.0941
Period length of solar activity	1858.5 – 1981.1	-0.7243

3. MUTUAL RELATIONS BETWEEN GLOBAL AIR TEMPERATURE CHANGE AND CO_2 CONCENTRATION

Here, both spectrum and coherence analysis are performed by the time series of global air temperature and CO_2 concentration. Data used is monthly average actual survey one of many parts of the world collected by World Data Centre for Greenhouse Gases (WDCGG) and Carbon Dioxide Information Analysis (CDIAC). Mauna Loa is by CDIAC and South Pole is by WDCGG. Analysis spots are shown in Figure 2. INSITU in this figure is the data which were observed on the site and Flask sampling is the data which were measured in the room after sampling on the site.

3.1 The tendency to change global air temperature and atmospheric carbon dioxide concentration.

Firstly, the relation between the past 140 years chronological data of global mean deviation air temperature and that of original atmospheric CO_2

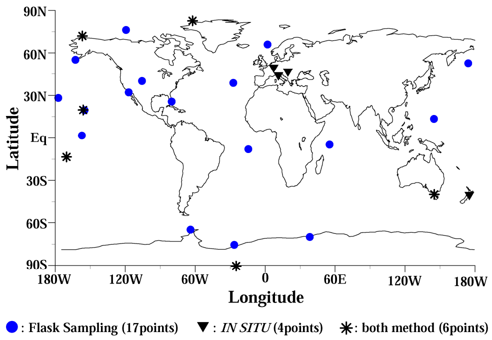


Figure 2. Analysis spots.

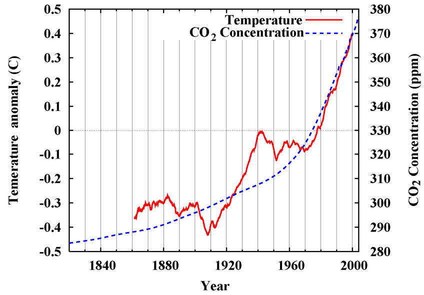
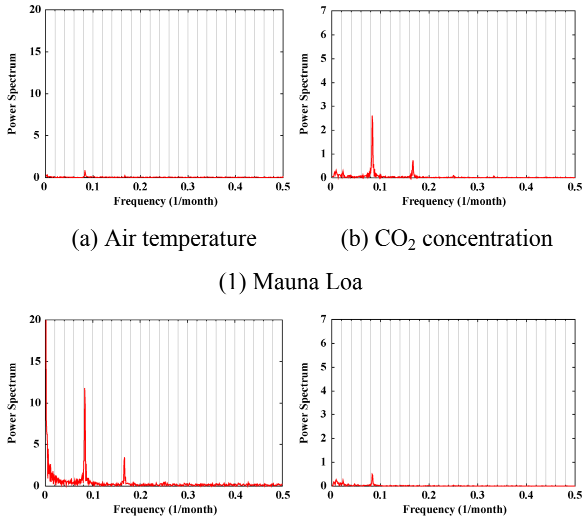


Figure 3. Relation between the past 140 years chronological data of global mean deviation air temperature and that of atmospheric CO_2 concentration.



(a) Air temperature (b) CO_2 concentration

(1) Mauna Loa

(a) Air temperature (b) CO_2 concentration

(2) South Pole

Figure 4. Spectrum strength distributions of air temperature and that of atmospheric CO_2 concentration.

concentration is shown in Figure 3. Atmospheric CO_2 concentration data is composition data of observation value in Mauna Loa shown in CDIAC and the value in the South Pole by European Project for Ice Coring Antarctica (EPICA). From figure, a tendency to change of the CO_2 concentration does not always accord with global air temperature of the past 140 years. For example, in about 30 years until the present from 1970, a tendency to increase is accord with both. However, atmospheric CO_2 concentration increases from the latter half of 1970's, but global air temperature decreases from 1940 to 1970. From the above, the mutual relation of global air temperature and atmospheric CO_2 concentration is different from the case of a short-term change and that of a long-term change. By these reasons, in this study, both spectrum and coherence analyses are performed to elucidate mutual relation of both.

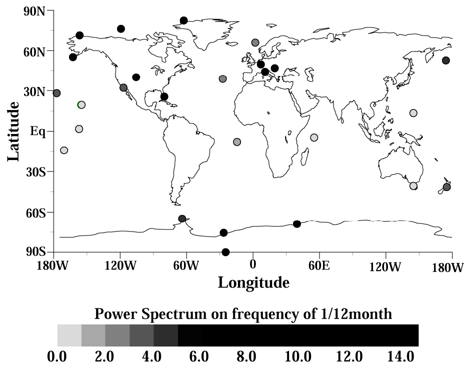
3.2 Spectrum analysis

The spectrum analysis is performed to grasp the periodic characteristics of global air temperature and atmospheric carbon dioxide concentration at 27 observation spots chosen in the world. Power spectrum is given by equ. (2),

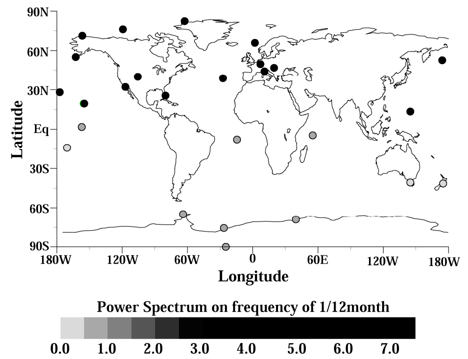
$$P_x(f) = \lim_{T\to\infty}\left[\frac{1}{T}\left|F_x(f)\right|^2\right] \quad (2)$$

in which T: domain, $F_x(f)$: Fourier component of variable x.

As one example of result, in the case of Mauna Loa and South Pole, the spectrum strength distributions of air temperature and that of atmospheric CO_2 concentration are shown in Figure 4. From this figure, as for air temperature, one–year period excels in both spots. One-year period is $f = 0.083$ cycle/year. And as for atmospheric CO_2 concentration likewise, though the spectrum strength is different, one-year period excels likewise. Though the spectrum strength is different by various observation spots, seasonal variation that one-year period exists was identified, as for both air temperature and atmospheric CO_2 concentration. As for this, size of a seasonal change means a different thing by a place. By examining the peak value of the spectrum strength, both spatial changes of both atmospheric carbon dioxide concentration and air temperature are investigated. The result is shown in Figure 5. From this figure, as for air temperature, the peak values of one-year become smaller with the approach to near the equator from both North Pole and South Pole. On the other hand, as for atmospheric CO_2 concentration, in the Northern Hemisphere, the peak values of one-year are smaller with the approach near to the equator. And, in the Southern Hemisphere, the

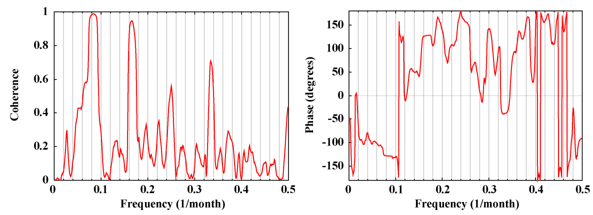


(a) Air temperature



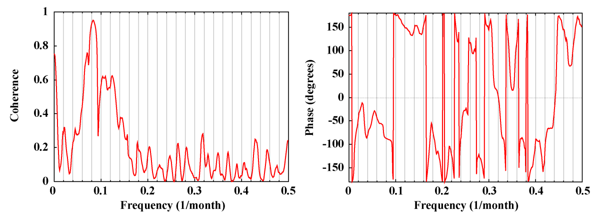
(b) CO_2 concentration

Figure 5. Spatial changes of the spectrum strength in atmospheric carbon dioxide concentration and air temperature.



(a) Coherence (b) Phase

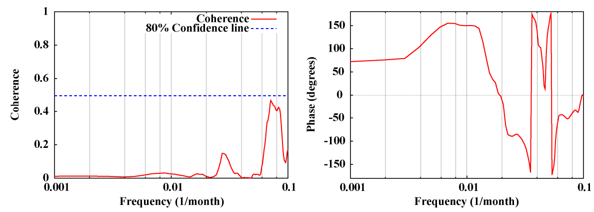
(1) Mauna Loa



(a) Coherence (b) Phase

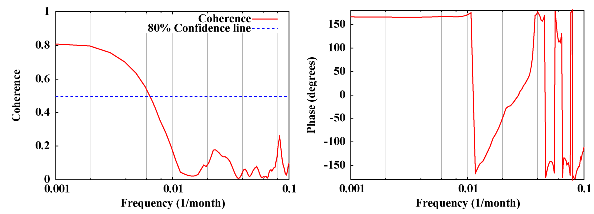
(2) South Pole

Figure 6. Coherence and phase between air temperature and atmospheric carbon dioxide concentration.



(a) Coherence (b) Phase

(1) Mauna Loa



(a) Coherence (b) Phase

(2) South Pole

Figure 7. Coherence and phase between air temperature and atmospheric carbon dioxide concentration without seasonal variations.

changes of them are very small and they are the same values in a whole hemisphere. As this reason, the ratio of land and marine and the vegetation between northern and southern hemisphere are thought to be caused. But by comparing a seasonal change of atmospheric carbon dioxide concentration with air temperature on the global scale, the correspondence among both is cannot confirmed.

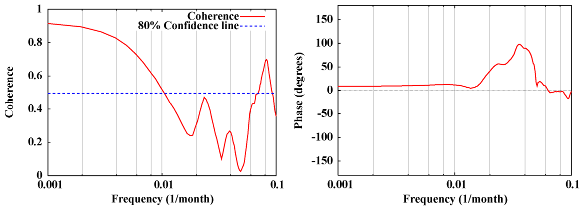
3.3 Coherence and phase analysis

Here, the relation between air temperature and atmospheric carbon dioxide concentration is described by coherence and phase analysis. Coherence and Phase are given by equ. (3) and (4),

$$Coh^2(f) = \frac{\left|P_{xy}(f)^2\right|}{P_x(f)P_y(f)} \quad \textbf{(3)}$$

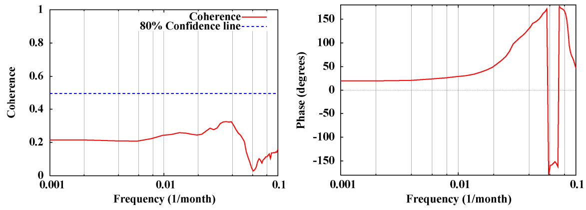
$$\theta_{xy}(f) = \tan^{-1}\left(\frac{Q_{xy}(f)}{K_{xy}(f)}\right) \quad \textbf{(4)}$$

in which $P_x(f)$: power spectrum of input variable x, $P_y(f)$ **:** power spectrum of output variable y, $P_{xy}(f)$: cross spectrum, $Q_{xy}(f)$: quad-spectrum $K_{xy}(f)$ **:** co-spectrum.



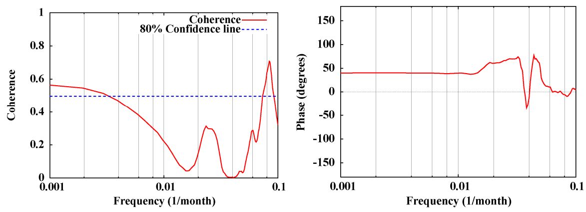
(a) Coherence (b) Phase

Figure 8 . Coherence and phase between air temperature and atmospheric carbon dioxide concentration on a global scale.



(a) Coherence (b) Phase

Figure 9. Coherence and phase between air temperature and atmospheric carbon dioxide concentration in the Northern Hemisphere.



(a) Coherence (b) Phase

Figure 10. Coherence and phase between air temperature and atmospheric carbon dioxide concentration in the Southern Hemisphere.

(1) The characteristics of a short-term change

Calculated result of both coherence and phase of Mauna Loa and South Pole are shown in Figure 6. The coherence of frequency that a period is equivalent to one-year cycle shows value of around 0.9. From the above, in the seasonal variation of both air temperature and atmospheric CO_2 concentration, the both correlation is high. On the other hand, the phase of frequency that a period is equivalent to one-year cycle shows negative value. As for a period for one-year cycle, the change of atmospheric CO_2 concentration goes ahead than that of air temperature. There is a remarkable correlation between air temperature and atmospheric CO_2 concentration as the phase exists. The possibility that the change of air temperature is affected by change of atmospheric CO_2 concentration to go ahead of became clear.

(2) The characteristics of a long-term change

The moving average for 12 months of both the chronological data of both atmospheric carbon dioxide concentration and air temperature is performed and the seasonal variation is removed for analysis of long period than a period for one-year cycle. Calculation results of coherence in Mauna Loa and South Pole is shown in Figure 7. Dashed line in figure shows 80% confidence limit line. As for the reason that adopted 80% confidence limit, it was not based a theory but based on conventional experience. From this figure, values of coherence of both spots are different greatly. About South Pole, the value is beyond 80% confidence line in a low frequency domain. Among 27 analysis points, low frequency domain is beyond coherence limit of 80% at six points. And the change characteristics of both atmospheric CO_2 concentration and air temperature that removed seasonal variation are different every analysis spots. As for phase analysis, the values of phase of both Mauna Loa and South Pole are positive in a low frequency. At the analysis spots where correlation of both is comparatively high, air temperature goes ahead than atmospheric CO_2 concentration.

Next, from a macroscopic point of view, the coherence and phase are calculated by global average air temperature or hemisphere average one and atmospheric carbon dioxide concentration. As data of atmospheric carbon dioxide concentration, data in Mauna Loa (19° 31'N, 155° 35'W) located in the vicinity of the equator as representation of global scale, is used. And as representation of the Northern Hemisphere and Southern Hemisphere, both data of Barrow (71° 19'N, 156° 36'W) and South Pole (89° 58'S, 24° 47'W) located on each high latitude level are used. Calculation results of coherence and phase are shown in from Figure 8 to Figure 10. About global cases, the coherence between and global air temperature and atmospheric CO_2 concentration exceeds 80% confidence limit in a low frequency domain than 0.01. Likewise, about the Southern Hemisphere, the coherence exceeds 80% confidence limit in a low frequency domain than about 0.004. However, about the Northern Hemisphere, the coherence does not exceed the frequency domain more than 80% confidence. On the other hand, as for phase analysis, these values show values of plus with 3 examples. As these result, the change of global air temperature goes ahead than that of atmospheric CO_2 concentration. When paying attention to the characteristics of long-term change of relation between at-

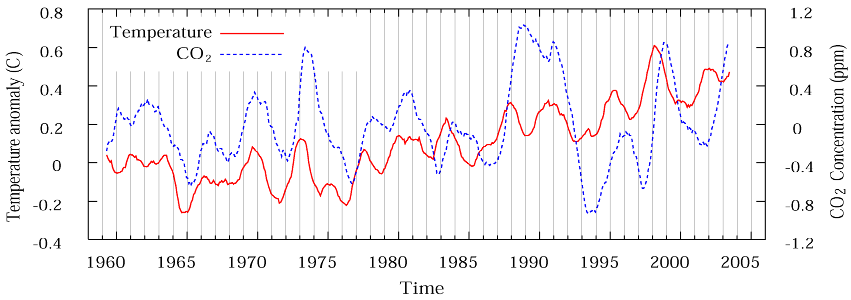


Figure 11. Comparison between the internal variations of air temperature and atmospheric carbon dioxide concentration.

mospheric carbon dioxide concentration and air temperature, it shows "possibility" that atmospheric carbon dioxide rises to with it when air temperature rises for some factors.

4. INTERNAL VARIATIONS OF AIR TEMPERATURE AND ATMOSPHERIC CO_2 CONCENTRATION

Here, about the internal variations of air temperature and atmospheric CO_2 concentration, mutual relations of both are investigated same as reference (Keeling *et al.* 1989). Both internal variations of air temperature and atmospheric carbon dioxide concentration of long-term change are shown in Figure 11. From this figure, the change of air temperature goes ahead than that of carbon dioxide concentration of long-term change.

The followings are possible explanations.

(1) Resolution promotion of soil organic matter by a rise of air temperature.

(2) A fall of production capacity of land level ecosystem by a rise of air temperature and drought.

(3) Increase of forest fire by drying with a rise of air temperature.

(4) And when the surface sea water temperature rises, the solubility of marine carbon dioxide decreases, and burst sizes of carbon dioxide from the ocean to the atmosphere increases. .

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