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Climate Change: What's in Store for Connecticut

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CLIMATE CHANGE

What's in store for Connecticut?

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The earth's climate is constantly changing. Natural causes, such as fluctuations in the earth's orbit, drive the long term, gradual variations which have time scales of tens of thousands of years. In addition, human activities also may impel future climate changes, but on a much shorter time scale of centuries or, possibly, decades. The earth's climate may already be in a state of transition due to the effects of atmospheric pollution.

Over the last few years the media have been quite fascinated with the "imminent" CLIMATE CHANGE about to overtake us, and much has been speculated about the effects of predicted changes. The purpose of this article is to outline what is currently known, what is not known, and what are the educated guesses of reputable scientists about the climate change issue.

ARE THE 'GREENHOUSE GASES' INCREASING IN THE ATMOSPHERE?

This question is one of the few on this topic that can be answered with a definite "yes". The global average concentration of CO_2 has risen from 315 parts per million (ppm) to 350 ppm in the last 25 years (Figure 1). Methane has been increasing 1% per year over the last decade, and the freons at about 5% per year. NO_2 and O_3 are also increasing at low altitudes where they are efficient infrared radiation absorbers.

WHAT IS CAUSING THE CO_2 INCREASE IN THE ATMOSPHERE?

Combustion of fossil fuels seems to be the major contributor to CO_2 build-up, although tropical forest deforestation probably plays a role. Figure 2 depicts the global carbon cycle as currently understood (Rotty, 1984). Numbers on the arrows indicate, in millions of tons, the total amount of carbon being exchanged with the atmosphere each year from or to the location indicated. The imbalance between the amounts going to the atmosphere and those coming from it is caused by the 5 million tons of carbon from the anthropogenic sources which are added to the atmosphere each year. Note that other fluxes of carbon to and from the atmosphere are many times larger than this. Therefore, the net addition as shown here may not be accurate because net amounts are determined from small differences between large numbers where even a minor error in any flux calculation could result in an entirely different conclusion.

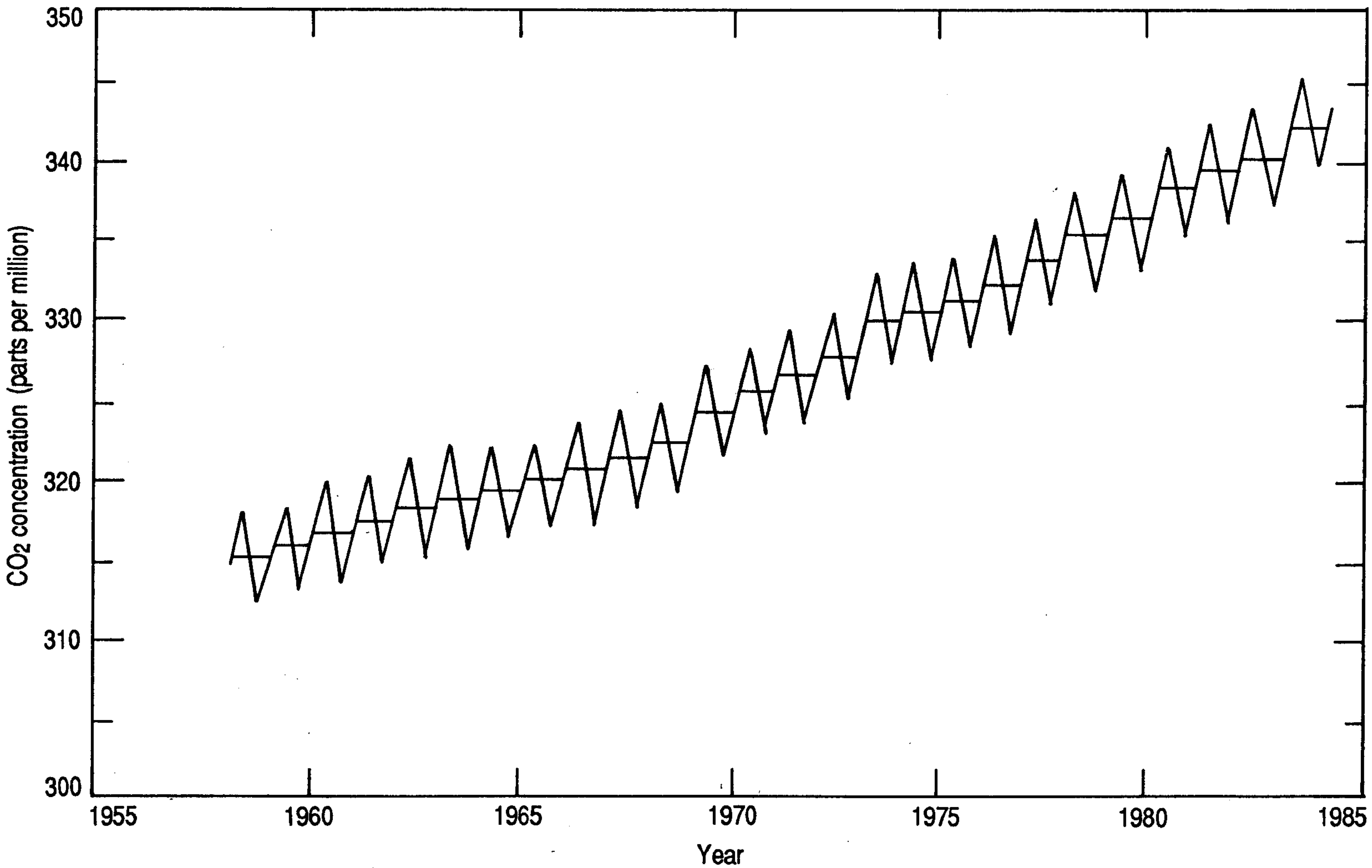

Figure 1. Carbon dioxide measured at the NOAA Observatory, Hawaii. Annual cycle shows effect of carbon dioxide uptake of plants during the northern hemisphere growing season (NOAA, 1988).

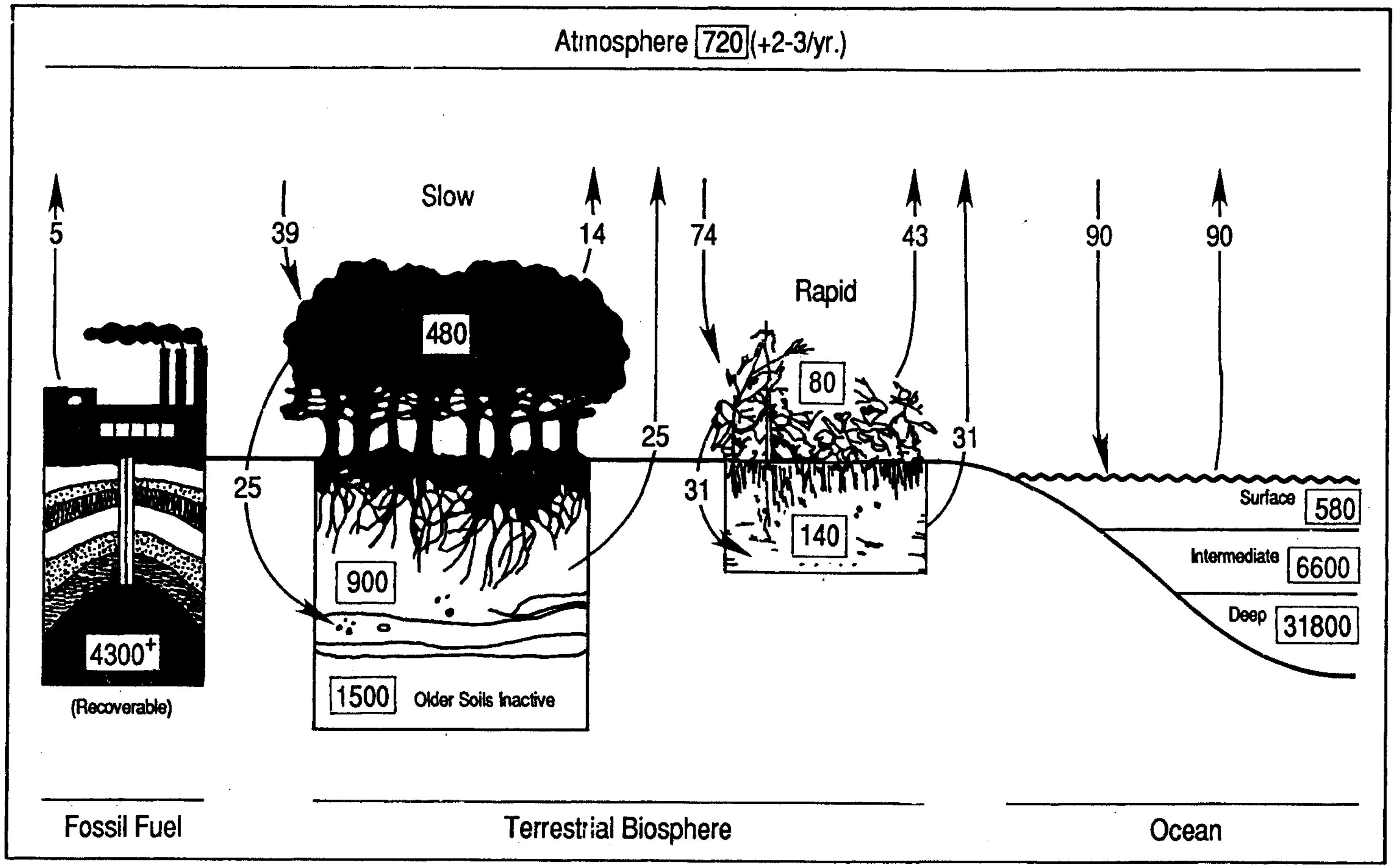

Figure 2. The global carbon cycle pool sizes, □, in 10^6 tons; fluxes, 14, in 10^6 tons (from Rotty, 1984).

ARE THERE PREVIOUS CASES OF GREENHOUSE GASES CAUSING CLIMATE WARMING?

Figure 3 shows the time series of temperature and CO_2 concentration from the present to 150,000 years ago as deduced from an Antarctic ice core. The record shows that we are currently in an "interglacial" period, the previous one ranging from about 120,000 to 140,000 years ago. During all the intervening time the earth was in various glacial stages. The temperature scale shows that the previous warm period reached about 2°C warmer than the present temperature and it was about 1°C warmer about 10,000 years ago. The intervening glacial period ranged from about 3° to 8°C colder than at present.

Note that the CO_2 concentration curve follows the temperature curve very closely with a high of about 300 ppm during the peak temperature period 140,000 years ago. Another peak of CO_2 is currently being experienced. Thus, we see that the CO_2 concentration in the atmosphere is at least very closely correlated with past climate changes and indicates a fundamental link between the climate system and the carbon cycle. Rapid increase in the last few decades has resulted in unprecedented concentrations of atmospheric CO_2.

IS THE CLIMATE CURRENTLY WARMING?

It appears that the worldwide average temperature is rising. Figure 4, an estimate of the global average temperature near the earth's surface from 1860 to present, indicates that the system has warmed about 0.7°C during this period. Since this magnitude of increase has occurred previously in the climatic record in the last few centuries, it cannot be taken as proof by itself that the "climate" is changing. Therefore, there is some argument in the atmospheric science community as to whether this is really a trend or just an anomaly. Furthermore, there are some valid criticisms of the accuracy of the data used to construct Figure 4, although that figure depicts the best data currently available.

WHAT ARE THE PREDICTIONS OF CLIMATE CHANGES?

Predictions of future climate changes resulting from increased greenhouse gas concentrations must be deduced from our understanding of atmospheric physics. The complexity of the physics when changes in the radiation energy balance are applied to a turbulent fluid, requires very large computer models to obtain even general ideas of what might happen. Furthermore, even with models that take several years to run (Hansen et al., 1988), the full reality cannot be simulated. On the other hand, models can be used to ensure that simulations of the evolution of climate resulting from realistic assumptions are accurate mathematical progressions, according to basic physical laws. Uncertainty in our understanding of complex "feedback" mechanics is the primary reason models cannot be trusted to accurately forecast future climates. Clouds are a good example of this feedback problem. They tend to form over warm, wet areas; but, depending on the immediate situation, they may provide either a positive feedback by acting as a greenhouse gas or a negative one by blocking solar radiation and cooling the surface.

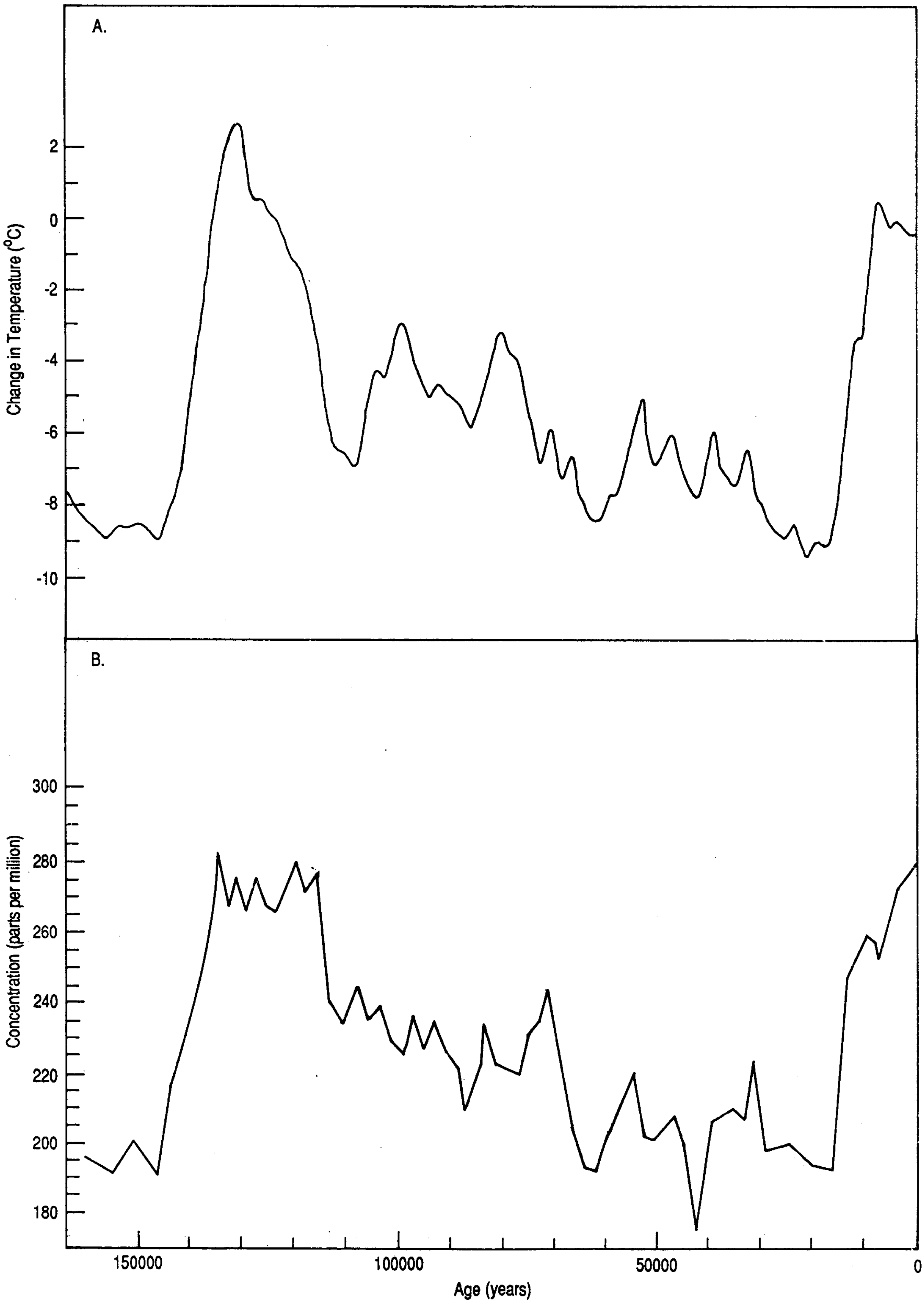

Figure 3. Vostok ice core smoothed isotope temperature record in degrees C difference from the current temperatures, curve a, and average CO_2 concentrations in parts per million by volume (ppmv), curve b.

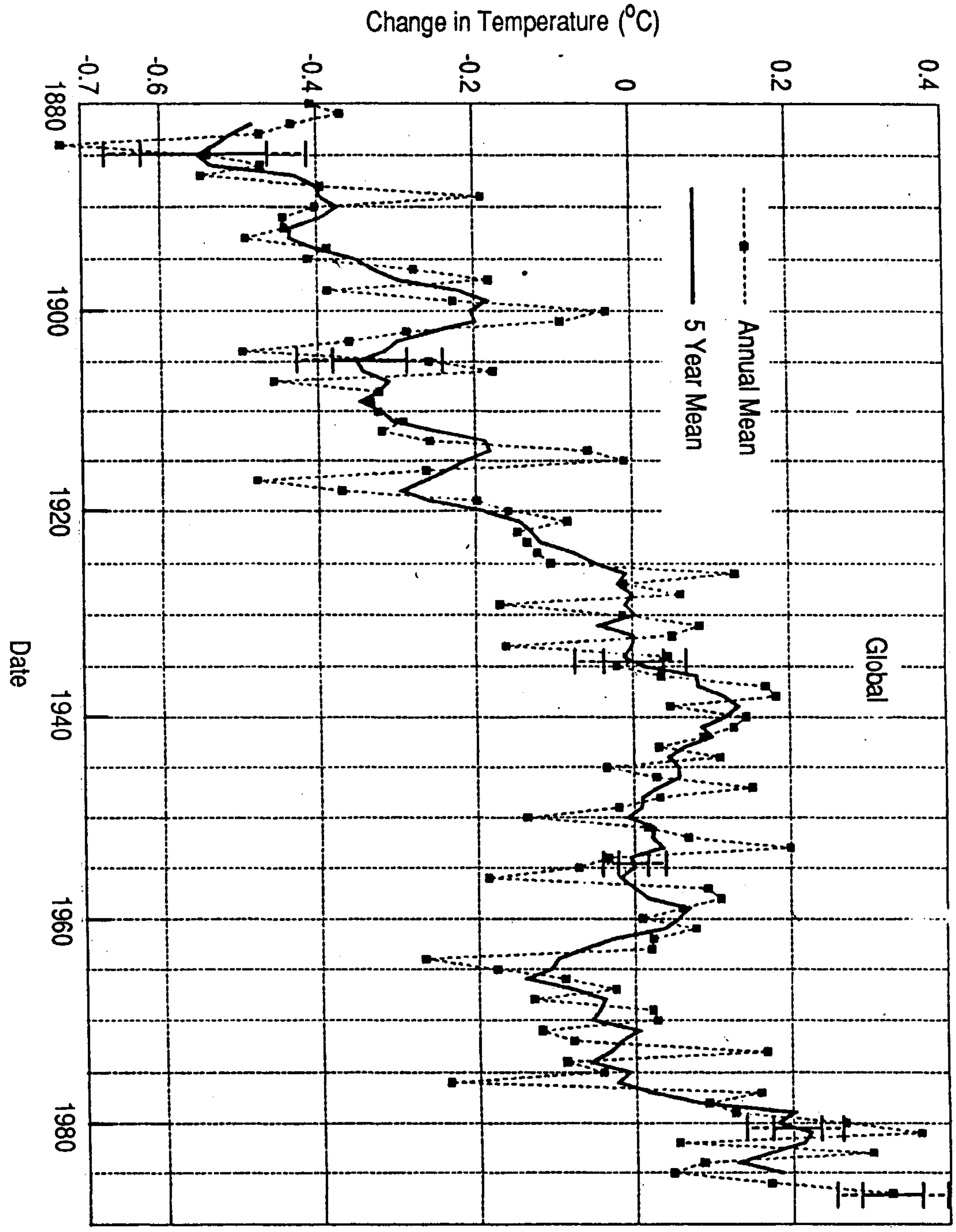

Figure 4. Global average temperature near the earth's surface (from Hansen, 1988).

In spite of these problems the several general circulation models (GCMs) constructed and run by independent research organizations are very consistent in their predictions of a warming trend resulting from increased CO_2. Recent model experiments (Hansen et al., 1988 and others) have indicated that a gradual increase until the CO_2 is doubled results in a temperature increase of 3°C ± 2°C.

The models also indicate that warming will be greatest at the higher latitudes during the winter season and in the atmosphere layer closest to the surface. Agreement among all the models ends here, and any further predictions depend on the model employed. One indicates that high above the surface, in the stratosphere, a major cooling will occur. Other atmospheric processes, like rainfall patterns, are related to the energy budget and, therefore, should also change. Worldwide, the rainfall might increase by about 5 to 7% (Weatherald and Manabe, 1981) with most of this occurring at high latitudes. In the long run, however, the middle latitude continents will most likely become dryer in the summer.

Current predictions by numerical simulations will surely turn out to be wrong, at least to some degree, and new predictions will be made as time progresses. The potential problems pointed out by current GCMs will ensure that future studies are closely followed.

HOW SOON ARE ESTIMATED CLIMATE CHANGES DUE?

This is a most difficult question, and estimates range from decades to a century or two. A conservative prediction is a temperature increase of about a 1°C by 2000 and 3° C by 2050, with resulting sea level rises of probably a few inches in the next decade, increasing to a total of two feet by 2050 (over the next 60-70 years). The more severe sea level rises involve melting of the western antarctic ice sheet which would take more than a century with the most extreme assumptions. But models cannot resolve whether change will be gradual or in abrupt jumps interspersed with long periods of no change.

WHAT CAN BE DONE TO FORESTALL ANY CLIMATE CHANGE?

Apparently, very little can now be done to stop or even slow down rise in CO_2 levels. It is not likely that worldwide fossil fuel use will decrease in the foreseeable future. All the other greenhouse gases, with the exception of methane, can be eliminated and replaced with other substances.

WHAT ABOUT CONNECTICUT?

Since regional and local changes cannot be resolved in the model, we can only speculate at this point. In general, increased variability in the weather events is possible. This can mean increases in intensity and frequency of coastal storms, including hurricanes, and droughts. Eventual sea level rise due to melting of ice and thermal expansion of the oceans has been estimated from 2 to 20 feet depending on what assumptions are made in the model experiments.

For Connecticut the combination of POSSIBLE sea level rises and POSSIBLE increased hurricane intensity are sobering. Conservative estimates of a 2 foot sea level rise and 25% increase in hurricane intensities will result in major disruptions of the coastal area in the next six decades. Flooding and saltwater intrusion of groundwater supplies will be the two most immediately obvious effects. Increased frequency of hot, dry periods would affect energy demands and community water supplies, among other things.

The very important question of hydrological impacts has not been analyzed in detail, but changes in rainfall patterns are likely to result in severe disruptions to present ecological systems. We are currently designing water resources infrastructures (i.e., bridges, dams, water supplies) based on rainfall and streamflow records of the last 30 to 40 years; but the future may see considerably different hydrologic regimes.

The following list contains the most likely problem areas for Connecticut:

WATER SUPPLY. Current and planned surface and ground water supplies in Connecticut are limited by reservoir storage capacities and relatively small areas of unpolluted high yield aquifers. Increases in the frequency and severity of droughts would overtax the current system rapidly. Also increased salt water intrusion in coastal areas due to higher ocean levels would make a number of water wells unusable in the coastal towns, further increasing the demand placed on the remaining public water supplies.

WATER QUALITY. Projected changes in water quantity will also affect water quality. During low flow droughts there would be less water to dilute pollutants. During winters, higher flows would probably improve water quality. Higher temperatures would increase lake stratification and stream water temperature, and in turn, increase alga production and degrade water quality. Ground water quality will be impacted by salt water intrusion along the coast. In the interior, increased pumping of aquifers may result in further transport and less dilution of pollutant plumes in the aquifers, thus contaminating more aquifer areas.

FLOOD MANAGEMENT. Higher frequency and intensity of our major storms, the hurricanes, may cause overtopping of current flood control infrastructure. The interior dikes (i.e., those protecting Hartford) and dams were designed using historic records of flood size. However, if storms become significantly larger, the structures will be inadequate. Along the coast, higher sea levels, together with higher storm surges, could increase the flood-prone area significantly. At the very least, the majority of coastal wetlands and beaches would be lost to inundation and the coastal configuration would change.

ENERGY. Air conditioning demands would probably increase in the summer requiring a higher generating capacity to meet peak demands. But, since the primary temperature effects are likely to take place in winter, total energy usage may decrease because of lower winter space heating demand.

WHAT CAN WE CONCLUDE FROM ALL THIS?

If we are VERY LUCKY, negative feedback mechanisms that we do not understand well enough to predict, will operate in the atmosphere's physical energy system and will offset the predicted effects of increased CO_2. Another possibility is that reabsorption of CO_2 will increase faster than currently expected, and the CO_2 will decrease before major disruptions to the current climate.

If we are SOMEWHAT LUCKY, the warming process and its accompanying secondary effects, will occur slowly enough that human populations will adjust easily and gradually. Although even if it takes two centuries, many natural ecosystems, such as forests, will not be able to adapt fast enough to avoid major losses.

If we are UNLUCKY, the current GCM predictions will be accurate and a major warming trend will occur over the next six to seven decades with the accompanying disruptions to human populations and food supplies. Even in this case, natural systems appear to be more vulnerable than society. Wetlands and forests will undergo changes that will be essentially irreversible, whereas human systems (i.e., coastal development, water resources systems) may be able to adjust.

APPENDIX

WHAT IS THE GREENHOUSE EFFECT?

Figure 5 illustrates the major pathways of energy exchange between the atmosphere and outer space above and the earth's surface below. About half incoming solar radiation penetrates through the atmosphere and reaches the earth's surface. Of this, most is absorbed by the surface and a small amount, about 5% of the total incoming, is reflected back to space. Of the half that does not penetrate the atmosphere, some (about 25% of the total incoming) is reflected back to space from the cloud cover, and the rest is absorbed by the atmosphere.

Since the atmosphere has a temperature, it radiates energy in the infrared wavelengths both upward to space and downward to the surface. The total amount of energy radiated and reflected back to space is generally in balance with the incoming solar radiation; that is, the outgoing is 100% of the incoming.

The energy absorbed by the surface heats the surface and is then returned to the atmosphere by three processes: hot air convection (thermals), evaporation of water, and infrared radiation, the last being of primary importance. Only about 4% of the total of that energy radiated to the atmosphere is not reabsorbed but, instead, passes directly through to space.

The so-called greenhouse effect results when the atmospheric absorption of the infrared energy emitted from the earth increases to the point where that which normally passes directly through is now absorbed. This extra energy causes a warming of the lower portion of the atmosphere and increases the amount of energy radiated from the atmosphere back to the surface.

WHAT CAUSES THE ATMOSPHERE TO ABSORB MORE INFRARED RADIATION?

A basic law of radiation physics (Planck's law) requires that the wavelengths of electromagnetic energy irradiated from a surface are determined by the temperature of the surface. Figure 6 (a) shows the spectra of wavelengths emitted from the sun, whose surface temperature is about 6000°C, contrasted to those emitted from the earth and atmosphere, whose mean temperature is about 15°C. The maximum amount of energy from the sun is at a wavelength of about 0.5 micrometers, which is the center of the visible wavelength range (0.4 to 0.7). The terrestrial maximum is at 13 micrometers, a much longer, lower energy wavelength. The INFRARED wavelengths are those longer than about 0.8 micrometers.Thus, some of the solar radiation and all of the terrestrial radiation is in the infrared range.

Each gas in the atmosphere absorbs radiant energy, but the absorption is wavelength specific. The sum total of this absorption by various gases results in the absorption depicted in Figure 5. Figure 6 (b) shows the absorption spectra for selected atmospheric gases. The atmospheric total, shown in the bottom graph, shows only a few wavelength bands that are transparent to radiation and only one of those, 8 to 14 micrometers, is significant in the range of infrared wavelengths emitted by the earth's surface. This range is often called the "atmospheric window" because it encompasses the wavelengths in which radiation emitted by the earth's surface passes through the atmosphere to space without being absorbed.

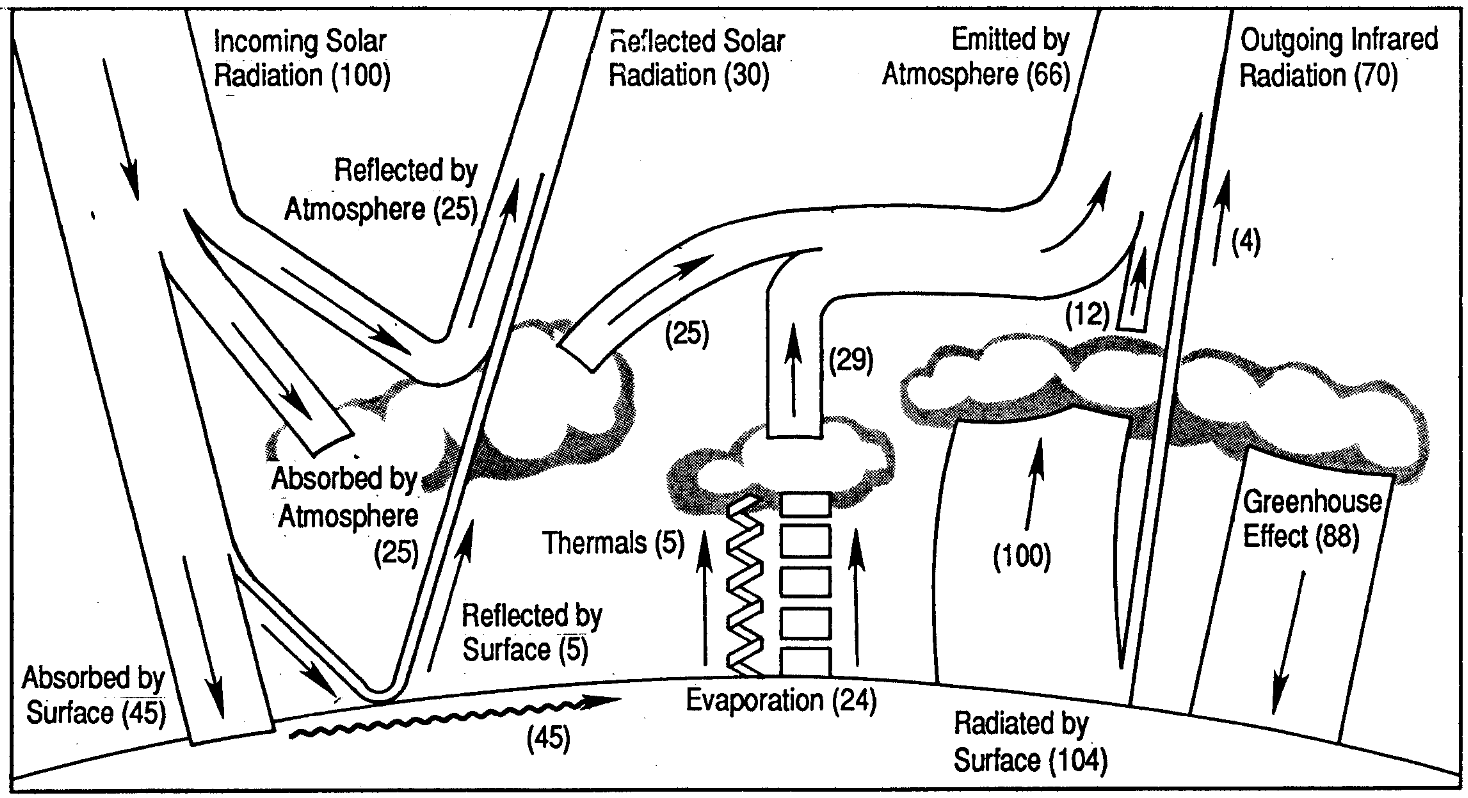

Figure 5. Global average energy exchange pathways to and from the atmosphere (adapted from Scheider, 1987). Numbers indicate percentages of incoming solar radiation.

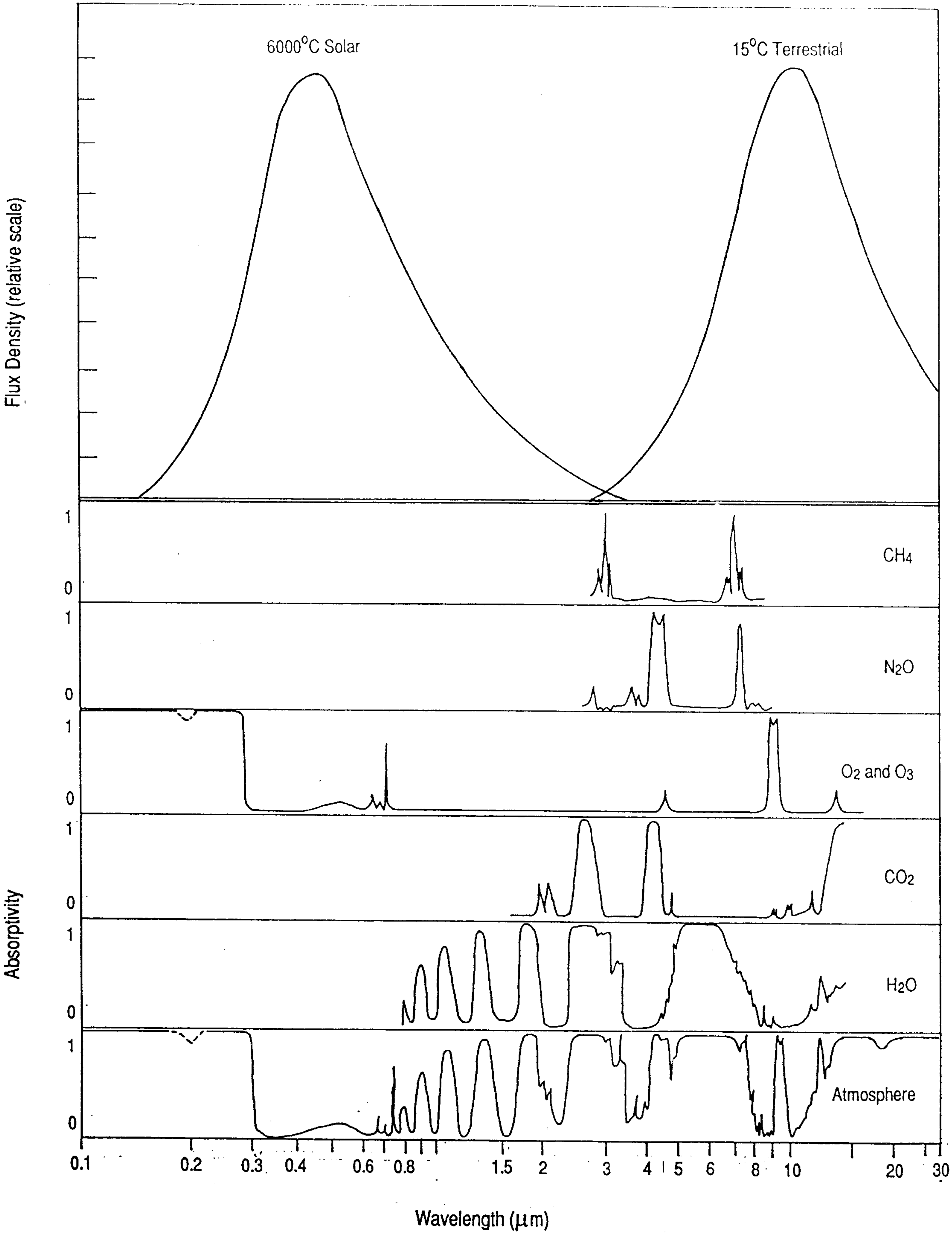

Figure 6. Spectra of solar and terrestrial radiation, each scaled with respect to the peak flux density and absorption spectra for various atmospheric gases (from Fleagle and Busigner, 1963 as presented in Rosenberg, 1988).

Table 1

Constituents of Clean, Dry Air

(Based on R. J. List, ed., Smithsonian Meteorological Tables, 1966, after Rosenberg, 1986.)

(a) **Constituent**	**Volume %**
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Carbon dioxide	0.035
Neon	1.8×10^{-3}
Helium	5.24×10^{-4}
Krypton	1×10^{-4}
Hydrogen	5×10^{-5}
Xenon	8.0×10^{-6}
Radon	6.0×10^{-18}
Ozone	Variable; about 1.0×10^{-6}
Water vapor	0-3%+
Dusts, Pollens	Highly Variable
(b) **Plus**	
Methane, CH	1.6×10^{-4}
Nitrous Oxide, N_20	3.0×10^{-5}
Freon 11, $CC1_3F_x$	2.3×10^{-8}
Freon 12, $CC1_2F_x$	4.0×10^{-8}
Carbon Tetrachloride, $CC1_4$	1.3×10^{-8}

Table 1 (a) lists the constituents of clean air. In addition, Table 1 (b) lists trace gases, mostly pollutants, in the atmosphere that absorb energy in the atmospheric window wavelengths. If the concentration of any of these gases which absorb infrared energy increases, then less energy will escape directly to space and more will be unchanged in the earth's atmospheric infrared balance. IF ALL OTHER CONDITIONS REMAIN UNTOUCHED, this will result in the atmosphere becoming warmer.

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