What Caused the Ice Age?

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It is possible that long range climatic variations may be a product of temperature fluctuations resulting from changes in the water vapor content of the earth's atmosphere, and hence from changes in the "greenhouse effect."

Quantum mechanics, which deals with radiation phenomena in terms of photons rather than the waves of classical mechanics, gives a new concept of the escape of radiant energy through a gaseous medium. A photon of infra-red radiation originating at the earth's surface will, after travelling a short distance, excite a molecule of carbon dioxide or water in the rotational quanta. The excited molecule will almost immediately revert to its original state, and ejects the photon in a haphazard direction to excite another molecule. Thus the escape of infra-red radiation through the earth's atmosphere is a "random walk" process which retains energy much longer than if the paths of the photons were not hindered by the molecules of carbon dioxide and water.

Only carbon dioxide and water can produce this "greenhouse effect" in the earth's atmosphere, as its other gaseous constituents have no permissible quanta in the infra-red range. Both carbon dioxide and water vapor have a quantum spectrum (mainly rotational) which covers the same general—the infra-red—range, and thus both should be about equally effective in producing the "random walk" effect, but water vapor should be dominant in producing the "greenhouse effect," as on the average there are more than a hundred molecules of water vapor in the air for every molecule of carbon dioxide.

Astronomers agree that water vapor is the dominating factor in obscuring the spectrum in the infra-red. In Kuiper's *The Earth As A Planet* (2), Goldberg writes (in connection with the absorption spectrum of the atmosphere): " . . . At longer wave lengths that atmosphere is made completely opaque from 24 to 1,000 microns (the infra-red range) by the pure rotational spectrum of water." (3). In this same volume Rodgers writes: "It is interesting to note that although water vapor usually comprises less than 2% of the (atmosphere's) gases it absorbs nearly six times as much of the solar radiant energy as all the other gases combined. Furthermore, it accounts for the absorption of nearly all the terrestrial radiation by the gases (4).

If indeed water vapor is the dominant factor in creating the "green house effect," then long range climatic changes might be explained in terms of the fluctuating water vapor content of the atmosphere. The warm periods that are known to have existed prior to and between the ice ages may have been caused by the greater "greenhouse effect" resulting from a higher than average atmospheric water vapor content. The extreme rapidity with which the vapor pressure changes with respect to the absolute temperature tends to cause climatic fluctuations over very long periods of time.

For instance, if a temporary increase in average world temperatures increased the ocean surface temperatures one degree Centigrade, the vapor tension of the oceans would increase from 11.98 mm of mercury to 12.79 mm. This would increase the average rate of evaporation, the water vapor content of the atmosphere would increase, and the associated increase in the "green house effect" would raise the temperature still higher. This would tend to set up a cycle by which the temperature would approach an asymptotic limit.

Only 47 percent of the solar energy intercepted by the planet reaches the earth's surface and is absorbed by it (6). Half the energy absorbed by the surface is expended in evaporating the water that falls as rain, and this energy, in going over to the latent form, is ineffective in raising the temperature of the earth's surface. Convection carries most of this latent energy to heights where the "greenhouse effect" is greatly reduced; condensation then releases the latent energy in the form of heat, which radiates into the cold of outer space with little "greenhouse" hindrance.

If this cycle were to operate until the average world temperature became 26° C., instead of the present 14° C., the water vapor tension would be 25 mm of mercury, a little more than double the present tension. Increased water vapor tension would cause such rapid evaporation from the oceans that all the energy absorbed would be required to sustain the evaporative process, and no energy would have to be radiated directly from the surface to maintain an energy balance. This would be the theoretical temperature the earth would attain if the "greenhouse effect" became so efficient that infra-red radiation were wholly unable to escape the surface. At this temperature the process of carrying energy bodily in the latent form, through the low altitudes where the "greenhouse effect" is predominant, becomes so efficient that it could maintain a radiation balance without help from direct radiation from the surface. The state of equilibrium thus attained may result in temperatures that may become as high as those that existed between the ice ages.

In an atmosphere with a high "greenhouse effect" due to the presence of water vapor, the temperature of the world would become cooler if a dry area developed through which radiation from the surface could escape with little "greenhouse" hindrance. This would reverse the cycle—cooler temperatures, cooler water, less rapid evaporation, less "greenhouse effect," and still colder temperatures. At this end of the fluctuation the asymptotic limit beyond which temperatures will not fall is the temperature that would prevail if the atmosphere's "greenhouse effect" were wholly due to carbon dioxide. The unstable equilibrium at the warm end of the cycle could have been upset by various factors, such as land uplift (geologic revolution), which seems to have occurred in the same periods as glaciation.

The cycle we postulate should develop conditions of unstable equilibrium at both ends of the fluctuation, and should cause the climate to change very rapidly during the period when the equilibrium became upset. At the warm end of the cycle the climate should warm up very rapidly when the last of polar ice disappears.

Except for a shallow surface layer, the oceans are now nearly ice cold even at the Equator, apparently because polar ice keeps the polar waters ice cold, and this dense cold water creeps along the bottom toward the equatorial regions by oceanic convection. But if the polar surface waters warmed up, there would be no ice to sustain cold water conditions, no cold water to sink, and the oceans would warm up very rapidly on a geological time scale. Geological cores from the polar oceans show that one time tropical mollusks suddenly appeared very far north, an indication that such rapid warming actually did take place.

If world temperatures increase, the first effect is to melt polar ice more rapidly, leaving the oceans ice cold as they are now, except for a shallow surface layer. The vapor pressure of the oceans remains nearly constant when the oceans are in this condition, as they must have been whenever there was polar ice. If this is true, as it must have been over a large part of the cycle, then other reasons must be sought for variations in the "greenhouse effect." It may well be that variations in the carbon dioxide content of the atmosphere, as postulated by Plass (5), were instrumental in causing the initial small increase in temperature required by our hypothesis. This small increase hastens the melting of the ice and thus triggers the long range cycle we propose.

The change in climate should also have been very abrupt at the end of the long fluctuation period. We postulate that the bulk of the glacier accumulated when the climate in other regions was still warm and humid. Warm, humid air can transport enormous amounts of water vapor, and glacial formation is explained by the fact that ice or snow falls faster than it melts. We postulate that considerable melting occurred as the glacier was forming. From mollusk evidence the oceans were then warmer throughout, but the melting glacier provided cold water to restore the condition that now keeps the oceans uniformly cold. The oceans began to get cold, from the bottom up, but at first the upper layers where evaporation occurs remained as warm as they had been. When the line of demarcation between warm and cold layers reached the surface, a very sudden change in climate would have occurred. Surface temperatures were lowered to much what they are now, vapor pressures dropped sharply, and with them dropped the average water content of the air, thus causing a much smaller "greenhouse effect" and a generally colder climate.

This theory seems corroborated by evidence from ocean bottom sediment cores. The nature of marine life found in the cores indicates that the change in climate must have been exceedingly sharp, and the sharp line of demarcation indicates that the change must have been extremely sudden. Ewing and Donn develop a theory concerning the ice age which differs considerably from the one developed here (7), but both theories agree that there should have been a radical change in ocean temperatures when the arctic ice disappeared.

Literature Cited

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