MECHANICS AND THERMODYNAMICS OF THE PRE-FLOOD VAPOR CANOPY†

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For years, the concept of a vapor canopy has met with great scepticism among some creationist scientists. The principle reason for such doubt has centered in the physics involved in maintaining vast amounts of precipitable water in the atmosphere. Our present atmosphere will only hold about 4.4 inches of water, and yet the vapor canopy idea requires many feet of water if it is to be the source of a global, 40-day rainfall. Also, this theory has been objected to on the grounds that intolerable hothouse conditions would result. In this article, an attempt is made to present a plausible support mechanism and to demonstrate that the surface temperatures may indeed have been quite mild.

For nearly 75 years, various theories of some kind of water canopy have been found in creationist literature.[1] As far as I have been able to determine, Morris and Whitcomb were the first to introduce the idea that this water canopy was in a specifically vapor form, i.e., superheated, invisible steam.[2] Others have shown the exegetical basis for belief in some kind of water canopy and that evidence will not be presented here.[3]

How much water did this canopy contain? For reasons detailed elsewhere, I believe that Moses intended to inform us that there is a conceptual tie between the waters above of Genesis 1:6-8 and the windows of heaven of Genesis 7:11.[4] If that is true, then it follows that the amount of water in the canopy was only what was necessary to sustain a global rainfall for forty days and nights. Simple calculations will show that, given even the most fantastic assumptions, recycled volcanic steam could only account for less than 1 percent of the total flood rainfall.[5] If we were to assume a moderate rainfall rate of 0.5 in/hr, this would mean that the canopy had to contain at least forty feet of precipitable water. In the following discussion, this minimum figure will be assumed.

The major problem associated with the vapor canopy hypothesis is simply that the atmosphere, as it is *presently* constructed, will not hold anywhere near the forty feet of water required to sustain a forty-day global rainfall. However, the ancient atmosphere would have been characterized by several unique phenomena that would have rendered it extremely stable. It will be necessary to explicate the factors generating this stable atmosphere configuration before explaining the proposed solution to the difficulty of maintaining the water vapor up above the ancient troposphere.

The Stability of the Pre-Flood Atmosphere

The geological record indicates that the topography of the ancient earth may have been considerably different from today's. One characteristic in particular that would have lent stability to the ancient atmosphere is the apparent lack of major mountain ranges. It is generally believed that most mountain building is a comparatively recent phenomenon connected (in conventional geology) with the Pleistocene. The Biblical statements indicate that the major mountain building activity did take place during the flood and immediately after it (Genesis 7:11; Psalm 104:8). In the model to follow, it will be assumed, then, that during the pre-flood era, there were *no* mountains. Certainly, there may have been rolling hills, but no major mountains. Thus, the lower edge of the canopy (about 30,000 feet) would never be in danger of intersecting the landscape. Furthermore, the convective updrafts produced by wind blowing against the sides of steep mountains would have been severely limited. This would tend to reduce eddy diffusion.

The only way a vapor canopy could have been maintained above the ancient atmosphere would have been to eliminate convective turbulence and reduce eddy diffusion, which would have caused the canopy quickly to mix with the lower atmosphere and to diffuse downward to the surface in a matter of hours. Is there any known physics that would have resulted in such a stability, and would it occur as a result of the existence of the vapor canopy? In fact, there are two such physical mechanisms that would severely reduce eddy diffusion and convective turbulence and provide a stable regime in which the atmosphere could conceivably contain enormous amounts of water above what it is able to sustain today. These physical mechanisms are a temperature inversion and Taylor stability.

The Canopy-Produced Temperature Inversion

When God divided the waters, our present theory requires that He must have immediately distributed the "waters above" in hydrostatic equilibrium in the gravity field. What is meant by "hydrostatic equilibrium"?

If one were to imagine a column of air with a cross-sectional area of 1 cm^2 extending to the top of the atmosphere, the pressure at the bottom of that column (i.e., sea level) is simply equal to the weight of the air above it. Due to the force of gravity, any water vapor placed above the atmosphere will immediately be acted upon by gravity and pulled toward the surface of the earth. The water vapor would continue its gravity-induced descent until the molecules of the air below became so bunched together that they began to "push up" against the downward pressure of the weight of the molecules above. When the upward force equals the downward force at every level, the system is said to be in hydrostatic equilibrium. Any amount of water placed above the atmosphere will quickly distribute itself into this equilibrium configuration due to the forces of gravity. It is for this reason that it is impossible to posit vast

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amounts of water vapor up above the atmosphere "floating" and maintained by great temperatures. As long as the water vapor molecules are in contact with the gravity field, they will quickly sort themselves into this equilibrium distribution. Once this equilibrium situation has been achieved, the vertical variation of pressure with altitude is given by the hydrostatic equation:[6]

$$dp = -g\varrho\, dz \qquad (1)$$

where g is the gravity constant, ϱ is the density at each level, and dz is the change in altitude.

A problem is encountered, however, with water vapor. The weight of all the water vapor above determines the pressure of the water vapor at the bottom level of the canopy, just as for any other gas. Unless the temperature is sufficiently high, that weight will result in a vapor pressure that exceeds the saturation vapor pressure of water vapor in the bottom increment, and it will condense out as rain. The saturation vapor pressure of water vapor is a function of temperature only and can be found by reference e.g. to the engineering steam tables.[7] Thus, in order to keep the water vapor in vapor form, it is necessary to assume a temperature distribution throughout the canopy high enough to keep the saturation vapor pressure of the weight of the water vapor above that layer. If a canopy model of 40 feet of precipitable water is assumed, that means that the weight of water vapor above the bottom layer of the canopy is 40 ft × 0.4335 lb/ft² = 17.34 lb/in². (About 1.2 atmosphere.) From the steam tables, it can be seen that, if this represents the saturation vapor pressure, the corresponding temperature must be 220 °F at the bottom of the canopy. Any temperature below that will not support water in vapor form, and rain would result.

Thus, it must be assumed that, when God set the vapor canopy above the ancient troposphere, He also established an initial temperature distribution in which the bottom layer of the canopy was at a temperature of at least 220 °F.

Is it physically possible that such a temperature could be maintained? It is not only possible, but quite likely. Water vapor is an extremely effective absorber of solar radiation. If the canopy were placed above the atmosphere, the canopy would absorb vast amounts of radiation and would be maintained at extremely high temperatures. Today, some infra-red and a lot of visible radiation and some short-wave radiation reach the surface of the earth where it is absorbed and re-radiated as infra-red. This re-radiated radiation is trapped under the atmosphere which is opaque to 95 percent of all re-radiated terrestrial radiation.[8] Thus, in today's climate, the surface of the earth is the main heat source. (I.e., secondary; the sun, of course, is primary.) However, under a vapor canopy, the canopy itself would be the major heat source, and the heat would have been distributed in the upper atmosphere. As a result, there would not have been intolerable hothouse conditions on the surface of the planet. Full discussion of this phenomenon is reserved for the places around equations (10) and (19) below, where it is shown that the temperature of the canopy base would be 887 °F. At this point, only the physical concepts involved are being surveyed.

Altitude of the Canopy

Where would the bottom of this canopy lie? The precise location is dependent upon calculation of the vertical temperature profile. However, a simple approximation that would not be too far off can be made by assuming that the vertical temperature profile is linear from 85 °F (29.4 °C or 302.4 °K) at the ground to 887 °F (475.0 °C or 748.0 °K) at the base of the canopy. (The variation is linear today.) In that case, the variation of pressure with temperature is given by:[9]

$$P = P_o(T/T_o)^{g/R\alpha} \qquad (1')$$

where P is the atmospheric pressure at the canopy base = 1.18 atmospheres (wt. of 40 ft. of water); P_o is the surface pressure = 2.18 atmospheres; T = temperature at the base of the canopy, 748 °K = 887 °F (to be explained below, see Eq. 16); T_o = temperature at the surface of the earth, 302.4 °K (also explained below, see Eq. 20); R = gas constant for dry air, 2.8704×10^6 erg/gm • °K; g = 980.6 cm/sec²; and α = the constant lapse rate of temperature, i.e., rate of change with altitude.

Rearranging and solving for α yields:

$$\alpha = \frac{g}{R}\frac{\ln (T/T_o)}{\ln (P/P_o)} \qquad (2)$$

which comes to −50.4 ° C/km.

Since $T = T_o - \alpha z$, one can find z, the altitude of the base of the canopy:

$$z = \frac{T_o - T}{\alpha} \qquad (3)$$

So z = 8.8 km. = 5.5 miles = 29,000 feet.

At the interface between the canopy and the troposphere, there would be an area in which some air was above the troposphere and in the bottom layer of the canopy. Also, there would be water vapor in the upper layer of the troposphere just below the canopy. This area might be called the pre-flood tropopause.[11]

The "top" of the canopy can similarly be approximated by assuming that the canopy is isothermal (a reasonable assumption). Then the variation of altitude with pressure is given by:[12]

$$Z = (-H) \ln (P/P_o), \qquad (4)$$

where H is the scale height of the canopy or $RT/_omg$; R = the universal gas constant, 8.3144×10^7 erg/gm • °K; T_o = the temperature at the canopy base which is *assumed* to be 748 °K (887 °F); m = the molecular weight of water vapor, 18.016; and g = 980.6 cm/sec². Thus, H = 35.2 km. In (4), P = the atmospheric pressure at the top of the canopy which, for practical purposes, will be assumed to be 0.01 of the pressure at the base. In other words, the "top" will be defined as the point at which the atmospheric pressure is reduced by 99%. (In a sense, since pressure decreases exponentially with altitude, there is no "top.") P_o = the pressure at the bottom of the canopy which is 1.18 atmospheres (i.e., the pressure produced by a column of water 40 feet high). Plugging these parameters into (4) gives for the height of the top of the canopy 162 km above the troposphere, or, from Equation (3), 170.8 km above the earth's surface, which is approximately 106 miles or

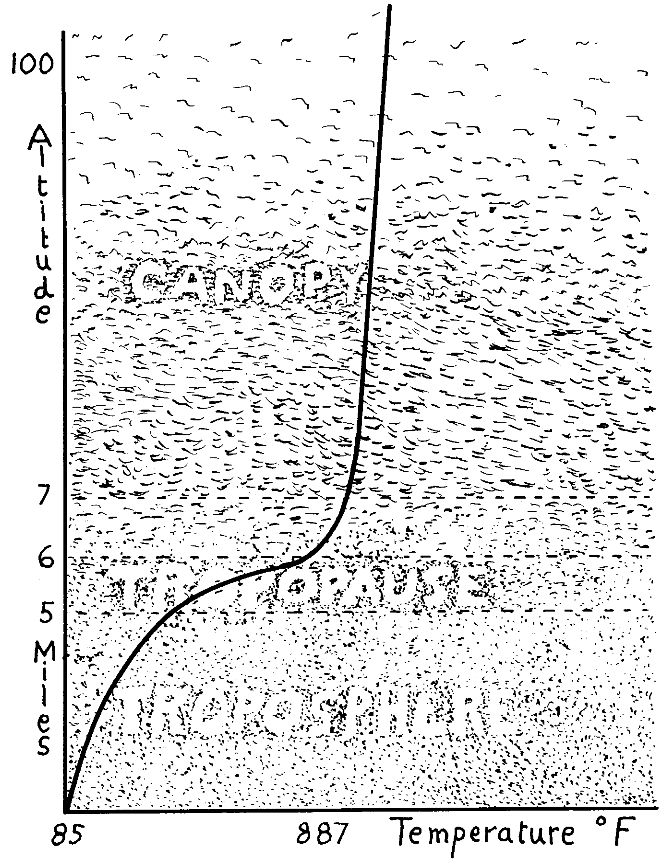

Figure 1. This shows the variation of temperature with altitude in the antediluvian world. Note that the scales are not uniform. Shading in ripple marks is intended to suggest water vapor in the canopy; in dots, air. The assumption here departs from the linear variation of temperature with altitude in the comment right after Equation (2). Rather, an exponential variation is represented as more likely.

560,000 feet. The assumed temperature profile is shown in Figure 1.

The Stabilizing Effect of a Temperature Inversion

Due to the absorption of re-radiated infra-red in the canopy by the water vapor, a strong temperature inversion would result in which the temperature of the ancient atmosphere increased with altitude. Due to the fact that in today's atmosphere the (immediate) heat source is the earth's surface, temperature normally decreases with altitude.

The relevance of all this discussion to the canopy model is simply this: such a strong temperature inversion would reduce eddy diffusion and convective turbulence at the tropopause and enable the atmosphere to maintain tremendous amounts of water above it.

The stabilizing influence of such temperature inversions are well known among meteorologists, and discussions of the physics involved can be found in any basic meteorology text.[13] For a simple conceptual model of the physics involved, consider Figure 2. Imagine a parcel of air, A, that is suddenly jostled and moved downward into the troposphere. As it moves downward, it moves from a region of 900 °F heat to 800 °F heat. As soon as it enters the lower region, it is now hotter than the surrounding 800 °F air. As a result, it is less dense and hence lighter than the surrounding air. This produces a buoyant force which drives the parcel back up into the canopy. In a similar way, if some cooler parcel was jostled from below and driven up into the hotter canopy, it arrives at a cooler temperature than the surrounding water vapor and is, therefore, heavier and more dense. As a result, it will immediately sink back into the troposphere. These stabilizing tendencies are further enforced by the expansion and contraction of the moving parcel. When our imaginary parcel moves from the canopy to the lower troposphere, it not only moves from a region of greater temperature to one of lower temperature, but it also moves from a region of lesser pressure to one of greater pressure. Pressure increases as the parcel moves downward because it is going deeper into the atmosphere and more atmosphere is above it. It is just like going deeper under water. As pressure on the parcel increases, the parcel is compressed, and a compression results in higher temperature inside the parcel. Thus, the parcel becomes even hotter than 900 °F and is even more forcibly restrained from penetration into the troposphere.

It is clear, then, that the canopy temperature inversion would result in an extremely stable regime at the interface of the canopy and the lower troposphere, significantly reducing any convective turbulence, and thus enabling much water to be maintained above the ancient atmosphere. In today's atmosphere, little water could be maintained, simply because there is no such global temperature inversion.

Taylor Stability

In the field of fluid mechanics, great attention has been given to the situations under which layers of fluids surrounding a rotating cylinder will remain in a lami-

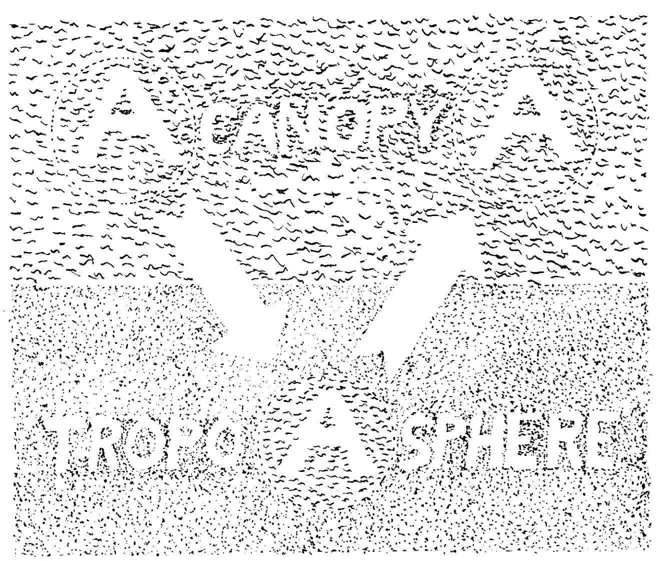

Figure 2. If a certain amount of vapor, in the canopy, were to sink into the troposphere, it would experience buoyant forces, as explained in the text, to cause it to return to the canopy. Thus there would be little tendency for mixing at the boundary, and the division into canopy and troposphere could be quite stable.

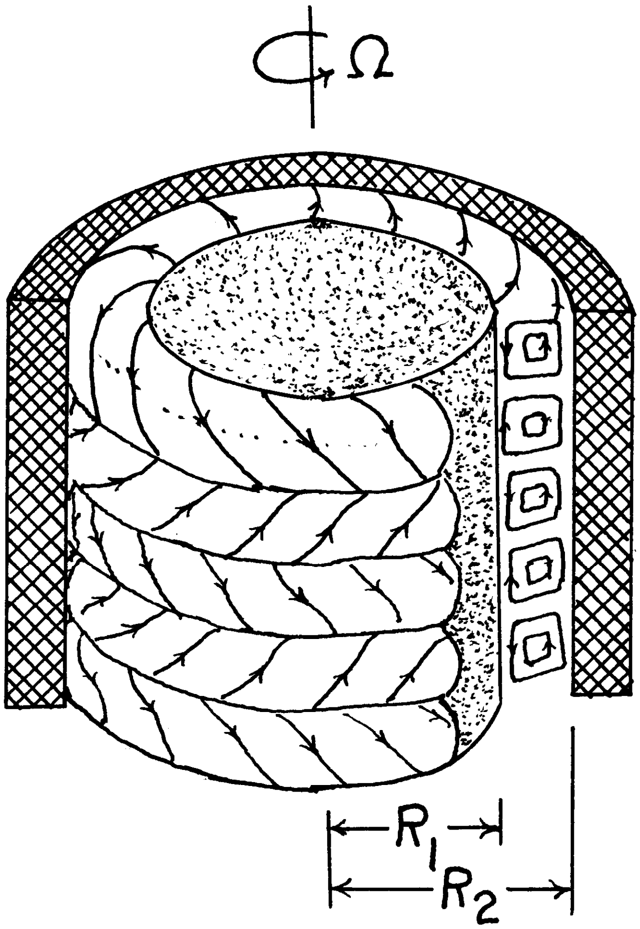

Figure 3. This shows an example of Taylor vortices between two cylinders, the outer at rest. The width of the gap $d = R_2 - R_1$. See also Reference 15.

nar flow. When the fluid remains in a laminar flow, it is said to be "stable." If mixing occurs between the layers of the fluid, so-called "Taylor instability" has developed, and Taylor vortices are observed (stable circular flows of fluid, see Figure 3). Taylor noted that when water in a tank was made to rotate steadily as a solid body, some interesting things occurred when ink was introduced into the system. The fluid would draw the ink into thin sheets, and these sheets always remained parallel to the axis of rotation. Taylor noted: "The accuracy with which they remained parallel to the axis of rotation is quite extraordinary."[14] Since this is precisely the situation under the vapor canopy, a discussion of this phenomenon is pertinent.

The pre-flood atmosphere can be visualized as the "ink." It is layered between two concentric cylinders—the earth and the canopy bottom. Under certain conditions, the atmosphere will stay parallel to the axis of rotation. In other words, there would be no turbulent mixing at the interface of the canopy and the lower atmosphere. This would, of course, contribute significantly to the maintenance of the vapor canopy.

Taylor defined a Taylor number to correlate certain parameters of the two rotating cylinders involved into a dimensionless ratio that could be used to determine when such a system would become unstable and the laminar flow disrupted. The Taylor number is defined as:[16]

$$K = \frac{4\Omega^2 R_1^4 (1 - \mu)(1 - \mu/\eta^2)}{\nu^2 (1 - \eta^2)^2} \tag{5}$$

where Ω = the angular velocity of the inner cylinder, or in the canopy model, of the earth; R_1 = the radius of the earth; μ = the ratio of the angular velocity of the outer cylinder (the inner rim of the canopy) to Ω; η = the ratio of the radius of the inner cylinder, R_1, to the radius of the outer cylinder, R_2; and ν = kinematic viscosity, or the coefficient of viscosity divided by the density of the fluid contained between the two rotating cylinders (the ancient troposphere). Figure 4 illustrates how the situation discussed could have applied to the ancient atmosphere.

Thus, the two cylinders correspond to the inner rim of the canopy and the surface of the earth. (Which, of course, are actually spheres; see later.) The fluid that is to be analyzed is the pre-flood atmosphere contained in between these two rotating plates. Modeling the outer rim as a solid plate is a common modeling technique in aerodynamics, even though no such plate actually exists. However, if the molecules of the fluid at the outer rim are everywhere parallel to the inner cylinder, then the effect is the same as if a literal solid plate existed. Due to the temperature inversion and the greenhouse effect, the bottom of the canopy would be very stable and would eliminate vertical and horizontal winds.

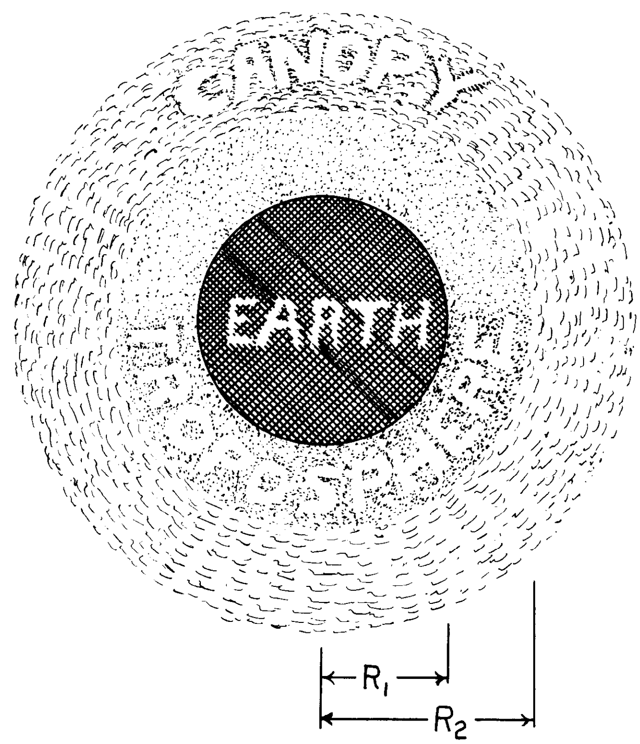

Figure 4. This shows how the notion of Taylor stability is applied, in the text, to the ancient atmosphere. This drawing, of course, is not to scale.

The kinematic viscosity is inversely proportional to the density and, hence, directly proportional to the temperature of the ancient atmosphere. This can be seen from the equation of state of an ideal gas.[17]

$$\varrho = P(m/R)(1/T) \qquad (6)$$

As long as the Taylor number remains below a certain critical Taylor number, K, the fluid contained between the rotating cylinders will remain in laminar flow, and there will be no convective turbulence. It would be of great interest to know what the critical Taylor number of the pre-flood atmosphere was. Unfortunately, while Taylor numbers have been defined for cylinders,[18] they have not been defined for spheres. However, "The Taylor number for a sphere in a fluid will have the same type of dependency as for a cylinder in a fluid. It will be highly dependent on the viscosity, density, and 'atmospheric thickness'."[19]

Thus, even though the earth's atmosphere is not a cylinder but a sphere, the similar factors defined in the equation for the Taylor number of a cylinder apply to a sphere.

Dr. John Burkhalter, an atmospheric physicist with Auburn University, did his doctoral work on supercritical Taylor vortex flow.[20] He has suggested that when God created the earth's atmosphere, He would probably have started it out in an equilibrium state, Couette flow.

> Now let us make the assumption that the earth and atmosphere were created in a perfect state (which I believe to be true). The initial flow field for the atmosphere in this perfect state would have been Couette flow for a sphere immersed in a uniform fluid. It is possible that this situation could have been maintained with the pressure gradient forces being slightly larger than the inertial forces. If the atmosphere were thicker than it is today, as one would logically conclude, then the critical Taylor number would have been fairly large.[21]

Assuming that the atmosphere was created in an equilibrium state, then the angular velocity of the inner rim of the canopy would be equal to the angular velocity of the surface of the earth, and from (5) the term $(1 - \mu)$ would equal zero. Thus, whatever the critical Taylor number was of the pre-flood atmosphere, it was clearly far above zero, and, as Burkhalter suggests, far above even today's values. As a result, it would appear that the atmosphere of the pre-flood world (i.e., the "fluid" between the plates) may have been in a very stable condition and lacked any turbulent mixing.

It is known that the Taylor number of today's atmosphere is above the critical value due to the fact that jet streams are apparent in the upper atmosphere. What would have caused the Taylor number of zero of the pre-flood world to rise above the critical value and induce Taylor instability and a global deluge?

A major factor would be a significant cooling. From (6) and (5), it is clear that the Taylor number varies inversely with temperature. Thus, a drop in temperature would raise the Taylor number. The activity of numerous volcanoes may have thrown a cooling volcanic cloud cover above the canopy and drastically reduced its temperature, precipitating extensive rainfall. As the rain fell, ν would decrease (as density decreased), and therefore the Taylor number would be forced upward even more. A third factor may have caused a gradual *decrease* of the critical Taylor number downward, i.e., the loss of water vapor and dissociated hydrogen off the top of the canopy into outer space. Burkhalter continues,

> As the earth continued to rotate in its infant stages (perhaps over a period of hundreds of years), it could have gradually lost some of its atmosphere to outer space as theorized for many other planets and moons. During this period, Couette flow would have been maintained as long as the Taylor number was below the critical value. As the atmosphere became thinner, the critical Taylor number decreased until at sometime in history, the atmosphere became inertially unstable. At this time, catastrophic phenomena would have taken place.[22]

Thus, the Taylor number of the pre-flood atmosphere was increasing and the critical Taylor number was decreasing. At some point, a global instability would have set in.

> The Couette flow would suddenly (hours, days, or weeks) have formed into toroidal shaped rings around the earth. Initially there would have been (perhaps) many rings which would have caused very large vertical air currents and consequent cooling, etc., of the vapor state atmosphere. Considerable condensation (rain) would have occurred, accompanied by strong winds. After some period of time, a specific pattern would have resulted in which the toroidal rings would have remained as long as the Taylor number was above the critical, as it apparently is today, and specific well-defined wind patterns would have resulted. It is a well-known and established fact that the cells or toroidal rings do exist on the earth today. There are three in the northern hemisphere and three in the southern hemisphere. As a matter of interest, the North East Trade Winds form a part of one of these cells.[23]

Burkhalter concludes,

> In conclusion, it is highly possible that the vapor state in the pre-flood era could have existed and the logical sequence of events described above could have occurred.[24]

In order better to understand the physical forces involved in Taylor stability, it is helpful to visualize the atmosphere as located between two concentric cylinders, each with a width equal to the distance between the equator and approximately 30 degrees North and South latitude. These cylinders are rotating at exactly the same velocity. Furthermore, as described above, the earth is under the influence of a universal temperature inversion. The canopy causes a universal greenhouse effect. Toward the top of the canopy, there would have been much movement of water vapor from the equator toward the poles in order to balance the heat budget. Since the area of the canopy located over the equator recieves much more solar radiation than the area over the poles, a movement from the high pressure over the equator to the low pressure over the poles would ensue. This transport of heat by atmospheric movement might keep the temperature of the canopy over the equator and the poles nearly the same (precisely the same situation that prevails on Venus). Therefore, in the lower regions of the canopy, just above the atmosphere, there could well have been little atmospheric movement. The temperature of the bottom of the canopy radiating earthward from the poles would then be close to that radiating earthward at the equator. As a result, there would be a pole-to-equator temperature equilibrium and hence only minor air transport in the lower atmosphere or in the lower area of the canopy (the outer "rim"of the two concentric cylinders). The Taylor number would, therefore, have been near zero as mentioned above.

The only forces acting upon a parcel of air in the lower atmosphere would be the centrifugal force throwing air out and gravity produced pressure gradient forces pulling the air parcel in. At what point will an instability set in? An instability (and hence, turbulent mixing) will occur when a random disturbance is amplified instead of being dissipated.

> The task of the stability theory consists in determining whether the disturbance is amplified or whether it decays for a given mean motion; the flow is considered unstable or stable depending on whether the former or the latter is the case.[25]

Under what conditions is a disturbance amplified? This would occur when a parcel of air below a disturbance is "bounced" upward into the disturbance carrying a large amount of angular momentum. If the horizontal velocity of flow of the parcel of air is greater below than above, then when that parcel is raised to the upper level it carries with it a greater amount of angular momentum than the surrounding air. In order for angular momentum to be conserved, the energy associated with the momentum increase must be dissipated by viscous transport to the surrounding air (fluid). If the disturbance is able to dissipate the additional energy at a greater rate than that energy is being added to the disturbance, then the disturbance will not be amplified, but will be "damped," and the atmosphere will return to a stable state. Its ability to dissipate energy is dependent upon the viscosity of the surrounding air which is related to density and temperature. However, if the angular momentum of the particles moved into the area of the disturbance is such that a larger amount of energy is transferred than the disturbance can dissipate, then the disturbance will continue to grow in intensity, and a large-scale instability will result. It is obvious that a key to creating a global instability is to introduce a velocity profile such that the velocity of the layers differs significantly so that *continuous* transport of momentum between the layers will result in instability. Momentum is a function of the mass, velocity, and hence of distance of the parcel from the axis of rotation. A change in temperature will change the density and hence the mass of the parcel. Therefore, either a change of temperature or a change in the velocity or a change in radius of the "outer rim" could result in a change in stability.

Now the Taylor number is a dimensionless ratio that relates all of these factors—mass, velocity, viscosity, radius, etc. Different masses and different velocities can exist in various layers of the atmosphere and the atmosphere still remain stable and laminar, provided the ratio of the masses, velocities, and radii is not such that the Taylor number which defines that ratio exceeds a certain critical value.

Burkhalter describes laboratory experiments in which he observed the introduction of a serious disturbance into the fluid located between two concentric rotating cylinders in which the Taylor number was sub-critical. He observed that, no matter how the fluid was stirred up, it would quickly return to laminar flow, and no turbulent vertical mixing would occur. The same situation may have existed in the pre-flood earth. Local and severe disturbances or variations in weather may have occurred, but it would have had no effect in generating a global instability and coincident convective turbulence and eddy diffusion. It seems likely then that, under these assumed antidiluvian conditions, no local disturbances would be amplified but would be damped, and the atmosphere would remain stable without any vortices or vertical motions.

The Maintenance of the Vapor Canopy

It will now become clear how many feet of water vapor may have been maintained, perhaps indefinitely, up above the ancient troposphere. Due to the stabilizing influences of the global temperature inversion and of Taylor stability, the atmosphere below the bottom of the canopy would have been in an extremely stable, laminar state so that little convective turbulence or mixing would have occurred between the canopy and the ancient troposphere. Only molecular diffusion needs to be considered, and eddy diffusion would be minimal.

Molecular Diffusion

In order to calculate how long it would take for the canopy to diffuse down to the surface of the earth, it will arbitrarily be assumed that in the 1 km layer under the canopy the air is *completely* stable. This is a reasonable assumption based on observation of present day temperature inversions. Furthermore, since the temperature inversion extends all the way to the surface, it is likely that eddy diffusion would be insignificant most of the way down. Thus, assuming only a 1 km totally stable layer is conservative. There is absolutely no eddy diffusion or convective turbulence due to the temperature inversion and Taylor stability. However, as one gets closer to the surface, it is possible that eddy diffusion might begin to play a more prominent role. This is due to the fact that the albedos of various parts of the earth's surface vary from 0.1 for forests, 0.2 for oceans, and 0.45 for sandy areas.[26] As a result, differing amounts of radiation will be absorbed at the surface in these different areas, and different temperatures will result. In order to balance these slight temperature variations, gentle breezes and winds might prevail as they do today. There would be no major wind systems, however. Thus, once the vapor had diffused down through the first 1 km layer, it might diffuse more rapidly the rest of the way down to the surface, due to the mixing and gentle breezes there.

The calculation of molecular diffusion involves computer iterative techniques. In order to secure a reliable approximation, Dr. Larry Vardiman, a meteorologist with the Bureau of Reclamation, was consulted.

Vardiman starts out *assuming* without proof a certain temperature profile similar to Figure 1. A profile similar to this is necessary to sustain the canopy as it is presently being conceived. He also assumed 34 feet of precipitable water in the canopy and a surface pressure of 2026.6 millibars and surface temperature of 300 °K or 27 °C. The temperature at the interface between the atmosphere (air) and the canopy is set at 400 °K or 127 °C. This is sufficient to sustain over 40 feet of precipitable water in vapor form in the canopy. The pressure at the bottom of the canopy would be 1013 mb (34 ft. of H_2O = 1 atm. = 1013 mb.). Due to the temperature inversion, there is no wind or vertical mixing in the 1 km below the canopy, and hence the primary mode of diffusion downward will be molecular diffusion. This process is described by Fick's law.[27]

$$\frac{dM}{dt} = -DA\frac{d\varrho}{dz} \tag{7}$$

where: dM/dt = the flux of water vapor through a boundary in units of gm/cm^2 • sec, D = the diffusivity of water vapor through air in units of cm^2/sec, A = an area through which water vapor is being diffused, assumed to be 1 cm^2, $d\varrho/dz$ = the density gradient of water vapor in the vertical direction z in units of gm/cm^3/cm.

Basically, this equation says that the rate of diffusion of water vapor through a unit area is proportional to the negative gradient of vapor density. Therefore, the largest rate of diffusion of water vapor downward will occur immediately below the interface at time zero. As vapor diffuses downward, the gradient below the interface will decrease, reducing the rate of diffusion. Thus, Vardiman assumes that the initial conditions involved a layer of water vapor and layer of air separated as if by an impenetrable membrane. As soon as the membrane is removed, vapor diffusion downward begins at time zero.

The equation for D is:

$$D = D_o(T/273\,°K)^{1.81}\,(1000\text{ mb}/P) \tag{8}$$

where D = diffusivity at pressure and temperature of interest, D_o = diffusivity of water vapor into air at T_o, P_o = 0.241 cm^2/sec, T_o = 0 °C = 273 °K, P_o = 1000 mb, and P = pressure of interest.

Because of the pressure and temperature dependence of the diffusivity, an exact solution is difficult, so a finite difference scheme was developed to integrate equations (7) and (8). Seventy 100-meter-thick layers were modeled from the surface to the air-water interface, as shown in Table 1. Layers are denoted by the numbers j running from 1 to 70. Seventy-one levels were modeled as denoted by the numbers i running from 1 to 71. A diffusivity was calculated at each layer.

Temperature, pressure, and diffusivity were assumed to remain constant with time.

Vapor was assumed to diffuse downward, but air was not assumed to diffuse upward. Neither was the upward diffusion of water vapor back into the canopy considered. If air and water vapor had been allowed to diffuse upward, it would have slowed the net diffusion of water vapor downward. Therefore, the present calculation will be conservative by overestimating the rate of diffusion downward.

The vapor density at level one (i = 1) is computed from the ideal gas law [Equation (6)] assuming vapor saturation at 400 °K.

Time steps of 10 years used in the integration were found to go unstable after about 300 years. These numerical instabilities have not yet been resolved, and, as a result, the calculations are only reported for 250 years. However, as illustrated in Figure 5, it is easy to extrapolate by graphical methods what the diffusion rate will be at the time of the flood, 1,656 years later. Methods are currently being investigated to extend the calculations beyond 1,656 years, thereby eliminating the need to base conclusions on an extrapolation.

Because of the assumption of no water vapor in the air below the canopy, no diffusion will occur below the first layer under the interface during the first time step. That is, no diffusion will occur between levels 1 and 2. At the second time step, diffusion occurs between levels 1 and 2 and between levels 2 and 3. At the end of 70 time steps, diffusion occurs through all 70 layers, although the rate at the lowest levels is extremely small. This "marching" of water vapor downward one layer at a time for the first 70 time steps is an artificiality of the initial assumptions, but does not affect the simulation after about five time steps from the time a layer has vapor in it.

The integration was run for a period of 300 years before numerical instabilities became evident. Figure 5 shows the rate of diffusion through layer 1 for the first 250 years in terms of an equivalent depth of liquid water. Since the rate of diffusion will always be greatest in layer 1, and since all water vapor must be diffused through this layer, this graph provides an estimate of the maximum rate of diffusion.

It can be seen from Figure 5 that the maximum rate of diffusion at the end of the first year is 0.77 cm/yr and it decreases rapidly to 0.2 cm/yr in about 120 years. If the curve in Figure 5 is extrapolated to 1,656 years, and the diffusion integrated over the entire 1,656 years, the

Table 1. This shows some of the divisions, there being 70 layers altogether, each 100 meters thick, used in investigating the diffusion of water vapor into and through the troposphere, by the method of finite differences. See the text.

P(mb)	*T(°K)*	*H(km)*	*Level (i)*	*Layer (j)*
1013	400.0	7.0	1	
1022	398.6	6.9	2	1
1031	397.1	6.8	3	2
1040	395.7	6.7	4	3
1049	394.3	6.6	5	4
⋮	⋮	⋮	⋮	⋮
1982	302.8	0.2	69	
2004	301.4	0.1	70	69
2026	300.0	0.0	71	70

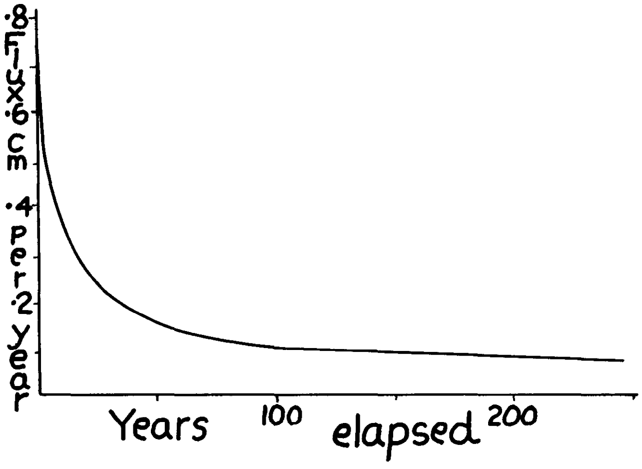

Figure 5. This shows the flux of water vapor through the nearest 100 meter layer beneath the canopy as a function of time, as is discussed in the text.

total water diffused through layer 1 is just over 1 meter of liquid water. This is less than 10 percent of the total 34 feet of water initially assumed to be in the canopy which has diffused through the first layer 100 meters under the canopy in 1,656 years! At this rate, it would take 12,190 years for the 40 feet of H_2O (1219 cm) to diffuse through the first 100-meter layer. Thus, it is evident that the canopy will take an extremely long time to diffuse to the surface.

The calculations show that the vapor initially diffuses downward rapidly then begins to slow as the gradient decreases. By 250 years, only 1 millibar of vapor (about 1 cm of liquid water) has reached the 5.75 kilometer level (about 1 km below the canopy). This is less than 0.1 percent of the total vapor pressure at the base of the initial canopy. At a rate of 1 cm/250 yrs, it would take 304,750 years for the canopy to diffuse through the 1 km level.[28]

Vardiman concludes,

> These results, based strictly on the molecular diffusion, show that with the assumed initial distribution of water vapor, air, and temperature, the vapor canopy is highly stable with time and could have easily remained in the upper atmosphere from its creation to the flood 1,656 years later.[29]

It appears likely, then, assuming completely stable air for 1 km under the canopy, that the canopy could be maintained for a very long period of time. In 250 years, only 1 cm would have diffused down to the areas of the troposphere where eddy diffusion might begin to play a part.

Of crucial importance is the demonstration of the assumed temperature profile which Vardiman used. Is there any basis for believing his assumption is approximately correct?

The Temperature Profile Under the Canopy

In order to calculate what the temperature profile would have been under such a vapor canopy, an extremely complicated computer simulated global climate model would have to be developed. The calculation of radiative heat transfer is very involved and is beyond the limits of this paper or my abilities.

The general procedure is as follows. First, a reasonable temperature-altitude profile is assumed. Then the hydrostatic equation (1) must be introduced to calculate the density and pressure of all the atmospheric constituents at each altitude. Fortunately, planetary atmospheric models are presently available for this purpose.[30] Then, knowing the density and pressure at each altitude, it is possible to compute the optical depth at that level and the reflectivity. The optical depth is simply the mass of absorbing medium per unit area normal to the radiation. From this, the absorption of the layer can be calculated for each wavelength. After each layer absorbs radiation, it will re-radiate it to the adjacent layers, ½ up and ½ down in the infrared. This radiation will be absorbed and will result in a new temperature profile slightly different from the assumed one.[31] Once the new profile is established, new optical depths are computed, and new absorption percentages result for the adjacent layers, and a new temperature profile results once again. This process is repeated by computer iterative techniques until the final profile agrees within a pre-determined amount with the "next to last" profile. At that point, the calculation is ended.

However, with simple approximations, it is possible to show that the temperature of the canopy will be hot enough to maintain the water vapor in vapor form and to establish the idea of a temperature inversion. It is even possible to indicate that the surface temperatures could conceivalby have been such that the earth would have been habitable.

The Temperature at the Base of the Canopy: The Importance of the Reflective Layer

Of crucial importance in the following approximations is the existence of a reflective layer at the interface of the canopy and the antediluvian troposphere. There is a possible mechanism that might produce such a reflective layer.

Because a rapid transition is being made from an atmosphere made up of water vapor to one made up of air, there would be a corresponding rapid change in the absorption of infrared radiation from above and below. Air absorbs infrared much less efficiently than water vapor. As a result, there would have been a sudden temperature change (in space) across the interface of the canopy and the lower atmosphere. This sudden temperature decrease might in turn produce a mist in this area through which good visibility could be maintained if it were formed only intermittently, but which would also significantly raise the albedo of that layer. In the areas where this mist formed, the canopy and the lower atmosphere have intersected (the pre-flood "tropopause"). Thus, these water vapor mists are mixed in an atmosphere of air, the density of which is probably higher than the density of the atmosphere today. The terminal velocity of fall of such mist droplets is very small and is given by:[32]

$$V_t = (2/9)\ \frac{\varrho L - \varrho}{\eta}\ (gr^2) \tag{9}$$

where, V, = terminal fall velocity, cm/see, ϱL = density of liquid water at 30°C[5] 0.99567 gm/ml, ϱ = density of the air through which the droplets are falling[33] = Pm/RT = (1000 mb) (28.96)/(8.3143 x 10') (600 "K) = 3.6 X 10^{-4} gm/cm^3, η = viscosity of air at 600°K = 31.23 x 10^{-5} poise,[34] g = 980.616 cm/se?, and r = radius of mist droplet[35] = 5 X 10^{-5} cm.. Therefore, V_t = 1.74 X 10^{-3} cm/sec.

This fall velocity is negligible. Byers comments, "It is seen that in the size range of cloud droplets, from 2 to 40 μm in diameter, the fall velocities a&negligible, and the droplets are, for all practical purposes, suspended in the air."[36] This suspension is due to the slow fall velocity and the fact that a droplet that size will evaporate before it falls 10^{-4} cm.[37] Thus, these mists in the canopy would fall very slowly and then evaporate immediately. As they evaporated, depending on the temperature profile and the mixture of air and water vapor above, it might be possible to conceive of a system by which they would then diffuse back upward, and, as a result, these mists would essentially hover.[38]

These mists could only occur irregularly if there were no condensation nuclei in the tropopause (and there probably were not). Thus, one is led to conceive of a sometimes misty, sometimes cloudy tropopause, but one which would be regularly much more reflective than today's atmosphere, with an albedo of 0.6 or higher.

Approximation for the Temperature of the Tropopause

With these assumptions in mind, it is possible to estimate the temperature at the base of the canopy just above this reflective layer. In order to do this, the approximations outlines by Goody will be used.[39] A simple estimate of the temperature of the radiative surface of the planet is given by:

$$T_b^4 = (1 + \text{optical thickness}) \times T_e^4 \qquad (10)$$

where T_b is the temperature at the base of the canopy (the radiative surface due to the assumed reflective layer), and T, is the effective temperature of the earth. The effective temperature of a planet is the temperature of its top radiating layer whose optical thickness is one.[40]

$$T_e = \left[\frac{S(1 - A)}{4\sigma}\right]^{1/4} \qquad (11)$$

where S = the solar constant, 1.94 cal/cm^2• min; A is the planetary albedo; and σ the Stephan-Boltzmann constant, 8.128 X 10^{-11} cal/cm^2• min • °K^4. The albedo of the earth today is about 0.36. Thus, 36% of incoming solar radiation is reflected. However, under the canopy, it is suggested that the global reflection may have-been considerably higher, perhaps 80% and thus the global albedo might have been 0.6 or higher. Using these values, the effective temperature of the earth for all wavelengths under the canopy would be 221°K. (Today's effective temperature is about 253°K.)

However, that temperature assumes atmospheric absorption in all wavelengths. Equation (10) is valid assuming that no solar radiation is absorbed as the beam penetrates to the surface of the earth and that 100% of the infrared radiation re-radiates from the surface of the earth (the reflective layer in this approximation) upward into space is absorbed by the atmosphere. However, water vapor absorbs only in selective wavelengths. From about 4 to 8 microns, water vapor absorbs 100% of the radiation. There is a "window" between about 8 and 13.5 microns, and after 13.5 microns 100% of all infrared radiation is absorbed. Since (10) assumes absorption at all wavelengths, T_e must be modified in that at the base of the water vapor canopy upward, absorption occurs only in the water vapor bands. When the areas under Planck blackbody radiation curves are integrated, it is found that for virtually all temperatures between 200°K and 2000°K, the ratio of the area of the water vapor bands for total absorption to the other bands ranges from about 0.3 to 0.7.[41] For this rough approximation then, it will be assumed that no matter what the temperature of the canopy is, about 50% of the infrared flux radiating upward from the cloud layer below the canopy base will be absorbed by the water vapor in the canopy. The upward infrared flux is given by[42]

$$F = \sigma T_e^4, \qquad (12)$$

and only 50% of F is actually absorbed by the water vapor, This has the effect of reducing T_e^4 by 1/2 so the real effective temperature of the earth in the water vapor bands, T_e', is given by

$$T_e' = \left[\frac{T_e^4}{2}\right]^{1/4} \qquad (13)$$

which comes to 186°K.

In order to solve (lo), the optical thickness must be known. Imagine the entire canopy divided up into various layers. Each layer is just thick enough completely to absorb all of the infrared radiation passing through it. Layers are too thick if radiation is emitted and reabsorbed in the same layer. Layers are too thin if radiation transverses one or more layers before undergoing absorption. Each layer, therefore, is just thick enough to absorb the radiation falling onto it. The mechanism of radiation transfer is one of passing energy from one layer to the next; the radiation emitted from each layer is absorbed by its two nearest neighbors, which in turn emit to their nearest neighbors, and so on. "The total number of layers into which an atmosphere can be divided in this manner is called the optical thickness of the atmosphere."[43] It turns out that about 1 cm of precipitable water will result in total absorption of all infrared radiation in the bands in which water vapor absorbs.[44] Thus, the optical thickness is simply the number of centimeters of precipitable water in the canopy (40 ft = 1219 cm), and Equation (10) yields,

$$T_b = [(1 + \text{optical thickness})\,(T_e')^4]^{1/4} \qquad (14)$$

which comes to 1099°K.

Thus, the temperature at the base of the canopy, assuming radiative equilibrium and no convect&e* heat transport, is 826°C or 1519°F. Since only 220°F was needed to sustain 40 feet of precipitable water in vapor form, it is clear that the trapping of heat by the canopy will create a strong temperature inversion.

It should be noted, however, that the temperature at the canopy base would never be as high as 1519°F. This is because convection will transfer tremendous quantities of thermal energy upward toward the cooler regions of the canopy, and global circulation will transfer it poleward where solar radiation levels are considerably reduced. This strong convection will work to keep the canopy approximately isothermal and will tend to keep the temperature of the base of the canopy over the poles at the same temperature as the base of the canopy over the equator.

While it is true that such a situation does not exist on the earth today, it may well have existed in the denser atmosphere of the pre-flood earth. A parallel with Venus is instructive. The Venus probes have revealed that even though larger amounts of radiation are obviously received at the equator than at the poles, the temperature at the poles an the equator is precisely the same. Goody comments, ". . . the temperature is the same at the equator as at the poles. Our theory still predicts that σT^4 is equal to the absorbed flux of solar radiation; although this is small at the poles and large at the equator, no variation in T_e, is, in fact observed."[45] ($T_e = \sigma T^4$)

What, then, would be the isothermal temperature of such a canopy? This is given by:[46]

$$T_{ave} = \frac{mgT_o}{\alpha R\left(\frac{mg}{\alpha R} + 1\right)} \qquad (15)$$

where, T_{ave} = the isothermal temperature of the canopy, °K, m = molecular wt, 18.016, g = acceleration of gravity, 980.6 cm/sec^2, T_o = temperature of the base of the canopy, $R = 8.3144 \times 10^7$ erg mol^{-1} °K^{-1}, and α = the vertical lapse rate. McKnight chose 10 °C/km as a good estimate. Thus, T_{ave} = 748 °K.

The Surface Temperature

What about the surface temperature? Again, this is an immensely complex calculation. However, the Eddington approximation could be applied to give an approximate solution for conditions of radiative equilibrium.[47]

$$T = \frac{(1 - A)\, S\, (2 + 1.5\lambda)}{8\sigma} \qquad (16)$$

where λ is the optical depth of the ancient troposphere below the canopy. The optical depth varies with wavelength. For the atmosphere in general, it is approximately 3, and for absorption in the infrared bands a number of 2 is often used.[48] Assuming that the canopy albedo was 0.6, the following results.

There will be two radiative fluxes coming down upon the earth. S_1 = the radiative flux due to the high heat of the canopy, and S_2 = the (radiation represented by the) solar constant. S_1 is given by

$$S_1 = \frac{\sigma T_b^4}{2} \qquad (17)$$

which comes to 12.72 cal/cm^2 • min.
Half of the radiative flux out of the bottom layer goes downward and half goes upward.

However, S_1 will be reduced considerably as it passes through the troposphere under the canopy due to the presence of several cm of precipitable water in the ancient troposphere. This water vapor under the canopy acts as a "resistor," reducing the intensity of the "current" (i.e., infrared radiation, S_1) passing down through it from above. The same phenomenon was observed in reverse from the canopy base upwards. Each optical thickness of the canopy can be conceived as a resistor. Thus, while the temperature at the canopy base was computed to be 1099 °K, by the time the radiation had passed through 1219 optical depths, the temperature had been reduced to 186 °K at the top layer. This was the effective temperature of the earth. In a similar way, the radiative flux is reduced as the radiation travels downward through optical depths in that direction. Figure 6 illustrates this phenomenon. Because of the high temperatures in this area, it would be possible to contain 4 or 5 feet just under the canopy. In the calculations, it will be arbitrarily assumed that God placed 2 feet (60 cm) in the 1 km layer below the canopy.

Each resistor represents an optical thickness of the water vapor under the canopy. Since 60 cm were proposed, this amounts to 60 optical thicknesses or 60 "resistors." The radiative heat exchange with the surface of the earth is the flux difference divided by the sum of the resistances.[49]

From the above discussion, it is clear that by the time S_1 reaches the surface of the planet, it has been reduced by a factor of 60. Thus, S_1 at the surface, $S_{1s} = S_1/60$ or $12.72/60 = 0.212$ cal/cm^2 • min. (Conceiving T_e this time as the temperature at the surface of the earth instead of as the effective temperature at the top of the canopy.)

The other source of radiation that penetrates to the earth's surface is the radiation that went right through the canopy and was not absorbed, scattered, or reflected by it, S_2. Assuming that the albedo of the canopy is 0.6, then once the solar radiation has passed the canopy, it has been reduced by 60% and $S_2 = 0.4 \times 1.94 = 0.776$ cal/cm^2 • min.

From the Eddington approximation (15) and (12), it is clear that

$$F_1 = \frac{(1 - A)\, S_{1s}\, [(2 + 1.5(\lambda)]}{8} \qquad (18)$$

which comes to 0.106 cal/cm^2 • min.
Similarly,

$$F_2 = \frac{(1 - A)\, (S_2)\, [(2 + 1.5(3)]}{8} \qquad (19)$$

which comes to 0.504 cal/cm^2 • min.
In the above, it was assumed that the revised albedo is simply the albedo that S_1 and S_2 "see" after passing through the canopy; i.e., the albedo of the surface of the earth[50] which is normally taken as about 0.2.

The total flux at the earth would then be simply $F_1 + F_2 = 0.61$ cal/cm^2 • min.; and since radiative equilibrium is assumed, this same amount must be absorbed and re-radiated back into the atmosphere. Therefore, from (12), $T_s = (0.61/8.128 \times 10^{-11})^{1/4}$ = 294 °K = 70 °F.

It should be strongly emphasized that these calculations do *not* prove the canopy temperature profile. They are much too simplistic. However, they do seem to indicate the plausibility of the proposed temperature inversion coupled with habitable temperatures on the sur-

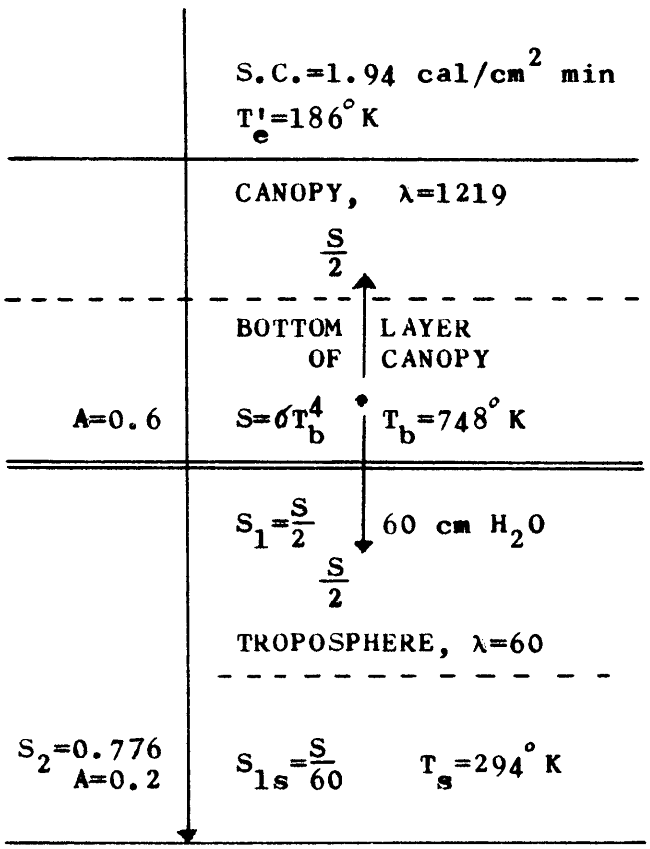

Figure 6. This illustrates the reduction in radiative flux from the base of the canopy to the surface of the Earth. The vertical dimensions in this drawing are not necessarily to scale.

face. The answer has been "bracketed" to a point that would justify further computer simulation to see if indeed surface temperatures would be this low.

It may seem perplexing that the base of the canopy at 6 miles altitude and at temperatures of 887 °F could result in such low surface temperatures. Robert Whitelaw has objected to the canopy hypothesis on these grounds: "In such a pressure-cooker world under a scalding 270 °F sky, life of course would be impossible." [51] As the above calculations indicate, a scalding sky does not necessarily result in a scalding hot earth below. There are three factors that tend to render the surface of the earth cooler than the base of the canopy.

First, the high albedo of the tropopause would reflect a large amount of the solar radiation. The presence of mists and clouds would not necessarily obscure the view of the antediluvian heavens. The mists need not be continuous but, like those of today, broken, and on many days and nights over a given section of the earth, it is quite possible that there would be no clouds or mists at all.

Secondly, the presence of water vapor under the canopy acting as "resistors" will reduce the radiative flux considerably. This vapor acts as "insulation" just as asbestos wrapped around a hot pipe renders it "touchable" by human hands.

Thirdly, infrared cooling at the surface will reduce the surface temperature. As the radiative flux from above, S_1 and S_2 hit the surface of the earth, they are reradiated as F_2 and F_2. The water vapor in the troposphere absorbs in only a portion of the solar spectrum. However, when the earth re-radiates back up, it re-radiates throughout the entire infrared spectrum and at greatest intensity in the water vapor "window" between 8μ and 13.5μ. Thus, the radiation that the earth radiates most intensely passes right through this window and is not trapped to heat up the earth below. As a result, the surface temperatures are cooler than they would be if it were not for this phenomenon.

Hess summarizes this phenomenon as follows:

> From roughly 5 to 8μ, there is a strong absorption band of H_2O. Beyond 8μ, the absorption becomes smaller up to about 13.5μ.... This relatively transparent window in the atmospheric absorption spectrum falls in the wavelength regions where the earth's surface radiates most strongly.[52]

Conclusion

The canopy problems introduced in this presentation have been discussed at a very elementary level. Full solution to these possible support mechanisms and the proposed temperature profile await a computer-simulated global climate model which will incorporate the equations of radiative heat transfer and convective heat transfer and atmospheric dynamics. Thus, what has been described should not be taken as proof that the canopy problem has been solved. The above discussion only indicates that it may be solvable and that there are certainly some good possibilities as to how God maintained the "waters above."

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PELEG'S DIVISION

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The Red Sea is a narrow strip of water extending south-eastward from Suez for about 1300 miles, separating the coast of north-east Africa from the coasts of Saudi Arabia and Yemen. "Its maximum width is 190 miles; its greatest depth 9,580 feet; and its area approximately 169,000 square miles. [It] occupies part of a large rift valley in the continental crust of Africa and Arabia."[1]

"The Rift Valley begins in the lower spurs of the Taurus Mountains in Turkey and runs south from there through the Jordan Valley to the Gulf of Aqaba. It includes the natural wonder of the Dead Sea . . . . At Aqaba the Rift is submerged beneath the waters of the Red Sea, to reappear on the African Continent in the Afar depression of northeast Ethiopia. At this point three rift valleys—the Red Sea, the Gulf of Aden and the African Rift—converge.

"It has been said of the Rift Valley that, although it may have its counterpart on another planet, there is nothing [else] like it on earth. There are other rift valleys, but none of these is so great in extent and variety . . . [However, a] rift valley is not really a valley at all; it only looks like one. Ordinary valleys are cut by rivers in their descent from mountains toward the sea; they may be steep-sided and narrow, but a big, old river valley often has a large flat alluvial plain on its floor and steep escarpments some distance back on either side . . . Rift

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