THERMODYNAMIC ANALYSIS OF A CONDENSING VAPOR CANOPY

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Abstract

A significant problem confronting vapor canopy theorists is the energy load on the atmosphere during the collapse of the canopy. Previous attempts to quantify this energy load have indicated that atmospheric temperatures would rise much too high to sustain life. However, up to this point the regulating effect of the ocean during canopy collapse has not been addressed. This investigation develops a more detailed energy balance than used in earlier work and also includes a simplified model to account for ocean-atmosphere coupling. Assuming that the entire energy load is released during the 40 days of the Flood, the simplified model predicts that the upper bound for canopy precipitable water is two feet.

Introduction

The possibility of a canopy of water vapor that rested on top of the atmosphere during pre-Flood times has generated a great deal of discussion by creationists. The existence of such a canopy has been used to explain a number of problems, including: 1. the source of water that would permit 40 days and nights of rain during the Noachian Flood, 2. the evidence for a more uniform and temperate worldwide climate in earth history, and 3. the longevity of the ancient patriarchs.

Whitcomb and Morris, in their classic creationist work *The Genesis Flood,* discussed the necessity of a pre-Flood vapor canopy. The Biblical evidence for the existence of a vapor canopy was exhaustively reviewed by Dillow (1981a). Dillow (1978, 1981a, 1981b) argued that, based on his analysis, the pre-Flood atmosphere could have supported a vapor canopy that would have provided an earth surface temperature hospitable to life. In his model Dillow assumed a canopy that held 40 feet of precipitable water. This proposition was challenged by Morton. Morton does not agree with the evidence for a worldwide temperate climate (1980), and thus asserts that the vapor canopy hypothesis was invented to solve a nonexistent problem. Believing that Dillow's assumptions were flawed, he attempted his own analysis (1979, 1981), where he concluded that a canopy with 40 feet of precipitable water would not have been able to provide an hospitable surface temperature, but would in fact result in surface temperatures over a thousand degrees. In addition, Morton found a critical error in Dillow's analysis (Morton, 1982). Dillow acknowledged the error, but proceeded to perform an improved analysis with a more detailed model (1983). His results again showed an hospitable earth surface temperature for a vapor canopy containing 40 feet of precipitable water.

This matter was left in a rather unsettled state until the recent work by Rush (1990). Rush used a much more rigorous analytical tool to investigate the canopy induced atmospheric temperature. Based on a detailed one-dimensional radiation balance analysis, Rush found that stable atmospheres would probably exist for vapor canopies containing up to 34 feet of precipitable water. However, surface temperatures increased dramatically with canopy thickness, although not nearly as high as estimated by Morton (1979). Rush speculated that the addition of clouds to the model would likely lower the surface temperature, but probably not enough to make feasible a canopy containing more than about 1.7 feet of precipitable water. These results were also discussed in Rush and Vardiman (1990).

The issue of the amount of precipitable water in the canopy is also of interest because of the effect of increased atmospheric pressure on living things. In today's 14.7 psi atmosphere the partial pressure of oxygen is about 3 psi. If the partial pressure deviated too far from this value, certain physiological effects can occur in humans, as well as in other animals and plants. As the earth surface pressure increases, the partial pressure of oxygen increases proportionally. Dillow (1981a) realized that more than 40 feet of precipitable water in the canopy (resulting in a surface pressure of 2.18 atmospheres) would likely be harmful to life, and constructed his model accordingly. Additional work by Smith (1980) indicated that atmospheric pressures above about 2 atmospheres were likely to be harmful. Thus, it is generally accepted that an upper bound for any hypothetical vapor canopy is about 40 feet of precipitable water.

Besides the surface temperature problem, Dillow (1981a) discussed the problem of energy load on the atmosphere during the canopy collapse. This energy load results primarily from the energy released by the canopy when it condenses. If it is assumed that all of this energy is transferred into the atmosphere, Dillow's preliminary calculations showed an atmospheric temperature increase on the order of thousands of degrees during the canopy collapse. Dillow attempted to sidestep this significant problem by hypothesizing that the canopy experienced a pre-collapse phase where energy was gradually released over a period of about a year, rather than just during the 40 days of the Flood. This was a rather weak hypothesis, and more work was clearly necessary. Rush's later work did not address this issue, although he acknowledged the problem and called for more work.

With Rush's more detailed pre-Flood canopy temperature profiles, a more indepth look at the collapsing canopy energy load is possible. This investigation attempts to improve upon Dillow's analysis (1981a) by adding the effects of ocean-atmosphere coupling.

A number of simplifying assumptions were made in the analysis, and are summarized below:

Assumptions

1. Radiative transfer of the energy generated during collapse is small when compared to the magnitude of other energy sources.

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2. All of the energy from the canopy collapse was released at a constant rate during the 40 days of the Flood.
3. The energy released by the canopy during collapse transfers directly to the atmosphere.
4. The atmosphere can be represented as a bulk system (i.e., a single node). This means that the atmospheric temperature at the ocean's surface is equal to the bulk atmospheric temperature because the atmosphere is well mixed by gross turbulent motion.
5. The ocean can be represented as a bulk system (i.e., a single node). This means that the ocean surface temperature is equal to the the bulk ocean temperature because the ocean is well mixed by gross turbulent motion.
6. The ocean is sufficiently massive and well mixed that its temperature change is negligible when energy is transferred from the atmosphere.
7. The canopy and atmosphere structure is given by the radiation balance results generated by Rush (1990).
8. Before the canopy collapses the ocean and atmosphere are in thermal equilibrium such that their respective surface temperatures are approximately equal.
9. Evaporation from the ocean is negligible.
10. The ocean surface area is equal to the earth surface area (i. e., the whole earth is covered with water).
11. Energy sources into the atmosphere due to other postulated cataclysmic geophysical phenomena associated with the Flood are negligible.
12. Physical laws were not violated during the canopy collapse.

Energy Balance

In general, the First Law of Thermodynamics can be stated:

$$\Delta U = \Delta Q - \Delta W$$

where work is defined positive when done by the system, and heat is positive when transferred into the system. The First Law describes how a system changes during an energy exchange process, but does not address the rate of change. However, it is usually the case that the equilibrium is established quickly in a system, so that the First Law can be used in rate equations. Thus, by applying the First Law, a steady state energy balance on the atmosphere during the canopy collapse can be expressed:

$$\left\{\frac{\Delta U_a}{\Delta t}\right\} = \left\{-\dot{Q}_0 + \dot{Q}_{c,1} + \dot{Q}_{c,s} + \frac{\Delta PE_c}{\Delta t}\right\} - \left\{\frac{\Delta PE_a}{\Delta t}\right\}$$

where:

$\dot{Q}_0$ = rate of sensible heat transfer from atmosphere to ocean
$\dot{Q}_{c,1}$ = rate of latent heat release from canopy
$\dot{Q}_{c,s}$ = rate of sensible heat release from canopy
PE_c = canopy potential energy
PE_a = atmosphere potential energy
U_a = atmosphere internal energy
t = time

The quantities in brackets represent the same quantities as expressed in the First Law statement. The change in the atmosphere's potential energy is another way to express the work done by the atmosphere. This will be demonstrated in a later section.

For clarity, the atmosphere to ocean energy transfer, $\dot{Q}_0$, is defined positive when flowing out of the system. To be consistent with the First Law definition of positive energy transferring *into* the system. a negative sign has been placed in front of $\dot{Q}_0$. Figure 1 shows the energy terms accounted for in the analysis. It is assumed that the atmosphere responds as a lumped mass to these energy inputs (Assumption #4). Rearranging the energy balance:

$$\dot{Q}_0 = \dot{Q}_{c,1} + \dot{Q}_{c,s} + \frac{\Delta PE_c}{\Delta t} - \frac{\Delta PE_a}{\Delta t} - \frac{\Delta U_a}{\Delta t} \quad (1)$$

Equation 1 states that in order to satisfy the First Law, the entire energy load on the atmosphere, including internal energy changes (everything on the right hand side of Equation 1) must be balanced by the energy transferring to the ocean. Each energy contribution will be discussed in turn.

Latent Energy

Energy is released when the vapor canopy condenses into liquid water. This energy due to the phase change into a liquid (i. e., latent energy) is relatively constant with temperature and is assumed to equal 1077 BTU / lbm. The released energy is,:

$$Q_{c,l} = m_c h_{lv} \quad (2)$$

where m_c is the mass of the canopy and h_{lv} is the liquid to vapor enthalpy difference (the latent energy). All symbols are defined in the nomenclature section. The canopy mass, m_c, can also be written

$$m_c = \rho_w A \Delta z_w \quad (3)$$

where ρ_w is the density of liquid water, A is the surface area of the earth (= 5.49 x 10^{15} ft^2), and Δz_w is the thickness of the canopy when in liquid form. By combining Equations 2 and 3 the latent energy can be expressed

$$Q_{c,l} = \rho_w A \Delta z_w h_{lv} \quad (4)$$

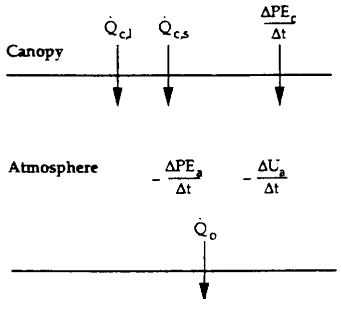

Figure 1. Schematic showing steady state energy balance on atmosphere.

Sensible Energy

Sensible energy is transferred between the condensed canopy waters to the atmosphere as it approaches the atmospheric bulk temperature. This energy is given by

$$Q_{c,s} = m_c c_{p,c}(T_c - T_a) \tag{5}$$

Combining Equation 3 with Equation 5 gives

$$Q_{c,s} = \rho_w A \Delta z_w c_{p,c}(T_c - T_a) \tag{6}$$

Dillow (1981a) approximated the temperature change, $T_c - T_a$ as being 75°C (135°F). However, this approximation is only reasonable if the final atmospheric temperature is near 75 °F. As the final atmospheric temperature increases, the sensible energy transfer decreases.

Potential Energy of Canopy

The potential energy of the canopy was postulated by Dillow (1981a) to transfer into the atmosphere through frictional heating from falling raindrops. This assumption is also retained. The canopy potential energy is

$$PE_c = m_c g z_{cg,c} \tag{7}$$

where g is the acceleration due to gravity (assumed to be constant with altitude), and $z_{cg,c}$ is the center of gravity of the canopy. Equation 7 can be rewritten by combining it with Equation 3

$$PE_c = \rho_w A \Delta z_w g z_{cg,c} \tag{8}$$

Dillow's (1981a) approximation for the canopy center of gravity was felt to be inaccurate. A better approximation was therefore developed. In general, the center of gravity can be expressed as

$$z_{cg,c} = \frac{\int_{z_b}^{z_t} \rho\, z\, dz}{\int_{z_b}^{z_t} \rho\, dz}$$

where *r* is the density of water vapor, z is altitude, z_b is the canopy bottom and z_t is the top. The bottom half of the fraction is merely the mass of the canopy divided by the earth surface area. The equation thus can be simplified to

$$z_{cg,c} = \frac{A}{m_c}\int_{z_b}^{z_t} \rho\, z\, dz$$

Using the ideal gas law this can also be written

$$z_{cg,c} = \frac{A}{m_c}\int_{z_b}^{z_t} \frac{P}{R_c T} z\, dz \tag{9}$$

For a linear temperature lapse rate, the temperature variation and pressure variation with altitude can be expressed as

$$T = T_b + \lambda(z - z_b) \text{ and}$$

$$P = P_b\left(1 + \frac{\lambda(z - z_b)}{T_b}\right)^{-g/\lambda R_c}$$

where λ is the temperature lapse rate. Substituting these relationships into Equation 9 gives the following integral

$$z_{cg,c} = C_4\int_{z_b}^{z_t} (C_1 + C_2 z)^{C_3} z\, dz \tag{10}$$

where:

$C_1 = 1 - \lambda z_b/T_b$
$C_2 = \lambda/T_b$
$C_3 = -(g/\lambda R_c + 1)$
$C_4 = P_b A/(R_c T_b m_c)$

From an integral table it can be shown that the solution to Equation 10 is

$$z_{cg,c} = C_4\frac{(C_1 + C_2 z)^{(C_3+1)}}{C_z^2}\left[\frac{C_1 + C_2 z}{C_3 + 2} - \frac{C_1}{C_3 + 1}\right]_{z_b}^{z_t} \tag{11}$$

Potential Energy of Atmosphere

Dillow (1981a) includes the effect of work performed by the atmosphere in an isothermal expansion. A better approximation is to account for atmospheric work as the change in potential energy of the atmosphere. The reasoning behind this assertion is given in the Appendix. The change in potential energy can be expressed

$$\Delta PE_a = m_a g \Delta z_{cg,a} \tag{12}$$

where m_a is the mass of the atmosphere (= 1.14 x 10^{19} lbm.). From Rush's results (1990), the atmospheric temperature profile before the canopy collapse is approximately constant. The center of gravity for such an isothermal atmosphere becomes:

$$z_{cg,a} = \frac{\int_{z_b}^{z_t} \rho\, z\, dz}{\int_{z_b}^{z_t} \rho\, dz} = \frac{\int_{z_b}^{z_t} P\, z\, dz}{\int_{z_b}^{z_t} P\, dz}$$

Hess (1959) shows that the pressure variation in an isothermal atmosphere is exponential:

$$P = P_b e^{(z-z_b)/H}$$

where $H = R_a T/g$ is the scale height of the atmosphere. Substituting in to the above equation gives

$$z_{cg,c} = \frac{\int_{z_b}^{z_t} P_b e^{(z-z_b)/H}\, z\, dz}{\int_{z_b}^{z_t} P_b e^{(z-z_b)/H}\, dz}$$

The solution to this integral is

$$z_{cg,a} = H\frac{e^{(-z_t/H)}\left(\frac{z_t}{H} + 1\right) - e^{(-z_b/H)}\left(\frac{z_b}{H} + 1\right)}{e^{(-z_t/H)} - e^{(-z_b/H)}} \tag{13}$$

For the atmospheric center of gravity at the end of the 40 days, the top of the atmosphere, z_t, goes to infinity and, remembering that $z_b = 0$, the center of gravity reduces to the atmospheric scale height:

$$z_{cg,a} = H$$

Incorporating this into Equation 12 gives:

$$\Delta PE_a = m_a g(R_a T_{a,f}/g - z_{cg,a,i}) \quad (14)$$

The additional subscripts i and f have been added to denote the initial and final canopy conditions.

Internal Energy of Atmosphere

Dillow's (1981a) assumption of an isothermal atmospheric expansion did not allow him to consider the internal energy change of the atmosphere. The internal energy of the atmosphere before and after the canopy collapse is easily determined with a relationship developed by Hess (1959). In summary, it can be shown that

$$U = \frac{c_v}{R} PE + \frac{c_v}{R} P_t A z_t \quad (15)$$

where P_t is the pressure at the top of the section of air and z_t is the altitude of the top. For today's atmosphere P_t is equal to zero, making the last term of Equation 15 zero. However, this term is not zero when a canopy is present. Adding together the internal and potential energy gives

$$PE_a + U_a = PE_a + \frac{c_{v,a}}{R_a} PE_a + \frac{c_{v,a}}{R_a} P_t A z_{a,t}$$

$$= \left(1 + \frac{c_{v,a}}{R_a}\right) PE_a + \frac{c_{v,a}}{R_a} P_t A z_{a,t}$$

$$= \frac{c_{p,a}}{R_a} PE_a + \frac{c_{v,a}}{R_a} P_t A z_{a,t} \quad (16)$$

The pressure on the right hand side is just the hydrostatic pressure of the canopy. Thus,

$$P_t A z_{a,t} = \rho_w g \Delta z_w A z_{a,t} \quad (17)$$

Combining Equations 2, 16 and 17 gives

$$PE_a + U_a = \frac{c_{p,a}}{R_a} m_a g z_{cg,a} + \frac{c_{v,a}}{R_a} \rho_w g \Delta z_w A z_{a,t} \quad (18)$$

Ocean/Atmosphere Energy Transfer

A well accepted method for modelling sensible energy transfer between the ocean and the atmosphere under varying stability conditions is the "bulk aerodynamic method." This method makes use of a simplified equation that correlated experimental data for ocean-atmosphere sensible energy transfer. The energy transfer is expressed by the following equation (with our definition that positive heat flow is from the atmosphere to the ocean):

$$\dot{Q}_0 = K \rho_a c_{p,a} V_{10} A (T_{10} - T_0) \quad (19)$$

where K is found by experiment. K varies depending on the investigator, although it is generally found to be near 0.001. Equation 19 is an approximate correlation that has been found to be valid over a wide range of conditions. Good agreement with this correlation has been demonstrated by Smith (1977) for a location in the North Sea experiencing gale force winds (50 mph). Kraus (1972) gives a value of 0.0013±.0003. Kraus also discusses data for hurricanes that indicates that the constant may be even higher under hurricane conditions. However, the data is sketchy and no attempt is made to use it here. Resch and Silva (1977) performed detailed water/wind tunnel experiments and determined a value of 0.003 for the constant. However, most actual ocean data point to a value much nearer 0.001. The data of Smith (1977) encompasses very broad wind velocity conditions, and therefore his value of 0.001 appears to be the best for the present analysis.

Rearranging Equation 19

$$\frac{\dot{Q}_0}{\rho_a c_{p,a} V_{10} A (T_{10} - T_0)} = K \approx 0.001$$

Heat transfer specialists will recognize the left side of this equation as the nondimensional Stanton number. The variables V_{10} and T_{10} are, respectively, the mean wind velocity and mean temperature at 10 meters height above the ocean surface. With the assumption of a single node atmosphere (Assumption #4), then V_{10} and T_{10} become V_a and T_a, the atmosphere's velocity and temperature. These quantities represent *averaged* values around the globe during canopy collapse.

Substituting these values into Equation 19 gives

$$\dot{Q}_0 = K \rho_a c_p V_a A (T_a - T_0) \quad (20)$$

where K = 0.001

It should be noted that application of Equation 19 in this analysis involves an extrapolation for which there are no data. That the correlation retains its accuracy for this analysis is only an assumption. However, as already mentioned, the data that do exist indicate a value for K somewhere near 0.001. Thus, using the correlation in this analysis appears reasonable.

Results

Combining Equations 4, 6, 8, 14 and 18, the right-hand side of Equation 1 can be written

$$E_{Total} = \rho_w A \Delta z_w \left(h_{lv} + c_{p,w}(T_c - T_{a,f}) + g z_{cg,c} + \frac{c_{v,a}}{R_a} g z_{a,t}\right)$$

$$+ \frac{c_{p,a}}{R_a} m_a g z_{cg,a,i} - m_a c_{p,a} T_{a,f} \quad (21)$$

Table I. Comparison of energy quantities during canopy collapse.

Precipitable Water (ft)	$Q_{c,l}$	$Q_{c,s}$	$PE_{c,i}$	$PE_{a,i}$	$PE_{a,f}$	ΔPE_a	$U_{a,i}$	$U_{a,f}$	ΔU_a	Total (BTU)
0.33	1.24E+20	5.16E+18	2.48E+19	4.04E+20	4.45E+20	4.11E+19	1.06E+21	1.12E+21	5.42E+19	5.82E+19
1.67	6.18E+20	2.58E+19	1.21E+20	4.73E+20	4.45E+20	-2.79E+19	1.40E+21	1.12E+21	-2.82E+20	1.08E+21
4.19	1.54E+21	6.45E+19	2.75E+20	4.62E+20	4.45E+20	-1.69E+19	1.59E+21	1.12E+21	-4.74E+20	2.83E+21
33.93	1.25E+22	5.23E+20	1.44E+21	2.14E+20	4.45E+20	2.31E+20	1.74E+21	1.12E+21	-6.20E+20	1.49E+22

Note: Final atmosphere assumed to be at 110°F and ocean assumed to be at 60°F.

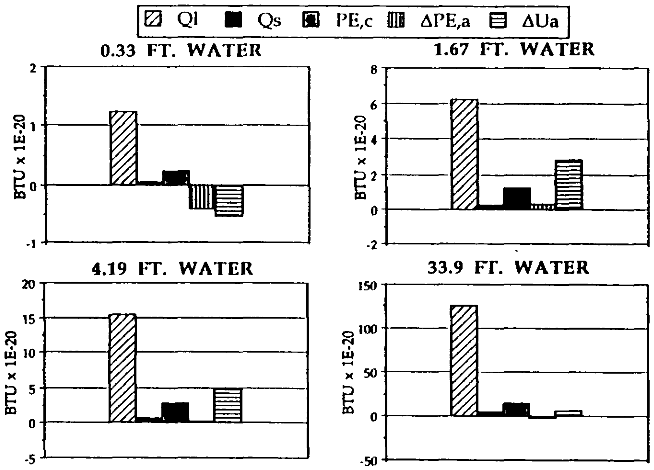

Figure 2. Relative energy magnitudes during canopy collapse for the four canopies analyzed by Rush (1990). Final atmosphere assumed to be at 110°F and ocean assumed to be at 60°F.

With an assumption of the mean canopy temperature after condensing, everything on the right-hand side of Equation 21 is known except for the terms containing $T_{a,f}$. For additional simplicity Equation 21 can be written

$$E_{Total} = E'_{Total} - (m_a c_{p,a} + \rho_w A \Delta z_w c_{p,w}) T_{a,f} \quad (22)$$

where E'_{Total} is everything on the right side of Equation 21 not containing a $T_{a,f}$ term.

Although results from Rush (1990) and Rush and Vardiman (1990) indicate that the atmospheric surface temperature before canopy collapse increases significantly with canopy thickness, it is assumed for the purposes of this study that the pre-collapse earth surface temperature was hospitable to life. It should be pointed out that this is somewhat inconsistent with Assumption #7. Rush's results are used as initial conditions only for the purpose of determining canopy potential energy and the pre-collapse atmosphere potential and internal energy.

The energy load on the atmosphere during canopy collapse results from the canopy/atmosphere initial conditions described by Rush (1990). Table I shows the magnitude of the terms in Equation 21. Since the final atmospheric potential and internal energy and the average sensible energy transfer from the canopy are not known yet because of the yet to be determined final atmospheric temperature ($T_{a,f}$), it is assumed for discussion purposes that $T_{a,f}$ is 110°F.

It is apparent from Table I that the latent energy contribution is generally larger than the other energy sources, especially above 4 feet of water. This is the same conclusion reached by Dillow (1981a). Figure 2 shows the relative contributions to the energy load for the four canopies that Rush analyzed. The total energy load as a function of canopy precipitable water is shown plotted in Figure 3.

It is interesting to note that the change in atmospheric potential energy shown in Table I is positive for the 0.33 and 33.93 foot canopies and negative for the 1.67 and 4.19 foot canopies. This results from competing effects on the change in atmospheric center of gravity. From Equation 12 it can be seen that an increase in the center of gravity (i.e., the center of gravity moves *upward)* corresponds to a net increase in potential energy. And conversely, a decrease in center of gravity corresponds to a decrease in potential energy. Further, an increase in potential energy corresponds to work being performed *by* the atmosphere (an atmospheric expansion) and a reduction in total energy load on the atmosphere (Equation 1). This atmospheric expansion occurs for the 0.33 and 33.93 ft. canopies. On the other hand, the center of gravity actually decreased for the 1.67 and 4.19 ft. canopies, resulting in work being performed on the atmosphere (an atmospheric contraction). This condition adds to the total energy load.

It is easy to visualize how the atmosphere would expand with the collapse of the canopy, because of the removal of the canopy weight. However, the canopy itself also induces a particular temperature distribution within the atmosphere, which also affects the mass distribution. The nature (and magnitude) of this distribution influences the location of the atmospheric center of gravity, just as the canopy weight does. The result is that the canopy weight, which compresses the atmosphere, plays a stronger role for the 0.33 and 33.93 ft. canopies, while the initial canopy induced temperature and mass distribution plays a stronger role for the 1.67 and 4.19 ft. canopies. This can be seen from Table I.

A similar line of reasoning holds for the atmospheric internal energy change. The relationship between the atmospheric potential energy and internal energy is given by Equation 15. In (15) it is seen that the atmospheric internal energy depends on the canopy base pressure. This dependence is what leads to the sign difference in Table I between potential and internal energy change for the 33.93 ft. canopy.

In order to satisfy the First Law, the energy transfer to the ocean must equal the total energy load shown on the far right in Table 1. Using (20) and (22), Equation 1 can be simplified to

$$K \rho_a c_{p,a} V_a A (T_a - T_0) = \frac{\Delta E'_{Total}}{\Delta t} - \frac{(m_a c_{p,a} + \rho_w A \Delta z_w c_{p,w})}{\Delta t} T_a \quad (23)$$

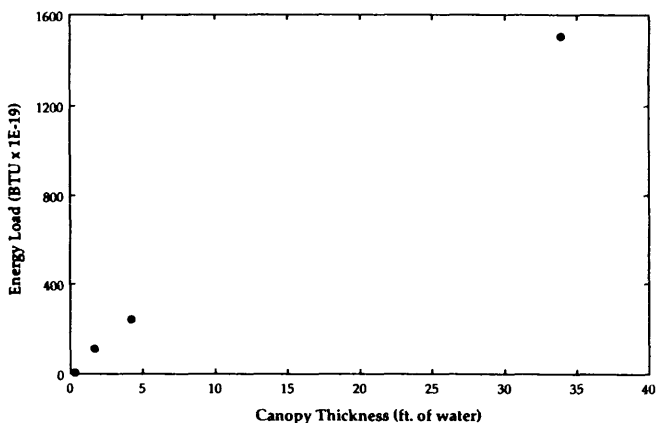

Figure 3. Energy load on the atmosphere vs. amount of precipitable water in the canopy (final atmosphere assumed to be at 110°F).

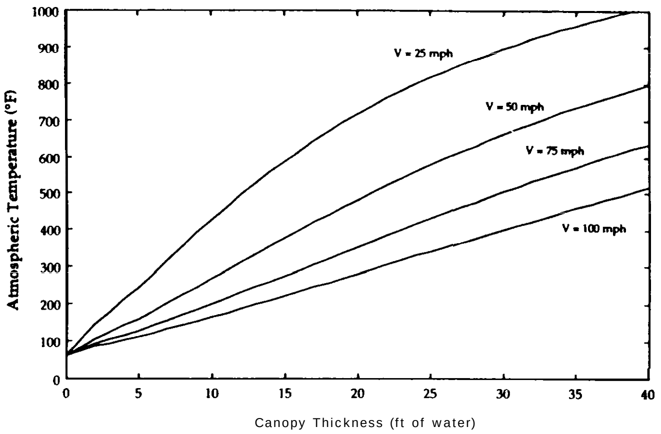

Figure 4. Atmospheric temperature vs. amount of precipitable water in the canopy for various average wind speeds around the earth (T_0 = 60°F).

where the f subscript has been dropped and it is to be understood that we are calculating T_a at the final conditions at the end of the 40 days. The average ocean temperature is not in fact a known term, but a reasonable approximation can be made in light of Assumption #8.

The rates of energy release, $\Delta E'_{Total} / \Delta t$, are constant for a given canopy thickness and assumed to be the average value over 40 days (Assumption #2). Since the specific heat of air is fairly constant with temperature, and the ocean temperature is assumed known, the only other variable in Equation 23 besides V_a is r_a, the density of air at the base of the atmosphere (i.e., at the ocean surface). The density will be affected by the change in air temperature and the change in air pressure at the surface. However, at the end of the 40 days, the canopy weight will have been removed and the pressure will be one atmosphere. Thus, using the ideal gas law with the surface pressure equal to a constant 1 atm., (23) can be written

$$\frac{KP_a c_{p,a} V_a A}{R_a T_a}(T_a - T_0) = \frac{\Delta E'_{Total}}{\Delta t} - \frac{(m_a c_{p,a} + \rho_w A \Delta z_w c_{p,w})}{\Delta t} T_a$$

or

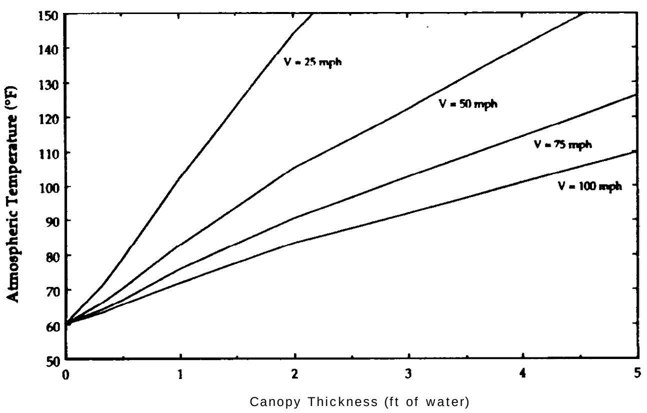

Figure 5. Enlargement of Figure 4 showing atmospheric temperature vs. canopy precipitable water thickness (T_0 = 60°F).

$$\frac{C_1 V_a}{T_a}(T_a - C_2) = C_3 - C_4 T_a$$

where:

$C_1 = KP_a c_{p,a} A / R_a$
$C_2 = T_0$
$C_3 = \Delta E'_{Total} / \Delta t$
$C_4 = (m_a c_{p,a} + r_w A \Delta z_w c_{p,w}) / \Delta t$

After some algebraic manipulation, this reduces to a quadratic equation of the form:

$$T_a^2 + \frac{C_1 V_a - C_3}{C_4} T_a + \frac{-C_1 C_2 V_a}{C_4} = 0$$

This can be solved using the quadratic formula yielding:

$$T_a = -\frac{C_1 V_a - C_3}{2C_4} + \sqrt{\left(\frac{C_1 V_a - C_3}{2C_4}\right)^2 + \frac{C_1 C_2 V_a}{C_4}} \quad (24)$$

Equation 24 relates the atmospheric driving temperature for various wind speeds that is required to transfer the energy load summarized in Table I. Equation

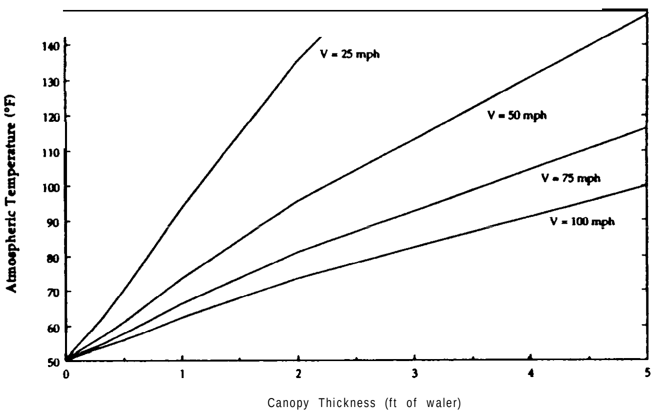

Figure 6. Atmospheric temperature vs. canopy precipitable water thickness for various average wind speeds around the earth (T_0 = 50°F).

24 is plotted parametrically in Figure 4 for an average ocean temperature of 60°F and mean canopy temperature after condensation of 212°F. The scale of Figure 4 is expanded in Figure 5 for clarity. It is apparent from Figures 4 and 5 that the wind velocity has a significant effect upon energy transfer from the atmosphere to the ocean, with higher wind velocities resulting in greater energy transfer, as expected.

A 60°F ocean temperature appears reasonable if Assumption #8 is true. For completeness, results are shown in Figure 6 for an average ocean temperature of 50°F and in Figure 7 for an average ocean temperature of 70°F. (Today's average ocean temperature is near 40°F.) The primary effect of varying the ocean temperature is to shift the scale of Figure 5-7 up and down.

Although the atmospheric temperature in Equation 24 technically represents the final temperature at the end of the 40 days, it is a simple matter to show that with a constant energy input the temperature would

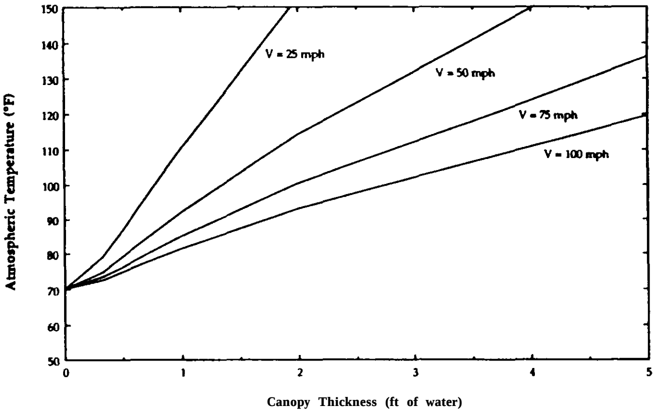

Figure 7. Atmospheric temperature vs. canopy precipitable water thickness for various average wind speeds around the earth (T_0= 70°F).

remain relatively constant at T_a for the entire 40 days. After the 40 days the rains ceased and the atmosphere would have begun to establish a new equilibrium temperature profile, probably similar to the present one.

Since the atmospheric temperature remains fairly constant over the 40 days, a T_a of 110°F is a reasonable upper boundary that sustains life on the ark. This would allow a pre-collapse average earth temperature of 60°F to increase 50°F. In addition, it is difficult to conceive of an average wind speed around the globe greater than 50 mph, although this may be possible. Using these two constraints, inspection of Figure 5 indicates that a canopy thickness of about 2 ft. of precipitable water is the maximum allowable that permits life to survive.

It is interesting to note that this is similar to the conclusion made by Rush (1990) based on radiation balance considerations. These two independent indicators (Rush's results and the results presented here) give strong evidence that the vapor canopy as conceived by Dillow probably contained much less than 40 feet of precipitable water. It should be noted, however, that the atmosphere/vapor canopy structure analyzed by Dillow and Rush is only one possible structure. Perhaps another structure can be conceived which holds 40 feet of precipitable water but is not subject to these constraints.

Ramifications of a Thin Canopy

If the upper limit for precipitable water in a hypothetical canopy is really 2 ft., is the Vapor Canopy Theory then disproved? This question deserves careful consideration by creationists. If rainfall is to be maintained around the clock for 40 straight days, then 2 ft. of water in the canopy could supply, on the average, about 0.5 inches of water a day for 40 days. Although 0.5 inches a day of rainfall is not torrential, it is nevertheless not insignificant. Dillow (1981a) assumed that the downfall must have been very heavy, but is this really so? And did the rainfall have to cover the entire earth? Could it have been concentrated near the equatorial belt, with lighter rains in the more extreme latitudes? If so, then the equatorial regions could have received 1-2 inches a day, which my experience tells me is quite a bit of rain. The preliminary conclusion, therefore, is that a thin canopy (with about 2 ft. of water) may have been adequate to supply the required rainfall for 40 days and nights.

Discussion of Assumptions

Assumption 1 does not rule out radiative energy transfer altogether, only net radiative transfer. The radiative energy from the sun was in balance with reradiated energy from the earth before the canopy collapsed, so that any additional radiated energy effects would be effectively superimposed on the initial radiation balance. Since radiation energy transfer is not very efficient at the low temperatures of interest, and the magnitudes of the released energy are comparatively large, the effects of radiation energy transfer can be neglected. It should be noted, however, that at the higher temperatures shown in Figure 4 (~1000°F) that radiative effects would become significant. In addition, if the atmosphere increased above 212°F the rain water would boil and evaporate. For these two reasons the model becomes less accurate as the temperature increases to large values. However, the constraints previously obtained at lower temperatures would still remain valid.

Along the same line, a question arises as to whether the processes involved in a collapsing canopy could change the earth radiation balance sufficiently to affect the energy balance developed in this investigation. Probably not. The mean solar energy rate to the earth is roughly 1.5 x 10^{17} BTU/hr, or 1.4 x 10^{20} BTU if integrated over 40 days. This is the total energy from the sun to the earth. However, any possible change to the planetary radiation balance would have to be only a fraction of this total. Keeping this in mind, a comparison with Table I shows this quantity to be about 10% of the 1.67 ft. canopy. Thus the *total* energy from the sun is much smaller than the collapsing canopy energy load when the canopy is 1.67 ft. thick. Since only a fraction of this total energy could be involved in a net radiation balance change, this contribution can be ignored for the majority of cases we have considered. Since the total solar energy is about twice that of the energy load for the 0.33 ft. canopy, there could be some effect there. However, a detailed analysis would likely show the planetary radiation balance changes to be insignificant in this case as well. In any case, the conclusion about the 2 ft. canopy limit remains intact.

It seems reasonable that a relatively constant rainfall occurred during the Flood, so the assumption of constant energy transfer rates (Assumption #2) also appears reasonable. That the entire canopy condensation process occurred during the 40 days of the Flood is more difficult to ascertain. This uncertainty, in fact, is what Dillow (1981a) used to sidestep the whole energy load issue. Before the Flood rains began, the canopy would have had to already begin to condense so that waters were available to supply the rain. However, it is doubtful that significant condensation could have occurred without prematurely destabilizing the canopy/atmosphere system. Therefore, the condensation process would probably have taken much closer to 40 days than the 500+ days assumed by Dillow. Thus, some relief on the energy load may be possible, but not enough to significantly change the results of this analysis.

Assumption 3 is more difficult to justify. It is not clear how much energy from canopy condensation would heat the vapor in the canopy (and stop the condensation process), and how much would transfer into the atmosphere. A detailed look at the dominating mode of heat transfer in the canopy may be necessary to answer this question.

Under Assumption 4 a single node atmosphere is assumed. It seems reasonable that large atmospheric disturbances during the canopy collapse and the Flood would result in strong mixing of the atmosphere. It is not clear how uniform the resulting atmospheric temperature profile would be. It is clear, though, that a single node assumption permits us to obtain reasonable results. The next step may be to assume a two node model of the atmosphere, which could change the results of this analysis, although probably by less than a factor of three. A two node model would allow an atmospheric temperature gradient that was hospitable at the ocean surface, but much higher at the top of the atmosphere.

Assumptions 5 and 6 appear very reasonable in view of the ocean's very large thermal capacitance and hence ability to absorb large amounts of energy. Although prior to the Flood the ocean would probably have been stratified, a mixing mechanism as would be expected during the Flood would serve to keep the ocean fairly well uniform in temperature. (Editor's note: See Smith and Hagberg, 1984, for possible reasons for stratified Flood waters.)

Assumption 7 is somewhat inconsistent with assumption 8. The whole basis for this analysis is that hospitable earth surface temperatures existed before the Flood. However, Rush's results (1990) showed otherwise. What is essentially assumed, therefore, is that there was a rapid change from Rush's high atmospheric temperatures to hospitable surface temperatures in the lower atmosphere.

Assumption 9 appears reasonable in light of the fact that evaporation would add energy to the atmosphere by mass transfer, but would remove a roughly equivalent amount of energy from the atmosphere in order to drive the evaporation. The reason for this is that energy must be taken from the atmosphere to evaporate the water from the ocean surface, thus resulting in a cooling of the atmosphere. In addition, evaporation would be self-limiting, because the atmosphere would approach a saturated condition and evaporation would gradually decrease.

Another consideration is whether the atmosphere will become saturated due to the rain falling through it. If this happened, the saturation pressure of the atmosphere could exceed that of the ocean surface because of the higher temperature in the atmosphere. This then could allow additional energy transfer through mass transfer of vapor from the atmosphere to the ocean. However, calculations show that the amount of vapor needed to exceed the ocean partial pressure of water vapor would be on the same order as the rainfall itself. Thus, it is concluded that evaporation from the ocean or condensation at the ocean surface are not significant effects.

Since most of the earth surface is covered by water, and this was probably the case before the Flood as well, the possible error introduced by Assumption 10 is small.

Since there is no way to characterize "the other energy sources" in Assumption 11, assuming that other sources are negligible is the only practical approach at this point. It should be noted, however, that many creationist Flood scenarios involve considerable amounts of energy transfer into the atmosphere, thus aggravating the problems outlined in this investigation.

A final word is in order concerning Assumption 12. It seems to the author that any creationist models that require violation of physical laws, especially for extended time periods, should be viewed critically. An investigation by Johnson (1986) took this approach. It is true that the Creator can override the "laws" of nature as we know them, but it is also true that He rarely chooses to do so. A look at the Biblical account of the Flood shows the Creator working His purposes through natural means. For example, the Creator could have removed all the men and animals He planned to destroy in the Flood by merely speaking a word. But instead, He chose to work through the natural elements by using a Flood to destroy the earth, and using a wooden ark, built by Noah, to preserve Noah's family and the animals. It would seem inconsistent with the context of the account (although certainly not impossible) for the Creator to have employed large scale miracles here and there to solve energy balance problems that arose.

Perhaps an even greater reason against using miracles in creationist models is that aside from Scriptural evidence, there is no way to determine whether the said miracles actually occurred. So what good are the models? If, on the other hand, there is clear Scriptural evidence for a miraculous process (e.g., the gathering of the animals to the ark), then this can be more confidently incorporated into creationist models.

Conclusions

A more detailed model of the thermodynamics occurring during the collapse of the vapor canopy was developed which included the effect of ocean-atmosphere coupling. Results indicate that the canopy structure as conceived by Dillow could not have contained much more than 2 ft. of precipitable water. Although additional work may modify this conclusion, it appears unlikely that the results could be changed significantly. Vapor canopy theorists should incorporate this constraint into their thinking, or develop a new model of the canopy which is not subject to this constraint.

Recommendations

1. A more detailed model of the atmosphere may alleviate somewhat the results obtained from the single node model. Specifically, a two node model of the atmosphere would allow a temperature gradient to exist, which may lower surface temperatures, thus allowing more water in the canopy. However, it appears unlikely that this could increase the allowable water in the canopy by more than a factor of three.
2. An analysis of the heat transfer mechanisms within the canopy would show whether the energy released would transfer into the atmosphere or be stored in the canopy itself.
3. A more rigorous analysis of the pre-Flood period in which the canopy began to collapse may place

an upper bound on the allowable time in which to transfer the energy load.

4. More thinking about other possible canopy structures should be done. The main obstacle to confront is the latent energy release, so effort should be directed at minimizing this contribution.

Acknowledgements

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Nomenclature

A = surface area of earth
c_p = specific heat at constant pressure
c_v = specific heat at constant volume
E = energy
g = gravitational acceleration
h_{lv} = liquid/vapor enthalpy difference (heat of vaporization)
H = atmosphere scale height (RT/g)
m = mass
P = pressure
PE = potential energy
$\dot{Q}_0$ = rate of heat transfer from atmosphere to ocean
$Q_{c,l}$ = rate of latent heat release from canopy
$Q_{c,s}$ = rate of sensible heat release from canopy
R = gas constant
T = temperature
t = time
U = internal energy
V = velocity
W = work
z = altitude
z_{cg} = center of gravity

Greek symbols

λ = lapse rate ($\Delta T/\Delta z$)
r = density

Subscripts

a = atmosphere
b = base or bottom
c = canopy
cg = center of gravity
f = final conditions
i = initial conditions
l = latent
lv = liquid to vapor
o = ocean
s = sensible
t = top
w = water (liquid)

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Appendix

The change in atmosphere potential energy is expressed in Equation 12. As shown in the equation, the change is calculated by determining the change in the atmosphere's center of gravity. Calculating work by assuming an idealized expansion process (such as isothermal) is not accurate because the atmosphere is not undergoing an idealized thermodynamic process. In reality, great quantities of heat are being transferred into the atmosphere while it is expanding/contracting. An easier way to account for the work performed on or by the atmosphere is to determine the change in potential energy of the atmosphere. Once the potential energy is determined, the internal energy is easily found from Equation 18. This is possible because we know (approximately) the initial and final conditions of the atmosphere.

The equivalence of potential energy change and work performed can be best understood by employing an analogy. Consider an insulated gas-filled con-

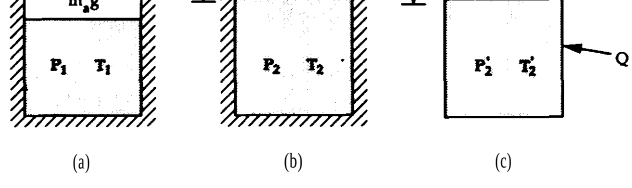

Figure 8. Illustration of work/potential energy analogy.

tainer that supports two weights (Figure 8a). The gas in the container represents the bouyant effect of the atmosphere, and the two weights represent the weights of the canopy and the atmosphere. When the canopy weight, $m_c g$, is removed, the gas will push the atmosphere, $m_a g$, upwards a distance Δz (Figure 8b). This distance is the change in potential energy of the atmosphere, and it is equal to the work performed by the gas.

The analogy can be extended further by considering an active heat source element transferring energy into the gas as it expands (Figure 8c). This energy transfer during expansion/contraction further changes the state of the gas and, hence, changes the height of the atmosphere, thus affecting the amount of work performed. With these considerations in view, it is apparent that the total work performed by the gas (and, by analogy, the atmosphere) is equal to the change in potential energy of the atmosphere. The internal energy of the atmosphere also changes, and can be calculated with a knowledge of the initial and final conditions of the atmosphere.

QUOTE

This find of fossil caddis pupae is quite remarkable, considering this stage lasts only about two weeks in the trichopteran life cycle, and how fragile the animals are at that precise moment when the most intensive histolysis of the larval tissues takes place. When natural mortality of the pupa occurs, the dead tissues decay rapidly (in a few days) and only an empty, floppy pupal cuticle remains in the case. Evidently, the caddisflies were encrusted very rapidly, just before emergence, at the precise moment when the tissues became firm; but the tissues themselves are not preserved and the two specimens are natural moulds of external surfaces of the pupae.

Hugueney, M., H. Tachet, and F. Escuillie. 1990. Caddisfly pupae from the Miocene indusial limestone of Saint-Gerand-Le-Puy, France. *Paleontology* 33:498