in question may very well have a tendency to overtax its own physical resources.

There is another point. Many reptiles and amphibians live in muddy places, or half in water and half out. It may be that in such a situation, to glide along on the mud, in a way which is half walking and half swimming, is the most efficient way of moving about. And for such a way of moving, the outstretched limbs seem ideal.

So it is still true that the best possible boned limb is the pentadactyl design. Variations within that plan, including various stances, are very well designed for the animals which possess them, and for their particular niches.

Incidentally, reconstructions of the oldest crocodiles known, from the remains, seem to show that they had what some would call a better stance, i.e. a more mammal-like one, than do modern crocodiles. (Although the stance was not by any means that of a mammal.)

This may serve as another example of variation on a theme. Also, the following consideration arises. If a mammal-like stance were truly better, crocodiles must have degenerated over their generations, becoming less fit, contrary to Darwinian theory. No, the stance of modern reptiles and amphibians is well suited to their mode of life, and to the niche which they occupy. As for the ancient ones, I suggest that we know too little in detail about the niche which they occupied to say dogmatically what stance would have been best for them.

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THE VERTICAL TEMPERATURE STRUCTURE OF THE PRE-FLOOD VAPOR CANOPY†

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In this article is described continued work on the possibility that a vapor canopy formerly surrounded the Earth, and on the conditions which would prevail in and under such a canopy. It is believed that it is shown that a canopy could indeed have existed; but more work is still needed on some aspects of the matter.

The early chapters of Genesis as well as other ancient writing testify to an ancient belief that the earth at one time was surrounded by a "water heaven."[1] It was this water heaven that supplied the source of the 40-day rainfall described in the book of Genesis. However, the physics of such a canopy presents rather immense problems for numerical modeling. While there have been some crude initial studies of this problem,[2] there have as yet been no attempts to model such a canopy in more rigorous ways for study by numerical simulation.

This paper presents a one-dimensional radiation transport model of a water vapor and air atmosphere with some preliminary results. The atmosphere under the canopy is assumed to be chemically the same as the present atmosphere. The canopy itself begins at an altitude of about 10 km and consists of 88% water vapor and 12% air. A Newton-Raphson iteration was employed for solving a coupled set of nonlinear radiation flux equations for the steady state vertical temperature structure.[3] Fifty spectral intervals are employed using published values for the mass absorption coefficients and other data for the absorbers H_2, CO_2, and O_3. The convective adjustment was not included, although this is a relatively simple addition;[4] neither was Rayleigh or Mie scatter modeled in a rigorous fashion.[5] A more serious limitation however, is the fact that lateral advective heat flow involved with global circulation was not included in the one-dimensional treatment and that oceanic coupling was only crudely approximated.

We assume a flood rainfall rate of 0.5 inches per hour. This implies that the ancient canopy contained 12.19 m of water (0.5 inches/hr × 24 hr × 40 days = 40 ft = 12.19 m). Thus, the surface pressure was 2.18 Atm.

The Canopy Temperature Profile

We first define a vertical coordinate system for the model calculations. In our model we divided the canopy atmosphere into 20 layers (Fig. 1).

In Fig. 1, P refers to the pressure, which for the canopy atmosphere varies from 2.18 atmospheres at the earth's surface to 0.05 (we defined 0.05 Atm as the "top" of the canopy); u refers to optical path or the product of the density and altitude; and z refers to altitude.

The solar input is denoted by Q. Here S_i refers to the Planck emission from the surface of the sun in spectral interval i; θ is the zenith angle; and f is the fraction of daytime. Q_i is then the solar flux at the top of the atmosphere in spectral interval i. D, the solar distance factor, is explained below.

The chemical composition of each layer is given in Table 1.

We wish to calculate the set of layer temperatures that will cause the sum of the upward and downward radiation fluxes at each boundary to vanish. This is to be understood as the radiative equilibrium profile of the vapor canopy. The basic equations for the fluxes at each boundary are given by:[6]

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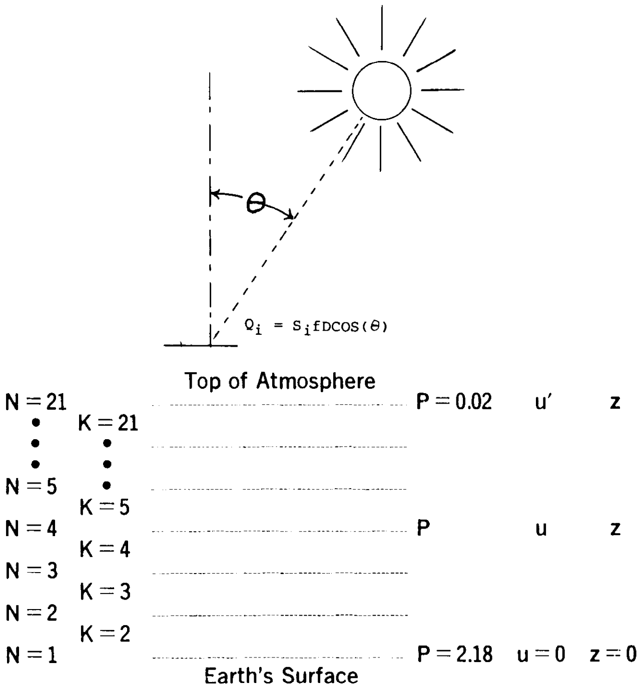

Figure 1 Vertical coordinate system for the vapor canopy computer model. (K = Layer no.; N = Node no.)

$$\left.\begin{aligned} F\uparrow(u) &= \sum_{i=1}^{NI} F_i\uparrow(u) \\ F\uparrow(u) &= \sum_{i=1}^{NI} \pi Bi(Ts)TRi(u) + \\ &\int_0^u \pi Bi[T(u')TRi(u-u')du' \end{aligned}\right\} \quad (1)$$

and

$$\left.\begin{aligned} F\downarrow(u) &= -\sum_{i=1}^{NI} Fi\downarrow(u) \\ &= -\sum_{i=1}^{NI} \int_{u_T}^{u} \pi Bi[T(u')TRi(u'-u)du \\ &+ QiTRi(u_T - u) \end{aligned}\right\} \quad (2)$$

where F represents flux, B the Planck emission, T absolute temperature, TR optical transmission, u optical path, n spectral interval and NI the total number of spectral intervals. Also, u_T denotes the optical path at the top of the atmosphere.

Equations (1) and (2) may be written in discrete form for numerical solution. As an illustration of the method (2) can be expressed in the following way:[7]

$$F\downarrow(N) = \sum_{i=1}^{NI}\left\{\sum_{K=N}^{NN} \pi Bi[T(K)][TRi(N,K) - TRi(N,K-1) + QiTRi(N,NN)\right\} \quad (3)$$

where K and N are the node indices; and NN is the index of the top node. The Planck function is evaluated at temperature $T(K)$ which is an average temperature for layer K. $TRi(N,K)$ is the optical transmission between nodes N and K in spectral interval i.

Table 1. Volume fractions for each layer of canopy atmosphere.

Layer	H_2O	CO_2	O_3	AR	O_2	N_2
1	0.0002	0.0003	0.00	0.0093	0.1950	0.7952
2	0.0002	0.0003	0.00	0.0093	0.1950	0.7952
3	0.0002	0.0003	0.00	0.0093	0.1950	0.7952
4	0.0002	0.0003	0.00	0.0093	0.1950	0.7952
5	0.0002	0.0003	0.00	0.0093	0.1950	0.7952
6	0.0007	0.0003	0.00	0.0093	0.1950	0.7947
7	0.88	0.003	0.00	0.0093	0.05	0.0577
8	0.88	0.003	0.00	0.0093	0.05	0.0577
9	0.88	0.003	0.00	0.00	0.05	0.067
10	0.88	0.003	0.00	0.00	0.05	0.067
11	0.88	0.003	0.00	0.00	0.05	0.067
12	0.88	0.003	0.00	0.00	0.05	0.067
13	0.88	0.003	0.00	0.00	0.05	0.067
14	0.88	0.003	0.00	0.00	0.05	0.067
15	0.75	0.03	0.00	0.00	0.05	0.170
16	0.75	0.03	0.00	0.00	0.05	0.170
17	0.75	0.03	0.00	0.00	0.05	0.170
18	0.0009	0.00	0.01	0.00	0.19	0.7991
19	0.0009	0.00	0.01	0.00	0.19	0.7991
20	0.0009	0.00	0.01	0.00	0.19	0.7991

In order to solve (1) and (2), several things must be known. The most crucial item is the form of the transmission function, TR. In our model of the canopy we used four different formulations for the transmission depending on the spectral interval and the absorbing gas, H_2O, CO_2, or O_3. Table 2 describes the spectral intervals we employed and the transmission function used. The transmission functions are described below, where u is the corrected optical path.

$$(1)\ TR1 = \exp[-xu(1 + xu/y)^{-1/2}] \quad (4)$$

Here $x = S/\delta$ and $y = \pi\alpha/\delta$; where δ is the line spacing, S is the line intensity, and α is the half width of the line. The values of the parameters x and y were taken from the tabulation of Rogers and Walshaw (1966)[8] as presented in Liou.[9] They are listed in Table 3. For discussion of the actual meaning of these parameters the reader is referred to Liou.[10]

$$(2)\ TR2 = \exp(-ku) \quad (5)$$

Here k is a mean mass absorption coefficient, $m^2\ kg^{-1}$, for the spectral interval i. This form of the transmission function was used in spectral intervals not only where customary, but also in intervals where absorption is neglected. For example, in modeling the present atmosphere, absorption in the visible bands (.85 to .4 microns) is usually ignored. In an atmosphere as dense as the canopy, however, it is reasonable to include some absorption. We used values of k in these bands ranging from 10^{-3} to 10^{-5}, $m^2\ kg^{-1}$.

$$(3)\ TR3 = \exp(-\Sigma Wi/\Delta v) \quad (6)$$

where ΣW_i is the sum of the equivalent widths of all the lines in the spectral interval; and Δv is the width of the spectral interval, m^{-1}. For full explanation the

Table 2. Spectral intervals and transmission functions for each absorbing gas.

Spectral Interval	Wavelength (microns)	Transmission Function H_2O	CO_2	O_3	Cloud Albedo
1	****-250.00	1	0	0	0.01
2	250.00-62.50	1	0	0	0.01
3	62.50-35.71	1	0	0	0.03
4	35.71-26.32	1	0	0	0.03
5	26.32-20.00	1	0	0	0.03
6	20.00-16.67	1	0	0	0.03
7	16.67-13.89	1	1	0	0.03
8	13.89-12.50	1	0	0	0.05
9	12.50-11.11	1	0	0	0.05
10	11.11-10.00	2	0	0	0.05
11	10.00- 9.94	2	0	1	0.05
12	9.94- 9.87	2	0	1	0.05
13	9.87- 9.81	2	0	1	0.05
14	9.81- 9.75	2	0	1	0.05
15	9.75- 9.69	2	0	1	0.05
16	9.69- 9.62	2	0	1	0.05
17	9.62- 9.56	2	0	1	0.05
18	9.56- 9.51	2	0	1	0.05
19	9.51- 9.45	2	0	1	0.05
20	9.45- 9.39	2	0	1	0.05
21	9.39- 8.33	2	0	0	0.05
22	8.33- 7.41	1	0	0	0.05
23	7.41- 6.90	1	0	0	0.05
24	6.90- 6.45	1	0	0	0.04
25	6.45- 6.06	1	0	0	0.02
26	6.06- 5.71	1	0	0	0.02
27	5.71- 5.41	1	0	0	0.32
28	5.41- 5.13	1	0	0	0.01
29	5.13- 4.88	1	0	0	0.01
30	4.88- 4.55	1	0	0	0.01
31	4.55- 4.04	2	3	0	0.05
32	4.04- 3.57	2	0	0	0.10
33	3.57- 2.94	3	0	0	0.15
34	2.94- 2.38	3	0	0	0.20
35	2.38- 2.22	2	0	0	0.20
36	2.22- 2.04	2	3	0	0.18
37	2.04- 1.72	3	3	0	0.15
38	1.72- 1.52	2	4	0	0.25
39	1.52- 1.30	3	4	0	0.35
40	1.30- 1.22	2	0	0	0.30
41	1.22- 1.08	3	0	0	0.30
42	1.08- 0.98	2	0	0	0.30
43	0.98- 0.89	3	0	0	0.30
44	0.89- 0.75	2	0	0	0.30
45	0.75- 0.68	2	0	0	0.45
46	0.68- 0.60	2	0	2	0.45
47	0.60- 0.50	2	0	0	0.45
48	0.50- 0.42	2	0	2	0.45
49	0.42- 0.30	2	0	2	0.45
50	0.30- 0.21	2	0	2	0.45

interested reader is referred to Houghton.[11] The equation for ΣW_i is given by:

$$\Sigma W_i = \frac{2R^2}{S}\left[\left(1+\frac{uS^2}{R^2}\right)^{1/2} - 1\right] \qquad (7)$$

The values of R^2 and S are tabulated in Table 3. Houghton[12] gives values of these parameters calculated from quantum mechanics for temperatures of 220, 260, and 300 °K. In some spectral intervals they are highly temperature dependent. To include this effect, we fitted the mean value of the parameter to an exponential curve using the following formulation:

$$R_T = R_{300}(T/300)^n \qquad (8)$$

where R is the parameter, T is temperature, and n is an exponent. It was found that in the range of 220 to 300 °K, the values of n reported in Table 3 yielded less than 2% error.

$$(4)\ TR4 = cu^{0.5}(P)^k \qquad (9)$$

Here P is the total pressure, mm of Hg; and c and k are physical constants derived from the experiments of Howard *et al.* (1956) and reported in Liou.[13] These data are summarized in Table 5.

Table 3. Random model band parameters in the infrared region for transmission function TR1.

Spectral Interval	Wavelength (microns)	Transmission Parameters (X in $m^2\ kg^{-1}$) X	Y
		H_2O	
1	****-250.00	57.90	0.093
2	250.00-62.50	721.03	0.182
3	62.50-35.71	602.48	0.094
4	35.71-26.32	161.41	0.081
5	26.32-20.00	13.90	0.080
6	20.00-16.67	2.164	0.068
7	16.67-13.89	0.292	0.060
		CO_2	
7	16.67-13.89	71.87	0.448
		H_2O	
8	13.89-12.50	0.039	0.059
9	12.50-11.11	0.007	0.067
		O_3	
11	10.00-9.87	69.9	5.0
12	9.94-9.87	14.0	5.0
13	9.87-9.81	279.0	5.0
14	9.81-9.75	466.0	5.5
15	9.75-9.69	511.0	5.8
16	9.69-9.62	372.0	8.0
17	9.62-9.56	257.0	6.1
18	9.56-9.51	605.0	8.4
19	9.51-9.45	769.0	8.3
20	9.45-9.39	279.0	6.7
		H_2O	
22	8.33-7.41	1.27	0.089
23	7.41-6.90	13.44	0.230
24	6.90-6.45	63.29	0.320
25	6.45-6.06	33.12	0.296
26	6.06-5.71	43.41	0.452
27	5.71-5.41	13.60	0.359
28	5.41-5.13	3.57	0.165
29	5.13-4.88	0.91	0.104
30	4.88-4.55	0.15	0.116

The Corrected Optical Path

In equations 4 to 9 the variable, u, or optical path occurs. It is defined as follows[14]:

$$u = \int \rho dz \qquad (10)$$

Table 4. Transmission function parameters for TR3 for H_2O and CO_2 bands.

Spectral Interval	Wave-length (microns)	Transmission Function Parameter S ($kg^{-0.5}$)	n	R ($m\ kg^{-1}$)	n
		H_2O			
33	3.57-2.94	3.61E3	0.265	1685	0.79
34	2.94-2.38	3.42E5	1.0	11025	0.209
37	2.04-1.72	3.397E4	1.0	2964	0.319
39	1.52-1.30	2.273E4	−0.015	2887	0.157
41	1.22-1.08	1.6E3	1.0	703	0.143
43	0.98-0.89	8.82E2	−0.026	642	0.055
		CO_2			
31	4.55-4.04	1.323E6	0.238	11005	0.61
36	2.22-2.04	3.267E2	0.273	385	0.71
37	2.04-1.72	1.392E3	0.246	766	0.73

Table 5. Carbon dioxide transmission function parameters for TR4 in 1.4 and 1.6 micron bands.

Spectral Interval	Wavelength (microns)	c	k
38	1.72-1.52	0.063	0.38
39	1.52-1.30	0.058	0.41

where ρ is density, kg m^{-3}; and z is altitude, m. In the model an optical path is computed for each layer and for each absorbing gas. However, the absorbing characteristics of a gas are sometimes significantly affected by temperature and pressure. The effect, generally, is to increase the absorption with increasing partial pressure of the absorbing gas up to a certain limit when the absorption lines become saturated.[15] In order to take into consideration the temperature and pressure effects on the line intensity, S, and the half width, α, various empirical approximations are often used. The procedure is to first calculate the optical path for each absorbing gas in each layer and then modify it to incorporate the pressure effect into the transmission function.

The density is obtained through the equation of state:[16]

$$\rho = mP/RT \qquad (11)$$

where m is the mean molecular weight, kg $kmol^{-1}$; P is pressure, Pa; R is the universal gas constant, 8314 J $kmol^{-1}$ °K^{-1}; and T is the mean temperature of the layer, °K. We make the assumption that each layer is isothermal so that we can describe the pressure variation in the layer in terms of a local scale height, H, given by:[17]

$$H = RT/mg \qquad (12)$$

P, the pressure, is given by:[18]

$$P(Z) = P(Z_0)\exp[-(Z - Z_0)/H] \qquad (13)$$

In (12) and (13), Z is an altitude in the layer and Z_0 is the altitude of the base of the layer; and g is the gravitational acceleration; 9.806 m s^{-2}. Inserting (13) and (12) into (11) and integrating over the layer thickness yields the optical path of the layer:

$$u = f_m(P_{k-1} - P_k)/g \qquad (14)$$

where f_m is the mass fraction of the absorbing gas. The optical path is then multiplied by a correction factor, C_f, to yield the corrected optical path employed in the transmission function calculations.

$$C_f = \frac{P(N)}{P_0}\left(\frac{T_0}{T}\right)^n \qquad (15)$$

where P_0 is standard pressure, 1 Atm; T_0 is standard temperature, 273.16 °K; n is an empirical constant; and T is the mean layer temperature. The values of n used are 0.9 for H_2O, 0.75 for CO_2, and 0.4 for O_3.[19]

Temperature and Pressure Correction for Line Half-Width

In transmission, *TR1*, the half width, α, was corrected for the effects of temperature and pressure by setting $n = 0.5$ and multiplying Y in 4 by C_f.[20]

Diffuse Transmission Approximation

The integration of (1) and (2) should first be carried out over all angles before the integration over wavelength. This is necessary to inculde the effects of the diffuse nature of the infrared radiation in each layer. Fortunately, a simple approximation is available that saves the expense of this integration. It has been found that by multiplying the optical path by 1.66, the effects of diffuse transmission are accurately included.[21]

The Planck Function

In order to solve (1) and (2) the Planck function must be evaluated for the sun, for the earth's surface, and for each layer of the atmosphere. We used the Planck formulation given by Paltridge and Platt,[22] to give, in Wm^{-2} per unit spectral interval:

$$B = \frac{P_1V^3}{\exp\left(\frac{P_2V}{T}\right) - 1} \qquad (16)$$

where P_1 and P_2 are the so-called first and second Planck constants: $P_1 = 3.74186 \times 10^{-16}$ (which includes the multiplication by π for flux units); $P_2 = 1.43884 \times 10^{-2}$; V is the wave number, m^{-1}; and T is the absolute layer temperature, °K. The integration of (16) over each wave number interval was carried out using four point gaussian quadrature.

Solar Flux at the Top of the Atmosphere

To determine the solar input into the canopy atmosphere we employed the following formulation:[23]

$$Q_i = S_ifDCOS(\theta) \qquad (17)$$

where Q_i is the solar flux at the top of the atmosphere in the spectral interval i, W m^{-2}; S_i is the solar flux at the surface of the sun; θ is the zenith angle, f is the fractional daytime; and D is a distance factor. For a global average, $COS(\theta) = 0.5$ and $f = 0.5$.

We define the solar correction factor, SC as:

$$SC = fCOS(\theta) \qquad (17a)$$

To determine the value of Q_i, the solar flux at the surface of the sun, S_i, was multiplied by a distance factor, D:[24]

$$D = 1353/\sigma T^4 \quad (18)$$

where 1353 is the solar constant, W m^{-2}; T is the surface temperature of the sun, 5762 °K; and σ is the Stefan-Boltzman constant, 5.6697 × 10^{-8} J m^{-2} $°K^{-4}$. Thus, D = 2.165 × 10^{-5}.

Vapor Condensation and Cloud Formation

We incorporated the possibility of two cloud layers in our model. There are several factors that could produce clouds. The fundamental requirement, however, is that the saturation ratio (the ratio of the partial pressure of water vapor in a given layer to the saturation vapor pressure in that layer, i.e., the relative humidity) be greater than 1. (In the absence of condensation nuclei, saturation ratios of up to 6 may be necessary to induce condensation.) The saturation vapor pressure, E, is accurately represented by the expression:[25]

$$E = (6.0278 \times 10^{-3})10^{aT/(b+T)} \quad (19)$$

where a = 7.5; b = 237.3, T is in degrees C, and E in mb.

Convective Stability

Once the vertical profile of temperature is calculated, the lapse rate of temperature in each layer is known. If this lapse rate of temperature exceeds a certain critical value, convection, which includes vertical lifting and expansional cooling will result. Cooling, in turn, may result in condensation and cloud formation. The dry critical lapse rate is given by:[26]

$$L_d = -g/Cp \quad (20)$$

where C_p is the specific heat. C_p for dry air = 1005 J kg^{-1} per degree and C_p for water vapor = 1850 J kg^{-1} per degree. Thus the critical lapse rate for the lower atmosphere under the canopy would have been 9.75 °C/km and for the canopy 5.3 °C/km. The actual lapse rate over a particular layer, K, is simply:

$$L_r = \frac{T(N-1) - T(N)}{Z(N-1) - Z(N)} \quad (20a)$$

The stability criteria for an unsaturated parcel of vapor are:[27]

$$\left.\begin{array}{l} L_d > L_r : \text{Stable} \\ L_d = L_r : \text{Neutral} \\ L_d < L_r : \text{Unstable} \end{array}\right\} \quad (20b)$$

Thus, unsaturated parcels in canopy layers whose temperature lapse rates exceed 5.3 °C/km will be unstable and experience lifting, expansional cooling, and possible condensation and resultant mist or cloud formation in that layer. Once this occurs, a convective adjustment must be made in the calculations.[28] This may be done by setting the temperature lapse rate equal to the moist adiabatic lapse rate which includes the effects of latent heat. The moist adiabatic lapse rate may be approximated by:[29]

$$L_s = (6.13 \times 10^{-8})PT/E \quad (20c)$$

where P is the mean atmospheric pressure in the layer and T is degrees K.

In our model we assumed that the canopy atmosphere was mostly free of condensation nuclei and hence only homogenous nucleation is considered in the cloud physics. Under these conditions, saturation ratios of up to 6 may be needed to induce mist formation.[30]

Method of Computer Solution[31]

We begin by specifying the pressure at each node. These are fixed throughout the calculation. From (1) and (2) the upward and downward fluxes at each node are calculated to arrive at the net flux at each node, $F(N)$. The aim is to find the values of T in each layer that will cause the net flux densities at each node to vanish. That is, we seek a set of values for T so that the following conditions are satisfied simultaneously

$$\left.\begin{array}{l} F(N,T(1),T(2),T(3)\ldots T(N)) = 0 \\ \bullet \quad \bullet \quad \bullet \quad \bullet \quad \bullet \\ \bullet \quad \bullet \quad \bullet \quad \bullet \quad \bullet \\ \bullet \quad \bullet \quad \bullet \quad \bullet \quad \bullet \\ F(3,T(1),T(2),T(3)\ldots T(N)) = 0 \\ F(2,T(1),T(2),T(3)\ldots T(N)) = 0 \\ F(1,T(1),T(2),T(3)\ldots T(N)) = 0 \end{array}\right\} \quad (21)$$

This is accomplished using an iterative procedure known as the Newton-Raphson method. For simplicity of notation, let $[F]^{(n)}$ represent nodal fluxes at iteration n; and let $[T]^{(n)}$ be nodal temperatures. Furthermore let $[DF]^{(n)}$ be the matrix of derivatives of nodal fluxes with respect to temperature at iteration n; and let $[DT]^{(n)}$ be a set of temperature corrections used to obtain the temperatures at iteration n + 1.

The Newton-Raphson method involves solving the following matrix equation for $[DT]^{(n)}$:

$$[DF]^{(n)} \times [DT]^{(n)} = -[F]^{(n)} \quad (22)$$

The nodal temperatures for iteration n + 1 are then given by:

$$[T]^{(n+1)} = [T]^{(n)} + [DT]^{(n)} \quad (22a)$$

One begins with an initial guess for the set of nodal temperatures and iterates the procedure until temperature corrections, $[DT]^{(n)}$, are smaller than a prescribed tolerance. To solve (22) we used a gaussian elimination algorithm with partial pivoting. Typically, the program converged after 3 to 5 iterations to within a root-mean-squared tolerance of 1 degree K and yielded the radiative equilibrium steady state vertical temperature structure of the canopy atmosphere.

Oceanic Heat Transport

Another factor of significance could only be guessed at in the present model, namely the coupling between the atmosphere and the oceans. In the present atmosphere, nearly half of the tropospheric heat in equatorial regions is removed from the lower layers of the atmosphere by coupling with the oceans and subsequent transport to the poles.[32] In our canopy we simulated this effect by specifying a net flux, SF, through the entire atmosphere. This flux can be assumed to be coupled to the ocean and transported poleward by ocean currents as the atmosphere and ocean system attempted to balance the heat budget between the equator and the poles. We made no attempt to calculate this effect on a rigorous basis as we only wanted to study the magnitude and include it as an approximation.[33]

Analysis of Results

Numerous numerical experiments were performed to identify the various factors necessary for the obtaining of a viable canopy atmosphere.[34] The one-dimensional model described above although inadequate to quantify in detail some aspects of the problem, does demonstrate its main features. A two-dimensional model is clearly desirable to be able to treat atmospheric and oceanic dynamics. This is no simple task. Global climate modeling is an immense problem and very expensive in computer time.

Comparison with the Present Earth

In order to check the validity of the canopy calculation a calculation using the US Standard Atmosphere was performed. The program yielded a figure of 282 °K for the surface temperature. This compares favorably with the US Standard Atmosphere global average of 288 °K. The comparison was made with SC = 0.25 and a 50% cloud cover.

The Canopy Temperature Profile

We modeled the canopy in several ways. It was found that if the canopy had a thick cloud, the surface temperature would drop nearly 5 degrees for each layer added to the cloud. Also, it was noted, as would be expected, that the canopy temperatures were quite sensitive to the value of *SC* chosen which varies from .0 to 1. Because the angle of the sun is changing over the 24 hours and because the sun "turns off" for a fraction of the day over most of earth, no canopy profile derived from the present model accurately reflects the real condition. When the sun is shining directly overhead, the value of *SC* (from 17a) would be 1. However, after the sun "turns off" its value drops to zero.

In order to model the effects of the removal of surface heat, *SF*, by oceanic coupling, we assumed various amounts of absorption and subsequent transport to the poles by the oceans. With relatively small amounts of oceanic and atmospheric transport one can see a very nice canopy profile results with a cool surface and a strong temperature inversion (see Fig. 2 and 3).

For comparison, we modeled the canopy at the equator at high noon with a cloud fraction of 100%; $SF = -120$ W m^{-2}; and a window mass absorption coefficient of 10^{-5} m^2 kg^{-1}. This produced the most viable canopy profile. The results are presented in Table 6.

Cloud Formation

In each of the canopy profiles calculated in Fig. 2 and 3 the saturation ratios were above 1 in the lower regions of the canopy. Also, beginning at about 12 km (just above the clouds in the present model) the temperature lapse rates exceeded the critical rate indicating that some convection, and subsequent expansional cooling would have occurred in the lower regions of the canopy. This effect coupled with saturation ratios greater than 1 should be sufficient to produce clouds in this region.

The major problem, however, is the value of k required, in the 8 to 13 micron "window" to achieve this inversion. The literature suggests values of 0.01 to 0.02 m^2 kg^{-1} as typical of this region. When it is temperature corrected, the values in the canopy could be of the order of magnitude[35] 10^{-3} m^2 kg^{-1}. While a strong inversion occurred with this value the best results were obtained when values of 10^{-4} or even 10^{-5} were employed. Values this small are not supported by current experimental data. There is of course, the possibility that more careful measurement may yield a lower value for the mass absorption coefficient in its continuum region. Measurements are difficult in this band where absorption is so small. Small loses

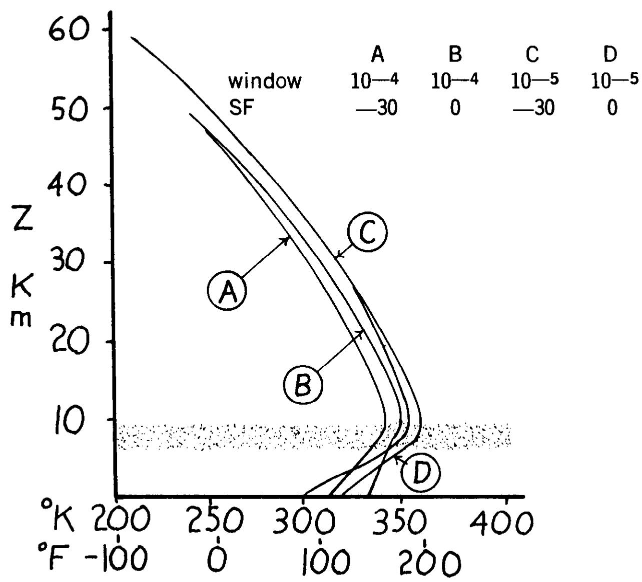

Figure 2. Annual average canopy at 45° latitude in July with various values of surface flux, SF, W m^{-2}, due to oceanic coupling, and window mass absorption coefficient, m^2 kg^{-1}.

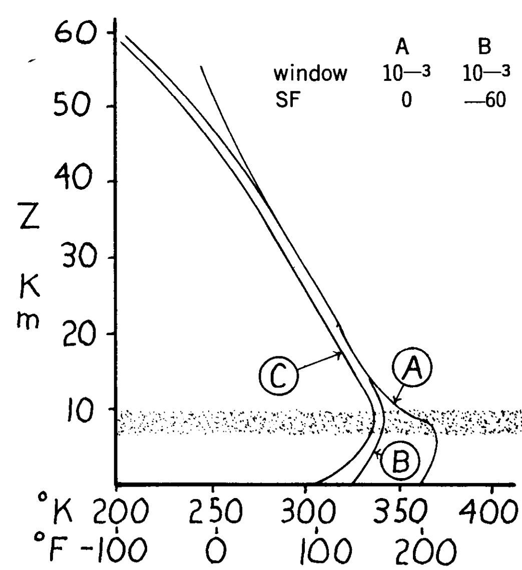

Figure 3. Canopy temperature profiles at 45° latitude for July with various values of surface flux, SF, W m^{-2}, due to oceanic coupling.

Table 6. Computer output of equatorial canopy profile.

Altitude (km)	Pressure (atm)	Temperature (°C)	Lapse Rate (°C km^{-1})	Saturation Ratio
0.0	2.18	19.54	0.0	0.0
0.12	2.15	37.94	15.000	0.011
0.78	2.35	36.44	0.082	0.007
1.50	1.85	46.84	11.5	0.005
2.30	1.70	51.14	6.5	0.003
3.19	1.55	57.04	6.4	0.037
4.18	1.40	64.34	7.4	0.037
4.93	1.30	74.74	14.00	0.045
5.76	1.20	82.54	9.73	0.042
7.20	1.10	94.34	7.9	1.68
9.77	0.95	111.24	6.74	0.917
12.82	0.80	99.64	−3.63	0.701
16.47	0.65	107.84	1.47	0.642
21.07	0.5	99.54	−1.23	0.513
24.92	0.40	92.24	−2.08	0.515
29.76	0.30	82.74	−1.96	0.558
34.81	0.22	68.24	−2.81	0.668
40.77	0.15	51.44	−2.81	0.940

not accounted for in the experimental apparatus can yield significant errors. There has in fact been a wide variation of reported values of k for the window region over the past 20 years. We leave this problem as a yet-to-be-resolved feature of our model.

Nighttime Visibility

A difficulty arises with the canopy model described above in that we are assuming a near total cloud cover (90 to 100%). This could lead to a conflict with the Biblical statements that indicate that the stars were created to be seen (Gen. 1:14). In the model we are proposing, a very thin mist constitutes our "cloud." During the day, this cloud will burn off due to solar heating and by sunset the sky would be clear. Then as the atmosphere cools, in the early hours of the morning, the cloud will gradually form once again only to be slowly burned away by solar heating in the day. The 24 hour cycle in heating and cooling sustains this effect. The effect is greatest at the canopy base where the cloud would reside. It should also be noted that the driving mechanism for convection at the canopy base, i.e., solar heating, will not be present at night. The lapse rate would probably go below the critical rate causing convection to cease and as a result no expansional cooling and cloud formation. (Apparently, in the equatorial profile, Table 6, no vertical convection occurs at the canopy base.)

The Emden Approximation

In an earlier publication a crude approximation for calculating the canopy temperature was employed. It has since come to my attention that I made a mathematical error which would yield canopy temperatures that were several times larger than what had been previously reported.[36] Canopy (and surface temperatures) that exceed 1000 °F derived from the Emden approximation are certainly far in excess of the values derived from the more rigorous aproach taken above.[37] Some explanation is needed.

In its simplest form, the Emden approximation gives a relationship between total optical depth and the temperature of the radiating surface of the planet (the surface or a cloud layer), where A is the albedo, S is the solar constant and σ is the Stefan-Boltzman constant.

$$T = \left[\frac{(1-A)(S)(1+1.5\tau)}{8\sigma}\right]^{1/4} \tag{23}$$

The optical depth is given by:[38]

$$\tau = \int k\rho dz \tag{23a}$$

where k is the mass absorption coefficient and ρ is density.

This formulation does indeed yield reasonable results when applied to the present atmosphere, however it fails when extremely dense atmospheres are involved unless there is some modification to include additional physics.

The first problem involves the selection of the proper value of k; and second involves a modification to the optical path, u. The value of k used should be that k for the most transparent portion of the atmospheric infrared absorption spectrum. The value is of the order of 0.01 kg m^{-2} to 0.001 kg m^{-2} or smaller for water vapor.[39] In the previous study, that value was applied only to the 8 to 13 micron region of the spectrum but a correct use of the Emden approximation for a dense atmosphere requires that it be applied for the terrestrial spectrum as a whole. The physics behind this may be illustrated as follows.[40]

Imagine that the flow of radiant energy from the surface upward through the canopy is analogous to the flow of water through a piece of cheesecloth which has a hole. The "window" region of the spectrum (8 to 13 microns) is illustrated by the hole in the cloth. The water will flow freely through the pores in the cheesecloth as well as the larger hole. Now if we begin to add layers to the cloth with the large hole in the same place, the pores become closed and more and more of the water will flow through the hole. Thus, even though the hole is reduced somewhat, the pores are closed almost entirely. In a similar manner as the optical thickness of the canopy increases, a larger and larger percentage of the radiant energy is transmitted through the window region. And for a very thick canopy the value of k for the window region would be the best value to choose for the grey approximation. If a value of 0.001 m^2 kg^{-1} is used then the canopy base temperature of 421 °K results (assuming an albedo of 0.45)[41] which accords well with the numerical model above.

However, a second factor needs to be taken into consideration. A glance at 4, for example, reveals that the value of the optical path does not increase linearly with increased amount of absorbing gas, but (for large amounts of precipitable water) with the square root. Thus the correct optical path to insert into 23a is considerably less than 12,190 kg m^{-2} of precipitable water. The precise amount can only be determined by the more rigorous approach taken above.

Conclusion

The above study represents the first attempt to model the vapor canopy theory in a rigorous way by computer simulation. It is my desire that the above be viewed more as a "progress report" than a complete solution to the problem. The perceptive reader has noted that in general the canopy seems to be a bit too cool when one moves away from the equatorial regions. If on the other hand, supersaturation is possible due to the relative purity of the atmosphere and absence of condensation nuclei, then saturation ratios of up to 6 may be allowed before condensation will occur. In that case, the canopy should be stable. Also, a key to producing the needed inversion was the removal of heat by coupling with the ocean and also the lateral heat flow due to atmospheric movement near the surface and in the upper regions of the canopy. The next step would be a precise calculation of this effect with a two- or three-dimensional model.

Acknowledgements

I would like to give special thanks to John Baumgardner who wrote the computer code upon which these studies were based. Dr. Baumgardner also read and critiqued the manuscript and offered many helpful suggestions. Also, Dr. Ed Holroyd, who is presently working on his own canopy model, read the manuscript and made many valuable observations.

An Offer

If anyone should be interested in carrying out some of the computation, Dr. Dillow will provide the information. Just send him a diskette, and he will return a fully documented copy of the program. The work would need a TRS 80 Model I or Model III with 48K of RAM. With twenty levels in the program, it takes approximately 10-13 hours to converge on a steady-state solution.

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[26]Reference 17, p. 93.

[27]*Ibid.*, p. 96.

[28]Reference 4. Manabe and Strickler, p. 363, and Manabe and Wetherald, pp. 254-256.

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[30]Reference 16, p. 347.

[31]Coakley, James A., Jr., 1977. An efficient numerical approach to radiative-convective equilibrium. *Journal of the Atmospheric Science,* 34(9):1401-1407. We follow the approach outlined in this article.

[32]Reference 11, p. 129.

[33]Reference 16, pp. 270-272.

[34]These calculations were done on an IBM 3033. The CPU time was typically about 9 seconds.

[35]Reference 6, 4.68b.

[36]Reference 1, 1st edition, p. 227. A conversion from CGS to SI should have given for the optical path of 12,190 kg m^{-2}. I am indebted to Mr. Glenn Morton, of Texas, for pointing out this error to me, July, 1981.

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[41]The albedo of 0.35 to 0.6 is a common value for clouds. See Reference 5, p. 138.

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Do you know of academic vacancies to which Creationists might be directed? The Creation Research Society would like to be in a position to be able to inform Creation scientists of such vacancies. If you know of such positions, will you please inform Dr. John W. Klotz, 5 Seminary Terrace North, St. Louis, Missouri 63105, describing the position, and the academic requirements and training required, and giving any other information which might be available?

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