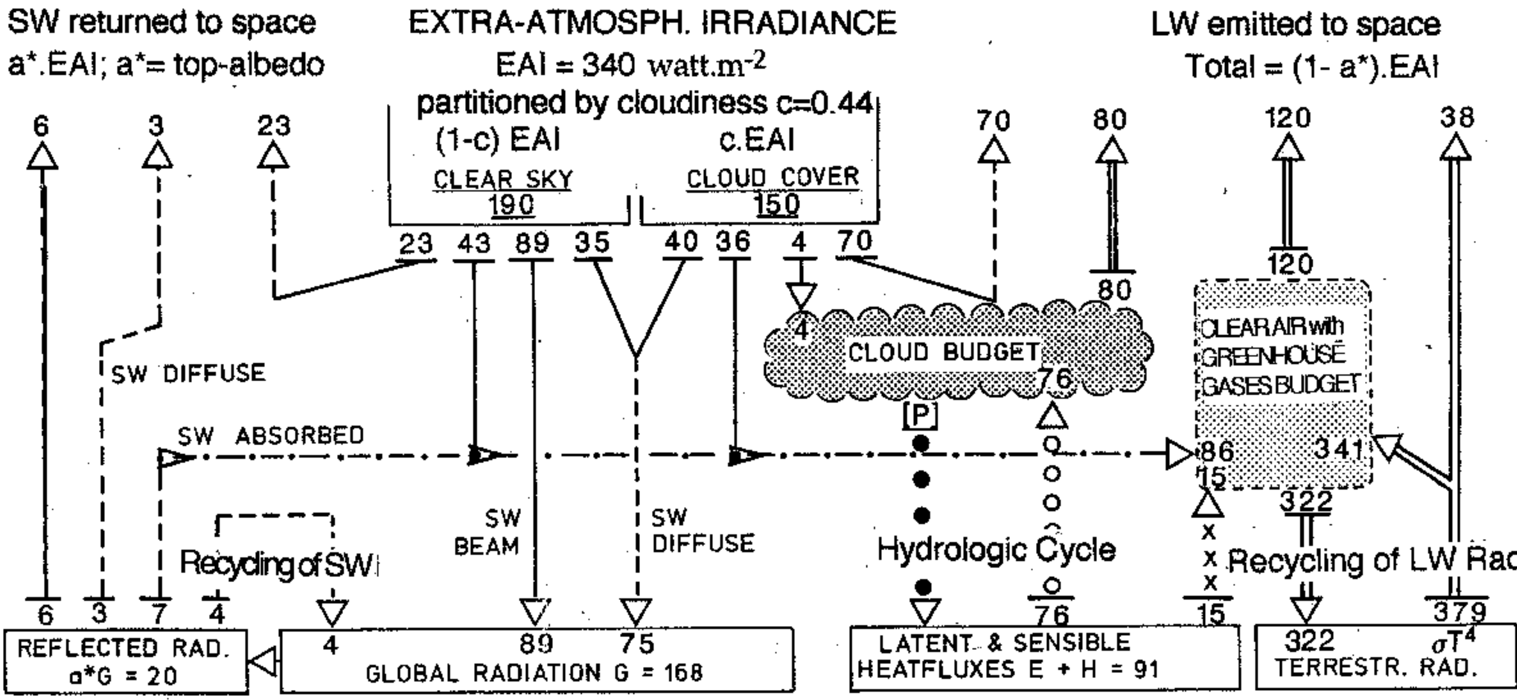
Chart of Energy Fluxes in the Earth's Atmosphere for Computiation of Radiation Temperatures
using σ= Stefan-Boltzmann constant numerically as $\sigma^{-0.25}$ = 64.8 kelvin.(watt.m^{-2})$^{0.25}$



I designed this chart for classroom discussions [Course *Micrometeorrology* and Course *Climatonomy* , University of Wisconsin, Madison] from 1960 to 1980. I supplemented the chart by an elementary 'Blackbox Model' for calculation of global mean radiation temperatures at top and bottom of the atmosphere and two intermediate levels

The *top of the atmosphere* is a virtual level H* near 100 km; temperature T* is determined by $\sigma T^{*4} = (1-a^*).S^*$, where σ =Stefan-Boltzmann constant, S* = 1/4 solar constant, a* = azimuth.

The*Nephopause* is a virtual level H′ between about 8 and 12 km; temperature T′ is determined by $\sigma T'^4 = +Fv + S$, where Fv =latent heat of eddy flux of watervapor condensed and forming clouds below H′; $S = (1-r').(1-a^*).S^*$ is the effective insolation determined by reflectivity r′ at H′; Fv follows from the global hydrologic cycle.

The *Thermopause,* is a virtual level H″ between about 0.8 and 2 km ; temperature T″ is determined by $(1-e'').\sigma T''^4 = +Fh + S$, where e″ = emissivity expressing the recycling of terrestrial radiation due to greenhouse gases above H″; Fh = eddy flux of sensible heat due to the diurnal cycle of S and absorbed by air above H″.

The *bottom of the atmosphere.* is the natural earth's surface where eddy fluxes Fv and Fh are generated; temperature T is determined by $(1-e).\ \sigma T^4 = -Fv - Fh + (1-a)S$ where e = emissivity expressing recycling of terrestrial radiation due to all greenhouse gases, and a=surface albedo.

My 'Blackbox Model' algorithm was designed for use of 'Scientific calculator SHARP EL-5100' . Page 2 provides examples of T-calculations. The *Pearson et al.* paper inspired me to an application determing parameter changes that counteract a postulated Greenhouse Effect.

Inputs: Constant: 64.8-->I; Fluxes: S*->F; Fv->G; Fh->H;
Dimensionless parameters: a*->A; r′->B; e″->C; a->D; e->E;

Algorithm:
(1) I x √√ ((Fx(1-A); = T*
(2) F x (1-A) x (1 - B; = S --> J
(3) I x √√ (J + G; = T′
(4) I x √√ ((J + H) / (1- C; = T″
(5) I x √√ ((J - G - H - JD) / (1 - E; = T

Model parameters that simulate conditions without and with Greenhouse Effect:

[i] Flux and parameter values yielding T″ = 270 and T = 288 kelvin:

S*	Fv	Fh	a*	r′	e″	a	e	T*	T′	T″	T
340	75	15	.300	.162	.3432	.150	.8360	254.5	259.7	270.0	288.0

[ii] Assumed warming by increase of greenhouse gases yields T″ = 271 and T= 290 kelvin; this is achieved by reiterating of the parameters e″ and e:

S*	Fv	Fh	a*	r′	e″	a	e	T*	T′	T″	T
340	75	15	.3000	.162	.3530	.150	.8368	254.5	259.7	271.0	290.0

Experimental changes of model parameters that restore T = 288 kelvin

[iii] Increasing a* from 0.300 to 0.3062; T*, T′,and T″ are also lower than in [ii]:

S*	Fv	Fh	a*	r′	e″	a	e	T*	T′	T″	T
340	75	15	.3062	.162	.3530	.150	.8368	254.0	259.2	270.3	288.0

[iv] Increasing Fv from 75.0 to 76.8 ,w m^{-2} ; other parameters remain as in [ii] ; T′ and T″ are higher than in [iii]:

S*	Fv	Fh	a*	r′	e″	a	e	T*	T′	T″	T
340	76.8	15	.3000	.162	.3530	.150	.8368	254.5	260.1	271.0	288.0

[v] Increasing albedo from a= 0.150 to 0.1598; only T is lower as in [ii]:

S*	Fv	Fh	a*	r′	e″	a	e	T*	T′	T″	T
340	75	15	.3000	.162	.3530	.1598	.8368	254.5	259.7	271.0	288.0

Relevant titles from my biobibliography :

1969: Shortwave radiation climatonomy; *Tellus* , **21**, 208 - 214
1969: Evapotranspiration climatonomy; *Mo. Weather Review* , **97** , 691 - 699
1976: Dynamic and energetic factors which cause and limit aridity along South America's Pacific coast; 182 -189, *World Survey of Climate-*, Vol. **15**, Climates of Central & South America
1977: Climatonomical modeling of temperature response to dust contamination of Antarctic snow surfaces; *Boundarylayer Meteorology*; **12,** 213 - 229
1979: Amazonia's hydrologic cycleand the role of atmospheric recycling in assessing deforestation effects *Mo. Weather Review* , **107**, 228 - 238
1992: Evaporable water and evaporation with and without irrigation; *Wetter und Leben- = Theoretical and Applied Climatology*, **42,** 17 - 27

Evapo Climatonomy, Hydrological Mode (General Outline for Time Series).

I. ALGORITHM 1. Balance Equation (primitive): $(\partial m/\partial t)_j = P_j - N_j - E_j$, where m = soil moisture (mm equivalent column of exchangeable water) = response; P = precipitation = forcing mass input; N & E = depleting fluxes of net runoff (out flow of water using geopotential energy) & mass equivalent of flux of latent heat into the air (using absorbed solar energy); P, N, & E in mm per time increment t_i to t_{i+1}, centered at $t_j = \frac{1}{2}(t_i + t_{i+1})$; annual mean equation (in stable climate, defined by $\overline{\partial m/\partial t} = 0$): $\bar{P} = \bar{N} + \bar{E}$.

2. Parameters: P_N & P_E : threshold values of P; n_N & n_E : "input discount" factors; r_N & r_E : respondances = flushing frequencies (in units of $1/t$).

3. Process Parameterization: $N = n_N(P-P_N) + r_N\, m$; $E = n_E(P-P_E) + r_E\, m$; where the first terms are ZERO if P does not exceed a threshold value.

4. Balance Equation (parameterized): $M = m + \partial m/\partial\tau$, where $M = P'/r$ with $P' = P - n_N(P-P_N) - n_E(P-P_E)$ = reduced input, and $r = r_N + r_E$ = effective flushing frequency; $\Delta\tau = r\Delta t$, or $\Delta\tau_j = r_j(t_{i+1} - t_i)$; τ = non-dimensionless time-scale from $t = t_1$ to $t = t_{i+1}$.

5. Solution by Climatonomical Transform: $m = e^{-\tau}\cdot(m_1 + \int e^{\tau} M\, d\tau)$, with integration limits from $t = t_1$ (where $m = m_1$) to $t = t_{i+1}$. Numerical Foreward Integration Formula: $m_{i+1} = Y_j\cdot m_i + (1 - Y_j)\cdot M_j$, where $Y_j = \exp(-\Delta\tau_j)$ = retentivity; $m_j = M_j + (m_{i+1} - m_i)/\log_e Y_j$; In a stable climate m_1 is determined by continued integration until $m_i = m_{i+12} = m_{i+24}$ for the 12 months cycle.

6. Complete Solution by Computation of N_j and E_j.
Use parameterized equations (3) with computed m_j values (5).

II. INPUT PREPARATION. 1. Mass Input: Prescribe representative P_j-series; if applicable add irrigation rates to P: if study region is not a natural watershed add inflow in river channels and canals to P.

2. Energy Input: Prescribe representative global radiation G_j and surface albedo a_j (which may vary with m_j requiring iterative steps) because parameters (especially $r_{E,j}$) will vary with absorbed solar energy $(1-a_j)\cdot G_j$.

3. Parameter Input: Take into consideration data on topography, terrain slope, channel gradient, surface types, surface cover by vegetation and its phenological cycle, etc., representative of the study region. Find representative parameter values by hydrologic-climatic "calibration". Thresholds $P_{N,j}$ and $P_{E,j}$ may vary with P_{j-1} ; flushing frequency r_N tends towards zero if soilmoisture freezes, while $r_{E,j}$ will be proportional to $(1-a_j)\cdot G_j/\bar{G}$; etc.; normally, set $P_E = n_N(P-P_N)$.

III. TESTING MODEL OUTPUTS. Compare computed N_j with river-gauge data (available for U.S. in "Ann.Reports, U.S. Geolog.Survey"). Obtain runoff ratio $C^* = \bar{N}/\bar{P}$; obtain evaporivities $e^*_j = L.E_j/(1-a^*_j)G_j$ (where L = latent heat) and compare $L.E_j$ with fluxes of the surface energy budget including R_j = net radiation. Check consistency between evapo-and-thermo-climatonomical modeling with the aid of $D^* = (1+B^*)\cdot(1-C^*)$, universally valid for stable continental climates where B^* = Bowen ratio and $D^* = \bar{R}/L\bar{P}$ = Dryness Ratio of annual means. Vary parameter-values (one at a time) to test sensitivity of output.

Evapo Climatonomy II: Basic Atmospheric Mode (Time t = Independent Variable)

1. Notation: w = precipitable water (mm); Evaporation (E) and Import (I) of w are the forcing inputs; Precipitation (P) and Export (X) are depleting fluxes in the tropospheric volume under consideration. Flux units: mm(of water) per Δt.

2. Balance Equation: (1) Primitive Form: $E + I = P + X + \partial w/\partial t$; (2) Parameterized Form: $E + I - P' = P'' + X + \partial w/\partial t$, where $P = P' + P''$ = "fast" + "delayed" return fluxes: P' of water evaporated or imported during the same Δt, and P'' of water stored during preceding Δt increments; (3) Climatonomic Form: $W = w + dw/d\tau$ where W is the reduced equivalent forcing and $d\tau$ = increment of dimensionless time; (4) Climatonomic Transform: $w = e^{-\tau}(w_1 + \int e^{+\tau} W\, d\tau)$ where w_1 is the initial w-value at $t = t_1$ and the integration is from t_1 (where $\tau = 0$), to τ.

3. Defining Equations for Parameterization of Depleting Fluxes:

$P' = p_E(E + I)$; $P'' = \nu_P\, w$; $X = \nu_X\, w$;

where p_E = dimensionless "discount factor" expressing fast return of input E + I and ν_E, ν_X are "flushing frequencies", per increment of time Δt. Let $\nu_P + \nu_X = \nu$ = effective flushing frequency in: $W = (P+I)(1-p_E)/\nu$, and $\nu dt = d\tau$. W is the reduced equivalent forcing (in mm or cm, same units as w); let $Y = \exp(-\Delta\tau)$ = retentivity of the tropospheric volume.

4. Algorithm: Numerical Forward Integration Using Climatonomic Transform:
In a study period lasting from t_1 to $t_1 + n\,\Delta t$, the i-th interval begins at t_i and ends at $t_i + \Delta t$ which is t_{i+1} = begin of the (i+1)-st interval. Prescribed inputs are representative for mid-interval time $t_j = \frac{1}{2}(t_i + t_{i+1})$, and include n values of forcing $(E_j + I_j)$ and information on the three parameters which properly combined yield the n values of W_j as well as Y_j.
By stepwise Forward Integration: $w_{i+1} = W_j + (w_i - W_j)Y_j$; the w for i=1 may be prescribed (in an "initial value problem") or is computed (if the problem is that of a "stable climatic cycle") by continuing the steps of forward integration until w_{i+n} agrees with w_i , using $W_j = W_{j+n}$.

5. Computation of Depleting Fluxes: $w_j = W_j - (w_{i+1} - w_i)/(t_{i+1} - t_i)\nu_j$ (i.e., the finite-difference form of the balance equation) is used to generate w_j, P''_j, and X_j, yielding as output P_j which must agree with $E_j + I_j - X_j - (m_{i+1} - m_i)/\Delta t$.

6. Evapo-climatonomic Restraints for Closure:
6.1 Coupled Mass Balance: Subtract primitive equations for m-balance from that for w-balance, yielding: $N + \partial m/\partial t = I - X - \partial w/\partial t$; thus, for steady mean states above and below the active surface: $\bar{N} = \bar{I} - \bar{X}$. Radiosonde data evaluations yield I-X with sufficient accuracy only for areas > about 0.1 Mm^2.
6.2 Coupling to Net Radiation (R) at the Active Surface: Use energy balance equation for the active surface: $R = \lambda E + Q + S = (1+B)\lambda E + S$ (where B = Bowen ratio) to eliminate E in soil moisture balance, $P - N = E + \partial m/\partial t$, yielding: $P - N - \partial m/\partial t = (R-S)/(1+B)\lambda$. For multi-annual means, $\overline{(\partial m/\partial t)} = 0$; normally, for land areas, $\bar{S} = 0$; Use annual mean fluxes to define the runoff ratio $C^* = \bar{N}/\bar{P}$ and the "dryness ratio" $D^* = \bar{R}/\lambda\bar{P}$ (Budyko's "index of dryness"), whereupon $D^* = (1 + B^*)(1 - C^*)$ where $B^* = \bar{Q}/\lambda\bar{E}$.
6.3 Coupling of Flux of Latent Heat (λE) to absorbed Insolation (F) and Submedium Storage of Sensible Heat (S): $F = (1-a)G$ where a = surface albedo and G = global radiation at the active surface. Define "evaporivities" e_F and e_S so that $\lambda E = e_F F - e_S S$. From energy balance, $F = LW + \lambda E + Q + S = LW + \lambda E(1+B) + S$, obtain $F(1 - e_F(1+Q)) = LW + S(1 - e_S(1+Q))$ and apply thermo-climatonomic transform yielding surface temperature response T, then S, then λE or E. (λ = 28.5 W m^{-2} per mm/day).

7. References: To 6.1: Rasmusson (1977), WMO Operational Hydrology Report 11, Geneva, Switzerland - To 6.2: Lettau (1969) M.W.R., Vol. 97, p. 693 - To 6.3: Lettau (1978) IES Report 101, p. 188, CCR, U. Wisconsin, Madison.

Course No: University of Wisconsin--Professor Heinz H. Lettau
Handout No: Date:

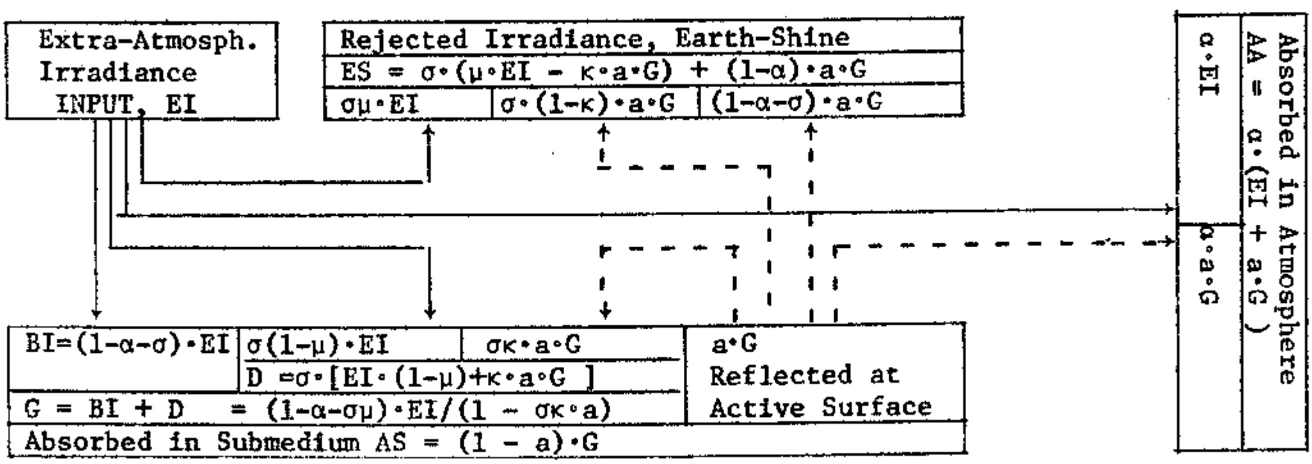
Insolation Climatonomy -- The Solar Energy Cascade

1. General: Insolation = Shortwave Radiation (SWR) in the wavelength-band of solar emission (about 0.3 to 3 micron). Radiation laws (such as Lambert's, Bouguer's, Kirchhoff's, etc.) are integrated over both wavelength and the sky's halfsphere. Thus, the atmosphere is simulated by a thin turbid slab in which SWR-attenuation is determined by only five coefficients (α, a, σ, μ, and κ): α = absorptivity of the atmosphere, a = albedo of the active surface, σ = scalar scattering coefficient so that $\mu\sigma$ = back-scattering (spaceward) of incoming SWR, and $\kappa\sigma$ = back-scattering (earth-ward) of reflected SWR.

2. SWR-Energy Balance Equation (in terms of <u>flux densities</u> (irradiances, with a horizontal m^2 as the reference area, measured in Watt/m^2, "fluxes" in short):

$\boxed{EI = ES + AA + AS}$, where EI = extra-atmospheric irradiance: ES = earth-shine = SWR rejected by the planetary albedo ES/EI; AA = flux absorbed in the atmosphere; AS = flux absorbed by the submedium at the atmosphere's lower boundary (the active surface).

3. Scheme of SWR Fluxes, with the additional notation: G = global radiation = total SWR received by a horizontal m^2 (at ground level); D = diffuse radiation = "diffuse sky light" = SWR which reaches the active surface after being scattered at least once; BI = G - D = beam irradiance at the active surface = shadow-producing SWR directed parallel to the solar rays:



4. Remarks on Availability of Climatic Data or Information on SWR Fluxes:
EI varies predictably with latitude, season, and daylight hour, and is determined by astronomical variables, including the solar constant; ES and thus, ES/EI = planetary albedo ("top-albedo") is measured by meteorological satellites (TIROS, NIMBUS); G derived from climate-station charts on seasonal-spatial variation and trends should be used with caution in view of frequent uncertainties of actinograph calibration; data on D are rare, available only for a few observatories. Surface albedo a has been charted independently by various authors.

For Thermo- and Evapo-Climatonomy AS is the solar forcing. Given EI and values of the five parameters (a, $\alpha, \sigma, \mu, \kappa$) AS together with ES and AA, also BI and D, follow as zero-order response to EI. A detailed computer program has been developed by Ed. Hopkins (1977).

5. <u>Problems</u>: Let EI = Solar Constant = 340 watt m^{-2}. Assume a = .10, α = .26, σ = .49, μ = .55, and κ = .60.
5.1 Compute fluxes ES, AA, and AS in Watt m^{-2}.
5.2 Substitute a' = .20 for a = .10 and compute new values of ES', AA', and AS'.
5.3 Compute flux values of BI, D, BI', and D' according to 5.1 and 5.2.
5.4 Compute the numerical values of planetary albedo according to 5.1 and 5.2.

Course Met. 503 <u>Climatonomy</u> University of Wisconsin - Professor H. Lettau
Handout No: (Supplement to No:) Date:

<u>Comments</u>, and <u>Problem Set</u>, Re: <u>Global-Mean Energy Balance and Planetary Temperature</u>.

1. <u>Comments</u>. 1.1 According to H. Lamb (QJRMS, 1973, p. 794) the "latest opinion" suggests 14.8 °C = 288 K for the Earth's global-mean surface temperature; Lamb notes that this is merely 0.2 °C from the value estimated more than a century ago by H.W. Dove in his work on "Klima" (Berlin, 1852).

1.2 The parameter t*, the "fraction of effective longwave transmission" is by definition the same as the Angstroem ratio A* for the Earth's atmosphere.

1.3 The balance equation for the global-mean planetary surface energy budget yields T* from: effective longwave-emission LW (in response to solar forcing), the surface parameter ε* and the atmospheric parameter t*. If one replaces LW by LW', ε* by ε*', and t* by t*', the new surface temperature follows as $T^{*\prime} = T^{*} \cdot (LW' \varepsilon^{*} t^{*} / LW\, \varepsilon^{*\prime} t^{*\prime})^{1/4}$. Since LW = F-R = F-E-Q-S-M-H, a change from LW to LW' can be produced by changing any one of these five fluxes. This invites climatonomic experimentation; see Problems 2.1 - 2.4.

1.4 The terrestrial energy release due to combustion of fossil fuels (H) was 1970 estimated at 0.0155 Watt/m^2; it is expected to grow over the next decades.

1.5 If Venus' T* of 744 K would prevail on Earth all ocean water would be (in vapor form) an atmospheric constituent resulting in a surface pressure more than 200 times larger than with T* = 287 K. H_2O clouds, comparable to CO_2 clouds on Venus, must have filled this primordial atmosphere. Earth's cooling must have been more rapid than Venus' cooling because of intense precipitation and re-evaporation at the surface while heat of evaporization is about four times greater for H_2O than for CO_2.

2. <u>Problem Set: Examples of Zero-order Climatonomic Experimentation</u>. In this simplified set the problem is to compute changes in equilibrium value, T*' - T*, which result from a <u>single-factor modification</u> (of either parameter or flux value) assuming that all other factors remain constant (i.e., at values as specified on the reference Handout No.).

2.1 In a partial simulation of increasing volcanic activity on Earth let the effective transmissivity for solar flux be reduced by 5%, from t** = .640 to t**' = .608. Result of Computation: T*' - T* = . °C

2.2 In simulation of future effects of man-made atmospheric pollution let the global-mean Angstroem Ratio be reduced by 5%, from t* = 0.1040 to t*' = 0.0908. Result of Computation: T*' - T* = . °C

2.3 In simulation of intensified and wide-spread geo-convection let the release of subcrustal heat be increased from S = 0.06 to S' = 0.20 Watt/m^2. Result of Computation: T*' - T* = . °C

2.4 In a formal extrapolation over the next 5 decades, let the rate of heat release due to combustion of fossil fuels be represented by doubling the global-mean of H after every 10 years, starting with the 1970 value of .0155.

Result of Computations:

Year:	1980	1990	2000	2010	2020	
H' :	.031	.062	.124	.248	.496	Watt/m^2
T*'-T*:	.	.	.	.	.	0°C

2.5 From physical-chemical standard tables extract values of latent heat of vaporization, freezing, and sublimation (in joule per kg), also of boiling and freezing points, for both CO_2 and H_2O, at temperatures representative of global-mean top and bottom values for the atmospheres on Venus and Earth.

Table [x] A 'Black-Box Model' assuming seven significant points of time for outlining the average life cycle of the five glaciations that occurred during the last 500 ka on subarctic land

The variation of ice volume V, lithospheric depression D and area A covered by non-permanent ice are organized by the sequence of points of time: t′*, t′, and t* denoting begin of glaciation, peripheral melt, and ice dome formation; **t***, **t′***, and **t′** denote the maxima of V,D,and A; t° denotes the completion of melt ; the inter-glacial high-temperature plateau is between t°and t′* of the next glaciation.

Part I: V,D, and A as fraction of the respective maximum values,

[1]	t′*	t′	t*	**t***	**t′***	**t′**	t°
[V]	0	0.2	0.8	1	0.1	0.01	0
[D]	0.05	0	0.2	0.8	1	0.8	0.2
[A]	0	0.8	0.85	0.9	0.95	1	0

Part II: V and D as fraction of assumed maximum values, yielding directly V-D = actual crest elevation relative to non-glaciated surroundings and indirectly a change of curvature from a convex ice-dome to a moderately concave central ice-hollow

[1]	t′*	t′	t*	**t***	**t′***	**t′**	t°
[V]	0	600	2,400	**3,000**	300	30	0
[D]	50	0	200	800	**1,000**	800	200
[V-D]	-50	600	2,200	2,200	-700	-770	-200

Feedback-causing changes of regionalgeophysical parameters :

Surface albedo of subarctic land may be assumed 50% for interglacial tundra, 80% for year-around ice cover and 20% for supraglacial and meltwater lakes

Table 1. Logarithmic scaling in steps of ***windpower-doubling*** applied succesively to *breezes* , *gales* , *hurricanes,* and *tornadoes,* according to Beaufort, Saffir-Simpson, and Fujita, respectively. P=*windpower* $=\rho v^3 10^{-3}$,kw m^{-2} ; v = characteristic windspeed, m s^{-1} ; air density [assumed const] ρ= 1.28 kg m^{-3} .

Breezes::	light	gentle	moderate	fresh	strong
P	<0.125	0.25	0.5	1.0	2.0
v	<4.6	5.8	7.3	9.2	11.6
Gales:	moderate	fresh	strong	whole	
P	4.0	8.0	16	32	
v	14.6	18.4	23.2	29.2	
Hurricanes:	weak	moderate	strong	devastating	
P	64	128	256	512	
v	36.8	46.4	58.5	73.7	
Tornados:	weak	strong	very strong	violent	extreme
P	128	256	512	1,024	>2,000
v	46.4	58.5	73.7	92.8	> 117