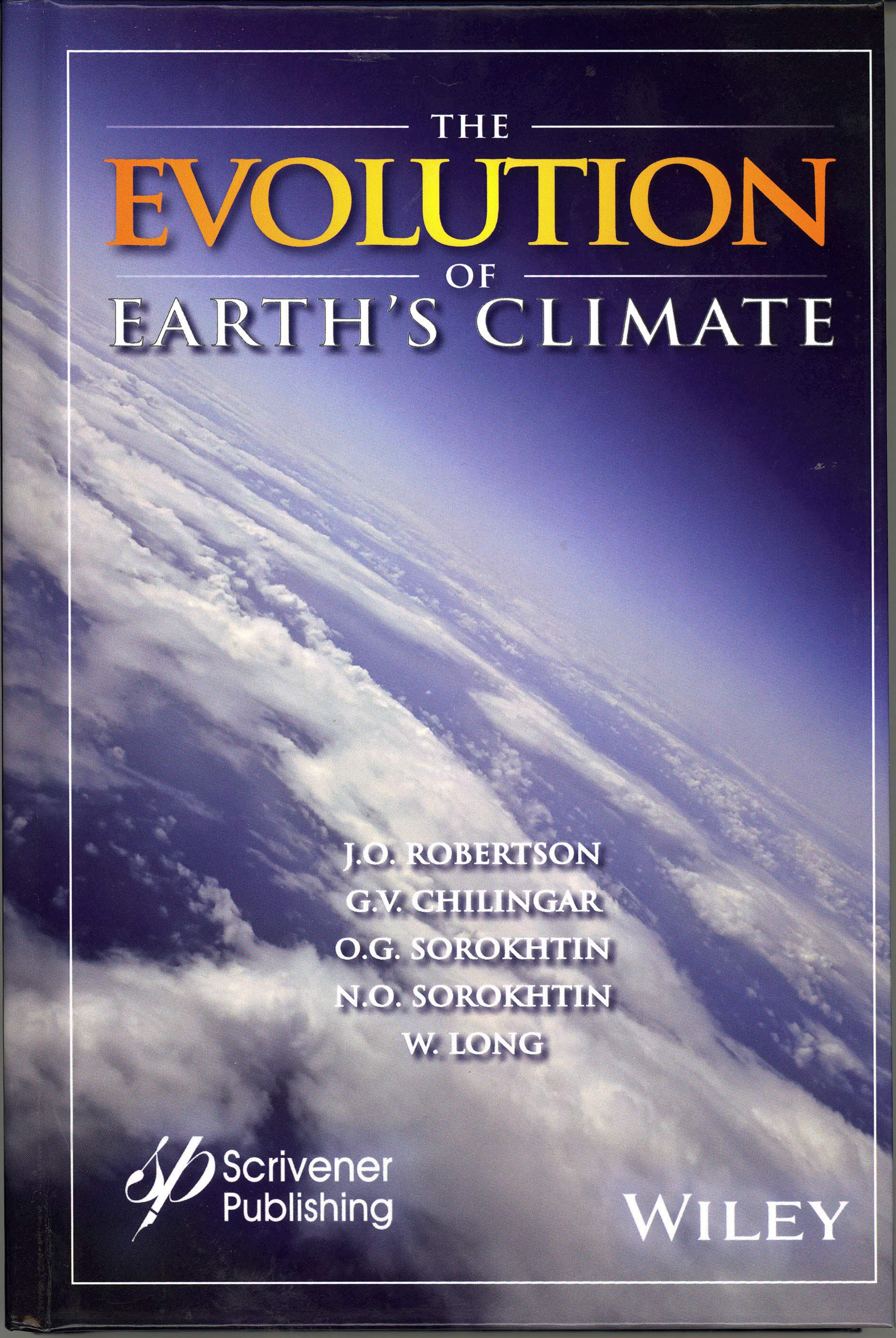

THE EVOLUTION OF EARTH'S CLIMATE

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Dedication

This book is dedicated to those politicians interested in the truth, basing their opinions on scientific facts, rather than emotions, personal profit, or conformity. An excellent example of this is the United States President. Donald J. Trump

Contents

2

Adiabatic Theory

A process that occurs without loss or gain of heat may be defined as adiabatic. In a flow path, $1 \rightarrow 2 \rightarrow 3$, $p_1 v_1^{\alpha} = p_2 v_2^{\alpha} = p_3 v_3^{\alpha}$, where p_i is the absolute pressure; v_i is the specific volume (volume/unit weight); and a is the adiabatic exponent. Because climate (weather) occurs within the troposphere, a climatic model is essentially one of the troposphere.

Troposphere

The troposphere is the lowest subdivision of Earth's atmosphere, where nearly all weather conditions (climate) take place. Approximately 75% of Earth's atmospheric mass and 99% of water vapor and aerosol mass lies within this layer. The thickness of this layer varies: (1) at the equator (20 km or 12 mi), (2) in the mid latitudes (17 km or 11 mi), and (3) at the polar regions in the polar regions in winter (7 km or 4.3 mi). The lowest portion of the troposphere, where the maximum friction between the Earth's surface and atmosphere occurs, is known as the planetary boundary layer. This layer varies from a few hundred meters to 2 km (1.2 mi) deep depending

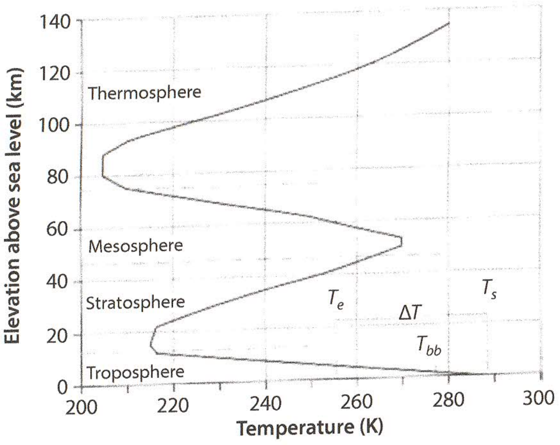
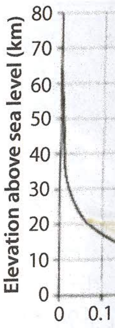


Figure 2.1 Temperature distribution vs. elevation (altitude) in the Earth's atmosphere. T_e is the Earth's effective temperature; T_s is the average Earth's temperature normalized for sea level; ΔT is the greenhouse effect value ($T_s - T_e$); T_{bb} is the absolute black body temperature at the Earth from Sun distance. (After Atmosphere of Earth, 1988.)

on the landform and time of day. The upper level of the troposphere is known as the tropopause, which is the border between the troposphere and stratosphere. This layer is a temperature inversion layer, where the air temperature ceases to decrease with height and remains constant through its thickness (Figure 2.1).

The Earth's weather occurs in the troposphere. Climate reflects the Earth's weather over a period of time. A model of the Earth's climate is essentially a model of the troposphere. The troposphere has the following characteristics (see Figures 2.1 and 2.2):

1. The boundaries of the troposphere are the Earth's surface as the lower surface and an upper surface ≈12 km (7 miles) above the Earth's surface (see Figure 2.1).
2. The troposphere is unique in that the movement of air is parallel to rather than vertical to the surface of the Earth as in the case of all other positions (layers) of Earth's atmosphere.
3. The troposphere is an exclusive layer as there is little mixing of air between the troposphere and the upper portions of the atmosphere.
4. What is often referred to as the Earth's *weather* (short time period) or *climate* (longer time period) occurs within the troposphere.



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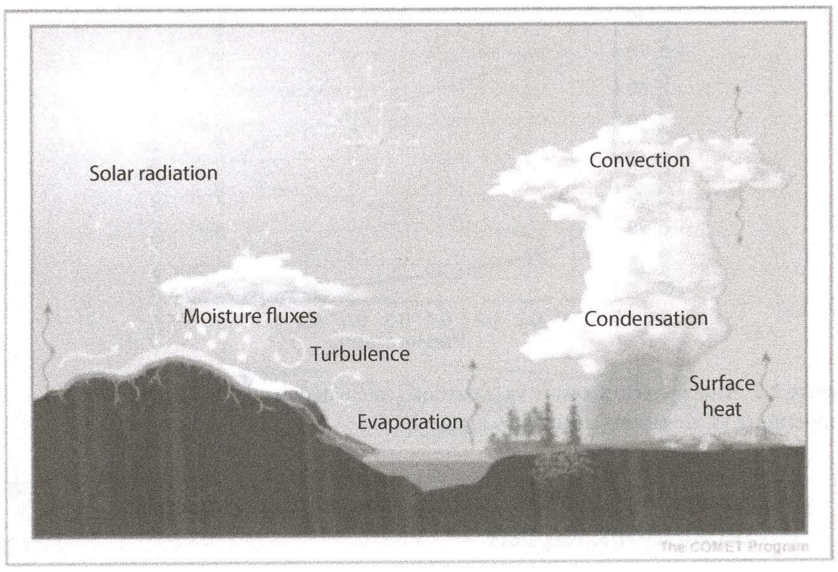

Figure 2.3 Various methods of energy transfer in the troposphere. (After UCAR, 2018, https://www.COVCAR.edu/learn/1_1_1.htm.)

can transmit heat through a vacuum. Energy travels from the Sun to the Earth by means of electromagnetic waves. The shorter the wavelength, the higher the quantity of energy associated with it.

2. *Convection* is the transfer of heat by transporting groups of molecules from place to place within a substance. In the atmosphere, convection includes the large- and small-scale rising and sinking of air masses and smaller air parcels. These vertical motions of air effectively distribute heat and moisture throughout the atmospheric column and contribute to cloud and storm development (where rising motion occurs) and dissipation (where sinking motion occurs). Meanwhile, the slow rotation of the Earth toward the east causes the air to be deflected toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere. This deflection of the wind by the Earth's rotation is known as the Coriolis effect.
3. *Conduction* is the transfer of heat (energy) through contact with the neighboring molecules. Air and water are relatively poor conductors of energy. Since air is a poor conductor, most energy transfer is by conduction occurring at the Earth's surface.

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The origin of almost all of Earth's energy comes from the Sun. Therefore, any climatic model developed, must include: (1) the energy coming from the Sun to the Earth, (2) energy intercepted by the atmosphere (absorption and reflection) and (3) energy absorbed and reemitted by the Earth's surface.

Modeling the Earth's Troposphere

The Earth's atmosphere is an example of the dissipative system (dissipating energy), as described by the nonlinear equations of mathematical physics. Therefore, the Earth's atmosphere can be organized and described by its physical fields and formation using the process parameters-defined stable thermodynamic structures in space and time. For instance, it is possible to examine only those physical parameters, such as, the mass of the atmosphere, its heat capacity, the average value of the solar radiation hitting the Earth as well as a strong negative feedback between the planet's spherical albedo and its averaged near-surface temperature. With this set of parameters, the local details in the *greenhouse effect* description is the first approximation model, single-dimensioned and averaged over the entire Earth.

This approach has several advantages. It enables obtaining analytical and unique results in the solution of global problems as well as the influence of the atmosphere's composition on the total value of the *greenhouse effect* for the entire Earth. It is also possible to include within this single-dimension model, additional and local parameters, e.g., the latitude of a locality, the Earth's revolution axis angle with the ecliptics, its precession, inflow of additional heat by the air flows (cyclones), the snow-cover albedo, etc. It is possible to construct either a 3-D or even 4-D (with the time as the fourth-dimension) *greenhouse effect* model.

Four primary factors responsible for the climatic conditions on the Earth are: (1) the amount of solar radiation, (2) the composition and pressure of the atmosphere, (3) the heat capacity of the Earth's atmosphere, and (4) the Earth's precession angle (Sorokhtin, 1990, 2001,2006; Khilyuk and Chilingar, 2003, 2004; Sorokhtin *et al.*, 2007a, b); and Chilingar *et al.*, 2014).

Features of the Earth's Atmosphere

The total mass of the Earth's atmosphere is $\approx 5.15 \times 10^{21}$ grams. The average atmospheric pressure at sea level, p_0, is equal to one physical atmosphere or 1.0132 bars (1013.2 millibars) or 760 mm mercury. At sea level the Earth's atmospheric density, r_0, is $\approx 1.27 \times 10^{-3}$ g/cm^3. The air pressure and density rapidly decline with altitude, or height above sea level, under the exponential rule expressed below or as shown in Figures 2.1 and 2.2:

$$p = p_o\, e^{\left(\frac{g\mu}{\mathrm{R}T}h\right)}, \qquad \text{(Eq. 2.1)}$$

where $g = 981$ cm/s^2 is the gravitational acceleration; μ is the average molecular weight of the atmospheric gas (for Earth's atmosphere at $p = p_o$, $\mu = 28.97$); $\mathrm{R} = 1.987$ cal/deg · mol or 8.314×10^7 erg/deg · mol is the gas constant; T is the absolute temperature in degrees Kelvin; and h (cm) is the elevation above the sea level.

The atmospheric nitrogen-oxygen dry-air composition is composed (by mass) of: 75.51% nitrogen, 23.15% oxygen, 1.28% argon, 0.046% carbon dioxide, 0.00125% neon and ≈0.0007% other gases. An important active greenhouse gas component of the atmosphere is the water vapor and the drops of water found in clouds. The total water vapor or water content in the atmosphere reaches the quantity of 0.12 to 0.13×10^{20} g. This is equivalent to an average water layer, 25 mm thick, covering the Earth (the pressure equivalent of 2.5 g/cm^2). If we take the average annual humidity evaporation and the precipitation, at a pressure of ≈780 mm of mercury, then the water vapor is renewed within the troposphere about 30 times per year (i.e., every 12 days).

In the stratosphere, a layer of ozone molecules absorbs a sizable portion of the UV solar radiation. The heat release in the formation of ozone molecules results in heating of the air masses at elevations of about 50 km. This can be seen by the temperature profile shown in Figure 2.2. The ozone (O_3) content in the atmosphere is $\approx 3.1\times10^{15}\,\mathrm{g}$, whereas the oxygen ($O_2$) content is 1.192×10^{21} g. Ozone is mainly found in two layers of the Earth's atmosphere. About 98% of the ozone resides in layers within the stratosphere ranging from 6 to 10 miles (20 to 17 km) above sea level and extends to 30 miles (50 km).

There are several transitional layers between the troposphere and stratosphere, and between the mesosphere and thermosphere. These layers are, respectively, the troposphere, with temperatures of 190 to 220 K, and the mesosphere with temperatures of 180 to 190 K.

The thermosphere is located above the mesosphere where the ionized gas glows at a temperature of 1000 K and greater. At elevations over 1000 km the thermosphere gradually transforms into the exosphere and above this, into the outer space.

There are several significant differences within the atmosphere between the troposphere and those layers above it. In the layers of atmosphere above the troposphere, air flows vertically, away from the Earth, rather than horizontally as in the troposphere where it tends to flow in spirals and parallel to the Earth's surface. One reason for this parallel-spiral flow pattern is the friction between the Earth's surface and atmosphere; as the Earth spins on its axis, it pulls the atmosphere along with it. Another reason is the *Coriolis effect*, a result of the rotation of the Earth. The daily turbulence of this zone of air flow in the troposphere is what is referred to as weather, or on a long-term basis, climate. Due to the difference in air flow in the troposphere as compared to the upper portions of the atmosphere, the average temperature distribution in the Earth's troposphere is radically different from its distribution in the stratosphere, mesosphere, and thermosphere. Temperature distribution is almost linear in the troposphere, whereas, as shown in Figure 2.2, in the upper layers of the atmosphere it is very nonlinear, with a characteristic maximum at the elevations of about 50 km and the temperature growth above 90 km above the sea level. The temperature in the stratosphere and mesosphere is mostly determined by the heat release in the oxygen dissociation process and the radiation mechanism of heat transfer, whereas the temperature distribution in the troposphere is determined by different processes. The most important of these processes is the convective heat release from the denser tropospheric layer into the stratosphere, where it then is lost as it radiates out toward the outer space.

Development of an Adiabatic Equation

Premise of the Adiabatic Theory

The Earth's troposphere is a relatively dense atmosphere with pressures ranging from 0.3 to 1 atm. For this reason, energy (heat) transfer in this lowermost layer of the atmosphere occurs mostly due to air-mass convection (Sorokhtin, 2001) and not just to radiation as often believed by the proponents of the classic *greenhouse effect*. A dense atmosphere, with an air pressure greater than $p > 0.2$ atm, will be dominated by the heat transfer in airflows by the mechanism of convection of air mass exchange. In this process of air-mass exchange, warmer masses of air expand and rise whereas the cooler air-masses contract and descend. Radiation heat exchange is dominant only in the higher layers of the atmosphere, e.g., stratosphere, mesosphere and thermosphere layers. Thus, the average temperature distribution within the troposphere, T, must be close to an adiabatic distribution:

$$T = Cp^{\alpha}, \tag{Eq. 2.2}$$

where, a is the adiabatic exponent, dependent only on the heat absorption capacity of the mixture of atmospheric gases. This does not mean that any specific temperature distribution, at a specific moment in time, must necessarily be entirely adiabatic. What is meant is that the average distribution, within time intervals, e.g., over a period of time, is adiabatic.

The Earth's illumination (by a flow of energy from the Sun) can be described by the temperature of an *absolute-black-body*, T_{bb}. This temperature may be determined by the Boltzmann's equation:

$$T_{bb} = \left(\frac{S}{4\sigma}\right)^{\frac{1}{4}}, \tag{Eq. 2.3}$$

where $S = 1.367 \times 10^{6}\ \mathrm{erg/cm^2 \cdot s}$ representing the solar constant or the incoming flow of solar energy; the Stefan-Boltzmann constant is $\sigma = 5.67 \times 10^{-5}\ \mathrm{erg/cm^2 \cdot s \cdot deg}$. Part of the solar radiation, at a radiation temperature, T_r, is reflected from the Earth and is lost to the outer space:

$$T_r = \left(\frac{SA}{4\sigma}\right)^{\frac{1}{4}}, \tag{Eq. 2.4}$$

where A is the planet's reflectivity or albedo (for the Earth, $A = 0.3$). In this case at $\psi = 0$, the Earth's radiation temperature, $T_r = 206$ K, where only part of the solar energy reaches the Earth, it has an effective temperature, T_e:

$$T_e = \left(\frac{S(1-A)}{4\sigma}\right)^{\frac{1}{4}} \tag{Eq. 2.5}$$

For Earth, $T_e \approx 255\mathrm{K}$.

The temperature determined by Eq. 2.4 is sometimes called the radiation temperature, T_r, because it describes a planet's radiation as it is seen from the outer space (although that is not totally accurate).

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Development

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The greenhouse effect, ΔT, is the difference between the planet's average surface temperature, T_s; and its effective temperature, T_e:

$$\Delta T = T_s - T_e. \qquad \text{(Eq. 2.6)}$$

The average temperature of the entire Earth is approximately 288 K or 15 °C, and its effective temperature according to Eq. 2.5, at ψ; = 0, is T_e = 255 K or −18 °C. Thus, the classical greenhouse effect value for the Earth is +33 °C.

Development of the Adiabatic Equation

In the troposphere, where the atmospheric pressure is more than 0.2 atm, the dominating type of heat transfer is by mass air flow through a convective mass exchange where the warmer air expands and rises and the colder air contracts and drops (Figure 2.3). Radiation heat transfer dominates only in the upper layers of the atmosphere, above the troposphere, where there is lower pressure ($p > 0.1$ atm) and where the molecules are further apart, e.g., in the stratosphere, mesosphere, and thermosphere. This suggests that the average temperature distribution in the troposphere must be close to adiabatic distribution. If no or little outside energy is added to the troposphere, then following the gas law, little energy either enters or leaves the troposphere:

$$\frac{p_i V_i}{T_i} = \text{constant}, \qquad \text{(Eq. 2.7)}$$

where there is no change in the volume of the gas, the adiabatic temperature distribution is controlled by the atmospheric pressure, p and by the effective heat capacity of the air (Landau and Lifshitz, 1979):

$$T^{\gamma} p^{(1-\gamma)} = \text{consant}, \qquad \text{(Eq. 2.8)}$$

and

$$\gamma = \left(\frac{c_p}{c_v}\right), \qquad \text{(Eq. 2.9)}$$

where c_p and c_v are the gas heat capacities respectively at constant pressure and constant volume. T and p may be determined by the formula:

$$T = Cp^{\alpha}, \qquad \text{(Eq. 2.2)}$$

where

$$\alpha = \left(\frac{\gamma - 1}{\gamma}\right) \text{ and } \left(\gamma = \frac{c_p}{c_v}\right) \qquad \text{(Eq. 2.10)}$$

Eq. 2.10 shows that under the adiabatic process, the gas temperature, T, is always proportionate with the gas pressure, p, to a power of the adiabatic exponent, α, which depends on the effective heat capacity of the gas mixture, atm. For all triatomic gases, e.g., CO_2 and H_2O, $\gamma = 1.3$ and $a_o = 0.2308$, and for the biatomic gases, e.g., N_2 and O_2, $\gamma = 1.4$. For dry air, without consideration of absorption of the Earth's heat (IR) radiation, $\alpha = 0.2857$.

Water vapor in the atmosphere generates the cloud cover which is a primary factor in determining the Earth's reflectance, A. Earth's reflectivity (albedo), A. The albedo creates a strong negative feedback between the near-Earth temperature, T_s, and the *absolutely-black-body* temperature, T_{bb}, which describes the solar irradiation intensity of Earth, S, at its distance from the Sun. Any increase in near-Earth temperature increases both the evaporation of moisture on the Earth which also adjusts Earth's cloud cover. Changes in the cloud cover will alter the Earth's albedo and reflectivity of the atmosphere. The result is a change in the reflection of the Sun's energy by atmospheric clouds to outer space and thus a change in the flow of energy to the Earth's atmosphere and surface. Because of this, the average temperature of the Earth's surface declines to its previous level. Any deep negative feedback in this system results in a linear correlation between the reaction of the system's output and the action at its input. This property of a system, with a negative feedback, is universal and manifests itself regardless of the system's nature, whether it is a planet's atmosphere, electron amplifier or Watt's centrifugal control in a steam engine.

For this reason, the near-surface temperature is always proportional to the effective temperature value, T_e (Figure 2.4).

The following conclusion can be made from this under the classic version of the theory, the near-surface temperature, T_s, and the temperature, T, in general at any level within the troposphere, are proportionate to the effective temperature of a revolving body, T_e, at the distance from the Earth to the Sun. The effective temperature, T_e depends on the solar radiation intensity, solar constant (S), and is proportional to the atmospheric pressure, p, raised to the power of adiabatic exponent, α. The adiabatic exponent depends on the composition of the atmosphere and its heat absorbing capacity:

$$T = b^{\alpha} T_e \left(\frac{p}{p_o}\right)^{\alpha} = \left(\frac{S(1-A)}{4\sigma}\right)^{\frac{1}{4}} \left(\frac{p}{p_o}\right)^{\alpha}, \qquad \text{(Eq. 2.11)}$$

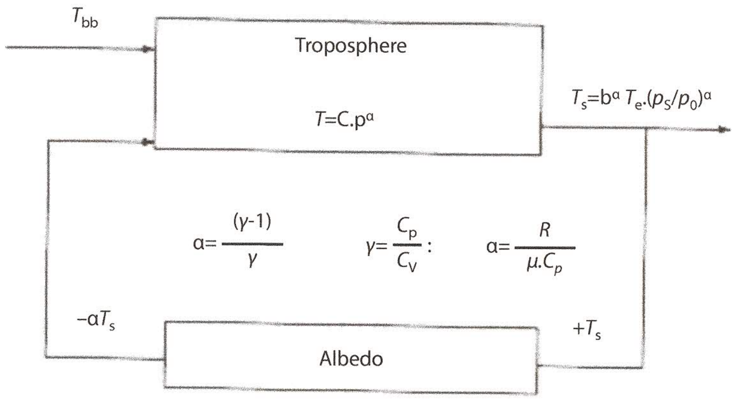

Figure 2.4 Flow diagram of the temperature transformation in the troposphere. T_{bb} is the absolutely black body temperature, K, at the distance of the Earth from the Sun; T_e is the effective Earth's temperature, K; T_s is the near-Earth temperature, K; p_s is the atmospheric pressure; p_o pressure unit; b is the scaling factor; α is the adiabatic exponent; c_p is the air heat absorbing capacity at constant pressure; c_v is the air heat capacity at constant volume; R is the gas constant; m is the molar weight of the air gas mixture.

where, p is the troposphere's atmospheric pressure; p_o is the pressure unit, for instance, $p_o = 1$ atm; α is the adiabatic exponent:

$$\alpha = \frac{(\gamma - 1)}{\gamma}, \qquad \text{(Eq. 2.10)}$$

and

$$\gamma = \frac{c_p}{c_v}, \qquad \text{(Eq. 2.9)}$$

where c_p and c_v, represent the specific heat of the air mixture at constant pressure and volume, respectively; b is the scale coefficient presented in Eq. 2.11 is equal to as:

$$b = \left[\frac{1}{(1-A)^{\frac{1}{4}}}\right]^{\frac{1}{\alpha}} \qquad \text{(Eq. 2.12)}$$

If the specific heat, c_p, is expressed in cal/g · deg and the gas constant R = 1.987 cal/mol · deg, the adiabatic exponent, α, is a function of the atmospheric composition and humidity and can be determined using the following formulas:

$$\alpha = \frac{\mathrm{R}}{\mu(c_p + C_w + C_r)}, \qquad \text{(Eq. 2.13)}$$

and

$$c_p = \frac{[\{p_{N_2}c_p(N_2)\} + \{p_{O_2}c_p(O_2)\} + \{p_{CO_2}c_p(CO_2)\} + \{p_{Ar}c_p(Ar)\}]}{p} \qquad \text{(Eq. 2.14)}$$

where the gas constant, $\mathrm{R} = 1.987$ cal/mol · deg; μ is the molar weight of the atmospheric air mixture (for Earth $\mu \approx 29$); $p_{N_2} = 0.7551$; $p_{O_2} = 0.2315$; $p_{CO_2} = 0.00046$; and $p_{Ar} = 0.0128$ atm are the partial pressures of, respectively, nitrogen, oxygen, carbon dioxide, and argon (Voitkevich and Kokin, 1990); $p \approx 1$ atm is the summation of all the gas components in the atmosphere that were included in the calculation; $c_p(N_2) = 0.248$; $c_p(O_2) = 0.218$; $c_p(CO_2) = 0.197$; $c_p(Ar) = 0.124$ cal/g · deg are the heat absorbing capacities of nitrogen, oxygen, carbon dioxide, and argon at constant pressure (Khodakovsky, 1971). $C_w + C_r$ are the adjustment factors considering the total heating effect of moisture condensation C_w (in a humid atmosphere) and of absorbing the radiation heat from the Sun to the Earth C_r. Thus:

$$C_w + C_r = \frac{\mathrm{R}}{\mu\alpha} - c_p \qquad \text{(Eq. 2.15)}$$

The best match of the theoretical temperature distribution in the Earth's troposphere with averaged empirical data occurs at $\alpha = 0.1905$. For the dry Earth's atmosphere air mixture, $c_p = 0.2394$ cal/g-deg. Thus, for a humid, IR-absorbing air of a real but averaged troposphere with the temperature gradient of 6.5 deg/km may be found by use of Eq. 2.15, $C_w + C_r = 0.1203$ cal/g · deg K. For planets of a different atmosphere, these examples should be understood as a description of any thermophysical or chemical processes resulting in the heat release or absorption ($C_w + C_r < 0$) within the troposphere.

To determine the characteristic temperature of a planet, one needs to determine the coefficients C_w and C_r:

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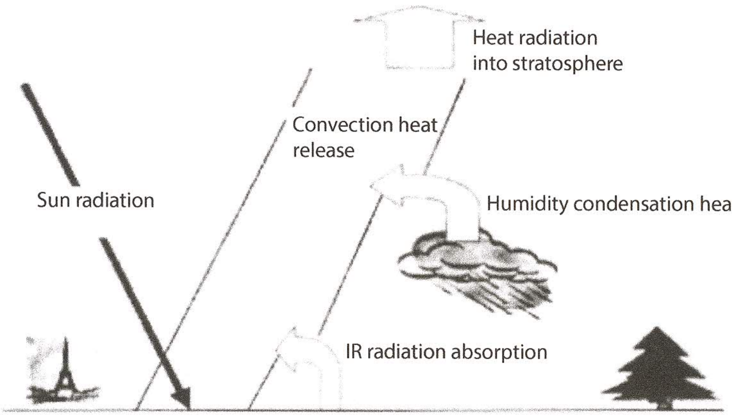

Figure 2.5 Balance of heat transfer in the Earth's troposphere. The loss with convective movements of air mass is 69%, moisture condensation adds another 25% and only 8% is the fraction of the radiation heat transfer. (After Sorokhtin *et al.*, 2011.)

$$C_r = \left\{\frac{\mathrm{R}}{(\mu \cdot \alpha)}\right\} \cdot \left\{\frac{(T_s - T_e)}{T_s}\right\}, \qquad \text{(Eq. 2.16)}$$

and

$$C_w = \left\{\frac{\mathrm{R}}{(\mu \cdot \alpha)}\right\} \cdot \left\{\frac{T_e}{T_s}\right\} - c_p \qquad \text{(Eq. 2.17)}$$

Inserting into Eqs. 2.16 and 2.17, the Earth's atmosphere parameter values are: $\alpha = 0.1905$, $\mu = 29$, $c_p = 0.2394$ cal/g · deg, $T_s = 288.2$ K, $T_e = 255$ K, and R = 1.987 cal/mole · deg one obtains $C_r = 0.0412$ cal/g · deg and $C_w + C_r = 0.1203$ cal/g · deg. Thus, one arrives at the same values as when determining these parameters from Eq. 2.15. This shows that a direct heat transfer by Earth's surface to the air mass participating in the tropospheric convective mass exchange reaches approximately 67%. The radiation component adds 8% to convective heat transfer and the heat release due to moisture condensation within the troposphere adds 25% more (see Figure 2.5).

Earth's Troposphere Model

A simplified equation for the tropospheric temperature, T, can be determined if one assumes: (1) $T_s = 288.2$ K; (2) the scaling factor as determined

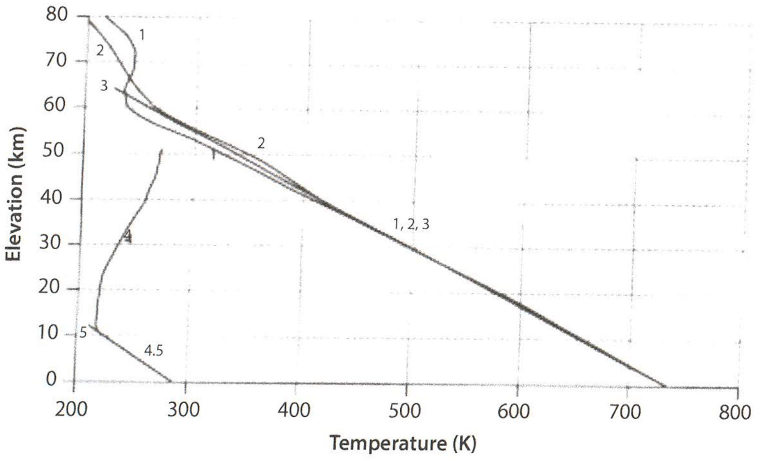

Figure 2.6 Temperature distribution in Earth's troposphere and stratosphere (*Curve 4*) and in the Venus troposphere (*Curve 2* at 30° latitude and *Curve 1* at 75° latitude) compared to theoretical temperature distributions (*Curves 5* and *3*) plotted in compliance with the greenhouse effect adiabatic theory, Eq. 2.25.

by Eq. 2.12 for the following conditions: ($\psi = 23.44°$, $T_e = 263.6$ K, $T_s = 288.2$ K, and at $\psi = 0°$; T_e=255 K, T_s; = 278.6 K); and (3) for the Earth a range of precession angles, $ba = 1.093$:

$$T_t = 288.2\left(\frac{p_t}{p_o}\right)^{\alpha} \qquad \text{(Eq. 2.18)}$$

At $\psi = 23.44$ °C, the best fit of the theoretical temperature, T_t, distribution in the troposphere and the averaged empirical data occurs at $\alpha = 0.1905$ (see Figure 2.6).

Effect of Precession Angle

By definition, the *greenhouse effect*, ΔT, is the difference between the planet's average surface temperature, T_s, and its effective temperature T_e:

$$\Delta T = T_s - T_e \qquad \text{(Eq. 2.19)}$$

Average temperature for the entire Earth's surface is approximately 288 K or 15 °C. Its effective temperature at $\psi = 0$ is $T_e = 255$ K or −18 °C. Thus, the present-day value of the *greenhouse effect* for the Earth is 33 °C.

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If we consider that the present-day Earth's precession angle is $\psi = 23.44°$, then the effective temperature of the Earth turns out to be $T_e = 263.49$ K (Sorokhtin, 2006).

The adiabatic model allows one to estimate the effect of the so-called *greenhouse gases* on the temperature regimes of the Earth's troposphere and the *greenhouse effect*. For asymptotic estimates, the writers assumed that the nitrogen-oxygen Earth's atmosphere was completely replaced first by carbon dioxide and, then, by methane, using the same atmospheric pressure, $p_s = 1$ atm or1.01324×10^2 KPa. The adiabatic exponent was determined from Eq. 2.14 at $\mu_{CO_2} = 44$, and $c_p = 0.197$ cal/g · °C, $\mu_{CH_4} = 16$, and $c_v = 0.528$ cal/gm · °C, thus, $\alpha_{CO_2} = 0.1423$ and $\alpha_{CH_4} = 0.1915$. Substituting these adiabatic, *a*, values into Eq. 2.13 with the same *b* factor value of 1.597, one can construct the temperature distribution for the hypothetical carbon dioxide and methane atmospheres. The corresponding near-surface temperature of the hypothetical carbon dioxide atmosphere would be 281.5 K, (6.4 °C) lower than that at the nitrogen-oxygen composition of the atmosphere, and for the methane atmosphere it will be 288.1 K, which is just 0.1 °C above the usual average Earth's temperature of 288 K. Thus, as the carbon dioxide atmosphere is denser and one, conversely lighter, the same pressures in these atmospheres will be attained at different elevations than those in the nitrogen-oxygen atmosphere:

$$h_{CO_2} = h_{N_2+O_2} \frac{\mu_{N_2+O_2}}{\mu_{CO_2}} \qquad \text{(Eq. 2.20)}$$

and

$$h_{CH_4} = h_{N_2+O_2} \frac{\mu_{N_2+O_2}}{\mu_{CH_4}} \qquad \text{(Eq. 2.21)}$$

where $\mu_{N_2+O_2} (= 28.9)$ is the molar weight of the nitrogen-oxygen atmosphere, and $\mu_{CO_2} (= 44)$ and $\mu_{CH_4} (=16)$ are the molecular weights of carbon dioxide and methane, respectively. The constructed temperature distributions within the hypothetical totally carbon dioxide and totally methane atmospheres are shown in Figure 2.7 together with the already presented the existing nitrogen-oxygen temperature distribution in the Earth's atmosphere (Figure 2.6).

Thus, for the hypothetical carbon-dioxide atmosphere with the same near-surface pressure of 1 atm, the average Earth's surface temperature

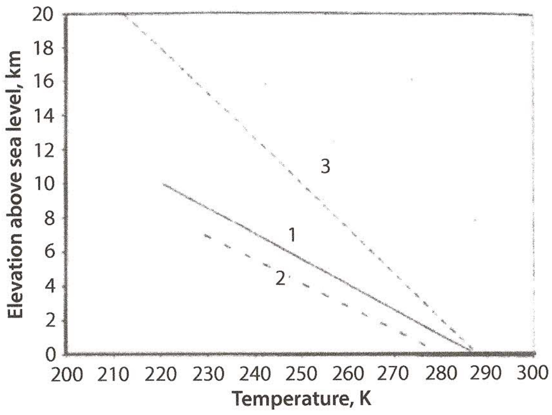

Figure 2.7 Averaged temperature distributions in the Earth's troposphere using Eq. 2.25: *Curve 1* – Earth's troposphere with a nitrogen-oxygen atmosphere; *Curve 2* – Earth's atmosphere composed totally of carbon dioxide; and *Curve 3* – Earth's atmosphere composed totally of methane. (After Chilingar *et al.*, 2009, p. 1210, figure 2.)

declines by approximately 6.5 °C (and not increasing significantly as commonly believed). Besides, due to a higher molecular weight of carbon dioxide, temperature within the entire thickness of such a troposphere is always lower than in a nitrogen-oxygen troposphere.

For a hypothetical methane atmosphere, the near-surface temperature at sea level remains almost unchanged, because $\alpha_{N_2+O_2} = 0.1905 \approx \alpha_{CH_4} = 0.195$. At the same time, in the troposphere it is higher than that for the nitrogen-oxygen atmosphere, because $\mu_{CH4}(=16) < \mu_{N_2-O_2}(=28.9)$, the methane atmosphere is much thicker than the nitrogen-oxygen one. That is why in the mountainous areas, surface temperature may significantly increase under such an atmosphere.

Similarly, on substituting a hypothetical nitrogen-oxygen for a carbon-dioxide Venetian atmosphere, at the same pressure of 90.9 atm, the Venetian surface temperature will rise from 735 to 795 K (462 to 522 °C; see Figure 2.7).

These estimates show that saturation of the atmosphere with carbon dioxide, with all other conditions being equal, results not in an increase, but rather a decrease of the *greenhouse effect* and the average temperature within the entire layer of the planet's troposphere. This happens despite intense absorption of the heat of radiation by CO_2. The physical explanation of this phenomenon is clear: molecular weight of carbon dioxide is 1.5 times higher and its heat-absorbing capacity is 1.2 times lower than those of the Earth's air. As a result (see Eqs. 2.14 and 2.18), the adiabatic exponent, for

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a carbon dioxide atmosphere, at the same conditions, is about 1.34 times lower than that for a nitrogen-oxygen humid air: $\alpha_{N_2+O_2} = 0.1905$.

From the thermodynamic viewpoint, the explanation of this phenomenon lies in the fact that the heat release from the troposphere occurs mostly due to air mass convection, which is a much more efficient mechanism, where the gas molecules are closer together, than the heat transfer by radiation. After the greenhouse gases absorb the heat of radiation, the energy of this radiation is converted into energy of thermal oscillations of gas molecules. This, in turn, leads to the expansion of the gas mixture and its rapid rise toward the stratosphere, where due to the rarified nature of the stratosphere, the excess heat is radiated into space.

Therefore, in a troposphere with an elevated carbon dioxide content the convection of the atmospheric gases will substantially accelerate.

Under the classic version of the *greenhouse effect* theory, the solar constant in Eqs. 2.3 and 2.5 are divided by four as the Sun-illuminated disk is four times smaller than the total surface of the revolving Earth. Strictly speaking, such action is valid only if the planet's revolution axis is perpendicular to the plane of the ecliptics, that is, if the precession angle $\psi = 0$. The precession angle, y, is the angle between the planet's revolution axis and the perpendicular to the ecliptics plane.

Examining an extreme situation of a planet *lying on its side*, its revolution axis is in the plane of the ecliptics and directed toward the Sun. The total area of the illuminated Earth is then somewhat lower than the visible Earth's circle, whereas when its revolution axis is perpendicular to the direction toward the Sun, the total planet's area is again four times the area of its illuminated circle. The determination of the effective temperature for the solar constant in Eq. 2.5 must be divided not by four, but by a value N where $4 > N > 2$. For intermediate cases, with the Earth's revolution axis inclined to the ecliptics, it is necessary to consider the proportionality of these two extreme cases to the inclination angle and its complement (for today's Earth, $N \approx 3.5$).

The Earth's equator is presently inclined to its orbital ecliptic at the angle $\psi = 23.44°$. Therefore, the areas beyond the polar circle are illuminated by the Sun on the average half a year and are devoid of the solar light during another half. While one near-polar area is illuminated by the Sun, another one is in the dark. Because of this, while calculating the average annual effective temperature for the polar areas, one should divide the solar constant by four, not by two. Taking sphericity of the Sun-illuminated polar area into account, the divisor should be $2(S_s/S_e)$, where S_s is the Earth's near-polar area beyond the polar circle and S_0 is the areal extent of the near-polar area projection onto the planet's equatorial plane:

$$\frac{S_s}{S_o} = 2\left[\left(\frac{1-\cos\psi}{(\sin\psi)^2}\right)\right] = \left[\frac{2}{(1+\cos\psi)}\right] \qquad \text{(Eq. 2.22)}$$

For the other areas of the Earth's regularly illuminated by the Sun, the Eqs. 2.3, 2.5 and 2.10 are valid. The Earth's effective temperature, T_e, can be determined using the following equation (Sorokhtin, 2006):

$$T_e = \left[\frac{S(1-A)}{\sigma\left\{4\left(\frac{\frac{\pi}{2}-\psi}{\frac{\pi}{2}}\right)+4\left(\frac{\psi}{\frac{\pi}{2}}\right)\left(\frac{1}{1+\cos\psi}\right)\right\}}\right]^{\frac{1}{4}} \qquad \text{(Eq. 2.23)}$$

Because the current precession angle of the Earth is $\psi = 23.44°$, the factor in the denominator of Eq. 2.23 is:

$$4\left[\left\{\frac{\left(\frac{\pi}{2}-\psi\right)}{\frac{\pi}{2}}\right\}+\left\{\frac{\psi}{\frac{\pi}{2}}\right\}\left\{\frac{1}{1+\cos\psi}\right\}\right] = 3.502 \qquad \text{(Eq. 2.24)}$$

For an Earth's albedo, $A = 0.3$, the effective temperature as calculated by Eq. 2.23 is $T_e = 263.6$ K. The tropospheric temperature, including the surface temperature, may be expressed through the planet's effective temperature:

$$T_t = b^{\alpha}\left[\frac{S(1-A)}{\sigma\left\{4\left(\frac{\frac{\pi}{2}-\psi}{\frac{\pi}{2}}\right)+4\left(\frac{\psi}{\frac{\pi}{2}}\right)\left(\frac{1}{1+\cos\psi}\right)\right\}}\right]^{\frac{1}{4}}\left(\frac{p_t}{p_o}\right)^{\alpha} \qquad (2.25)$$

Empirically, the average near-surface Earth temperature at a pressure of $p = p_o = 1$ atm and $\psi = 23.44°$ is approximately 288 K or +15 °C (The Atmosphere, 1988; Reference Book, 1951).

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Using today's values for the Earth, e.g., the present-day precession angle at $\Psi = 23.44^\circ$, $A \approx 0.3$, $\alpha = 0.1905$ and the near-surface pressure at the sea level $p_s = 1$ atm, the proportionality coefficient, b, as defined by Eq. 2.10, can be determined based on a condition that the present day average Earth's surface temperature is 288 K or +15 °C (Bachinsky *et al.*, 1951). Then $b = 1.597$ and for the oxygen--nitrogen atmosphere $b^\alpha = 1.093$. At a constant albedo, A, but a different composition of the atmosphere, b, (coefficient value for Earth) remains the same, whereas b^α will change depending on the value of the adiabatic exponent α describing the atmosphere composition.

Table 2.1 was developed using Eq. 2.25, the equation used for estimating Earth's troposphere temperature distribution, T_r, based on a pressure set taken from the standard atmosphere model (Bachinsky *et al.*, 1951). These results were based on the present-day precession angle $\Psi = 23.44^\circ$, assuming $p_s = p_o = 1$ atm as shown in Figure 2.6. Table 2.1 shows that the estimates for the Earth agree with the temperature distribution in the tropospheric model of the standard Earth atmosphere within an accuracy of about 0.1%. The standard Earth atmospheric model in its substance is averaged over the entire Earth based upon correlation of the temperature and pressure vs. the elevation above the sea level. This tropospheric model with the gradient of 6.6 K/km is customarily used for tuning aviation altimeters and calibrating barometers intended for surface observations.

Application of Adiabatic Equation to the Planet Venus

A more rigid check of the Eq. 2.25 is its application to another planet, Venus. The estimation of temperature distribution for Venus's troposphere of a different atmosphere of dense carbon gases is based on actual measurements of its atmospheric pressure and composition. The temperature for the Venus troposphere was measured by using satellites. Two sets of data are available for this study: (1) the one presented in Planet Venus (1989): $p_s = 90.9$ atm and $T_s = 735.3$ K; and (2) data presented by Marov (1986): $p_s = 95$ atm, $T_s = 740$ K, $S = 2.62 \times 10^6$ erg/cm$^2 \cdot$ s, $A = 0.77$ and $\Psi \approx 3^\circ$. It was assumed that $A = 0.76$ and $\Psi \approx 3.18^\circ$. Using a similar technique for Venus as was done for the Earth, the best fit of the theoretical temperature distribution with its empirical values occurs at the adiabatic exponent $a = 0.1786$ and ba factor of 1.429 ($b = 7.37$). For Venus, $c_p = 0.2015$ cal/g $\cdot$ °C, $T_s = 735.3$ K and $T_e = 230.5$ K. Then, $C_r = 0.1756$ cal/gm $\cdot$ °C, $C_w = 0.1213$ cal/g $\cdot$ °C and $C_q = (C_r + C_w) = 0.0543$ cal/g $\cdot$ °C. The C_r

Table 2.1 Temperature distribution in the Earth's troposphere and tropopause based\upon the Earth's standard atmosphere.

Standard atmospheric model (Bachinsky, 1951)					**Theoretical estimate (Eq. 2.25)**		
***h*, km**	***p*, mm Hg**	***T*, °C**	***T*, K**		***p*, atm**	***T*, K**	***T*, °C**
0.0	700.00	15.00	288.00	Troposphere	1.00	288.00	15.00
0.5	716.01	11.75	284.75		0.9421	284.75	11.77
1.0	67411	8.50	281.50		0.8870	281.50	8.50
1.5	634.21	5.25	278.25		0.8345	278.24	5.24
2.0	596.26	2.00	275.00		0.7846	275.00	2.00
2.5	560.16	−1.25	271.75		0.7371	271.74	−126
3.0	525.87	−4.50	268.50		0.6919	268.49	−431
3.5	493.30	−7.75	265.25		0.6491	265.24	−7.76
4.0	462.40	−11.00	262.00		0.6084	262.00	−11.00
4.5	433.10	−14.25	258.75		0.3699	285.75	−14.25
5.0	405.33	−17.50	255.50		0.3333	255.49	−17.51
5.5	379.04	−20.75	252.25		0.4987	252.25	−20.75
6.0	354.16	−2400	249.00		0.4660	249.01	−23.99
6.5	330.72	−27.25	245.75		0.4345	245.71	−27.29
7.0	308.52	−30.50	242.50		0.4059	242.55	−30.45
7.5	287.55	−33.75	239.25		0.3784	239.33	−33.67
8.0	267.79	−37.00	236.00		0.3524	236.10	−36.90
8.5	240.16	−40.25	232.75		0.3278	232.87	−40.13
9.0	231.62	−43.50	229.50		0.3048	229.67	−13.33
9.5	215.09	−46.75	226.25		0.2830	226.44	−46.56
10.0	199.60	−50.00	223.00		0.2626	223.24	−19.75
10.5	185.01	−53.25	219.75		0.2434	220.03	−52.97
11.0	171.34	−56.50	216.50		0.2254	216.84	−56.16
11.5	160.11	−56.50	216.50	Tropo-pause	0.2107	214.07	−58.93
12.0	I40M	−56.50	216.50		0.1969	211.32	−61.68

Table 2.2 Venus tropos
mated from Eq. 2.25.

Empirical data from		
***h*, km**	***T*, K**	***p*, b**
0	735.3	92.
1	727.7	86.
2	720.2	81.
3	712.4	76.
4	704.6	71.
5	696.8	66.
6	688 8	62.
7	681.1	58.
8	673.6	54.
9	665 8	50.
10	658.2	47.
12	643.2	41.
14	628 1	35.
16	613.3	30.
18	<97.1	26.
20	580.7	22.
22	564.3	19.1
24	547.5	16.2
26	530.7	13.7
28	513.8	11.4
30	496.9	9.5
Measurement latitude 0-		
33	471.7	7.2
36	448.0	5.3
39	425.1	3.9
42	403.5	2.8
45	385.4	1.9
48	366.4	1.3
51	342.0	0.9
54	312.8	0.6
57	282.5	0.3
60	262.8	0.2

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stimate	
K	*T*, °C
00	15.00
75	11.77
50	8.50
24	5.24
00	2.00
74	−126
49	−431
24	−7.76
00	−11.00
.75	−14.25
.49	−17.51
.25	−20.75
.01	−23.99
.71	−27.29
.55	−30.45
.33	−33.67
.10	−36.90
.87	−40.13
.67	−13.33
.44	−46.56
.24	−19.75
.03	−52.97
.84	−56.16
.07	−58.93
.32	−61.68

Table 2.2 Venus troposphere: empirical temperature and the temperature estimated from Eq. 2.25.

Empirical data from Planet Venus, 1989					**Theoretical calculated data, Eq. 2.25**		
***h*, km**	***T*, K**	***p*, bar**	***T*, K**	***p*, bar**	***h*,km**	***p*, atm**	***T*, K**
0	735.3	92.10			0	90.92	736.9
1	727.7	86.45			1	85.34	728.6
2	720.2	81.09			2	80.05	720.3
3	712.4	76.01			3	75.03	712.1
4	704.6	71.20			4	70.29	703.8
5	696.8	66.65			5	65.79	695.5
6	688 8	62.35			6	61.55	687.3
7	681.1	58.28			7	57.53	679.1
8	673.6	54.44			8	53.74	670.9
9	665 8	50.81			9	50.16	662.7
10	658.2	47.39			10	46.78	654.4
12	643.2	41.12			12	40.59	638 1
14	628 1	35.57			14	35.11	621 8
16	613.3	30.66			16	30.27	605.5
18	<97.1	26.33			18	25.99	589.2
20	580.7	22.52			20	22.23	573
22	564.3	19.17				18.92	556.8
24	547.5	16.25			24	16.04	540.6
26	530.7	13.70			26	13.32	524.3
28	513.8	11.49			28	11.34	508.1
30	496.9	9.581			30	9.458	491.9
Measurement latitude 0–30”			Meas. latitude. 75’		Theoretical estimate		
33	471.7	7.211	471.7	7.211	33	7.118	467.6
36	448.0	5.346	4465	5.345	36	5.277	443.2
39	425.1	3.903	420 5	3.894	39	3.848	418.9
42	403.5	2.802	394.5	2.78	42	2.755	394.6
45	385.4	1.979	368.7	1.941	45	1.935	370.5
48	366.4	1.375	3433	1.321	48	1.331	346.6
51	342.0	0.9347	318.5	0.8741	51	0.8905	322.6
54	312.8	0.6160	290.0	0.3582	54	0.5796	298.7
57	282.5	0.3891	258.2	0.3392	57	0.3595	274.3
60	262.8	0.2357	2373	0.1918	60	0.2125	249.7

parameter determines the absorption of the planet's heat radiation by atmosphere. Its relatively elevated temperature value is due to a high atmospheric pressure and very hot troposphere. One can assume $C_w < 0$ for the Venus troposphere where endothermic reactions predominate, especially in its lower and middle layers. There is dissociation of some chemical compounds, for instance, dissociation of the sulfuric acid into $SO_3^{=}$ and water: $H_2SO_4 + Q \rightarrow SO_3^{=} + H_2O$, where $Q \approx 15$ kcal/mol. For the upper layer of the Venetian troposphere at the elevations between 40 and 60 km, $C_w > 0$. Therefore, the exothermic chemical reactions, e.g., the reduction of sulfuric acid, and condensation of water vapor in the clouds prevail. The best match of the theoretical curve with empirical data occurred at $a = 0.1786$, coefficient $b = 7.372$ and $b^a = 1.429$.

Again, a check was conducted using Eq. 2.25. The data from the check is included in Table 2.2 and is shown in Figure 2.6. As shown in Table 2.2, the theoretical temperature distribution in the Venus atmosphere shows a good match with the experimental measurements as quoted in Planet Venus (1989). Up to an elevation of 40 km, the accuracy is in fractions of a percentage point, whereas at the elevations between 40 and 60 km, theoretical temperatures are positioned between two series of empirical data. At higher elevations, $p < 0.2$ atm, the tropopause begins in the Venus atmosphere, and the adiabatic theory no longer applies as convection is no longer the primary transfer of heat.

It should not be considered accidental that a match of the derived temperature distributions is found for the troposphere's of the Earth and Venus. This is a solid confirmation of the validity of Eq. 2.25. This equation may be used for determination of the Earth's climates in the past geologic epochs and their forecast for the future. However, for this purpose it is necessary to review the evolution of the Earth's atmospheric composition and pressure of the atmospheric gases in the following chapters.

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Conclusions

"It's a paradox" (as described in Chapter 1) that despite the continual increase in ther Sun's average solar energy emissions of approximately 30% (Figure 1.10) since the beginning of the Earth's origin, the Earth's climate has cooled over the past 65 MY (see Figures 1.3 and 1.5). Furthermore, as indicated by Figure 1.7 and other temperature charts for time spans of greater than 100,000 years, the temperature of the Earth is cyclical, dependent upon the distance of the Earth from the Sun. The temperature charts prove that the average Earth's temperature is cooling rather than warming as claimed by some. Temperature charts obtained by satellite for the past 22 years show no meaningful change in temperature (Figure 1.8); this is likely due to the fact the time period is too short to display the full temperature cycle.

Chapter two develops the relationship of atmospheric pressure to temperature. In order to utilize equation for an ideal gas, the gas pressure should be less than 0.1 atmospheres. The troposphere gas pressure ranges from 1 atmosphere at sea level to about 0.3 atmosphere at its outer limits (7 to 10 miles) (see Figure 2.1). As a result, energy (heat) is primarily transferred in the troposphere by mass air convection (Figure 2.3, 2.4, and 2.5) and not radiation. Figure 2.7 demonstrates that if the Earth's atmosphere consisted of entirely carbon dioxide (at the same pressure) the Earth's surface temperature would be significantly lower and not higher as some individuals have proposed. Adding carbon dioxide to the atmosphere, lowers the amount of energy absorbed from the Sun, not increases it as proposed by many. Eq. 2.25 can be used to determine the temperature for various mixture of gases at various pressures.

As discussed in detail in the text, the development of the oceans and atmosphere have resulted in a variety of climates for the Earth over time. One must look at the long-term changes and the reason for those changes, not the short term of only a few years, as some have done, if one is to predict climate change.

Looking at the future evolution of the Earth's atmosphere, one can see a major increase in temperature that will blot out life as we know it in 600 MY. This will occur as a result of the degassing of the Earth's mantle.

Unfortunately, today the scientific community has been politicized by individuals refusing to discuss ideas different than their own. The time has come for scientific reasoning where hypotheses rise and fall by scientific facts, rather than political ones. Everyone is entitled to their own opinion, but they are not entitled to force their opinions down other people's throats; that is censorship

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