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A GENERALIZED THEORY OF SUN–CLIMATE/WEATHER LINK AND CLIMATIC CHANGE *

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ABSTRACT

We generalize the theory of Sun–Climate/weather links and climatic change developed earlier by the author. On the basis of this theory, we show mathematically that key climatic/weather parameters are continuously subjected to determinable amplitude modulations and other variations which may be useful in climatic prediction work. A number of new and known terrestrial oscillations in climate and atmospheric behaviour in general, including the known quasi-biennial oscillations and many others, are deduced from the theory and accounted for in terms of their causative physical processes. Finally we briefly discuss the possibility of applying the theory to the planets Mars and Venus as well as Saturn's largest satellite, Titan.

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1. INTRODUCTION

It has been shown that the energetics required to run the climate/weather system are directly generated by the continuous interaction among incoming solar energy, the Earth's spinning motion, and the (thermal) non-linearity of the Earth–Atmosphere system 1)–4). Consequent to a previous derivation of only the few most dominant terms in this interaction, the latter terms were used to predict climatic periodicities in different places on the Earth at time scales ranging from some months up to thousands of years. Interestingly, the predicted periodicities agreed quite well with those correspondingly deduced from actual observations or past records 3),5),6). This agreement indicates that reasonable climatic predictions may possibly be made for the future on the basis of a sufficiently detailed understanding of the interaction among the incoming solar energy, the Earth's spinning motion, and the (thermal) non-linearity of the Earth–Atmosphere system. Moreover, deeper investigations of this interaction as well as its consequences are likely to unearth new avenues in as far as meteorology and the physics of the atmosphere as a whole are concerned.

In this paper, we extend and generalize the terms which mathematically represent the interaction mentioned above. We also generalize the list of different frequencies that are expectedly generated within the Earth–Atmosphere system by this interaction. The list includes several new frequencies together with previously known frequencies. Finally, we indicate how the generalized formulations presented in the text may be applied to some of the other heavenly bodies in the solar system.

2. GENERALIZATION OF THE SUN–CLIMATE/WEATHER LINK AND CLIMATIC CHANGE THEORY

Consider a trans–equatorial area along the Earth's surface which together with the atmosphere above it will be referred to as "region ST". We assume that the latter region has the maximum possible meridional extension and that whenever the Sun scans across this region, there is a period at least equal to half of the current minimum sunrise–sunset duration in region ST in which all the parts of the region receive solar energy simultaneously with an instantaneous difference of less that $\frac{1}{2}I_0$ between the solar energy I, falling upon an arbitrary vertical column in region ST, and that correspondingly falling upon another vertical column of similar cross–sectional area located anywhere in the region, where I_0 is the maximum possible value of I within the sunlit part of the Earth–Atmosphere system. The period just mentioned is centred around the point (in time) at which region ST as a whole receives maximum solar energy per unit time as the Sun scans across. It is during this particular period that region ST receives at least $\sim 70\%$ of the total solar energy incident upon it during the whole of the corresponding Sun's scan across the region.

Straightforward analysis shows that during equinox, a single "region ST" is approximately of the form sketched in Fig. 1, being widest along the Equator and narrowing poleward up to latitudes $\sim 45^\circ N$ and $\sim 45^\circ S$.

Due to the seasonal exposure of the Earth to solar radiation, region ST shifts up to latitude $\sim 68\frac{1}{2}^\circ N$ (i.e. up to point X in Fig. 1) at the June solstice and also shifts down to latitude $\sim 68\frac{1}{2}^\circ S$ (i.e. down to point P in Fig. 1) at the December solstice. Besides, the southern edge of region ST shifts to latitude $\sim 21\frac{1}{2}^\circ S$ at the June solstice while the northern edge shifts to latitude $\sim 21\frac{1}{2}^\circ N$ at the December solstice.

Let the Earth's surface portion PGBXAF (see Fig. 1) together with the atmosphere above it be collectively termed "region A". Note that the noons for all the points along the zonal centre of region A occur simultaneously. On the basis of Fig. 1, the entire Earth–Atmosphere system is ideally divided into about 12 to 15 dimensionally equal "region A's" and two separate regions, one located southward of latitude $\sim 68\frac{1}{2}^\circ N$ and the other located northward of latitude $\sim 68\frac{1}{2}^\circ N$. The latter two regions will hereinafter be referred to simply as "polar regions". As may easily be deduced from Fig. 1, the boundary between the polar region in each hemisphere and the stack of $\sim$ 12 to 15 region A's contains a series of troughs and ridges, and apparently coincides with the Arctic front (in the northern hemisphere) and the Antarctic front (in the southern hemisphere). Theoretically, the presence of $\sim$ 12 to 15 region A's around the Earth would imply corresponding presence of no more than 8 large, zonal, thermally–driven circulation cells at any latitude covered by the region A's, notably along the Equator. According to Lockwood [7], Trewartha and Horn [8], Krishnamurti [9], Newell et al. [10] as well as the WMO [11], plots of zonal air flow near the Equator during mid–season months (i.e. June–August and December–February) and the other months revealed a maximum of 6, 4, 7, 8 and 6 main zonal circulation cells, respectively, around the Earth, in agreement with the prediction just mentioned. It should be noted that the air flows along the two adjacent arms of any neighbouring zonal circulation cells may all be in one direction or the flow in one arm may be opposite to that in the other arm as already shown [8].

The sunrise–sunset duration in each polar region varies from zero up to $\sim$ 6.3 months, quite in contrast with any of the region A's in which sunrise–sunset duration varies from $\sim$ 3.6 hours up to $\sim$ 22.0 hours. Thus each region A effectively samples out earthward solar radiation through a variable sampling "window" which is basically different from that through which a polar region effectively samples out earthward solar radiation. Note that in this paper we have used the terms "sampling window" with respect to a polar region or region A to specifically mean the non–zero part of the year–long (in the case of a polar region) or a day–long (in the case of any region A) structure of the three–dimensional plot of $\frac{\Omega(\phi,t)}{\Omega_0(\phi,t)}$ versus time t and latitude ϕ such that $\Omega(\phi,t)$ is the solar radiation incident upon the portion (at latitude ϕ) of the region involved at time t while $\Omega_0(\phi,t)$ is the corresponding solar radiation that would fall upon the maximum horizontal cross–sectional

area of the portion just mentioned but supposedly placed perpendicular to earthward solar rays and positioned at latitude ϕ on top of the region involved. Conceptually, we are using sampling windows here as samplers of earthward solar energy for a specified region in the same sense and manner that some sampling pulses are used in electronics as samplers of different voltage signals.

Since the horizontal daily displacements of any atmospheric or oceanic motion systems (with time scales exceeding $\sim$ 0.1 hour) are much smaller than the horizontal scales of the bulk of region A or any of the two polar regions [12], we may make the two following conclusions both of which are consistent with sampling theory [13]. Firstly, we may consider each polar region as a single terrestrial receiver for discretely sampling earthward solar radiation as the Earth orbits around the Sun, using a variable, three–dimensional sampling window whose time–width varies from zero to 6.3 months, depending upon season and latitude. We shall comment on this aspect later on. Secondly, we may consider portion ABGF of region A (see Fig. 1) as a single terrestrial receiver for discretely sampling earthward solar radiation as the Earth spins, using a three–dimensional sampling window whose time–width varies from about 10.9 hours to about 13.3 hours, depending upon season and latitude. Alternatively, we may consider the whole of each region A as a single terrestrial receiver for sampling earthward solar radiation provided that the variable three–dimensional sampling window used properly takes into account the seasonal and latitudinal variations upon the sampling mechanisms involved, notably for those portions located south of latitude $\sim 21\frac{1}{2}^\circ S$ and also those located north of latitude $\sim 21\frac{1}{2}^\circ N$. Clearly such a sampling window has a variable time width which changes from about 3.6 hours to about 22.0 hours, depending on latitude and season. Thus the actual solar energy that falls into region A during arbitrary time–length T is mathematically represented by a product of the earthward solar radiation $E(t)$ and a function $D(t,\phi)$ which represents the solar radiation sampling mechanism of region A during the period T as a function of time t and latitude ϕ.

We may express $E(t)$ as follows:

$$E(t) = \alpha + \sum_{k=1}^{N} f_k(t), \tag{1}$$

where α is a constant representing the constant component of incoming solar radiation, k is a positive integer, $f_k(t)$ is a regular function whose radian frequency is denoted by ω_k and N is the maximum number of sinusoidal components that make up the variable component of earthward solar radiation. Thus the variable component of $E(t)$ includes the seasonal cycle, variations in incoming solar energy due to corresponding variations in the Earth's orbital geometry (at periods ~19000 years, ~23000 years, ~41000 years, ~100000 years and ~400000 years) [14] and variations in the incoming solar energy due to corresponding solar activity (at periods ~11 years, ~22 years, 80–90 years, 170–200 years, ~400 years, ... etc.) [15].

For $\phi = 0$, function $D(t,\phi)$ takes the following form 16):

$$D(t,\phi) = \frac{2}{\pi}\left\{\lambda_T + B_T \sin\omega_{01}t + \sum_{n=1}^{\infty} b_n \cos(c_n\omega_{01}t)\right\}\left\{\sin\omega_{02}t + \right.$$
$$+ \sin(2\omega_{02}t) + \frac{1}{3}\sin(3\omega_{02}t) + \frac{1}{5}\sin(5\omega_{02}t) + \frac{1}{3}\sin(6\omega_{02}t) +$$
$$\left. + \frac{1}{7}\sin(7\omega_{02}t) + \frac{1}{9}\sin(9\omega_{02}t) + \frac{1}{5}\sin(10\omega_{02}t) + \ldots\right\}, \tag{2}$$

where the parameter $B_T \to \frac{1}{2}$ as $T \to \infty$, b_n is a constant for a given n, c_n is an even integer for a given n, λ_T is a constant parameter whose magnitude $\to \frac{1}{\pi}$ as $T \to \infty$, $\omega_{01} = 2\pi$ radians per day and $\omega_{02} = \frac{\pi}{2T}$ radians per day. On the other hand, for $\phi \neq 0$, $D(t,\phi)$ takes the mathematical form already given by Njau 17).

The solar energy incident upon region A for the whole of period T is then represented mathematically by the product $D(t,\phi)E(t)$. But due to the (thermal) non-linearity of the Earth-Atmosphere system, the corresponding response or solar energy $F(t,\phi)$ actually absorbed by region A during the period T is essentially a power series of $D(t,\phi)E(t)$. Thus if $\alpha D(t,\phi)$ and $D(t,\phi)\sum_{k=1}^{N} f_k(t)$ are denoted by $R(t,\phi)$ and $S(t,\phi)$, respectively, then:

$$F(t,\phi) = a_1(R+S) + a_2(R+S)^2 + a_3(R+S)^3 + \ldots, \tag{3}$$

where $a_1, a_2, a_3, \ldots$ are all constants. The second and higher order terms in (R+S) reflect the non-linear behaviour of the system. Obviously, as regards the Earth or any other planet, non-linearity is enhanced by the presence of exposed liquid bodies such as oceans in addition to an atmosphere. Eq. (3) may be reorganized into the following equivalent but certainly more informative form:

$$F(t,\phi) = \left\{ \underbrace{a_1 S\left[1 + \frac{2a_2}{a_1}R\right]}_{\text{amplitude-modulated terms}} + \underbrace{a_2 S^2\left[1 + \frac{3a_3}{a_2}R\right]}_{\text{amplitude-modulated terms}} + \underbrace{a_3 S^3\left[1 + \frac{4a_4}{a_3}R\right]}_{\text{amplitude-modulated terms}} + \right.$$
$$\left. + \underbrace{a_4 S^4\left[1 + \frac{5a_5}{a_4}R\right]}_{\text{amplitude-modulated terms}} + \underbrace{a_5 S^5\left[1 + \frac{6a_6}{a_5}R\right]}_{\text{amplitude-modulated terms}} + \ldots\ldots\ldots\ldots\ldots \right\} +$$
$$+ \underbrace{\left\{a_1 R + a_2 R^2 + a_3 R^3 + a_4 R^4 + a_5 R^5 + \ldots\right\}}_{\text{terms whose variabilities are largely dictated by the Earth's spinning motion}} +$$
$$+ \left\{ S\left[3a_3R^2 + 4a_4R^3 + a_5R^4 + 6a_6R^5 + 7a_7R^6 + \ldots\right] + \right.$$
$$+ S^2\left[6a_4R^2 + 10a_5R^3 + 15a_6R^4 + 21a_7R^5 + 28a_8R^6 + \ldots\right] +$$
$$\left. + S^3\left[10a_5R^2 + 20a_6R^3 + 35a_7R^4 + 56a_8R^5 + 84a_9R^6 + \ldots\right] + \ldots \right\}. \tag{4}$$

We shall first analyze and interpret the last equation in fair detail with respect to region A before generalizing the results over the entire Earth-Atmosphere system. An analysis of Eq. (4) clearly shows that all the oscillation frequencies contained in $F(t,\phi)$ may be given generally by the following equation:

$$\begin{aligned}\text{Frequencies in } F(t,\phi) = \Big\{&\text{Each frequency in non} - \text{zero } a_m R^m, \text{ where}\\ &m = 1,2,3,\ldots\Big\},\ \Big\{\text{Each frequency in non} - \text{zero}\\ &a_m S^m, \text{ where } m = 1,2,3\ldots\Big\},\ \Big\{\Big|\Big[\text{Each frequency}\\ &\text{in non} - \text{zero } a_m S^m, \text{ where } m = 1,2,3,\ldots\Big] \pm \Big[\text{Each}\\ &\text{frequency in R}\Big]\Big|\Big\},\ \text{ and } \Big\{\Big|\Big[\text{Each frequency}\\ &\text{in } S^k\Big] \pm \Big[\text{Each frequency in } a_{k+p+1}R^{p+1} \text{ for}\\ &p = 1,2,3,\ldots\Big]\Big|,\ \text{where } k \text{ which is initially}\\ &\text{equal to 1 is raised by 1 each time } p \text{ completes}\\ &\text{an increasing cycle}\Big\}.\end{aligned} \tag{5}$$

An analysis of Eq. (4) also shows that in the limit that $T \to \infty$, the significant oscillations in $R(t,\phi)$ are only the diurnal cycle and its even harmonics. This means that the significant oscillations correspondingly present in $F(t,\phi)$ are: the diurnal cycle and its harmonics, cycles in $\left(\sum_{k=1}^{N} f_k(t)\right)^n$, where $n = 1,2,3,\ldots$, and a string of oscillations due to interactions between the latter cycles and the diurnal cycle as well as its harmonics. This should not be surprising because as T is increased, all the non-zero oscillations in $D(t,\phi)$ except the diurnal cycle and its harmonics become progressively weaker until they are all virtually zero at $T = \infty$. If this were not the case, it would be possible for the Earth to be plunged into unusually warm conditions or an ice age for an indefinitely long period, leading to possible substantial destruction of living species. Let us now look at what happens when T is finite. In this case, $R(t,\phi)$ contains a string of significant frequencies spread around that of the diurnal cycle and each of its harmonics. In addition, $R(t,\phi)$ contains a number of other oscillations at different T-dependent frequencies if α (in Eq. (1)) > 0. These other oscillations (which will hereinafter be referred to as "RO oscillations") are generated by the continuous interference among (solar) energy influences/disturbances from the solar energy sampling windows for region A over the period T 16),18). In physical terms, RO oscillations basically result from leakage of energy from the constant-component of incoming solar energy into other (non-zero) frequencies. For further clarity, let us assume that there are a total of N sampling windows over period T, and that the phase difference between any two adjacent windows is δ. Then, whenever δ is an integer multiple of 2π, the energy disturbances from all the N windows are exactly in phase and hence they interfere constructively. Consequently, maximized influences are channelled to the frequencies concerned. This condition occurs and hence favours oscillations at zero frequency as well as at the frequencies corresponding to the diurnal cycle and its harmonics. On the other hand, RO oscillations are continuously generated under the condition $\delta \approx \left(\frac{2m\pm1}{N}\right)\pi$ or $\left(\frac{2m\pm1}{N}\right)\frac{1}{2}\pi$ or $\frac{\pi}{2N}$ or $\frac{\pi}{N}$, where m is a positive integer 1)-4). In other words, RO oscillations are produced at those frequencies for which the energy disturbances/effects from all the N windows interfere with each other to form a resultant disturbance DS whose phase is an odd multiple of π or an odd multiple of $\frac{\pi}{2}$. However, no oscillations are formed at the frequencies for which the phase of DS is an integer multiple of 2π, that is $\frac{\delta}{2} = \frac{m\pi}{N}$. This is because the mini-disturbances that make up DS cancel each other vectorially. It is obvious that if $T \to \infty$, then $N \to \infty$ and hence $\delta \to 0$. On this basis, RO oscillations virtually disppear when $T \to \infty$, as already implied.

As indicated by Eq. (4), both the RO oscillations and the cycles in $E(t)$ do exist rather independently in the Earth–Atmosphere system, and that these two types of variations exist simultaneously anywhere in the latter system at which $\alpha > 0$. Now since both RO oscillations and the cycles in $E(t)$ coexist together in time and space, we should expect them to (at least partly) interact or physically mix with each other. In fact, it has been shown 16),17) that RO oscillations, which were first discovered about three years ago 1),2), do interact with any given cycle in $\sum_{k=1}^{N} f_k(t)$, say at period H, to form a number of quasi-stable oscillations at periods $\sim 2H$, $\sim 1\frac{1}{3}H$, $\sim \frac{4}{5}H$ and $\sim \frac{2}{3}H$ (these are the relatively most dominant), $\sim 4H$, $\sim \frac{2}{5}H$, $\sim \frac{4}{7}H$, $\sim \frac{2}{7}H$, $\sim \frac{2}{3}H$, $\sim \frac{4}{9}H$, $\sim \frac{4}{11}H$, ... and a number of others. This, in my opinion, gives us a clue regarding the causes of several climatic quasi-stable oscillations (including the well-documented quasi-biennial oscillations) which have been widely observed but whose causes had hitherto remained unknown 14). Thus, on the basis of the known cycles comprising $\sum_{k=1}^{N} f_k(t)$, we would expect quasi-stable oscillations to be formed continuously in the Earth–Atmosphere system at the following periods: ~2 years, $\sim 1\frac{1}{3}$ years, $\sim \frac{4}{5}$ year, $\sim \frac{2}{3}$ year (these are relatively most dominant within a time-length of up to some few thousand years), ~6.9 months, ~4.8 months, ~3.4 months, ~5.3 months, ~4.0 years, ~14.7 years, ~22 years, ~6.3 years, ~7.3 years, ~8.8 years, ~9.8 years, ~12.6 years, ~17.6 years, ~29.3 years, 32–36 years, ~44 years, 53–60 years, 64–72 years, 107–120 years, 113–133 years, 136–160 years, 160–180 years, 227–267 years, ~320 years, 340–400 years, ~533 years, 680–800 years, ~1300 years, ~1600 years, ~2400 years, ~12700 years, ~15200 years, ~18400 years, ~25000 years, ~27000 years, ~30600 years, ~32800 years, ~38000 years, ~46000 years, ~53300 years, ~67000 years, ~80000 years, ~92000 years, ~130000 years, ~164000 years, ~200000 years, ~267000 years, ~320000 years, ~532000 years, ~800000 years, ~1600000 years, and others as may be deduced from Eqs. (4) and (5). The periods just reproduced above are only some of the most dominant ones among those produced by physical interactions between RO oscillations and the known cycles represented by the variable components of $E(t)$ in Eq. (1). In fact, the list of periods resultant from the latter interactions may be further elongated to include other relatively less dominant periodicities.

Just as the cycles in $E(t)$ continuously interact with RO oscillations to produce quasi-stable oscillations (such as quasi-biennial oscillations and others), harmonics of the cycles in $E(t)$ also interact with corresponding RO oscillations to form other quasi-stable oscillations. Let us consider an arbitrary cycle in $E(t)$ whose period is denoted by H.

The harmonics of this cycle do interact with some RO oscillations to produce quasi-stable oscillations at periods $\sim \frac{1}{3}H$, $\sim \frac{2}{5}H$, $\sim \frac{2}{3}H$, and $\sim H$ (these are the relatively most dominant periods), $\sim \frac{1}{5}H$, $\sim \frac{2}{7}H$, $\sim \frac{2}{9}H$, $\sim \frac{1}{7}H$, $\sim \frac{4}{15}H$, $\sim \frac{4}{9}H$, $\sim \frac{4}{21}H$, $\sim \frac{2}{15}H$, $\sim \frac{2}{21}H$, $\sim \frac{4}{21}H$, ... and others. For example, if H is the period of the seasonal cycle, then we would expect production of quasi-stable oscillations at periods ~8.0 months, ~4.0 months, ~4.8 months, and ~1 year (these are the most dominant periods), ~73.0 days, ~3.4 months, ~81.1 days, ~52.1 days, ~3.2 months, ~5.3 months, ~69.5 days, ~48.7 days, ~34.8 days, ~54.1 days, ... and others. A deeper and wider picture of the oscillations present in the Earth–Atmosphere system may be realized from a more detailed analysis of Eqs. (4) and (5).

It is quite encouraging to note that all the periods of the widely observed climatic variations already reported in the literature 6),7),15),16) coincide with the periods cited or discussed above 6),14)–17). This implies that the causes of these widely observed variations may be given by the (climatic change) theory outlined above and which will be further discussed later on in the paper.

It is expected 16),17) that quasi-biennial oscillations and the other quasi-stable oscillations at periods $\sim 1\frac{1}{3}$, $\sim \frac{4}{5}$ and $\sim \frac{2}{3}$ years (mentioned earlier in connection with interactions between the seasonal cycle and RO oscillations) would manifest themselves more significantly in the regions sandwiched between latitudes $\sim 68\frac{1}{2}^{\circ}S$ and $\sim 68\frac{1}{2}^{\circ}N$. Outside the latter range, these oscillations become less pronounced mainly due to complications introduced by the fact that the time-width of the solar energy sampling window at the northern or southern polar region varies widely from zero in winters up to ~ 6.3 months in summers. These complications effectively make the corresponding RO oscillations at periods of up to a few years significantly weaker than their counterparts at non-polar regions 17), and even much weaker than the polar seasonal cycle. But since it is these significantly weakened polar RO oscillations which are expected to interact with the polar seasonal cycle in order to produce quasi-stable oscillations at periods ~2 years, $\sim 1\frac{1}{3}$ years, $\sim \frac{4}{5}$ years, $\sim \frac{2}{3}$ years and other relatively weaker ones, we would not expect oscillations at the latter periods to show up at polar regions as distinctly as they do at non-polar regions.

It is now clear that if the version of $D(t,\phi)$ for which $\sim 68\frac{1}{2}^{\circ} \lesssim \phi \leq 90^{\circ}$ (see Njau 17) for further details) is introduced into Eqs. (4) and (5), the resultant equations would be specifically suitable for the polar regions. In this case, these regions are looked upon as samplers of earthward solar energy which are equipped with latitude-dependent sampling windows whose dimensions are oscillated or modulated in line with the corresponding seasonal influences 17). The maximum time-width of each of the latter sampling windows is approximately equal to half of the seasonal cycle period, implying that even harmonics of the seasonal heat/temperature cycle are suppressed at polar regions. Similar analysis over Equatorial regions (where sunrise-sunset duration is about half of the diurnal cycle period) leads to the conclusion that even harmonics of the diurnal heat/temperature cycle in the latter regions are expectedly suppressed as verified by hourly temperature records from these regions.

As shown by Eq. (4), the continuous interactions among the Earth's spinning motion, earthward solar energy and the (thermal) non-linearity of the Earth–Atmosphere system continuously introduce a pattern of heat/temperature distribution cycles in region A. Also as shown earlier in the paper, the entire Earth–Atmosphere system may be subdivided into ~12–15 region A's and 2 main polar regions each of which is characterized by respective patterns of heat/temperature cycles appropriately derived from Eqs. (4) and (5). Ideally, the patterns for any two region A's are fairly identical except for phase differences. Apart from the periodicities due to interactions between seasonal cycles and RO oscillations, the main periodicities in the polar regions should be fairly similar to those in any of the region A's. Now when viewed together, all these heat/temperature patterns continuously maintain uneven and time-dependent heat/temperature distributions in the whole of the Earth–Atmosphere system. These patterns in turn create density inhomogeneities and hence pressure forces which directly drive or influence the atmospheric and oceanic circulation systems on which climate/weather ultimately depends. Hence any changes in these heat/temperature distribution patterns give rise to corresponding changes in the circulation systems and hence in climate/weather. In short, this is how the heat/temperature distribution patterns shown mathematically in Eq. (4) give rise to significant winds, ocean currents, rainfall and temperature changes [16]. It has been shown [1–4,16] that aside from the diurnal cycle and its harmonics, the amplitude of the most dominant cycle in $R(t,\phi)$ for any value of finite T is $\sim 1\%$ to $\sim 20\%$ of the corresponding constant component of incoming solar energy [1–3,5,6,16,17]. This clearly implies that, on the basis of realistic climatic and weather energetics [10], the variations represented by Eq. (4) are energetic enough to drive any normal climatic/weather processes over any length of time.

The Earth–Atmosphere system absorbs solar energy mostly in three separate regions, namely, the surface–troposphere region (which absorbs solar energy at wavelength range $\sim 0.34\mu m - 3\mu m$), the ozonosphere (which absorbs solar enegy at wavelength range $\sim 0.175\mu m - 0.34\mu m$) and the ionosphere (which absorbs solar energy at wavelength range $\sim 0.0001\mu m - 0.175\mu m$). The implication is that each of these regions would have its own particular version of Eqs. (4) and (5), depending on the corresponding form of $E(t)$ since the function $D(t,\phi)$ would be, at least approximately, similar for all the three regions provided they have fairly equal latitudinal and longitudinal locations [17,18]. As is well known [20], the variable component in $E(t)$, which is solely due to solar activity, is almost entirely in the far ultra-violet region. The effects of this component are restricted to the upper atmosphere where it is completely absorbed. We may draw two conclusions from this observation. Firstly, the upper atmosphere is expected to be significantly influenced by solar activity. Secondly, solar activity does not significantly influence the versions of Eqs. (4) and (5) that are specifically tailored for any surface–troposphere region and hence does not significantly influence climatic/weather variations. This is fully supported by past observations which have confirmed that solar activity has profound influence on the behaviour of the upper atmosphere but its influence upon the climate of the lower troposphere still remains very obscure [21,22]. In my opinion, this is good news for meteorology because it implies that it is not necessary to predict solar activity before making reasonable climatic predictions. On the other hand, reasonable ionospheric predictions have to involve prediction of solar activity.

Each of the planets Venus and Mars as well as Saturn's largest satellite, Titan does possess a substantial atmosphere and receives virtually all of its energy from the Sun just as the Earth does. Both Venus and Mars also perform regular spinning motions. Although Titan does not perform spinning motion, it revolves around Saturn at a period of 15.945 days while keeping the same face turned towards Saturn. This effectively means that Titan somehow rotates its face in front of the Sun regularly, making a complete rotation in 15.945 days. Note that Titan's axis of rotation is inclined at 26° with respect to the plane of the solar system. Thus in either Venus or Titan or Mars or the Earth, the Sun-induced horizontal differences in heat/temperature are the driving mechanism of the local atmospheric (and any oceanic) circulation system [23]. This implies that we could easily modify Eqs. (4) and (5) into versions that may be applied directly to Venus, Mars or Titan as follows. Firstly, the components in $E(t)$ are modified in order to represent the characteristics of the solar energy stream reaching the chosen heavenly body. Secondly, the value of parameter ω_{01} in $D(t,\phi)$ is changed from 2π radians per day to 2π radians per 116.8 days (in the case of Venus) or 2π radians per 24 hours 37 minutes (in the case of Mars) or 2π radians per 15.945 days (in the case of Titan). Thirdly, the value of parameter ω_{02} in $D(t,\phi)$ is changed into $\frac{\pi}{2T}$ radians per 24 hours 37 minutes (in the case of Mars) or $\frac{\pi}{2T}$ radians per 116.8 days (in the case of Venus) or $\frac{\pi}{2T}$ radians per 15.945 days (in the case of Titan). Fourthly, the ϕ–dependent terms in $D(t,\phi)$ are formulated in accordance with the situation involved. Finally the constants $a_1, a_2, a_3, \ldots$ are evaluated according to the (thermal) non-linearity of the particular body–atmosphere system involved.

On the basis of the short account just given, two main categories of oscillations expectedly exist over Venus and Titan. The first category includes obvious oscillations on both Venus and Titan such as the cycles in solar activity (i.e. at periods ~11 years, ~22 years, 80–90 years, 170–200 years, ~400 years, ..., etc.), a seasonal oscillation at period 224.7 days on Venus, a seasonal oscillation at period 29.46 years on Titan, and periodic variations on both Venus and Titan due to corresponding variations in the orbital elements and axial inclinations of Venus and Titan as analogously detailed in the Milankovitch theory for terrestrial ice–ages. The second category includes less obvious quasi-stable oscillations which are formed by physical interactions comparable to those mentioned earlier as being the causes of terrestrial quasi-stable oscillations. Those which are partly related to the seasonal cycles have periods ~ 19.6 years, ~58.92 years, ..., etc. over Titan and ~104.3 days, ~449.4 days, ... etc. over Venus. On the other hand, those quasi-stable oscillations which are partly related to solar activity cycles have the following periods on both Venus and Titan: ~7.3 years, ~8.8 years, ~22 years, ~29.3 years, ~44 years, 53–60 years, 107–120 years, 160–180 years, ..., etc. Note that the length of a "solar day" (i.e. a complete local diurnal cycle) on Venus is approximately equal to the period of the ~104.3 days oscillation given above. This information together with the nearly anti-phase relationship between the latter and the local diurnal cycle may be at least one of the reasons that make temperatures over the visible surface of Venus remain virtually constant regardless of day or night [24].

Modification of Eqs. (4) and (5) in order to be applicable to Mars is relatively more involving than in the cases for Venus and Titan because Mars has an albedo which varies considerably with time [25]. This is unlike the case of Venus whose albedo is about 76% and Titan whose albedo is about 18%. Besides, about 2% and 5–10% of the overall incident solar energy reaches the surfaces of Venus and Titan, respectively [26,27].

Unfortunataly, we cannot modify Eqs. (4) and (5) that easily so that they may suit the other planets Jupiter, Saturn, Uranus, Neptune, Mercury and Pluto. This is basically because even though they have substantial atmospheres, the planets Jupiter, Saturn, Neptune and (possibly) Uranus emit more energy (from internal sources) than they receive from the Sun, and that Mercury and Pluto hardly possess substantial atmospheres [25].

3. CONCLUSION

We have generalized the theory proposed earlier by the author, which basically explains Sun–climate/weather links and the process of climatic change. Climatic oscillations whose periods are larger or much smaller than those of the Milankovitch cycles are well accounted for by the theory, something which the Milankovitch theory apparently failed to do. The oscillations which, according to this theory, are created in the Earth–Atmosphere system over any given length of time T may be determined by using Eqs. (4) and (5). Thus climatic variations on all possible time scales are covered by our theory. Moreover, the latter equations may be modified as indicated in the text so that they may apply directly to Mars or Venus or Titan. Finally, it is expected that the contents of the paper will be a worthwhile contribution to the ongoing World Climate Research Programme (WCRP) whose overall goal is to understand climate variability and its causes [28,29]. As Houghton [29], the chairman of WCRP Joint Scientific Committee, recently put it, "the climate problem is not one to be solved quickly or easily, but contributing to its solution is enormously worthwhile". In a separate paper [30], the salient features of the atmospheric circulation system are accounted for mainly on the basis of the contents of the present paper.

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Figure Caption

Fig. 1 Schematic diagram of the horizontal size of a typical "region *A*" (indicated by the shaded area) at Equinox. Note that point 0 represents the Earth's centre, and the value of θ lies between $\sim 24^\circ$ and $\sim 30^\circ$.