Climate augmentation of erythemal UV-B radiation dose damage in the tropics and global change

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Skin cancer (UV carcinogenesis) causing erythemal solar ultraviolet-B (UV-B) radiation dosages received at tropical latitudes are about five times higher compared to mid-latitudes. The tropical environment also experiences high levels of temperature and humidity which are detrimental to human health. We show that more significantly, prevailing high levels of temperature, humidity and UV-A also directly augment the environmental UV-B dosages, doubling the UV-B damaging effect. Additionally, this can be further impacted in a significant way by future climate change. This understanding is particularly important for human health to populations in the tropics and should be taken into account when evaluating the UV-B radiation and climate impact on immune deficiency, viral infections and other environmental health considerations in the context of present and future climate scenarios.

Keywords: Global change, humidity, skin cancer, temperature, tropics, UV-B radiation.

SOLAR radiation is the basic thermal energy source for the planetary surface. A small portion of the incoming solar flux lies in the short-wave ultraviolet (UV) radiation region (UV-B) which is harmful to humans, resulting in sunburn and skin cancer. Most of the incoming radiation is absorbed by the stratospheric ozone layer, thereby providing an important protective shield.

The effect of some human activities on the ozone layer has been studied and intensive efforts have been made to evaluate the effects of ozone-layer depletion on the environment. This is particularly important in the tropical region as UV-B radiation reaching the surface is generally high[1–3]. Lately, human activities resulting in ozone-layer depletion, such as release of CFCs into the atmosphere are being effectively controlled through the Montreal Protocol[4], resulting in total phase-out of most ozone-depleting gases in the industry. As a result, the recovery process for the ozone layer is making progress.

The most immediate concern emanating from ozone-layer depletion is the increase in UV-B radiation reaching the earth's surface, with a direct effect on human skin[5]. Hence through phase-out of CFCs, ozone depletion-enhanced UV-B effects will be gradually eliminated. However, it is estimated that it will take many decades before a full ozone recovery is realized and increased amounts of UV-B radiation in the intermediate period are anticipated[6].

It is generally recognized that the 'temperature–humidity' combination is particularly potent for human health in the humid and hot tropics, and contributes adversely to the aging of human skin and general decline in human health. Primarily for this reason, the British are reported to have introduced the early retirement age of fifty-five years in Malaysian Civil Service, presuming that due to high air temperature and humidity conditions to which people were exposed over a long period of time, they would have done all the productive work by this age and should retire for a well-deserved rest[7].

Early indications that climate plays an important role in human health and well-being came from physiological studies on thermal comfort. From these we recognize the temperature 'comfort zone' for optimum environmental condition. As a result, we try to regulate environmental thermal conditions through cooling and heating in order to achieve thermal comfort for the human body[8]. Environmental humidity also plays a discomforting role in the physiological sense for the human body[9]. For instance, an increase in humidity can be translated into an 'equivalent temperature' increase; in other words, greater the air humidity level, lower the temperature needed to maintain the same physiological body comfort. In this sense an increase in temperature is equivalent to an increase in humidity, and vice versa.

Despite the above-mentioned temperature and humidity impact on skin and human health (immune system), it is not easily recognized that under prevailing hot and humid environmental conditions, temperature and humidity can have a significant additive contribution to the damaging UV-B effects experienced at present, which would prevail during and even after the ozone recovery phase[6,10]. Also, future climate change involving higher temperatures, increased humidity and other related parameters may further exacerbate the cumulative contribution to UV radiation damage dosage on humans.

Besides the thermal comfort considerations of temperature–humidity effect on humans, direct experiments involving animals were undertaken about 70 years ago, which have remained obscure. These showed clearly that both temperature and humidity contribute to skin cancer in a way similar to the UV-B effect and this can be quantified. These studies also provide us with a confirmation of the general physiological impact in the thermal comfort considerations and enable us to evaluate climatic impact under different environmental temperatures.

So far, no effort has been made to understand the augmentative temperature and humidity effects on UV-B radiation for real environmental conditions in a practical way. In this communication, we present the results from such a study undertaken to provide insight into this matter. For this we have applied the results of available experimental studies to current environmental conditions prevailing in

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the tropical region and have shown significant additive effect of hot and humid climate on radiation dosage with reference to human skin cancer (UV carcinogenesis), in particular to the non-melanoma skin cancer problem. This would help us recognize the magnitude of the danger and evaluation of future climate change. The experimental data relating to temperature and humidity effect on carcinogenesis are based on animal studies. In order to gain an understanding on the magnitude, we assume that the effect will be similar in humans.

Bain *et al.*[11], and Freeman and Knox[12] studied the temperature impact on UV-B dose damage (DD) using animals (mice) as is common for carcinogenesis studies. It shows that the effect of temperature on UV-B radiation dosage for skin cancer (UV carcinogenesis) is positive and contributes to greater damage for the same radiation dosage under a higher temperature condition, above 23°C. This leads to an increase in the dose damage, which we define as Effective Dose Damage (EDD). This temperature effect on damage is not strictly linear and varied between +3% and +7% for each degree celsius temperature increase. We adopt a value of +5% per 1°C temperature as a reasonable estimate. van der Leun and de Gruijl[13] have explained that the results for animals could be applied to humans as a first approximation, in a way many other insights on carcinogenesis in humans were also initially based on experiments with mice and could be confirmed later by epidemiological observations.

Bulk of the UV-B radiation at the surface is received within a couple of hours of solar noon. Hence the best indicator for the temperature condition prevailing during this time would be daily average maximum temperature. Valuable data on thermal and humidity condition at numerous places using many years of measurements are available[14]. For our reference we consider surface-level location in the equatorial zone as the radiation input is nearly constant for a wide latitude zone. Typically, we find[14] that annual mean daily average maximum temperatures in the equatorial–tropical region are about 30–32°C or close to 10°C higher than the threshold for positive temperature effect[12]. Later we will see that in our comparison with higher latitudes, even a smaller temperature difference would lead to considerable augmentation in the tropics. There would be some months with greater temperature differential and others with smaller values, but in the tropical zone the daytime maximum temperature would be effectively above the threshold with positive augmentation. Thus temperature enhancement to EDD for skin cancer is about +50% (5% per °C × 10°C).

Experimental work pertaining to humidity effect on UV carcinogenesis involving mice was undertaken by Owen and Knox[15], which clearly showed the positive effect of humidity in augmenting the UV-B injury; greater the humidity more the damage. Quantitative evaluation of dose damage under humidity was done using albino rabbits. The measurements showed up to 40% reduction in energy requirement for erythema production, with a mean value of 33%. Assuming linear damage impact between the two ends and taking the end values to represent 100% and 0% humidity, we estimate an average effect of +4% for 10% humidity change. Since humidity values in the tropics[14] around noon-time are in the range 70–80%, a linear interpolation is not particularly critical as we are close to one end of the measurement range. For the humid (highly populated) tropical region, taking an annual mean daily average humidity value around midday (minimum value for the daytime) as 70%, we estimate humidity augmentation of +30%. Again assuming that the effects in mice and rabbits can be applied to humans as discussed for the temperature case, we can translate it into damage dose for human skin as a first approximation[13].

Another approach to evaluate the effect of humidity in a somewhat more direct way to humans is to utilize the method of ‘equivalent temperature for same physiological comfort’ for humans. Even though the physiological effect relationship[8,9] to erythema is not clear, we should get some indication of how this approach compares with the experimental work mentioned above. It has the advantage that we have intermediate data for better interpolation. In this, we utilize the fact that greater the humidity level, lower is the temperature that we need, to provide comfort equilibrium for the human body. In other words, an increase in humidity is equivalent to an increase in temperature. The UV-B DD may be assumed to be affected by humidity in a positive way, similar to temperature as mentioned earlier. Based on standard thermal comfort approach for the human body[16], we can translate a particular humidity level to an equivalent temperature to provide the same physiological comfort level under a typical wind condition (10 cm/s) as given in Table 1.

As mentioned earlier, for our discussion, considering the lower tropical region we take a typical humidity level of about 70% requiring 30°C temperature for the same comfort. In other words, 70% humidity level amounts to an effective temperature increase by +8°C, which is equivalent to an effective ‘UV-B damage enhancement’ for skin cancer or EDD increase by 40% (5% per °C × 8°C). It is interesting to note that this leads to a value similar to the one above based on animal measurements and therefore our assumption to translate results for animal studies to humans is reasonable.

UV-A radiation by itself does not seriously contribute to skin cancer, but in the presence of UV-B, it enhances the damaging effect as well[17]. In the tropics, we receive large

Table 1. Samples of humidity and temperature sets for same thermal comfort

Humidity (%)	Temperature (°C)
0	38
42	32
100	27

amounts of UV-B and UV-A radiations[18,19]. As a result, we estimate a small additive UV-A contribution to EDD by +10% in the presence of high UV-B radiation present.

To evaluate UV-B radiation dosage due to climatic conditions, first we combine the above three factors for skin cancer damage enhancement for the tropics:

Total EDD enhancement (50 + 40 + 10%) = +100%.

Based on direct measurements of UV-B radiation both outside the atmosphere and at the surface-level and incorporating the global cloud cover effect[20] at the surface, we estimate that we receive DD (Figure 1) as follows (dose units in J per sq. cm)[2]:

Mid-latitude, 27; tropics, 145.

We find that the damaging UV-B dosage received in the tropics compared to mid-latitudes (EDD) is close to 5.4 times (i.e. more than about 500%).

While evaluating the overall EDD in the tropics, we can now incorporate the +100% (or a factor of two) increase due to augmentative effect of temperature, humidity and UV-A. The basic EDD in the tropics would be therefore enhanced from 500 (145 units) to effectively 1000% (500 × 2, i.e. ten times) relative to the mid-latitudes, as the humidity and temperature contributions at mid-latitude will be not significant as explained later.

It is widely known that generally human populations in the tropics have developed darker skin tan, which provides a greater measure of protection against the above-mentioned intense UV-radiation damage. While this (positive role) may well be true, the great disparity in the input radiation dosage between the tropics and mid-latitudes is generally not taken into consideration in such evaluations[1–3,6]. Typically for similar radiation conditions, the damage efficiency dose (DE; i.e. photon damage effectiveness) varies between 100 for white skin, 10 for brown skin and 1 for dark skin (J. C. van der Leun, private commun., 2006). For vast populations in the tropical context, this factor could well be between 30 (equatorial region – Indonesia, Malaysia) and 70 (near-white populations of Iran, North India, especially Kashmir, and parts of Indo-China region) especially if the damage factor is incident radiation-dependent. Despite this negative demodulation due to skin pigmentation, the ten-times more effective dosages received in the tropics (Figure 1) would still mean a great deal of damage to most populations in the region; the damage dosages approach similar values (and perhaps even more in some cases) to those for light-skinned populations living in the mid-latitudes.

To obtain an overall perspective of the relative degree of danger in the tropics, we calculated the total Danger Factor (TDF), i.e. EDD × DE using a rather conservative value of 15 for DE in the tropics under the present climatic condition for a best-case scenario (not including future climate change):

TDF (tropics) = (290 × 15) = 4350 units.

We now compare this with a similar factor applicable to the higher latitude region. The incoming radiation input at higher latitudes (say 60° latitude) is quite small (about 5 units) for any appreciable effect. Populations with light skin reside in the mid-latitudes and need to be considered. We find that places near the 40° latitude such as Akita, Cagliari, Napier and Palma experience annual

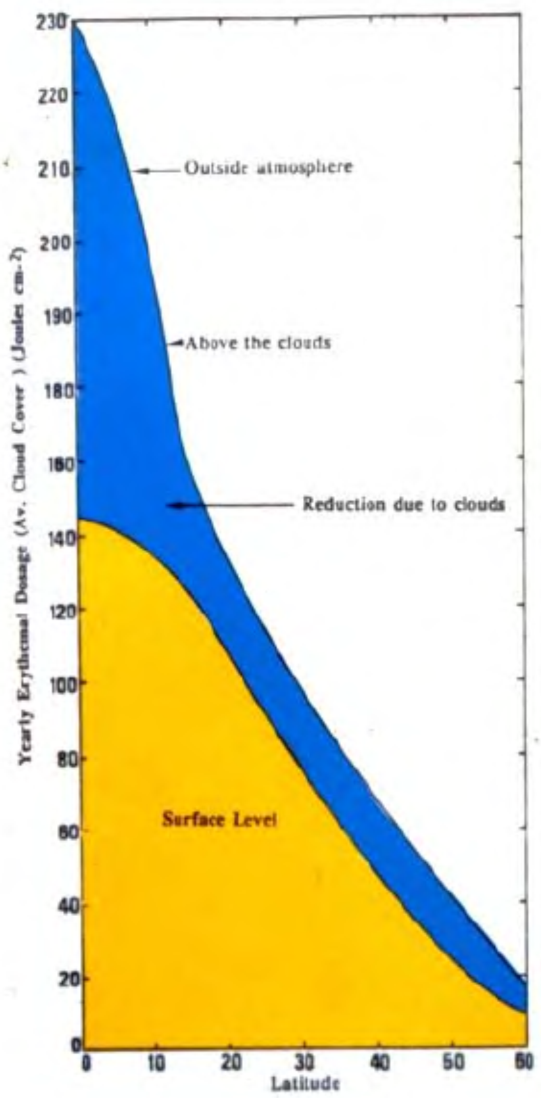

Figure 1. Yearly incoming surface erythemal solar UV radiation dosage (J per sq. cm) for clear sky and after modulation due to average cloud cover. The large reduction in the radiation at the equatorial–tropical region is due to relatively high cloud cover experienced in the region. The net surface-level radiation is responsible for skin cancer and related medical effects such as immune suppression as discussed in the text. The radiation effect is further augmented by the large climate parameters in the tropics.

mean temperature and humidity of 19°C and 65% respectively, while those near 45° latitude such as Christchurch and Venice experience annual mean temperature and humidity of 17°C and 65% respectively. These temperatures are generally below the threshold level of 22°C and thus would not contribute to temperature augmentation to UV-B at these latitudes.

Owen and co-workers had conducted their studies at around 32°C; we cannot use these results for cooler conditions. However, from the thermal comfort perspective, near 20°C environmental temperature, humidity does not contribute to physiological discomfort. Therefore, at mid-latitude the temperature and humidity augmentation of the UV-B dose will be insignificant. Though we have significant UV-A radiation input at mid-latitudes comparable to that we get at the tropical latitudes, the additive effect for skin cancer and immune deficiency effects may not be significant. This is because UV-A has an augmentative effect in the presence of UV-B input, and as the surface-level UV-B flux at mid-latitudes is relatively small (27 units), the overall contribution from this factor is not expected to be large. We can compare the 27 units producing a TDF (using an upper range value for DE as 85 for a worst-case scenario):

$$\text{TDF (mid-latitudes)} = (27 \times 85) = 2295 \text{ units.}$$

We see that the total damage factor for the tropical region for a best-case scenario is as significant as it is in the mid-latitudes for a worst-case scenario, even if we include greater effects due to UV-A, etc. as a result of high radiation input and large climate augmentation.

Among the various climatic change scenarios[21,22], there are wide variations in the amount of projected temperature increase.

However a median plausible condition for temperature (T) and humidity (e) is: (i) $\Delta T_{\text{increase}} \sim +4°C$; (ii) $\Delta e_{\text{increase}}$ (70% $\rightarrow$ 90%) or an equivalent temperature effect of +2°C; (iii) Hence total effect ~ +6°C or ~ +30% (5% per °C × 6°C) increase to UV-B radiation EDD.

As a result of global warming, there would be an increase in clouds. We assume a cloud cover increase by 20% for the above base consideration (due to humidity increase from 70% to 90%). We estimate[20,21] the decrease in UV-B radiation reaching the surface to be about –11%. Therefore, the overall effect will be a significant +19% (30 – 11%) increase to EDD or UV-B radiation SC dose damage.

There are two key elements which have an exacerbating effect on the damage dosage in the tropics. First, we deal with large populations which lag behind in education and awareness. They tend to have a carefree attitude with respect to taking protective action against exposure to UV radiation. Secondly, due to widespread poverty, populations suffer from malnutrition as well as poor health and are increasingly susceptible to UV radiation damage to the immune system and associated diseases (e.g. herpes) – contributors to lower life expectancy! This is further enhanced due to the fact that considerable work-related daytime exposure to high solar UV radiation (Figure 2) prevails in the tropical region with high temperature and humidity conditions. This would heat up the darker skin more than the white skin due to stronger visible radiation absorption as well as discussed[23] (and De Fabo, private commun., 2006).

Given the above information, we find that overall the potential for skin damage in the tropics is comparable to that in the mid-latitudes. Unfortunately, there is little information regarding the incidence of skin cancer in the tropics. This could well be because of the lack of any organized study, since skin ailments (except acne) are treated in a general way. Also, average life expectancy in the tropics is relatively lower and many people perhaps do not live to the age when the cumulative effect becomes easier to see. Indeed, early death could well be due to the impaired immune system and frequent infections which commonly inflict the tropical populations. Dermatologists, biologists, health authorities, etc. could undertake organized studies in compiling data for these regions and also for immune deficiency in this context. In addition, specific measurements of UV-B radiation in the

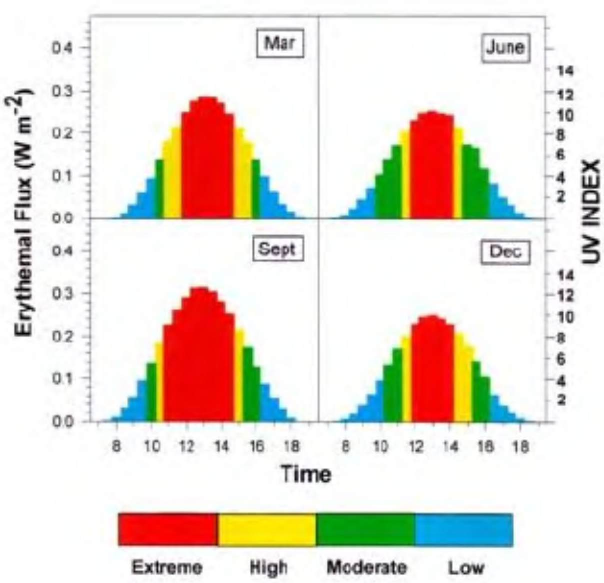

Figure 2. Measured data on erythemal UV radiation at near equatorial location (Malaysia) for clear weather show that radiation flux remains between extreme and high levels on the UV index system through most of the day, practically homogeneously during much of the year. It indicates great potential for erythemal and related damaging health effects through radiation and climatic augmentation. Given this high radiation level for clear sky condition, we can understand that the use of average cloud-modulated UV-B radiation data in the study shows that the calculated values for DD are indicative of lower threshold or a best-case scenario; for clearer weather the values will be revised upwards.

tropics are sparse[24–26] and more effort is needed for wider coverage.

We have highlighted the need to recognize that in hot and humid environmental conditions, the temperature and humidity can have a significant additive contribution to the damaging UV-B effect. Besides, future climate change may further exacerbate the cumulative contribution to UV radiation damage dosage on humans. This effect will be particularly serious in the tropical–equatorial region, where existing UV-B levels are higher than those at mid and higher latitudes, and protective mechanisms against sunlight are far less effective due to outdoor activities at wrong times (Figure 2), e.g. physical education lessons in schools. This is important for human health to most populations in the tropics and should be taken into account while evaluating the UV-B and climate impact in immune deficiency, viral infections and overall health considerations in the context of present and future climate scenarios.

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Chlorination by-products and their discharge from the cooling water system of a coastal electric plant

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Chlorination is one of the most widely used techniques for controlling biofouling in power plant cooling water systems. It often leads to the formation of chlorination by-products (CBPs). Amongst these, trihalomethanes (THMs) are more predominant, relatively long-lived and have possible toxicity to organisms. Thus, THM levels in the coastal marine environment are of great concern. This communication discusses the concentration levels of THMs at various points in the cooling water system of a coastal nuclear power station located on the Bay of Bengal coast. The studies revealed the

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