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SULTRINESS AS A CHARACTERISING FEATURE OF HUMID TROPICAL WARM CLIMATE: WITH SPECIAL REFERENCE TO THE PHILIPPINES

With 5 figures, 5 tables and 1 supplement (IV)

Philip Tilley

Zusammenfassung: Schwüle als charakteristisches Merkmal der warm-feuchten Tropen unter besonderer Berücksichtigung der Philippinen

Die feuchten und trockenen Tropen sind durch das gemeinsame Merkmal der geringsten photoperiodischen und thermischen Saisonalität gekennzeichnet. Eine der charakteristischen Eigenschaften der feuchten Tropen ist jedoch, daß Teile von ihnen dauernd, jahreszeitlich oder täglich feucht und warm genug sind, um schwül zu sein, d. h. klimatische Bedingungen zeigen, die von den Menschen als drückend heiß und feucht empfunden werden. Das Phänomen der Schwüle – obwohl nicht auf die tropische Welt beschränkt – unterscheidet die warm-humiden Tropen stärker von denjenigen tropischen Regionen, die nachts oder permanent zu kühl sind, um schwül zu sein, als von den Gebieten, die jahreszeitlich oder permanent zu trocken sind.

Die meisten Versuche zwischen den feuchten und trockenen Tropen zu unterscheiden, folgten dem Beispiel Köppens (1900) mit der Abgrenzung der ganzjährig und

jahreszeitlich feuchten Tropen aufgrund von klimatischen Kriterien, die unmittelbar für die Pflanzenwelt, nicht aber für die Menschen bedeutsam sind. Taylors singulärer Versuch (1916), die tropischen Klimate des nördlichen Australien und anderer Gebiete aufgrund ihrer Schwüle *(mugginess)* zu differenzieren, ging dem Versuch Scharlaus (1952) voraus, eine erste, weltweite kartographische Darstellung von Gebieten episodischer, periodischer und ganzjähriger Schwüle zu liefern. Taylor tat nichts anderes als festzustellen – auf der Basis der mittleren Monatswerte der Temperatur und Humidität –, wie oft und wie lange pro Jahr eine Station schwül *(muggy)* war. Scharlaus Einführung einer Schwüle-Skala (1950) erlaubte ihm, den Grad der Schwüle und deren Andauer zu messen. Die durchschnittlichen täglichen Terminwerte der Temperatur und Humidität, die Scharlau benutzte, um seine Weltkarte der Schwüle zu zeichnen, zeigen an, daß die Philippinen nicht nur zu den Teilen der Erde mit ausgeprägter Schüle, sondern auch zu der weltweiten innertropischen Zone ganzjähriger Schwüle gehören.

Die räumliche Differenzierung der tages- und jahresperiodisch wechselnden Beziehung zwischen Lufttemperatur, Humidität, Niederschlag und Bewölkung an drei von vier repräsentativen Stationen auf den Philippinen bestätigt dies. Jedoch wechselt der Grad der Schwüle beträchtlich, von einem konstant hohen Niveau für Hinatuan zu jahreszeitlich stark wechselnden Werten für Cebu und insbesondere Manila. Nur in Baguio ist es kühl genug, um nicht oder nur gerade eben schwül zu sein, und dann nur zur Zeit der größten Feuchtigkeit und Bewölkung. Als eine tropische monsunale Inselgruppe mit von Insel zu Insel deutlich unterschiedlichen und in einigen Fällen stark saisonalen Klimaten bieten die Philippinen eine „geeignete Versuchsanordnung der Natur“ zur Prüfung von regionalen Unterschieden der Schwüle.

> It's because people know so little about themselves, that their knowledge of nature is so little use to them.
>
> Bertolt Brecht

The hygrothermal differentiation of tropical climate

The humid tropics can be delimited on climatic criteria alone. Garnier (1961) does so to define 'humid tropicality' without reference to the 'reactions . . . only partly governed by climate' of either plants or humans. With Garnier we can regard a month as 'humid tropical' when its mean atmospheric water vapour pressure is 20 mbs or higher and its mean relative humidity is 65% or more with the mean temperature no lower than 20 °C. We can then, like Garnier, distinguish the continuously or seasonally humid tropics as the area with at least eight such humid months. But we can also differentiate the 'hot' humid tropics, continuously, diurnally or seasonally humid and probably warm enough to be sultry, from the 'cool' humid tropics which are not. In as much as the cool and cold humid tropics lack the monotonously oppressive humid heat or 'sultriness' humans find so discomforting which is so characteristic of much of the tropical world, they are less typically 'tropical'. Yet as Garnier admits, they are areas that display other characteristics 'found only within the tropics in a locational sense'.

Intertropic low latitudes are inherently the most tropical in more than just a conventional or technical sense. As the latitudes in which the lengths of the longest and shortest period of daylight in the year differ by no more than about three hours they are the latitudes of most nearly constant photoperiodicity, the latitudes least seasonal in their insolation and therefore their thermal regime. Warm as the lowland intertropic world constantly is its highland areas are just as constantly cold. Both are thermally so unseasonal that their difference in temperature between daytime and nighttime easily exceeds that between the coolest and warmest times of the year. They have been aptly described as the latitudes of 'diurnal' rather than 'seasonal' climate as far as light and temperature is concerned (Troll 1943), or as those 'where winter never comes' no matter how constantly cold anymore than does 'summer' no matter how constantly warm. So we need to differentiate the most tropical, least seasonal coldness of intertropic highlands not only from the less or non-tropical, more seasonal coldness of extratropic higher latitudes but more especially from the equally tropical warmth of intertropic lowlands. How cool can tropical climate become and still be warm as far as plants or humans are concerned, still form part of the warm or hot tropics? Without reference to either plants or humans Garnier (1961) suggests a 'hot' tropical month has a mean temperature no lower than 20 °C. With reference only to plants Lauer has suggested (1975) that average temperatures of between 16 °C and 18 °C or more recently (1987) of between 12 °C and 15 °C separate the warm tropics from the cold.

Köppen's (1884) division of the earth surface into warmth zones, among others a tropical zone, is based on the number of months annually with mean temperatures above threshold values thought critical for 'Man and the whole organic world'. He stresses how very directly significant warmth is for plants and so-called cold blooded animals, only much more indirectly so for 'warm blooded animals whose body temperature . . . is almost completely independent of the temperature of the surroundings'. He goes on to add in a footnote: 'fewer human beings know from experience that their body temperature remains at its maximum not only under low air temperatures *but also if it exceeds the normal temperature of the blood'.* As a measure of how constantly warm the tropical condition is, KÖPPEN divides it from the subtropical of potentially greater but more seasonally varying warmth by the isotherm of 20 °C mean temperature for the coolest month, the value GARNIER adopted on quite different grounds.

But in KÖPPEN's later (1900) attempt to classify areas by climate type '. . . chiefly in relation to the plant world', 'Man is somehow left standing along the sidelines' (TERJUNG 1966a). For KÖPPEN the tropical condition is still one of the coolest month's mean temperature exceeding a threshold value of warmth, though this is now 18 °C. But he is now more concerned to separate the constantly wet as well as warm tropical latitudes from those effectively dry at least seasonally in conditions no less constantly warm. Effective dryness is judged from the degree to which the potential natural vegetation shows a predominance of plants xerophytic in form and behaviour or with the ability to minimise their transpirative loss of moisture when the lack of moisture becomes stressful. KÖPPEN's idea of tropicality is now so definitively associated with constant or seasonal wetness as well as constant warmth he can recognise tropical climate well beyond the tropics though not in equatorial highlands!

Most (though certainly not all: BOWEN 1933, DAVIDSON 1936, FITZPATRICK et. al. 1966, GARNIER 1961, for example, and notably TAYLOR 1916, 1923, 1940) subsequent efforts to geographically differentiate 'humid tropicality' from more arid follow KÖPPEN in using natural vegetation as an indicator of effective dryness to indirectly measure tropical atmospheric humidity or aridity. But they differ fundamentally in seeking to calculate an hygrothermal index of the functional relationship between rainfall and the atmosphere's heat energy available to evaporate this. Numerous formulae have been developed to index annually or month by month, how moist or dry tropical conditions constantly are, or seasonally become. This is done by correlating mean monthly rainfall either with dry bulb air temperature as a surrogate measure of the atmosphere's heat energy to evaporate (ANDREWS a. MAZE 1933, LAUER 1951, 1952, JÄTZOLD 1979) or with atmospheric water vapour pressure or saturation deficit if not evaporation as such (PRESCOTT 1938, THORTHWAITE 1948). More recently, to take some account of the role the ground surface's plant cover itself plays in mediating the degree to which 'potential evapotranspiration' from the landscape is actually realized, LAUER and FRANKENBERG (1981 a, 1985) have correlated mean monthly total rainfall with a temperature equivalent to the available heat energy reduced by a factor allowing for six landscape variables. By using such formulae GENTILLI (1970) evaluates the 'hydroxeric balance' or 'hydric biopotential' of a month, LAUER and FRANKENBERG (1985) it's 'optimal landscape evaporation' to then map by 'isothermomens' area differences in the number of months annually with mean temperatures above significant threshold values (*à la* KÖPPEN) and by geoecological *(landschaftsökologische)* 'isohygromens', area differences in the number of humid or arid months annually.

Only as unashamed an environmentalist as TAYLOR would have tried in 1916 to likewise differentiate humid from arid tropical warm climate with direct reference not to plants but to the discomfort heat stress produces in humans (TAYLOR 1916). TAYLOR's immediate purpose was to compare the variety of Australia's climate especially in its tropical north with that expectably similar elsewhere "where the white settler has had longer to adjust" than he has in Australia (cp. TROLL 1933). As part of his campaign against the then prevalent view of 'Australia Unlimited' (BRADY 1918), TAYLOR's central concern is to compare the climate of different areas as to how often they are likely to include conditions threatening the bodily comfort or even health of white anglo-saxon settlers of the British race *(sic)* or "our type of European settler", and so put "climatic difficulties in the path to a white Australia". His immediate purpose is to demarcate the climatically "most favourable areas (of Australia) for closer settlement by whites . . . the limits within which the British race may be expected to exhibit its optimum development" (TAYLOR 1916).

TAYLOR compares by what he calls *climographs* selected places' twelve monthly means of wet bulb temperature and relative humidity with that for an ideal "most habitable type for white settlers" (TAYLOR 1940) the climogram for which is a composite of twelve cities selected as "typical of the regions where white energy is at its best" (TAYLOR 1916) (Fig. 1). But places are compared not only with this composite ideal but also with each other as to in how many months of the year their climate tends towards becoming chillingly 'raw' or 'keen' or no less discomfortingly 'scorching' or oppressively 'muggy'. TAYLOR constrasts Melbourne, muggy on only a few days in the year with Sydney, where "there are usually many unpleasant muggy days in February" (TAYLOR 1923), with Bisbane's two such disagreeable

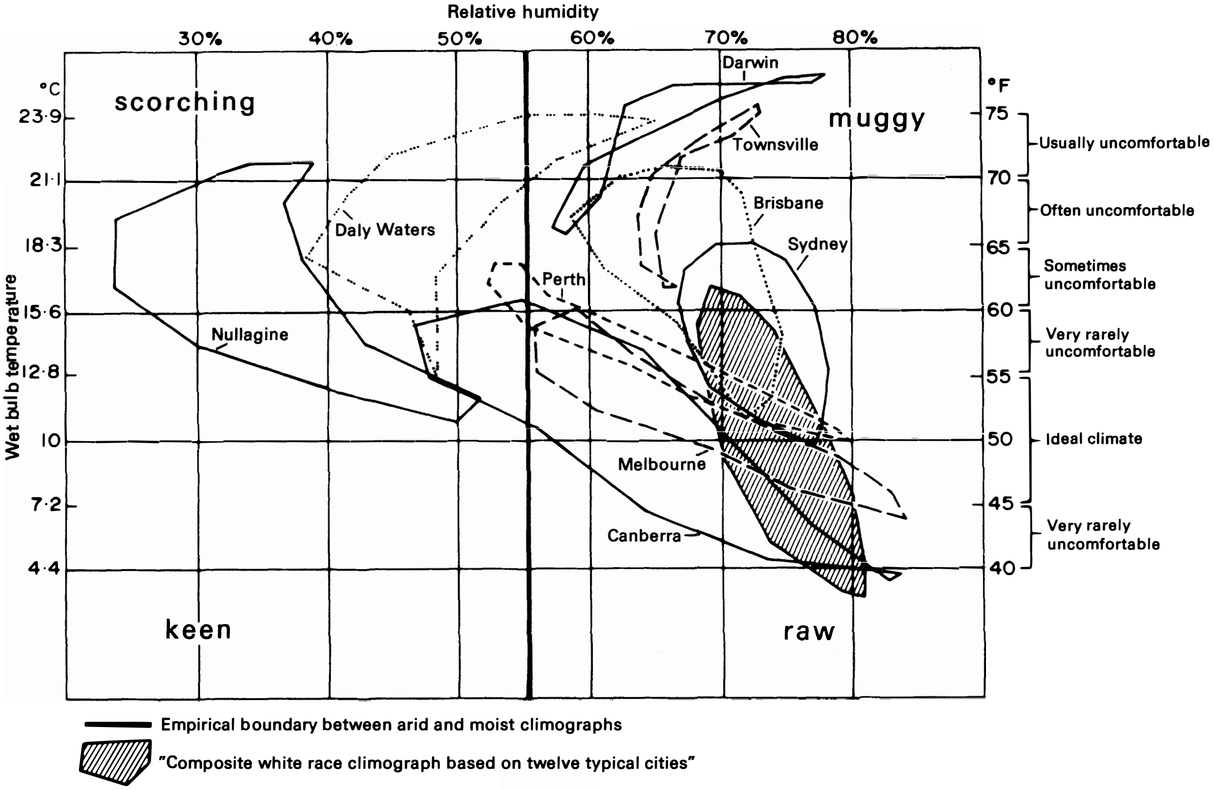

Fig. 1: Climograms (Climographs) of mean monthly relative humidity and wet bulb temperature at nine Australian stations, and a 'composite white race climograph' (after TAYLOR, 1916)

Klimagramme der mittleren monatlichen relativen Feuchte und der Feuchttemperatur für neun australische Stationen sowie ein ‚composite white race climograph' (nach TAYLOR, 1916)

months, Mackay's six, and Thursday Island's twelve. He draws 'isohygromens' of the number of months in the year the climate of Australia can be expected to become muggy when their mean wet bulb temperature exceeds 21 °C.

Determining when a climate is sultry, and to what slowly or quickly varying degree – its sultriness

TAYLOR's is an early attempt to differentiate geographically the several quite different interactive combinations of air temperature and humidity which impose thermal stress on the human body. Theoretically TAYLOR is just as concerned with how often and how extremely conditions approach a stressful 'raw' or 'keen' coldness as he is with climate becoming stressfully hot. But in fact he has his tentative scale of discomfort apply only to conditions producing heat stress, "to those warmer regions where humidity and temperatures are the chief factors". And though TAYLOR theoretically distinguishes a 'scorching' kind of heat stress, his scale of discomfort ranks representative station climograms only as to the likelihood of their climate imposing that particular kind of discomfortingly hot condition on humans he calls 'muggy' but more generally termed *sultry*. TAYLOR is convinced that the best test of the habitability of a tropical region is for how long 'day after day for months at a time' a climate is sultry (TAYLOR 1923). He claims that 'white anglo-saxon' humans do not sense the atmosphere as sultry when the wet bulb air temperature is below 21 °C – a value he adopts as corresponding to a dry bulb air temperature of about 32 °C 'in most dry climates'. His grading of conditions within a range of wet bulb temperatures as likely to produce discomfortingly sultry conditions 'very rarely', 'sometimes', 'often' or 'usually' depends on the likelihood of wet bulb temperatures above 21 °C recurring that these mean monthly wet bulb temperature category ranges represent. It is not a hygrothermal scaling of the interactive combination of specific air temperatures and humidity to produce sultriness. And TAYLOR applies the same wet bulb temperature test to all warm conditions regardless ofhow absolutely humid, of how much warmer the human body senses air warmer than about 12–14 °C to be the higher its water vapour content, and of the ratio between the air's latent and 'sensible' warmth he takes wet bulb temperature to represent (LAUER a. FRANKENBERG 1982). Primarily based on conditions with mean monthly relative humidity above an arbitrarily selected 'empirical' 55%, TAYLOR uses his scale of discomfort as 'an approximate standard' for all warm climates including those so hot and dry that, as TAYLOR himself says, "comfort controls are somewhat different again", climates where "humidity is always fairly low (by definition) and the absolute amount of insolation is the chief control" (TAYLOR 1916). TAYLOR's tentative scale of discomfort is one that attempts to scale warm climate in general, but in particular the warm tropical climate of northern Australia, as to how often and how persistently it is sultry or non-sultry, not on its degree of sultriness.

Geographers now generally recognise how characterising a feature of an area's climate the total thermal stress it imposes on the human body is; many also recognise how characteristic and significant a feature of some warm intertropic areas' climate sultriness is as one particular kind of heat stress. But some would still question the purpose of seeking to geographically differentiate the conditions in which air temperature and humidity interact to produce sultriness; "no particular significance should be attached to atmospheric moisture in the thermal context, *apart from the reduction of evaporative heat dissipation and the corresponding increases of strain imposed upon the body*" (my italics) (AULICIEMS a. KALMA 1981). These authors dispute that "in conditions of free air movement ... any particular biological significance" can be attached to specific temperature value thresholds, at least not to the 21 °C wet bulb value used by TAYLOR. They evidently do not question that in some conditions air temperatures are warm enough for the body to have to increase its normal heat loss to keep its inner temperature close to 37 °C mainly by the cooling evaporative loss of skin surface moisture. The water vapour content of the air is a very significant factor in that evaporative heat dissipation. Perhaps they doubt the value of trying to relate only the two most important variables, air temperature and humidity, and not solar radiation and air movement. Or do they question that we can standardise the threshold interactive combination of temperature and humidity at which individual humans let alone whole groups first feel it to be oppressively 'muggy'? For admittedly, our autonomic response to sensing that our need to dissipate body heat evaporatively is being inhibited is psychoculturally as well as physiologically conditioned, and changes with acclimatization. We should be less concerned however with "precisely defining and exactly understanding the physiological significance a given stress represents" (LEE 1954) and more with gaining a detailed appraisal of where sultriness occurs, how long it persists if it is not perennial, and how more or less sultry it becomes from time to time. We are then in a position to geographically differentiate the complex of conditions that produce and maintain a condition so readily discomforting because so potentially health-even life-threatening.

Sultriness is the condition of climate we subjectively sense as oppressively hot or 'close' not simply because we feel hot but because we also sense how difficult it has become for us to lose body heat at the rate necessary to keep inner body temperature close to 37 °C. And this not necessarily if especially only when our body is exposed to direct and atmospherically diffused solar radiation. Typically it is a condition in which the still and stable air around us feels warm enough for the normal healthy body to spontaneously increase its normal loss of body heat by all available means, but increasingly as body heat rises by the cooling evaporative loss of body moisture diffused and sweated to the skin surface. But it is also one which, if the air already holds more than a quite specific amount of water vapour (14.08 g/m^3), causes us to sense the need to regulate our use of vital body moisture to effect evaporative cooling.

Our sense of sultriness is associated, as has long been known, with quite specific combinations of relative humidity with air temperatures as low as 16.5 °C if the air is saturated (relative humidity 100%) though not at the highest 'scorching' temperatures if the relative humidity is too low. During twelve years work in tropical East African climate CASTENS and later his co-worker BERKÉ (1925, 1929) drew up a 'curve of sultriness'. Using and verifying boundary values LANCASTER had already experimentally established (1898) they approximately delimited the non-sultriness producing interaction of temperature and humidity from that at temperatures higher than 16.5 °C producing sultriness, and at lower temperatures above 16.5 °C the greater the relative humidity. Implicit in this curve of the limit of sultriness is that temperatures certainly high enough to produce discomforting heat stress do not result in our sensing the condition sultry unless it is also humid enough. So establishing an effective upper temperature limit to thermal comfort may but does not necessarily mark the onset of sultriness.

Table 1: Sample series of co-related relative humidity and temperature delimiting the onset of sultriness (after Scharlau, 1950)

Datenreihe zum Verhältnis von relativer Feuchte und Temperatur an der Schwülegrenze (nach Scharlau, 1950)

Relative humidity (%)	Temperature (°C)	Relative humidity (%)	Temperature (°C)
100	16.5		
98	16.8	58	25.4
96	17.2	56	26.0
94	17.5	54	26.6
92	17.8	52	27.2
90	18.2	50	27.9
88	18.5	48	28.6
86	18.9	46	29.3
84	19.3	44	30.1
82	19.7	42	30.9
80	20.1	40	31.8*)
78	20.5	38	32.7
76	20.9	36	33.6
74	21.3	34	34.7
72	21.8	32	35.8
70	22.2	30	36.9
68	22.7	28	38.2
66	23.2	26	39.6
64	23.7	24	41.1
62	24.2	22	42.8
60	24.8	20	44.6

*) Taylor's (1916) 21 °C wet bulb limit in most dry climates

For this reason many older and more recent attempts to calculate minimum sultriness-producing values of temperature and humidity, and to standardize a scale measuring how far above these minima the actual temperature and humidity is, have concentrated on measuring the most important factor: the air's evaporative cooling power, aided perhaps by its ventilating movement. More or less complicated equations formulated to do this incorporate as a principal value either the readings of standard or developed varieties of wet bulb thermometer such as the Katathermometer (Hill 1923, Stone 1938, Thom 1959) or an equivalent temperature calculated to represent the air's heat energy to evaporate cp. Lauer and Frankenberg 1981 (Leistner 1951, King 1955). They assume that the human body is a kind of wet bulb thermometer simply giving up its vital moisture in the measure that the atmosphere can evaporate it. In reality the healthy body regulates the use of its moisture to dissipate heat by sensing the vapour pressure gradient between itself and the ambient air. Barkley (1934) realized this in setting a vapour pressure of 12.7 mm Hg as the limit above which "transpiration outflow is checked sufficiently to raise the body temperature, causing discomfort and perspiration in the average white man". Two years earlier Ruge (1932) had tested and experimentally confirmed the Lancaster-Castens curve separating the sultry from the non-sultry condition. Assuming that the regularity of the curve must reflect some calculable physical relationship of constant physiological significance, Ruge also found that the curve of a water vapour content of 14.08 g/m^3 coinciding with the lower temperature end of the Lancaster-Castens curve at 16.5 °C and a relative humidity of 100%, so closely follows it throughout as to suggest that this absolute water vapour content of the air was the decisive factor in the body sensing it to be sultry. This was confirmed by Scharlau's finding (1941) that the vapour pressure curve of 14.08 mm Hg (18.8 mbs) virtually coincided with the Lancaster-Castens curve. He experimentally established that a water vapour pressure of 18.8 mbs (a figure somewhat lower than the 20 mbs selected by Garnier (1961) as one of the criteria defining a humid tropical month) was a physiologically significant constant causing us to so regulate our using vital body moisture that we feel the air around us to be oppressively 'close' or sultry at temperatures as low as 16.5 °C and when its % relative humidity is great enough to give it a vapour pressure of 18.8 mbs (14.08 mm Hg). Having established this relationship as a constant Scharlau could calculate the inversely varying but quite specifically co-related values of relative humidity and temperature above which we sense the condition sultry (Table 1). Conversely, he had quantified an approximate "threshold of sultriness" (cp. Troll 1933) short of which we feel the condition non-sultry, or "comfortable" as Scharlau and others have loosely termed it, threateningly close to sultry though the condition may be. Lee (1955, 1957) recognised that "relative humidity" (alone) is not a good measure of humidity in so far as it affects the cooling of a (human) animal". And he expected that "the relative effects of temperature and humidity upon animal function may be well enough known, *in the not too distant future,* to be expressed . . . as lines superimposed upon the psychometric chart". He was apparently unaware of Scharlau's work. And although he does not distinguish a condition of sultriness for humans as such, his psychometric nomogram of thermal strain-line values of relative humidity, dry bulb temperature and vapour pressure coincide exactly with SCHARLAU's. Moreover, we can read from it that at a vapour pressure of 14.08 mm Hg the dry bulb temperature of 32 °C coincides not only with SCHARLAU's limiting relative humidity of 40% but also with TAYLOR's (1916) wet bulb limit for 'mugginess' of 21 °C!

SCHARLAU's limiting values of warmth and humidity represent only the two most important variables interacting to produce sultriness; no allowance is made for any modifying effect ventilating air movement, solar radiation, or indeed individual human differences of constitution and health may have in determining the exact combination of temperature and relative humidity at which we first sense the atmosphere as sultry. More important for geographers however is that by using as a zero marker the limiting temperature at which, given the air's actual relative humidity we first sense it sultry, we can use the difference in °C by which the actual temperature exceeds or falls short of this marker as a measure of "thermal sultriness" or non-sultriness, and gain a value we can map by "isohygrotherms". We have a scale against which to compare conditions as they vary from time to time as well as from place to place. And not simply as they vary from being non-sultry to sultry and *vice-versa,* or for how long they stay sultry and thereby become increasingly stressful; just comparing actual values of relative humidity and temperature with their correlated limiting values would tell us that. But in the degrees of thermal sultriness or non-sultriness by which the actual temperature exceeds or falls short of the limiting temperature we have a measure of how rapidly or slowly sultriness increases or decreases in intensity to reach its maximum and minimum values diurnally, monthly or annually. And we know from what level of intensity in the immediately preceding period it has moved upwards or downwards and at what rate: a factor as important in the increase or lessening of discomfort and stress as the intensity of sultriness itself. For it is sudden shifts towards a non-sultry condition becoming sultry, or sultriness increasing, or conversely towards the condition becoming less or even non-sultry, which most discomfortingly induce an increased sense of oppressive 'closeness' or relief therefrom, rather than how sultry or non-sultry it actually is. Since SCHARLAU already had for sultriness an "index of the combined effect that climatic elements have upon Man" he did not have to "postpone serious consideration of classifying (tropical) climate until that index is available" (LEE 1957); he could move to make a first provisional attempt to geographically differentiate the complex of conditions imposing the "hygrothermal stress" on humans so characterising of humid tropical warm climate areas that sultriness represents (SCHARLAU 1952) (Fig. 2).

How extremely and constantly sultry a part of the intertropic world are the Philippine Islands?

Using only three daily daytime observations of relative humidity and temperature to calculate the monthly mean sultriness at more than a thousand stations, worldwide but very unevenly distributed, SCHARLAU recognises areas of particularly intensive sultriness. In lowest latitudes of sustained sultriness he singles out places such as Mogadiscio on the east African coast of the Somali Republic, Jaffna at the northern tip of Sri Lanka, Rangoon in southermost Burma, or Hue on Vietnam's east coast and Dadanawa in Guyana, as those where mean monthly maxima of sultriness, usually at the time of highest midday sun elevation, exceed 10° although these extreme values are not always that much higher than annual mean values (Mogadiscio: extreme (April) 10.7°; annual mean 9.5° for example). On the other hand he points to places in somewhat higher latitudes such as Swatau on the Tropic of Cancer on China's southeast coast, Bushire on the Persian Gulf, and Muscat and Karachi on the Gulf of Oman and the Arabian Sea as having no less extreme values but ones well above their annual means (Swatau: extreme (August) 10.6°; annual mean 1.1° for example). And these are values LEE (1957) confirms in 'climagrams' for Maracaibo and Bahrein. SCHARLAU suggests that the 'pole of sultriness' lies off Djibouti in the southern Red Sea or Gulf of Aden where extreme values may reach 12.8°, and exeed 10° from June to September, although SCHULZE (1956b) gives an extreme monthly mean of 8.1° (May) for nearby Berbera. In any event it seems certain that maritime conditions off the high sun, seasonally mist-laden coasts of arid Arabia and the Horn of Africa (TROLL 1964) come closest to the popular concept of the humid tropics as a condition of maxmimu human discomfort hygrothermally (FOSBERG 1961). These areas provide the stable conditions in which the lower atmosphere of constantly warm tropical air can most fulfil its potential to evaporatively attain such high humidity, given its constantly extreme water holding capacity. While this reduces direct solar radiation it greatly increases the diffused sky radiation so significant in intensifying otherwise

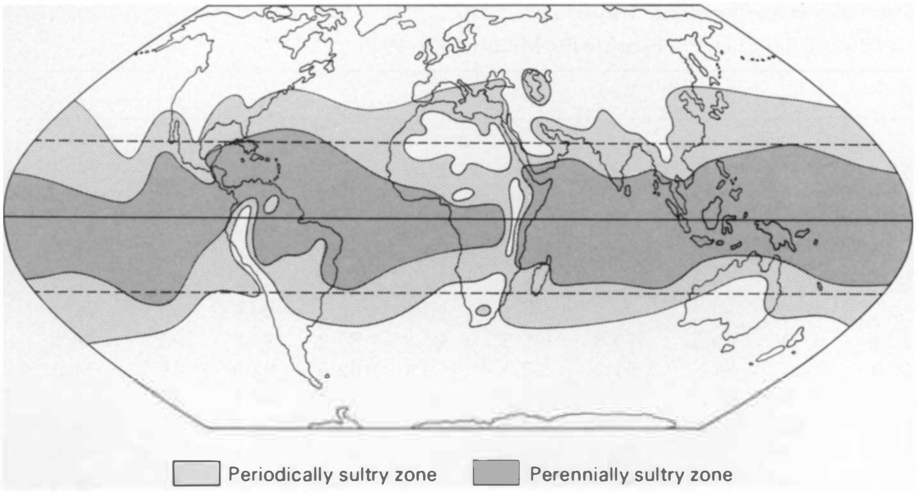

Fig. 2: The perennially and periodically sultry zones of the earth (after SCHARLAU, 1952)
Die Zonen dauerhafter und periodischer Schwüle (nach SCHARLAU, 1952)

only moderate sultriness (DAMANN 1964). A similar condition for the Port Sudan and Massawa areas of the Red Sea coast is confirmed, albeit using an essentially different measure of sultriness from SCHARLAU's, on 'comfort climagraphs' for the Sudan and a map of 'Physiological climates' for Africa as a whole by TERJUNG (1966b) and OJO (1977).

In keeping with his view that important as the intensivity of sultriness is in the final analysis its duration is more important, SCHARLAU does not add to his earlier (1950) map of the intensity of sultriness by isohygrotherms for the southeastern Mediterranean coastland of Egypt, southern Lebanon and Israel and the northern Read Sea. He does not attempt a map for larger areas like the whole of Africa such as SCHULZE does for annual mean sultriness, or by isopleths, the number of months sultry or non-sultry, the number of months with 'extreme' sultriness (> 6°) and in which of four monthly groupings if at all the sultriest month occurs (1956a, 1956b). Again emphasising the concentration of the longest period of extreme sultriness along the African west coast from Monrovia to Luanda beyond the mouth of the Congo, and expecially along its east coast from Massawa to the mouth of the Zambezi (Lindi: extreme 8.3° (March); annual mean 6.2°) SCHULZE confirms SCHARLAU's preliminary attempt to map worldwide the occurrence of sultriness by its duration as well as intensity. But SCHARLAU did not reach the insight that not only are areas of highest annual mean values of sultriness those with more sustanied levels of extreme sultriness, but that mean annual sultriness appears proportional to its duration.

In the Philippines monthly mean values of sultriness commonly exceed SCHULZE's 'extreme' of 6° but not SCHARLAU's 10°. Even at lower latitude Hinatuan on Mindanao's east coast where, with a mean monthly temperature of 26.5 °C and relative humidity of 88% scarcely varying through the year, highest values can be expected, sultriness exceeds an annual mean value of 7.9° to reach its maximum of 8.4° in May although it exceeds 8° for the eight months April–September (Suppl. IV). At the central Visayan island of Cebu an annual mean sultrines of 6.9° is exceeded in the seven months May–November to reach a maximum of 7.6° in June, and a February minimum only 2.2° lower. At somewhat higher latitude Manila as well, a rather lower mean annual sultriness of 5.5° is exceeded in the six months May–October; but Manila's February minimum of 2.5° is well below its June maximum of 7.6°, a rather greater annual range than that at lower latitude Lagos with only 2.4° with the same mean annual value of sultriness as Manila (SCHULTZE 1956b). Only at Baguio in Luzon's Mt. Province at 1482 m. is it cold enough to give a non-sultry annual mean of -0,7° and a monthly mean minimum of -2,7° in coolest and driest 'lower sun' January; Baguio's sultriness, less than 1° through five months May–September, peaks at only 0,7° in June with the sharp increase in rainfall, cloudiness and humidity of the 'high sun' period. Hinatuan's markedly seasonal but, even at its 'high sun' minimum, appreciable rainfall is, with its lesser thermal seasonality, enough to maintain high if not extreme sultriness throughout the year. The lesser but not very seasonally varying rainfall and cloudiness of Cebu combine with some-

Table 2: Relative humidity in hourly means at Manila, 1961–1970
Stündliche Mittelwerte der relativen Feuchte für Manila 1961–1970

MONTHS:	J	F	M	A	M	J	J	A	S	O	N	D
Hours												
1	78.4	75.4	74.2	72.1	76.3	86.0	89.1	88.2	88.1	86.4	84.7	84.2
2	80.1	76.5	75.2	73.9	77.7	86.9	88.7	88.7	88.4	87.3	85.8	83.5
3	81.1	78.3	76.7	75.0	79.1	87.7	89.1	89.4	88.8	87.6	86.3	84.7
4	81.6	79.5	77.8	75.6	80.1	88.1	89.1	89.9	89.2	88.2	86.7	85.2
5	82.6	80.1	79.1	77.8	81.2	88.0	90.3	90.4	89.6	88.7	87.5	86.0
6	82.7	81.6	80.2	79.2	81.1	88.9	90.5	89.5	90.2	88.9	88.0	86.4
7	82.6	81.0	79.3	73.3	75.5	84.8	87.8	89.6	88.7	88.1	85.7	85.2
8	76.1	72.7	68.3	64.0	67.5	79.4	82.6	82.9	84.3	81.5	79.8	78.2
9	67.6	63.7	61.3	58.9	62.0	74.3	77.8	78.2	79.0	75.6	71.7	70.1
10	62.2	59.0	57.8	56.0	58.1	70.3	73.4	74.7	75.4	71.8	68.5	65.4
11	58.8	55.9	54.8	53.3	55.5	66.7	72.1	73.1	72.9	69.4	66.5	63.2
12	57.8	54.3	52.9	50.4	52.6	64.6	70.5	71.8	70.8	68.3	65.6	61.8
13	56.5	53.0	51.1	48.1	50.8	63.2	68.9	71.0	69.6	67.7	64.0	61.0
14	55.5	51.4	50.4	47.4	49.9	62.7	69.2	70.1	68.8	67.2	63.5	59.9
15	55.3	51.4	50.6	48.7	50.8	64.4	69.4	71.0	70.8	67.7	64.8	60.9
16	56.7	53.7	51.6	49.1	53.7	67.0	70.9	72.2	72.4	69.5	66.9	63.6
17	59.9	55.7	54.7	52.2	57.3	70.4	74.2	75.5	75.0	72.1	70.0	67.4
18	65.1	60.9	60.7	57.0	62.4	74.2	77.5	77.9	78.3	76.8	74.9	73.0
19	68.6	65.1	64.2	61.6	66.0	77.3	80.8	82.6	80.8	79.2	77.7	75.4
20	71.0	67.9	67.2	62.9	68.4	79.6	83.0	82.8	83.1	81.0	79.5	77.3
21	74.2	69.7	69.0	65.7	70.4	81.6	84.5	85.5	84.7	82.7	81.0	78.8
22	75.5	70.5	70.3	68.1	71.7	82.7	86.0	85.8	85.9	84.1	82.1	80.2
23	76.9	72.0	71.6	68.8	72.9	83.8	86.7	86.8	86.6	85.0	83.4	81.3
24	78.5	73.5	72.6	70.8	74.5	85.3	87.8	87.6	87.9	86.1	84.2	82.1

what higher temperatures to give it sultriness intensities only a little less than Hinatuan's if definitely more seasonal. Manila's highly seasonal rainfall and cloudiness produce sultriness levels as great as Cebu's and little less than Hinatuan's at the time of 'high sun' and temperatures higher than either Cebu or Hinatuan, but reduce it to much lower levels in drier as well as cooler 'lower sun' January and February.

SCHARLAU's main purpose is twofold: firstly to delimit those areas worldwide never warm and humid enough together for sultrines ever to occur; secondly, to separate the largely intertropic areas constantly warm and humid enough to have a perennially sultry 'energy-sapping and sleep-inducing' climate from the areas intertropic and extratropic where sultriness gives way with periodic regularity to 'stimulating' as well as relieving non-sultry conditions (Fig. 2). With an isoline of 0 days of sultriness annually based on his monthly mean values of relative humidity and temperature SCHARLAU can most accurately delimit the perennially non-sultry areas of intertropic highland coldness such as those of central and south America, east and southeast Africa, or southeast Asia. And he can delimit accurately enough the intertropic lowland areas of constant dryness such as part of the Saharan and Arabian, the southern African and central Australian deserts; in both instances monthly mean values are most accurately representative of the predominantly diurnal variation of temperature and with it of relative humidity. But of the much more extensive perennially non-sultry areas of the mid-latitude, more markedly seasonal continental areas, for example, mean monthly values are not an accurate enough indicator of how only episodically but for days on end, summer incursions of warm tropical air brings sultry conditions to otherwise perennially non-sultry areas (DAMANN 1964). It is not unreasonable therefore for SCHARLAU to fix the absolute limit of sultriness altitudinally in the colder, thermally least seasonally varying, tropical highland climate areas of near-equatorial latitudes at between 1600 m and 1700 m. Following MARNER's (1940), SEMMELHACK's (1942) and SCHULTZE's (1956a) lead in Africa, all three presumably following RUGE's (1932) rather than TAYLOR's (1916) still earlier example, DOMRÖS (1981) plots in 'climagrams' the twelve monthly means of relative humidity and temperature, not sultriness, and compares them with the SCHARLAU

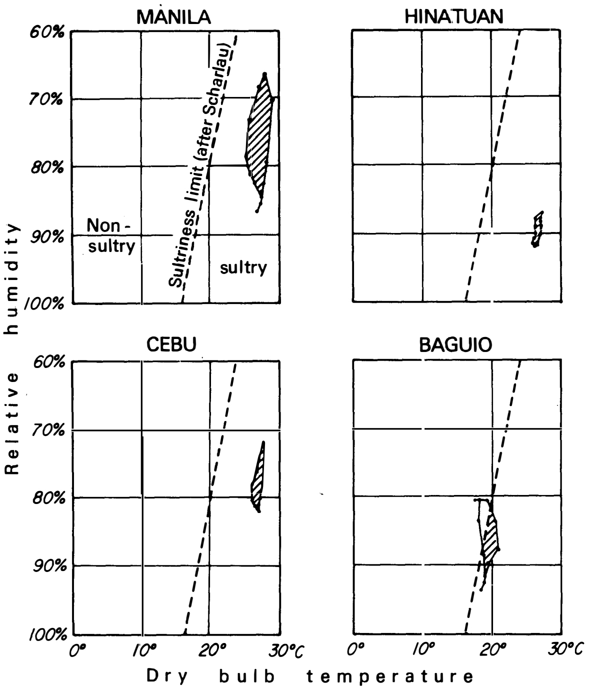

Fig. 3: 'Climagrams' of mean monthly relative humidity and dry bulb temperature at four stations in the Philippines and the threshold of sultriness (after Scharlau, 1950)

Klimagramme der mittleren monatlichen relativen Feuchte und Trockentemperatur für vier Stationen auf den Philippinen sowie der Schwellenwert der Schwüle (nach Scharlau, 1950)

sultriness threshold. He uses the evidently periodically sultry station of Diyatalawa (1248 m) and the equally evidently perennially non-sultry station of Nuwara Eliya (1896 m) to fix the absolute altitudinal limit of sultriness in Sri Lanka at about 1500 m.

None of the four climagrams of mean monthly relative humidity and temperature for four Philippine stations lies completely on the non-sultry side of the Scharlau threshold: three lie compactly parallel to it on its sultry side and one athwart it (Fig. 3). This suggests that monthly mean values of either sultriness or of relative humidity and temperature can accurately demarcate intertropic areas of lowland tropical warm climate seasonally too dry rather than too cold to be perennially sultry. Three of the Philippine stations fit into this category. But the much less readily available mean values of both relative humidity and temperature through the 24 hours of the day and night at at least 3 hourly intervals are indispensible if we are to determine the limit of perennial sultriness in the warm tropical highland areas not warm and relatively humid enough nocturnally throughout the year to remain uninterruptedly sultry. And these are just the areas where it becomes non-sultry with greatest periodic regularity. Scharlau provisionally put the altitudinal limit of perennial sultriness in the Venezuelan Andes, in southeast Abyssinia and the Malayan Peninsula at 1000 m (Domrös a little higher at 1100 m in Sri Lanka on the basis of diagrams for three hourly daily means for four selected months). In doing so Scharlau recognises how critical a feature the 24 hour diurnal as well as the 12 month seasonal variation of sultriness is methodologically. Both are indispensable in our differentiating humid tropical warm climate geographically as to how hygrothermally seasonal or predominantly diurnal its sultriness to which humans are sensitive as well as in terms of its hygric seasonality so important for plants (Troll 1964, Lauer a. Frankenberg 1985).

At about the same time as Scharlau first published his work on the measurement of sultriness Troll had revived the isopleth diagram technique to correlate and visually characterise the simultaneous variation seasonally through the 12 months of the year and diurnally through the 24 hours of the day of not only

Table 3: Relative humidity in three-hourly means at Cebu City, 1961–1970

Dreistündliche Mittelwerte der relativen Feuchte für Cebu City 1961–1970

MONTHS:	J	F	M	A	M	J	J	A	S	O	N	D
Hours												
2	87.4	86.8	87.2	86.7	87.9	90.1	90.0	89.6	90.2	92.7	91.5	90.2
5	88.5	87.5	88.6	88.6	90.2	91.5	90.8	90.4	91.3	93.3	92.6	91.1
8	79.9	79.4	77.1	73.8	75.7	78.7	80.2	79.0	78.9	79.5	83.5	81.4
11	67.2	65.5	63.3	59.6	62.8	68.4	70.9	69.7	69.8	70.1	70.3	69.2
14	64.9	63.5	59.6	55.4	58.8	65.2	69.6	68.7	70.0	69.9	68.4	67.0
17	70.7	69.1	65.9	62.7	64.8	72.0	75.6	75.5	76.9	78.1	77.1	76.0
20	83.4	81.6	80.9	78.2	79.5	83.9	86.8	85.6	86.1	88.6	87.6	86.8
23	85.8	85.0	84.6	83.1	84.6	87.6	89.2	88.2	88.9	91.4	90.1	89.1

Table 4: Relative humidity in three-hourly means at Hinatuan, 1961–1967
Dreistündliche Mittelwerte der relativen Feuchte für Hinatuan 1961–1967

MONTHS:	J	F	M	A	M	J	J	A	S	O	N	D
Hours												
2	96.5	97.1	97.5	97.4	97.0	96.5	96.0	96.3	96.7	97.2	98.0	97.6
5	-	98.4	98.2	97.8	97.7	97.1	97.2	97.4	97.3	97.6	98.2	97.9
8	93.2	93.7	93.0	95.3	89.1	86.9	87.3	86.3	86.3	87.7	88.7	91.6
11	84.2	85.9	83.4	76.5	76.9	73.0	73.0	73.5	72.3	92.6	78.0	79.5
14	86.0	84.8	81.8	77.0	74.2	73.6	73.1	72.7	72.7	73.7	76.9	78.6
17	87.1	89.7	85.5	82.4	83.1	80.6	81.1	82.2	83.2	84.0	85.2	93.5
20	93.8	94.4	93.7	91.5	92.3	91.1	91.8	93.3	92.4	92.7	94.0	93.6
23	95.8	96.4	97.0	95.9	96.2	95.0	95.9	95.6	96.3	96.1	96.9	96.3

temperature, in the thermoisopleth diagrams, but also sultriness, in so-called kaumatoisopleth diagrams. Using both thermoisopleth and kaumatoisopleth diagrams together with graphs of rainfall and in one case cloudiness he later analysed the seasonal and diurnal variation of sultriness at four tropical African stations with which Hinatuan, Cebu, Manila and Baguio in the Philippines may be usefully compared (Troll 1969).

a) Hinatuan (Supplement IV)

Even more strikingly than its west African counterpart Tiko, Hinatuan represents the near equatorial lowland condition of least seasonal variation in temperature. Like Tiko its time of 'lower sun' falls in December. But quite unlike Tiko Hinatuan's very pronounced period of maximum rainfall occurs with this 'lower sun' from November to January exposed as Hinatuan is to the northeast monsoon. Though relatively protected from the southwest monsoon during the 'highest sun' period of July, August and September, its rainfall from easterly trade winds and occasionally typhoons at this time is still appreciable. Under conditions of daily cloudiness the temperature difference between daytime and nighttime is in all months markedly greater than that between the coolest and hottest month, especially constant as is the temperature at night throughout the year. With the relative humidity in the coolest early hours of the morning before sunrise rising as high as 98% in all months a degree of sultriness greater than that of Tiko is maintained by daytime high temperatures and nighttime high relative humidities throughout the year (Fig. 4).

b) Cebu (Supplement IV)

At Cebu neither thermal nor hygric seasonality is very pronounced, although like its east African counterpart Daressalam temperatures rise to their early afternoon maximum in the shorter period between the times of 'highest sun' to somewhat increase the diurnal variation of temperature at this time of relative wetness especially from typhoons. This results in higher relative humidities at night to main-

Table 5: Relative humidity in three-hourly means at Baguio 1956–1960
Dreistündliche Mittelwerte der relativen Feuchte für Baguio 1956–1960

MONTHS:	J	F	M	A	M	J	J	A	S	O	N	D
Hours												
2	91	91	92	92	92	94	95	96	96	93	90	90
5	91	92	92	92	92	94	94	95	96	91	90	90
8	78	79	78	78	79	86	86	89	90	82	77	77
11	63	63	61	66	69	78	78	83	83	73	68	64
14	68	67	67	73	77	81	81	86	86	77	73	70
17	80	78	78	82	88	92	92	94	95	90	85	83
20	91	89	88	90	93	96	95	96	97	94	91	91
23	91	92	91	92	92	95	95	96	97	93	91	90

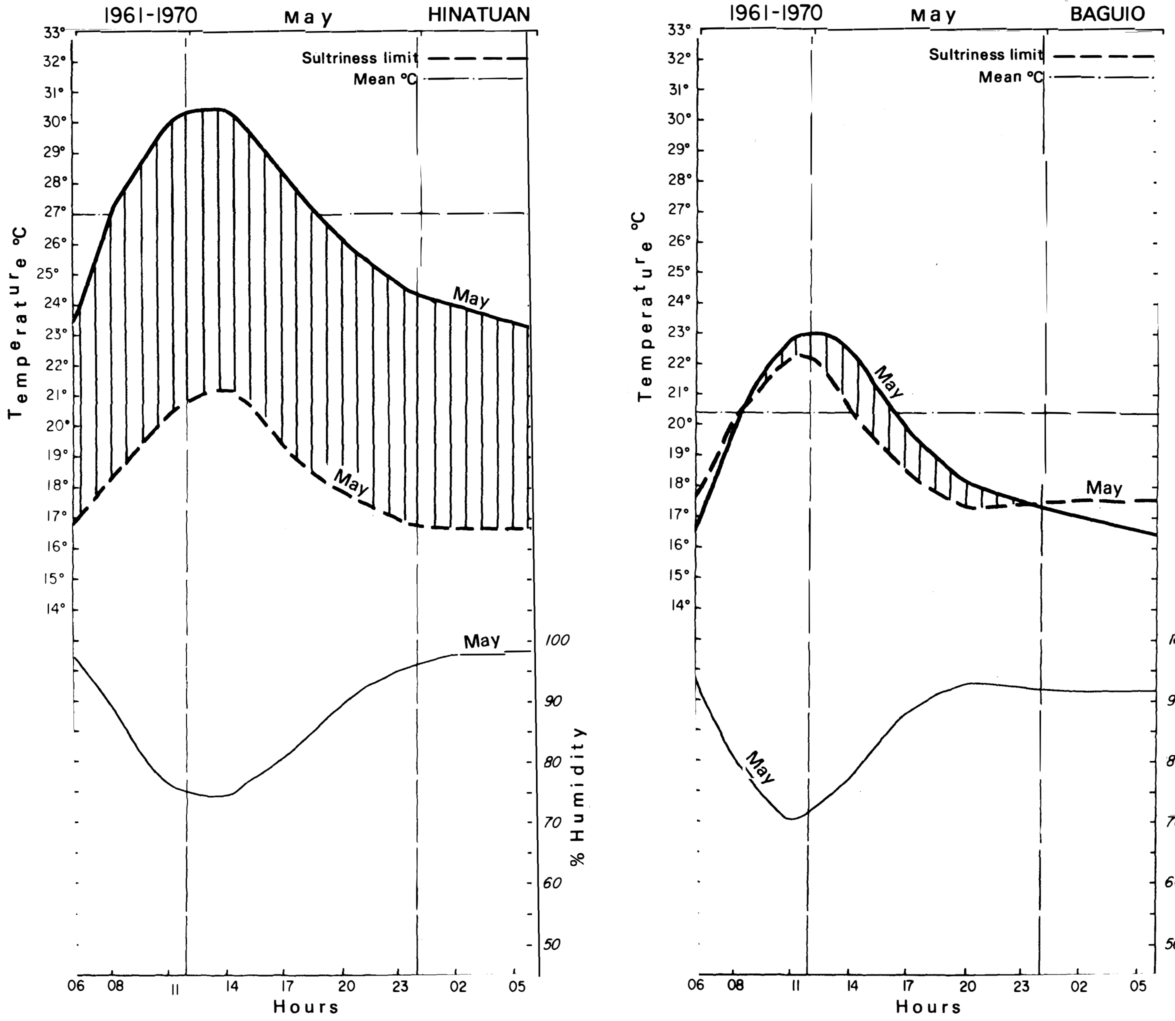

Fig. 4: Mean daily variation of thermal sultriness for May (1961–1970) at Hinatuan and Baguio
Mittlere tägliche Schwankung der thermischen Schwüle im Mai (1961–1970) für Hinatuan und Baguio

tain higher levels of nocturnal sultriness than at other times of the year, and as noteworthy a diurnal variation in sultriness as at Daressalam. But like Daressalam and in contrast with Hinatuan and Tiko Cebu's sultriness shows a clear if limited seasonality corresponding to the short but definitely drier season in February and March.

c) Manila (Supplement IV)

As at Tabora on the east African plateau, lowland Manila has a much more pronounced seasonality of rainfall than Cebu or Daressalam: a dry season from November to April sheltered as it is from the northeast monsoon, followed by a distinctly warmer as well as wetter season during the southwest monsoon. Like Tabora, but for the northern hemisphere, Manila's temperature curve is of the so-called Indian type, reaching its highest daytime and nighttime levels at the end of the dry season with 'highest sun' to be followed by somewhat lower temperatures as the wet season ensues, only to rise again somewhat with the end of the wet season about October. At its much lower altitude than Tabora Manila's diurnal variation of temperature is also less, but still an appreciable 8° in the dry season, 5° in the wet. Correspondingly, Manila's diurnal variation in relative humidity is not as great as Tabora's; there is a much more marked variation between dry season and wet season to accentuate the difference in sultriness between the high

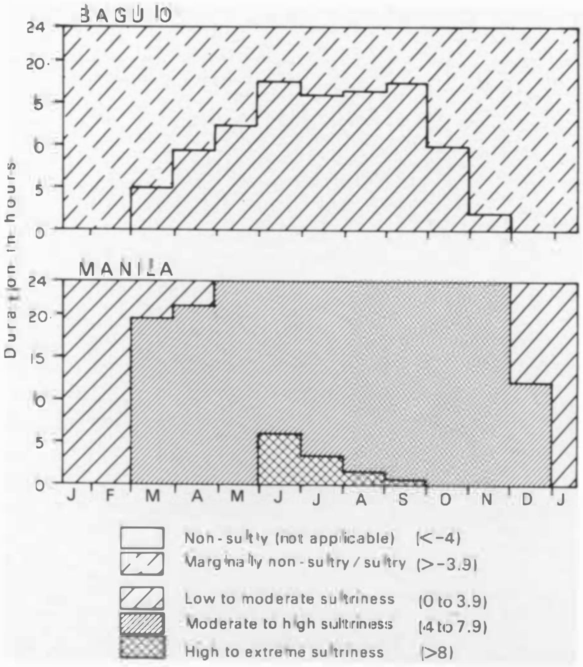

Fig. 5: Mean monthly duration of thermal sultriness at Manila (1961–1970) and Baguio (1956–1960)
Mittlere monatliche Dauer der thermischen Schwüle für Manila (1961–1970) und Baguio (1956–1960)

values of 7° and 8° day and night in the wet, only 2° and 3° in the dry. Quite unlike high altitude Tabora's dry season, Manila is never sultriness-free. And its lower sultriness intensities of nighttime December and throughout the days of January and February and at least the early morning hours of March are more than offset by the rapid change to higher than moderate intensities throughout the rest of the year, high to extreme in the hottest if not most relatively humid midday hours of June to September (Fig. 5).

d) Baguio (Supplement IV)

At 1482 m probably close to but not above the altitudinal limit of sultriness and the northernmost but still clearly tropical of the four Philippine stations, Baguio's thermal regime is a somewhat lower elevation replica of its African highland counterpart Tandala, though distinctly warmer at night and with less seasonal difference during the hottest hours of daytime; the very marked, extreme wetness of August and September does little to reduce midday temperatures. But were it not for this wetness even midday warmth and humidity would not be great enough to sustain even a low level of sultriness through from early morning to late evening in the 'highest sun' phase of the year (Fig. 4). The coolness of the later hours of darkness, close to if not below the thermal limit of sultriness (16.5 °C) is too great even in conditions of high humidity to make it more than marginally sultry. And in the cooler, drier months of the year Baguio is either marginally non-sultry (December–February) or sultry to a low degree for only the early afternoon hours of the day in March and November (Fig. 5).

The Philippine Islands form part of the worldwide intertropic zone in which the atmosphere over land and sea is diurnally if not constantly sultry throughout the year, but to varying degree. They represent conditions under markedly maritime influences especially favourable for sultriness compared with the rest of even the humid warm tropics; the annual range of temperature is unusually small even for the intertropic low latitudes though it increases nonetheless with distance from the Equator; nocturnal cooling in the highlands increases the degree to which the range of temperature between daytime and nighttime characteristically exceeds that between the coolest and warmest months of the year, and brings temperatures down closer to but not usually below that at which conditions become non-sultry; the different islands are subject to very different, sometimes highly seasonal regimes of rainfall, cloudiness, atmospheric water vapour content, and therefore direct and diffused solar radiation and sultriness despite their lack of thermal seasonality. The archipelago as a whole offers a testing natural laboratory, a 'geeignete Versuchsanordnung der Natur', to geographically differentiate the complex phenomenon sultriness is as one of the 'natural handicaps' of the tropics (Huntington 1914).

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ENVIRONMENTAL PLANNING AND APPLIED GEOGRAPHY IN PAPUA NEW GUINEA

With 3 figures

Marjorie E. Sullivan and Philip J. Hughes

Zusammenfassung: Umweltplanung und angewandte Geographie in Papua-Neuguinea

Die traditionelle Bedeutung der Umwelt und ihrer Ressourcen für die Gesellschaften Melanesiens wurde in der Verfassung von Papua-Neuguinea besonders berücksichtigt. Die wichtigste Gesetzesgrundlage für den Umweltschutz ist der Environmental Planning Act von 1978, der die Erstellung eines Umweltplanes für jedes Entwicklungsvorhaben fordert, das eine nachhaltige Auswirkung auf die Umwelt haben könnte. Dabei ist der Begriff „Umwelt" weit gefaßt: er umschließt sowohl die soziale und kulturelle als auch die biophysische Umwelt. Bis heute wurde diese Gesetzgebung bei Projektplanungen allgemein berücksichtigt, ohne jedoch in einem regionalen Maßstab angewandt worden zu sein.

Der Erlaß weitreichender Gesetzesvorschriften zur Umweltplanung hatte in Papua-Neuguinea ähnliche Auswirkungen auf die Nutzung von Ressourcen wie z. B. vergleichbare Gesetze in Australien. In beiden Fällen wurden die bereits existierenden Gesetzesgrundlagen, denen nur mit Schwierigkeiten Geltung verschafft werden konnte, gestärkt, insofern die Entwicklungsgesellschaften verpflichtet wurden, während der Projektplanung die voraussichtlichen Wirkungen auf die natürlichen und kulturellen Ressourcen zu berücksichtigen.

In Papua-Neuguinea haben Geographen bisher schon eine große Rolle im Bereich der Umweltplanung gespielt. Es ist zu erwarten, daß sich deren Einfluß noch verstärken wird, wenn bei den Verwaltungen das Bewußtsein der Notwendigkeit von regionalen Umweltplänen wächst.

The physical and social setting

Papua New Guinea, an equatorial country, consists of the eastern part of the island of New Guinea and also several island groups (Fig. 1). It has a total land area of about 463,000 square kilometres and is environmentally remarkably diverse (see e. g. Löffler 1977, Paijmans 1976). The interiors of all the main islands are mountainous, with the highest peak, Mount Wilhelm, rising to 4,500 metres. There are a large number of volcanoes (some of which are still active), especially in the seismically more active northern part of the country. The largest areas of lowlands occur along the south coast; within these are extensive areas of freshwater swampland.

Most of Papua New Guinea experiences a hot and wet climate with temperatures generally between 22 and 31 degrees C and an annual rainfall of more than 2,500 mm. Such areas support tropical rainforest. Other parts of the country, especially along the south coast, are also hot but have a much lower rainfall and a pronouced dry season; these areas support savanna and grassland vegetation. The highland areas, above about 1,200 metres, are cooler and experience a larger daily temperature range.

The people of Papua New Guinea are generally regarded as Melenesians but there is in fact a great deal of diversity in their ethnic structure. This diver-

Beilage IV zu ERDKUNDE 42,2 Beitrag Tilley

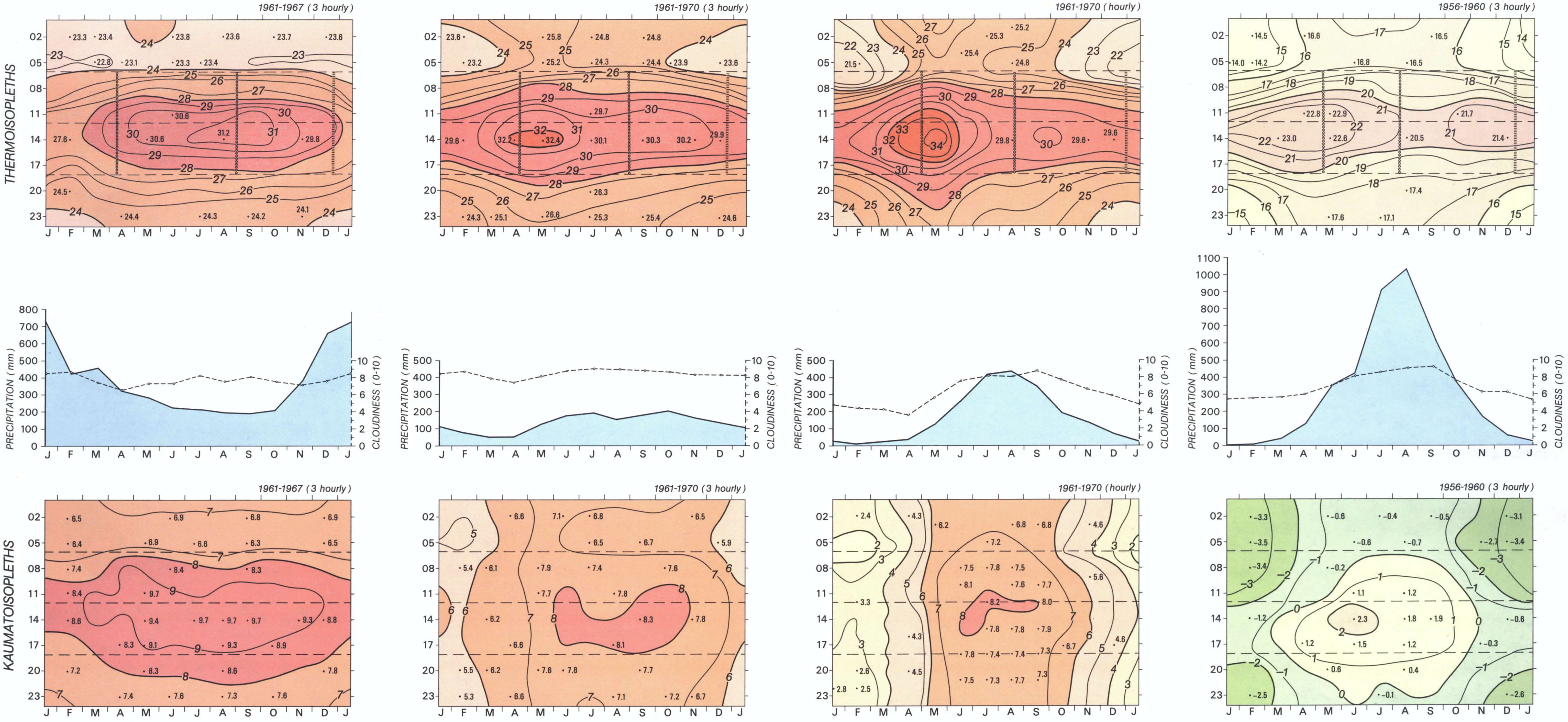
SEASONAL AND DIURNAL VARIATION OF TEMPERATURE AND SULTRINESS / NON-SULTRINESS IN THE PHILIPPINES

HINATUAN — *LAT. 8° 20′ N LONG. 126° 18′ E H: 14m*

CEBU — *LAT. 10° 17′ N LONG. 123° 56′ E H: 20m*

MANILA — *LAT. 14° 36′ N LONG. 120° 59′ E H: 30m*

BAGUIO — *LAT. 16° 25′ N LONG. 120° 37′ E H: 1482m*



TEMPERATURE

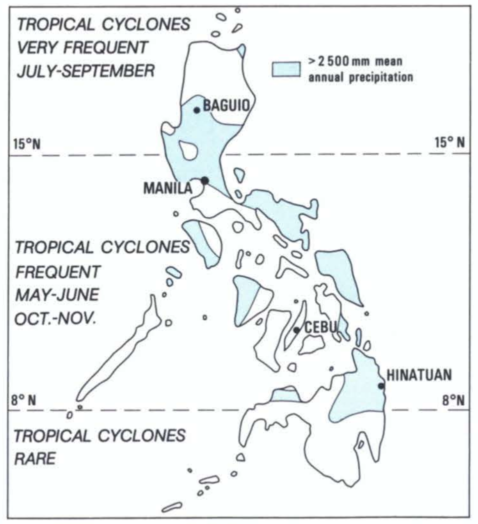
- ▨ 12°–16°C
- ▨ 16°–20°C
- ▨ 20°–24°C
- ▨ 24°–28°C
- ▨ 28°–32°C
- ▨ 32°–36°C

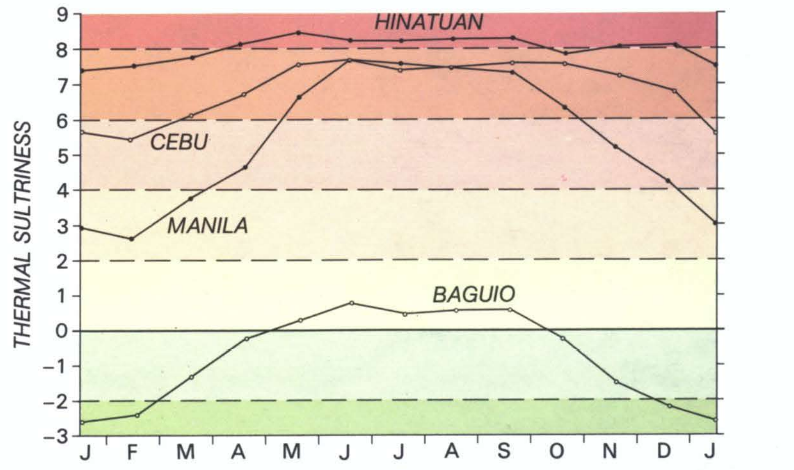
SULTRINESS / NON-SULTRINESS (after Scharlau)

- ▨ over 8
- ▨ 8 to 6
- ▨ 6 to 4
- ▨ 4 to 2
- ▨ 2 to 0
- ▨ 0 to −2
- ▨ −2 to −4

┆ *Times of lowest sun*

┆ *Times of highest sun*





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