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MAN'S BEHAVIOUR: ITS RELATIONS TO THE ATMOSPHERIC ENVIRONMENT

by

Simon M. Kevan*

A search through the volumes of abstracts concerning most of the physical and social sciences reveals that relatively little is understood about the effects of the atmospheric environment upon the social and psychological behaviour of man. When one consideres the amount of time that people spend discussing, or perhaps it would be better to say blaming, the weather's action upon their moods, it is surprising to find out just how few research programmes have been devoted to the study of social and psychological bioclimatology. It would be misleading to imply that little has been written about this matter, for statements concerning the effects of the atmospheric environment upon our mental performances and abilities as well as our constitutions have been made throughout historical times (Kevan, 1971). Most of those statements, however, have been made as a result of highly subjective experiences.

A thorough review of the innumerable articles that discuss "psycho-climatic" relations yields a confusing array of conclusions. Much of this confusion arises because of the complex nature of the atmospheric environment and as a result of man's poor understanding of his psychological processes. The lack of co-ordinated research also has helped to inhibit the growth of knowledge about our psycho-climatic environment. This lack of co-ordinated research has given rise to a great deal of repetitive and sometimes pointless research, and, it has allowed research workers to publish their findings and theories in every conceivable type of journal and magazine. Such a diffusion of relevant information has meant that

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a large number of works, some of which are of great value, pass unnoticed or get forgotten. It is the purpose of this paper to help rectify these problems by: 1) outlining some of the approaches towards research that could be employed by social and psychological bioclimatologists; and 2) by reviewing some of the theories that have been proposed in order to explain the effects of the atmosphere upon human behaviour. The value of the survey will be limited because of the heavy reliance upon information which has been written in English. For a good review of the pertinent literature that has been published in German the reader is referred to the book Wetter und Mensch by Faust (1976).

Before entering into a discussion of the approaches towards the study of social and psychological bioclimatology mention must be made of the best relevant works that have been written in the past. Works such as those by Dexter (1904) and by Huntington (1924, 1945) and by Sorokin (1928) provide an excellent general background to the many facets of the psycho-climatic environment. The well-known treatises on medical climatology by Petersen and Milliken (1934), by Mills (1939), by Tromp (1963) and by Licht (1964) provide a deep insight into physiological aspects of bioclimatology, and they all mention some of the psychological reactions of men to the atmospheric environment. Seasonal rhythms in men have been discussed by Fitt (1941). The frequency of hospitalization for mental illness in relation to the time of year has been looked at by Faust, Sarreither and Wehner (1974) and by Faust and Sarreither (1975). The effects of the month of birth upon mental development has been reviewed by Pintner and Forlano (1943), by Dalén (1975) and by Kevan (1975) and Kevan and Tromp (1976). The relationship between weather/climate and crime has been outlined by Falk (1952), by Wolfgang (1958) and by Kevan and Faust (1976); and the effects of the atmospheric environment upon suicide has been analysed by Faust (1973). An excellent review of the philosophical doctrine of environmental determinism has been provided by Thomas (1925) and additional comments can be found in the works by Barnes (1925) and by Tatham (1951). Other works that give literature reviews of some of the more specific psychological/psycho-physiological-climatic relations will be found in the sections below that concern the theories with which they are normally associated.

Approaches Towards the Study of Social and Psychological Bioclimatology

There are several methods by which one can attempt to establish the degree to which man's feelings and behaviour are affected by the changing states of the atmosphere. It is possible, for instance, to analyse objectively some of the cultural habits of man that appear to be influenced by the atmosphere. Though many such attempts were made at the turn of the nineteenth centure, they tended to be extremely general and usually exceedingly biased (Sorokin, 1928). One of the few good examples of an objective analysis of cultural phenomena and how they may be affected by climate was produced by Robbins, DeWalt and Pelto (1972). They undertook a cross-cultural study of various customs and beliefs of primitive peoples. It appears that there is a statistically significant difference in the customs and beliefs of peoples living in warm climates from those living in colder regions. The people who live in warmer areas are shown to be more aggressive, more permissive and more emotional, but they appear to be less suicidal than those people who live in cooler countries.

Primitive man tends almost to embody weather into his culture through his mystical and religious philosophies and practices (Frazer, 1926). It probably is by no means coincidental that where weather gods are the most powerful members of the deity human activity depends upon the weather. The Norse beliefs in Odin and Thor serve as adequate examples of such a relationship. Human sacrifices were made to the weather gods by the Aztecs of Mexico (Spence, 1923). Even in our contemporary "Western World Civilization" one can find references to the religious-weather complex. Insurance companies like to consider that damage caused by lightning, hurricanes, hail and winds are "Acts of God".

Meteorological metaphors such as meetings having climates, rooms having atmospheres and people being under the weather are quite frequently used. There are psychological implications to the fact that laymen make weather prognostications on the basis of their feelings - "It feels like rain" is said in much the same manner as "I feel sleepy". The psychological dimension to the role of weather in the works of playwrights, novelists and poets also could be examined. Shakespeare, Dickens and Keats all used atmospheric imagery to set their audiences' moods and to emphasize their themes. Of course, the most effective use of weather has been made by film producers. They have an advantage over other artists in that they can employ both visual and audial imagery.

One can study even the strictly visual media from a psycho-biometeorological point of view. Students of British art are well aware of the fact that British painters seldom portray winter scenes. Constable, one of the world's greatest natural landscape painters, is not known to have portrayed a single winter landscape; furthermore, it should be pointed out that he lived during a period when England had a longer and colder winter season than it does now. On the other hand, many continental landscape artists have produced a multitude of winter scenes. This dichotomy which arises between British and continental artists has been attributed to the fact that British winters are cold, damp and generally unpleasant; whereas, continental winters, though they may well be colder, generally are not felt to be as unpleasant nor is winter considered to be a depressing time of year. The ancient Greeks' interest in geometry, which had an overwhelming influence upon their architectural designs, has been considered to have been inspired because the climatic conditions of Greece were such that tall objects cast markedly defined shadows that would allow angles to be perceived with clarity (Cameron, 1974).

A second method of investigation requires the use of questionnaires and observations in order that individuals' personal reactions to climatic stimuli can be synthesized objectively. When a general questionnaire is given it is usually found that an overwhelming majority of the population believe that weather affects human behaviour; however, the complexity of the relationship readily becomes apparent from the host of reactions reported to be induced by every atmospheric phenomenon. A better understanding of the influence of the atmospheric environment upon man has been gained through questioning and by testing the performance of subjects who have been placed in controlled climatic conditions. The greatest number of these tests have been undertaken with controlled temperature and humidity conditions. Tests also have been conducted under controlled atmospheric pressure and ionic composition of the air. In general, it has been found that under controlled conditions variations of single meteorological elements account for only a few of the perceived reactions to climate.

A third approach, which is used to explain the exact nature of the relations, relies upon the observation of physiological reactions to the atmospheric environment. The physiological reactions are related to psychological effects through neuro-physiological principles. As neuro-physiological mechanisms are not well understood, it will probably be a long time before practical experiments concerning atmospheric interference upon those mechanisms will reveal the causes for man's weather sensitivity.

Behavioural Factors

Pepler (1971) arranged numerous theories concerning the relations between the thermal environment and human response into three classifications: 1) psychological hypotheses; 2) physiological mechanisms; and 3) psycho-physiological hypotheses. Those catagories are equally applicable to the theories that have been proposed in order to explain the effects of any single or combination of atmospheric factors upon human behaviour; consequently, those three sub-divisions will be used below. As psychological and physiological prosesses are so closely aligned the categorising of some theories proved to be very difficult. This was especially true for those theories that have been placed within the psycho-physiological catagory. The criterion used in this study for placing a theory within that section was that the behaviour was a result of two distinct processes: one of the processes must have been defined as psychological, the other must have been termed as physiological. It also should be emphasized that behavioural responses to atmospheric phenomena are extremely varied so that under a certain set of conditions one specific mechanism may be operating, whereas under a different set of conditions a combination of mechanisms may be at work.

Psychological Hypotheses

Within the catagory of "psychological hypotheses" Pepler placed such concepts as distraction, criterion of response, change in motivation, and channel capacity. A person's attitude towards a task can affect significantly the degree to which the former three responses will be altered. When a subject has a poor attitude towards a task - which may arise from either disinterest or fear - distraction is at its greatest.

That also is the time when the subject subconsciously or consciously changes his standards of adequacy; in other words, he considers a lower level of performance to be acceptable. On the other hand, when the subject has a good attitude towards the task the effects of distraction, the change in criterion and motivation are all at a minimal level. That does not mean, however, that distraction ceases to take place; it just takes on a lesser role. An important fact to remember about "the role of attitude in response to environmental stress" is that attitudes can be changed by factors that appear to be unrelated to the stress and also with the aid of training (Lee, 1966).

There are two distinct forms of distraction; those that are physiological in nature and those that are psychologically rooted. Pepler mentions the physiological irritants such as sweat or tears. When the subject is disinterested or is under unwanted stressful situations these physiological distractions can become overpowering; consequently, interest in and care about the task diminishes. The psychologically distressful situation causes distraction through a process of association with things from the past or with an awareness of the existence of other more enjoyable situations. Associations are made more readily with the more violent or dramatic meteorological conditions such as wind, rain, thunder, or lightning. The specific condition is then related to happy or, more often, unhappy events and the distraction is brought about with the use of the memory. One author even went so far as to suggest that the unconscious foundation for the fear of the cold is derived from the fear of separation from the mother's womb (Jones, 1923)! An example of the result of the awareness of the existence of more enjoyable situations is given by Mueser (1953). He found that men arrived at work significantly later on sunny days than on cloudy days. He commented: "Thus it is easy to imagine that when it was sunny and beautiful outside the chore of earning a livelihood was put off..."

The channel capacity hypothesis, which has been borrowed from communication engineering, views man as an information channel of finite capacity and that his capacity to process information can be reduced by environmental stress (Pepler, 1971). In other words, this theory suggests that at any one time the human brain is capable of processing only a certain amount of information. When the body has to have more physiological information processed because of new environmental stresses, the brain will process that additional information at the expense of other psychological processes, such as those used for more academic pursuits.

Physiological Mechanisms

There are a large number of theories that can fit into the category of "physiological mechanisms". The oldest of these relate temperature, humidity and/or sunshine to human behaviour. Well over two thousand years ago Hippocrates, the father of medicine, suggested that it was the ambient temperature regime of a locality that determined the character of its inhabitants. He believed that it was the violent and frequent changes of temperature that take place in the northerly areas of Europe that caused those Europeans to be wild, unsociable, and fierce; whereas it was the uniformity of the weather which caused the Asians to be less warlike and more gentle - for uniform weather conditions do not induce violent physical changes or mental shocks. That type of philosophy has become known as "Climatic Determinism" and has been upheld by a great many authors. Pliny the Elder, the great Roman natural historian, also believed that ambient temperature directly affected human behaviour. He justified his theory with what one might term a physio-convective hypothesis. The people of warmer climates are more docile because the hot temperatures cause the body fluids to rise into the upper portions of the body; the people who inhabited cooler climates were barbaric because cold air caused the body fluids to stay in the lower regions of the body and in order to counter that tendency and to maintain good circulation a great deal of activity was required. Burton (1651) makes reference to several Renaissance physicians who believed that temperature and humidity exert a direct influence over melancholia. The philosophy of climatic determinism, especially the theory of the temperature depencence of behaviour, gained a substantial following during the late 1800's and the early 1900's. The stimulation and justification of their cause was found in the works of Darwin. Darwin himself, however, should not be considered as an environmental determinist, even though he does consider climatic adaptation necessary for the "preservation of favoured races in the struggle for life" (Darwin, 1859).

The most prominent advocates of climatic and environmental determinism were the early criminologists of Italy and Germany. A group of philosophers who were led by Cesare Lombroso had discovered that there were both geographical and seasonal trends to crime rates. Specifically, their findings were: there is a per capita rise in the number of crimes against the person, e.g., murder, rape, assault, etc., with decreasing latitude, and that crimes against propert, e.g., theft, burglary, larceny, etc., increased as the latitude of the location increases; also, crimes against the person were committed more often in the summer months and crimes against property were committed more often in the winter months. The only factor that was thought to have the same seasonal and geographical distribution shown by the above findings was the ambient air temperature. Lombroso (1911) felt that these findings could be explained adequately by the "fact" that heat directly excites the nervous system in much the same way as does alcohol. Heat, like alcohol, in moderate doses made a person active and aggressive, but when the heat comes in excessive doses, just as when a man consumes too much alcohol, it causes apathy. This theory explained Corre's (1889) findings that in the French West Indies the greatest number of crimes against the person were committed during the cooler months of the year. Ferri (1917), one of Lombroso's students, maintained that the distribution of aggressive acts was related to the fact that foods that tend to increase the body temperature, such as cereals and wines, are more readily available during the summer and in warmer countries. Those foods were thought to intensify the effects of heat. A convincing counter-attack against the environmental criminologists was delivered by Tarde (1912). He argued that if warm climates produced aggressive people, why then was the Roman Empire destroyed by the blood-thirsty hordes from the North. In explaining the seasonal incidence of crimes of violence he pointed out that the summer maximum occurred because people are outside more often and come into contact with other people a lot more frequently. This increase in social contact was thought to increase the likelihood of aggressive behaviour. Tarde did not think that the physiological effects of heat had much to do with increasing rates of crimes against the person in the summertime.

Controlled temperature experiments have been conducted since that time and they have shown that changes of behaviour, especially those tasks that are affected by muscular co-ordination, do take place when environmental conditions are such that they can raise or lower body temperature (Pepler, 1963, 1971; Poulton, 1970). According to Pepler (1971) one can presume that "even a small rise in the temperature of the brain will affect the neuro-physiological substrate of cognitive processes and thereby affect these processes and their control over behavior". One would suspect that a small increase in the temperature of the brain could have a similar effect upon behaviour. A second theory, which also was outlined by Pepler, suggests that the deterioration in performance may be related to "the effects of neuromuscular processes of changes in circulation and redistribution of blood flow", through the alternation of the oxidation of the cerebral tissues.

Oxygen theories gained prominance during the late nineteenth century. Dexter (1904), an American educationalist, was a leading advocate of the oxygen theory. He analysed a great quantity of information which he had collected in New York City and in Denver, Colorado. He showed that there appeared to be some sort of weather influences upon deaths, suicides, insanity, errors made by bank clerks, arrests for brawling and drunkeness as well as upon the number of misdemeanors that took place in local schools and penitentiaries. He concluded that:

> "High temperatures, high winds (better ventilation), fair days with low humidities as an accompaniment are anabolic [accelerate physiological and psychological processes by providing a good oxidation of tissues]; while low temperatures, high barometric conditions, calms, rainy and cloudy days with high humidities, because of their opposite characteristics, are katabolic [decelerate physiological and psychological processes by providing poor oxidation of the body and mind]."
>
> (Dexter, 1904: pp. 267-8)

Dexter also considered that atmospheric pollution had a katabolic effect upon people. He argued that in a given volume of polluted air there would not be as much oxygen as there would be in the same volume of fresh air. The polluted air would have less oxygen, sc that the person breathing polluted air would encounter a deterioration in both physical and mental performance. Hoverson (1935) proved that different weather conditions could alter the oxygen concentration of inhaled air. Using elementary gas laws he showed that within the realms of the normal temperature and pressure changes, which take place with the passage of a front, the quantity of air inhaled with each breath can change by several percentiles. These changes in oxygen concentration could alter the reactivity of cerebral cells and this change in cellular reactivity may be expressed in terms of abnormal or psychotic behaviour. Petersen and Milliken (1934, 1935), and Petersen and Reese (1940) argued that tissue composition and the rates of cellular oxidation can be changed by the weather. They showed that frontal activity is associated with physiological changes and with episodes of mental instability. They found that leptosome (skinny) people are prone to attacks of schizophrenia during the cold period that follows the passage of a cold front; and that pyknic (fat) people are more likely to have manic depressive outbursts during the warm period that follows the passage of a warm front. Petersen (1943) even went so far as to analyze the effects of the atmospheric environment upon the lives of Lincoln, who was a leptosome, and the leader of his opposition party, Douglas, who was a pyknic.

Huntington (1945) thought that ozone could account for the higher than average marks that were obtained by a group of students who were being tested when the low pressure centre of a hurricane was passing over the building in which the examination was being given. Curry (1948) put forward an aran hypothesis. Aran, he claimed, is a mysterious substance, probably an ozone compound, the presence or absence of which causes air to be perceived as fresh or stale respectively. Some people are greatly affected by higher or lower concentrations of aran; W-type people, who according to Petersen's classification would be described as pyknic, are sensitive to warm aran - lacking southerly air; C-type people, who would be classified according to the Petersen scheme as leptosomes, dislike cold aran-rich northerly air.

The psychological effects of light and sunshine have been queried for a long time. Hercules de Saxonia (c. 15th-16th C.) thought that the reason so many Venetian women were melancholic was that they terried too long in the sun (Burton, 1651). Daylight length has been suggested as the cause for the regular annual distribution of suicides and rapes (Aschaffenburg, 1913, citing Chaussinaud, 1881). The rates for these reach a maximum during the spring and early summer. The regular distribution of rapes was supposed to have its roots in a latent photoperiodic mechanism that exerts an influence on the mating behaviour of man. Rape was thought to be a consequence of abnormal man's primitive instincts that he could not contain.

Experiments conducted by Tromp (1963) in the Netherlands have indicated that the increase in the restlessness of institutionalized schizophrenics and oligophrenics during the winter months may be related in part to the lack of sunlight during that season. His observations did not reveal the existence of any direct relationship between restlessness and sunlight.

Barometric pressure has been thought to exert an influence upon human behaviour. Mills (1939) believed that such a relationship existed because atmospheric pressure fluctuations are capable of affecting the functioning of the brain cells by changing their water content. Oswald (1970) proposed that "if atmospheric pressure fell slightly one could expect a very slight expansion of the arteries, particularly the cartoid sinus, and therefore a tendency for sleep" would be promoted.

Less obvious meteorological factors have been considered to exert an influence upon human behaviour. In the early 1800's, when the study of electricity was in its infancy, it was thought that fluctuations in the electrical gradient of the atmosphere were capable of depriving a man of "the energies of the brain and the nervous system" (Forster, 1823). Dexter (1904) believed that the enervating effects of days with high humidities were due to changes in the electrical potential of the atmosphere. In more recent years experiments have shown that it is possible for fluctuating electrical fields to interfere with neural-synapse connections of the nervous system (Ludwig, 1968). Electromagnetic longwaves also have been shown by Reiter (1952) to produce reactions in human beings. A great deal of research has been undertaken concerning the effects of ionized air upon physiological and psychological processes. It is generally assumed that negative ions generate a feeling of well-being, whereas positive ions produce adverse effects such as headaches and nausea. In his review of literature concerning the effects of ionized air Davis (1963) pointed out that there is a great deal of contradictory information concerning this matter.

Psycho-physiological Hypotheses

Pepler (1971) outlines one psycho-physiological hypothesis. This theory, which was proposed by Provins (1966), is based upon relations among behaviour, cortical arousal and physiological reactions to thermal stresses. Arousal in the psychological sense means a general state of alertness, vigilance, responsiveness and wakefulness (Hebb, 1966). It is known that performance and attention are affected by both high and low levels of arousal; also, physiological experiments have indicated that "an important aspect of the neural arousal mechanism is the balance between heat production and peripheral vascular blood flow" (Pepler, 1971) which are known to change in accordance with the prevailing thermal environment. It is thought that chronic exposures to cold or heat stress would cause a continuing state of "overarousal" with effects similar to those that have been found in sleep deprivation experiments - effects such as irritability and bad temperedness. Controlled studies conducted by Griffit (1970) on the subject of "environmental effects on interpersonal affective behavior" have provided some support for this theory. Griffit found that attraction was negatively related to "effective temperature" and positively related to similarity of the attitude of subjects. The habituation, or process by which something becomes less responsive to stimuli, of nerve junctions to thermal stimuli has been reported by Glaser (1957). As the habituation of the nervous system is dependent upon the amount of time that nerves are exposed to external stimulation, it is possible to explain the lethargic effects of continued chronic exposure to heat or cold stress in terms of an habituation process.

Another hypothesis (Lee, 1950) explains the "general disinclination for work and the spirit of manana that commonly occurs in tropical regions" in terms of "cerebral ishemia of a low degree". Lee added:

> "It should also be remembered that active cells of heat-regulating 'centers' are in close association with other hypothalmic cells often loosely refered to as the 'sleep center'. It is quite possible that activity in the former irradiates to the latter and assists in producing feelings of lassitude, inattentiveness and drowsiness."
>
> (Lee, 150: p. 728)

Sleep deprivation and heat stress tests were made by Pepler (1959) in order to varify this hypothesis. Pepler's evidence indicated that Lee's hypothesis was not valid because heat stress reduced accuracy, whereas sleep loss reduces activity. As very little is known about the functioning of the brain, theories such as the type produced by Lee may yet be of importance to the psychological bioclimatologist.

The last theory that I wish to refer to is one that relates weather to neuro-chemical reactions. Studies conducted by Sulman (1971) in Israel show that the hot dry desert wind "the Sharav" induces the production of excessive amounts of serotonin, a chemical that is vital to the normal functioning of the brain. These excessive concentrations of serotonin can act in such a way as to cause such symptoms as depression, migraine, sleeplessness and nausea. Relief from some of these symptoms has been achieved through the use of chemicals and by negative ion treatment (Sulman and Pfeifer, 1973).

Conclusion

There are few people who question the existence of some kind of relationship between the atmospheric environment and human behaviour and emotions, nevertheless, after well over two thousand years of philosophizing there is still very little known about the nature of this relationship. From the host of hypotheses that have been formulated one fact becomes evident: the relationship is by no means simple!

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WIND PROFILE ESTIMATES FOR A HARDWOOD FOREST

by

B. Singh*

Introduction

After a thorough scrutiny of the literature the author has not encountered a single investigation of wind profile estimates for a hardwood forest. All of the published literature to date appear to relate to conditions over either agricultural crops or pine forests. The present study is an attempt to give estimates of D (the zero plane displacement) and z_o (the roughness length) over a predominantly beech-maple forest.

In neutral or near neutral conditions the shape of the logarithmic wind profile can be written (Penman and Long, 1960):

$$u_z = \frac{u_*}{K} \ln \left[\frac{z-D}{z_o} \right] \quad (1)$$

where u_z is the wind measured at height z, u_* is the friction velocity of the surface in question K is von Karman's constant (0.41), D is the zero plane displacement and z_o is the roughness length. Equation (1) can be simplified to give:

$$u_z = \frac{u_*}{K} \{\ln (z-D) - \ln z_o\} \quad (2)$$

If wind speed measurements (u_z) are taken at say three different heights above the canopy at levels z_3 (the highest), z_2 (the middle) and z_1 (the lowest), one can form what is called the "shape

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factor" of the wind profile, which is given as $\frac{u_3 - u_2}{u_2 - u_1}$.

By substituting the "shape factor" into (2), one derives:

$$\frac{u_3 - u_2}{u_2 - u_1} = \frac{\frac{u_*}{K}\{\ln (z_3 - D) - \ln z_o\} - \frac{u_*}{K}\{\ln (z_2 - D) - \ln z_o\}}{\frac{u_*}{K}\{\ln (z_2 - D) - \ln z_o\} - \frac{u_*}{K}\{\ln (z_1 - D) - \ln z_o\}} \quad (3)$$

which reduces to:

$$\frac{u_3 - u_2}{u_2 - 1} = \frac{\ln (z_3 - D) - \ln (z_2 - D)}{\ln (z_2 - D) - \ln (z_1 - D)} \quad (4)$$

In order to obtain the value of the zero plane displacement, D, several methods are available (Rider, 1954). One consists of a graphical solution of equation (4). Alternatively, plots may be made of observed values of u_z against ln (z-D) using likely values of D. When the best approach to a straight line is obtained the required value of D is attained. A third technique employs an iterative solution to equation (4) by making small adjustments to D until convergence or close to convergence is reached.

z_o, the roughness length, is then derived by basically a graphical solution. Using the appropriate value of D, z_o is found by plotting u_z against ln (z-D) to give an intercept ln z_o on the axis u = 0 (Monteith, 1964, 1973).

Site and Experimental Procedure

Wind-profile measurements were collected over a predominantly beech-maple forest at Mont St. Hilaire, Quebec (43°33'N, 73°10'W) from August 19 to August 28, 1975. The area is fairly hilly with elevations up to 410 metres and a local relief of 250 to 300 metres. The experimental site was however located on the southern side of the mountain. This was done to optimize upwind fetch effects. These are taken as at least 300 times the greatest height of observation (Pasquill, 1972). The experimental site conformed to these characteristics with respect to south and west, which is the predominant wind direction at the time of year of the experiment. Weather conditions during the week of data collection were fair with mainly sunny conditions prevailing.

The mean height of the canopy at the data collection site was approximately 1800 cm. Wind measurements were made at three levels above the canopy, using Cassella Type 16108/1 sensitive anemometers with 3 cup metal rotors. The observations were made at 1829 cm, 2012 cm and 2195 cm. The anemometers were mounted into an angle-iron mast that was supported above the forest by a 1800 cm tall triangular television tower. Wind counts which were signalled to the bottom of the tower were taken every hour, so that mean hourly wind speeds were derived.

Discussion of Results

Plots of wind speed (u_z) against height (z) were made for a range of wind speeds to get an idea of the shape of the wind profiles (Fig. 1). Because of the extreme difficulty in detecting temperature differences over a surface as aerodynamically rough as a forest, and because the thrust of the main topic of investigation did not include profiles of temperature, the experiment yielded no objective means of depicting stability conditions over the forest. In fact, this is the major drawback of the present investigation.

However, the following procedures were employed to approximately derive neutral conditions. A close scrutiny of Figure 1 showed that there was a definite and perceptible change in the shape of the wind profiles where u_1 (lowest level) reached about 125 cm $sec.^{-1}$. A similar change was detected for profiles with u_3 (highest level) values greater than 500 cm $sec.^{-1}$. Reference to other work (Penman and Long, 1960; Oliver, 1971) indicates that profiles with u_1 values less than 125 cm $sec.^{-1}$ approximate very stable conditions. Similarly, profiles with values of u_3 greater than 500 cm $sec.^{-1}$ would likely represent considerable turbulence and unstable conditions.

Thus it was decided that for the estimation of D and z_0 only those wind profiles with u_1 values greater than 125 cm $sec.^{-1}$ and with u_3 values less than 500 cm $sec.^{-1}$ would be used. As a further attempt to approximate neutral conditions as closely as possible only those profiles for overcast, early morning and early evening conditions were selected, since at these times the temperature gradient between surface and air is likely to be the least in magnitude.

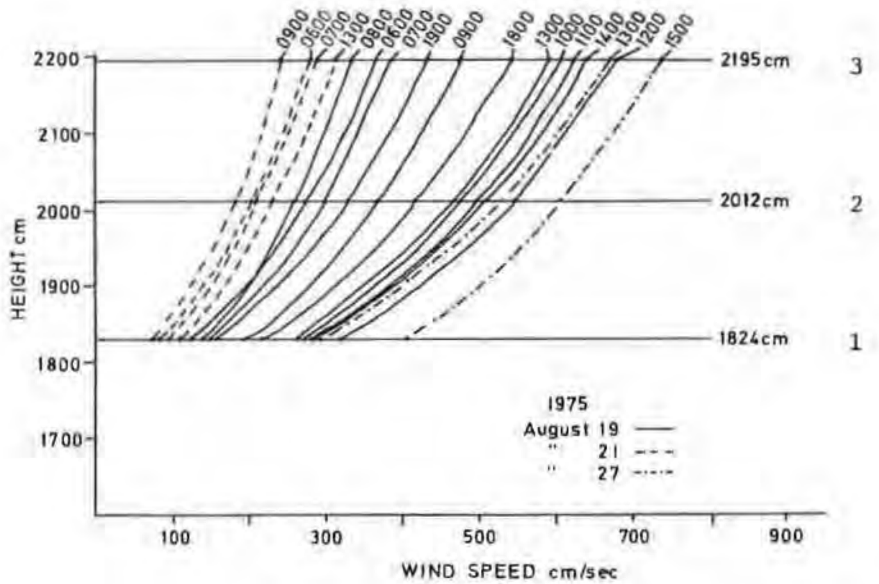

Fig. 1 Selected wind profiles for the entire range of measured values.

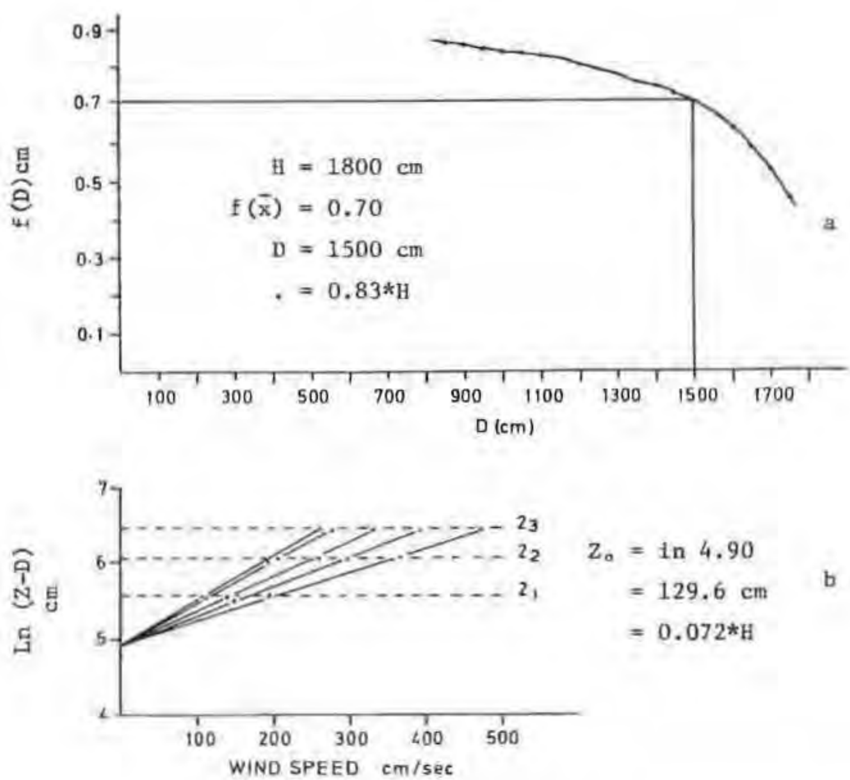

Fig. 2a. Graphical solution of D.

2b. Graphical estimation of Z_o with D = 1500 cm.

All three methods listed earlier for the estimation of D were attempted. The iterative technique was abandoned because convergence was achieved on the first run for values of D ranging from 800 cm to 1700 cm. The inappropriateness of this method here can be attributed to the fact that the left hand side of equation (4) is conservative and the insensitivity of the right hand side of equation (4) to changes in D, especially for the lower values of D.

Since the iterative technique proved inappropriate it was necessary to estimate by means of a graphical solution of equation (4). The left hand side of the equation, which expresses the "shape factor" can be restated as:

$$f(x) = (u_3 - u_2)/(u_2 - u_1) \qquad (5)$$

where f(x) is derived from different mean hourly wind speeds. Alternatively, the right hand side can be expressed as:

$$f(D) = \frac{\ln(z_3 - D) - \ln(z_2 - D)}{\ln(z_2 - D) - \ln(z_1 - D)} \qquad (6)$$

where f(D) represents a range of values of D for given values of z_1, z_2 and z_3.

Values of f(D) were then plotted against the corresponding values of D (Fig. 2a). The appropriate value of D is then derived by locating the mean value of f(x), i.e., $f(\bar{x}) = 0.70$, $s_D = \pm 0.05$, on the axis of f(D). By projecting this value to the plot of f(D) against D and extending this point down to the axis D, the intersection of these points gives the value of D (1500 cm, Fig. 2a).

In order to test the validity of the value of D obtained by the above procedure, the method of graphical smoothing was then applied. This involved plotting observed values of u_z against ln (z-D) using likely values of D. This was done for values of D that ranged from 1320 cm (0.73*H) to 1710 cm (0.95*H). The best approach to a straight line was found when a value of D equal to 1500 cm (0.83*H) was used (Fig. 2b).

The value of z_o is subsequently derived by plotting ln(z-D) against u_z using the appropriate value of D (Fig. 2b). The mean intercept of these with ln (z-D) at u = 0 gives the value of z_o in log form. Taking the antilog, this gives a value of z_o of 129.6 cm (0.072*H).

It is noticeable that the values of D and z_o derived in the present work, namely 0.83*H and 0.072*H, are within the range of values found for these same parameters by others in their work over pine forests (Hicks, et. al., 1974; Thom, et. al., 1975). The value for D, however, is on the high side of the range of D values which have been derived for pine forests. This is to be expected. It would indeed be surprising if the value for D over a hardwood forest had been found as radically different from that over a pine forest. Its location in the higher part of the value range for pine forests, however, is reasonable. The virtual sink for momentum ($D+z_o$) would be closer to the canopy top for a densely canopied hardwood forest with its relatively smooth surface, than is the case for the irregular surface of a coniferous stand.

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URBAN SURFACE THERMAL RESPONSE ASSOCIATED WITH LAND USE

by

J.E. Lewis, Jr., S.I. Outcalt and R.W. Pease*

Introduction

An essential task that faces climatology is the development of procedures to improve the climatic description of urban areas. The employment of remote sensing methods, more specifically the use of thermal imagery, provides a means to enhance this urban climatic characterization. Additionally, a need exists to demonstrate the relationships between land use and microclimate with their implications for determination of the environmental impact of land use changes in an urban context.

Theoretically, the nature of the surface has a primary effect on the magnitude and partitioning of energy at the earth's interface. These primary characteristics of the land surface which affect the local climate are its thermal properties, its surface (aerodynamic) roughness, and the distribution of moisture (evaporation and transpiration) at the interface. A type of land use then might be considered as a surrogate measure for the surface's physical and thermal properties which influences the energy exchange (Nicholas and Lewis, 1976). The underlying assumption is that each land-use type with its characteristic mix of surface properties generates an energy expenditure regime unique to that type. Procedures for obtaining land use data by remote sensors are relatively well established. However, the suitability of remote sensing for use in determining the spatial climatological impact of land use on thermal climate of an urban area is just beginning to be demonstrated (Outcalt, 1972).

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Method

Multispectral electro-optical scanner imagery was collected for the city of Baltimore, Maryland on May 11, 1972 by the Environmental Research Institute of Michigan's aircraft. The aircraft flew at 1524 meters (5000 ft.) above sea level for three separate times during the day - 0615, 1015 and 1345 EDT. The flight sequence included a west-east calibration run, a NW-SE flight across the central business district and two other flight paths which we shall report on at a later time. Data were collected in the following radiation bands: .58 - .64 μm, .62 - .70 μm, 1.0 - 1.4 μm and 9.8 - 11.7 μm. However, this report is confined to an analysis of the thermal imagery (9.8 - 11.7 μm) for the NW-SE flight at 1345 EDT. The synoptic conditions on May 11, 1972 were dominated by continental polar air mass resulting in low vapor pressures, no cloud cover, and substantial solar radiation input (Table One).

TABLE ONE

Global Incoming Solar Radiation
(Beam and Diffuse)
Fairgrounds Parking Lot - Timonium, Md.
May 11, 1972

Time (hrs.)	Radiation (ly/min.)	Time (hrs.)	Radiation (ly/min.)
0600	.12	1100	1.35
0700	.41	1200	1.43
0800	.69	1300	1.37
0900	1.04	1400	1.22
1000	1.16	1500	.95

It was necessary to calibrate the M-7 scanner, used to collect the image data, to surface radiance because of the transmission and emission characteristics of the air column intervening between the surface and airborne sensor. This calibration was accomplished with the aid of ground truth targets, for which radiances were measured at the time of overflight; the scanner possessed an internal calibration source which produced absolute values for the recorded radiances at flight elevation. A mobile survey of global radiation incidence was made at the time of the 1345 flight to ensure that the urban atmosphere posessed similar characteristics of the atmospheric column for the calibration flightline. Measured values of global radiation are essentially coincident with global radiation values measured at one of the surface calibration sites (Table One). In addition, information from an atmospheric sounding taken on the southern side of the city inferred fairly homogeneous atmospheric conditions existed during the time of the experiment. Attention is drawn to the synoptic conditions mentioned previously. (The interested reader is referred to Pease, Alexander and Pease, 1970 amd Pease and Nichols, 1974, for further details of the calibration procedures.)

The thermal imagery (Fig. 1a) was digitized and smoothed to produce a computerized map of surface radiant temperature along the flight line (Fig. 1c). The production of this digitized thermal map was completed by the Environmental Research Institute of Michigan (ERIM). The surface temperature map was produced by the use of the Stefan-Boltzmann relationship assuming an emissivity of .95. This emissivity assumption is reasonable because the city does not have widely varying types of moisture sources due to the existence of mostly man-made impervious materials, and the range of radiant temperature values for emissivities from .90 to .95 is subsumed in the class of 5°C used in the digitized map.

The original resolution element size of the thermal imagery was 5.03 x 5.03 m. (16.5 ft x 16.5 ft) and after the analog to digital conversion, the element size becomes 7.62 x 7.62 m. (25 x 25 ft). This scale posed an information problem for the production of a digital map, in that too much spatially high frequency information was present in the data. To overcome this problem, the digitized map was block-smoothed 4 points x 4 lines which reduced the original data by a factor of 16 (30.48 x 30.48 m)(100 x 100 ft). On this 4 x 4 smoothed data, a 3 x 3 sliding Hanning filter was used recursively four times to further reduce the spatial variability; however, this data smoothing procedure does not reduce the amount of data, but performs weighted averaging of 3 point by 3 line data blocks. A registration problem occurred between the digitized map (Fig. 1c) and the video replay of the thermal imagery (Fig. 1a) as a result of an offset in the initial replay. The problem had no effect on the data analysis.

Figures 1a and 1c depict very explicitly, both qualitatively (Fig. 1a) and quantitatively (Fig. 1c), the urban surface "skin" temperature. The darker tones represent cooler temperatures, and as the tones become lighter, the temperature increases. The dynamic range of temperature for Figures 1a and 1c are 19°C to 55°C. The temperature categories for the digitized map (Fig. 1c) are in intervals of five degrees, going from the darkest shading representing 16°C to 20°C through lighter shades at five-degree C intervals, to complete white representing 46°C to 55°C. Map 1a represents essentially a continuous spatial sample, while map 1c offers a sampling grid net that is rarely obtained in urban climate analysis. With this grid density, a minimum interpolation error occurs in describing surface temperature variation.

Results

The physical nature of the surface is seen to have a significant influence on the temperature response. A gradient of increasing temperatures is displayed from the NW suburbs to the high-density residential and central business district (CBD) in the SE. However, the maps show that the urban heat island is not a monolithic feature, but rather a thermal surface characterized by a patchwork design of interlaced pockets of cooler and warmer temperatures which is strongly correlated with land use type (Fig. 1b). These land use types are coded as follows, following Anderson, et. al., 1972:

11 residential;
12 commercial and services;
14 transportation, communication and utilities;
17 urban, other (parks, golf courses, cemeteries, etc.)
31 deciduous forest;
52 lakes.

The arrows on the figure point to examples of surface effects. Druid Hill Lake (water) highlights the coolest temperature (19°C); the vegetative areas such as Druid Hill Park, Greenmount Cemetery and Patterson Park, noticeably stand out as cooler areas (25 - 30°C) especially the latter two, with their proximity to the major built-up area (45 - 55°C) in Baltimore. Additionally, the effects of vegetation juxtaposed with changing residential densities can be seen in the upper portion (NW-end) of the photograph 1a. In area 2, where there is a greater preponderance of vegetation and residential densities are less than area 1, the surface temperatures are lower by 10 - 15°C. The effect of arterial commercial-institutional build-up on surface temperature is shown on the upper west side of 1a and 1c.

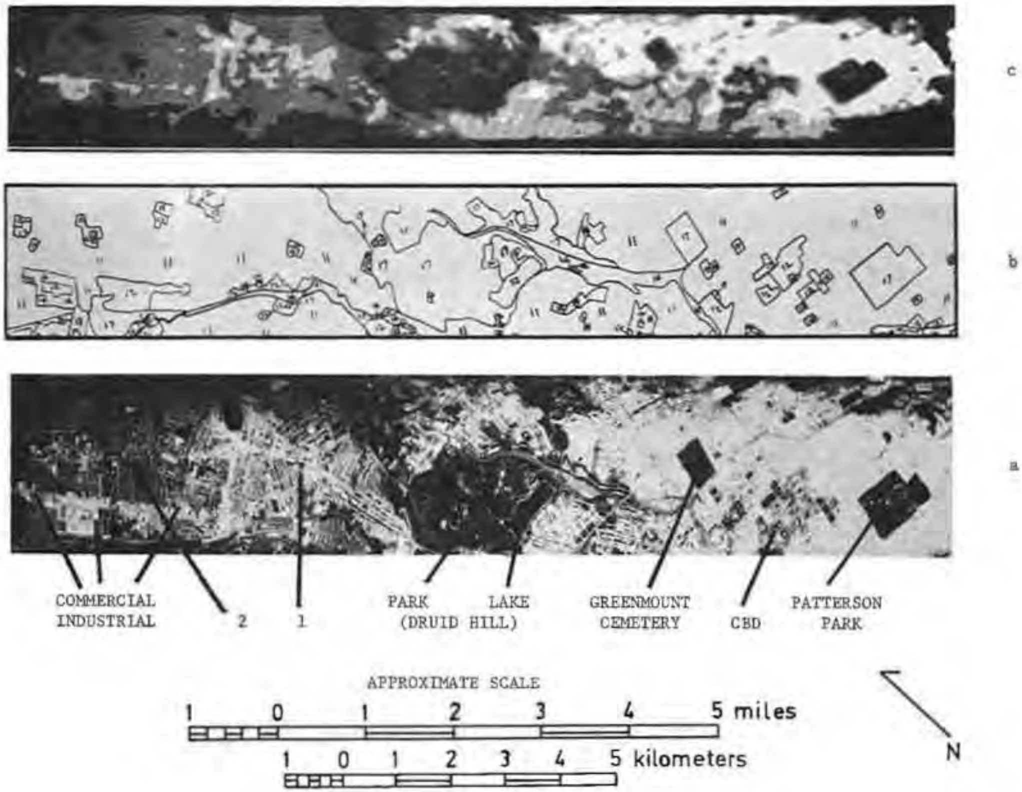

Fig. 1. Surface Radiant Temperatures - Baltimore.

a) Video replay of 9.8 - 11.7 µm band showing surface radiant temperatures by grey tones (1345 EDT)

b) Land use map of study area.

c) Digitized map of surface radiant tempeartures.

Outcalt (1972a) has displayed thermal imagery for Ann Arbor, Michigan, which he used to compare the surface temperatures with four land use categories (farmland, city center, new subdivision and old residential). The visual correlation between surface temperature and land use for Baltimore (Fig. 1a, 1b; Fig. 1c, 1b), which represents a major metropolitan area with more detailed catogorization of land use types, appears even more striking than Outcalt's results. Outcalt (1972b) also demonstrated some of the physical basis for the association of land use and the urban thermal regime. He points out the significant seasonal influence that land use (as functions of surface roughness and percent of surface wet fraction) has on a simulated urban climate.

The land use classes (Anderson, Hardy and Roach, 1972) shown in map 1b were originally developed for use with remote-sensor data in describing general characteristics of land cover. The authors feel, with some additional information such as a finer division of residential densities and a consideration of building heights and spacing, land use maps used as surrogates of surface energy exchange characteristics might well provide indications of surface temperature response given a set of initial meteorological conditions (Pease, 1975). In addition, thermal maps produced by remote sensing techniques supply valuable information for the testing and verification of energy budget simulation models that are increasingly being used to describe urban climate process. Examples showing the coupling of remote sensing with urban climate modeling are illustrated in the work of Lewis and others (Lewis, Outcalt and Pease, 1975; Lewis and Outcalt, 1975).

ACKNOWLEDGEMENT

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NEWS AND COMMENTS

The 1976 meeting of the Friends of Climatology was combined with the University of Guelph Annual Symposium which this year concentrated on the general theme of "Modelling the Climate - Plant - Soil Complex". The discussions centered around six papers, three of which were concerned primarily with agriculture applications of the modelling process and three with essentially physical relationships.

The three papers in the former category were given by D.M. Brown (University of Guelph), D. Holt (Purdue University) and J. McQuigg (U.S. Weather Bureau, University of Missouri). Dr. Brown examined hay drying as a function of meteorological parameters. Through the use of modelling procedures it is hoped to enable a farmer to better optimize his time and improve crop production since it has been found that soil and hay moisture levels can be reasonably simulated by means of a relatively simple model using readily accessible meteorological parameters. In a similar vein, Dr. Holt provided an account of a sophisticated computer-based model which simulated the physiological parameters affecting crop growth as well as the soil mechanisms influencing growth. The results were applied to illustrating plant-climate interaction by reference to the change in dry matter (growth) of a lucerne crop. The paper by Dr. McQuigg dealt with climate-plant relationships at a regional scale. He provided substantial evidence that crop productivity on a regional scale could be adequately modelled employing (a) the role of specific phenomena on crop yield and (b) the use of historical data in prediction.

The discussion of models involving essentially physical relationships at the earth's surface was given by J.E. Lewis (McGill University), P. Taylor (University of Southampton, England) and B.D. Kay (University of Guelph). Dr. Lewis examined the validity of the Outcalt simulation model as a means of evaluating surface radiative temperatures in an urban area. The verification process involved comparing the results from infrared sensing from an aircraft across a section of the Baltimore urban area with the computer output obtained from the simulation model. Although the satisfactory resulting correspondence could perhaps be largely attributed to the ideally-clear weather during the time of the flyover, the paper did nevertheless indicate the potential for mathematical simulation routines in the modelling of urban area climates. Dr. Taylor critically reviewed several approaches to modelling the planetary boundary layer and elaborated on recent contributions to the development of higher order "closure" hypothesis associated with the turbulent motion of the atmosphere immediately above the surface. The paper looked forward to further developments by means of three-dimensional simulation models in the understanding of how surface topographical variation is coupled with the overlying atmospheric motion. The contribution by Dr. Kay centered around the mechanisms of how heat and water transport are coupled in a frozen soil. He made a plea for some degree of soul searching by the modeller so that the purposes and goals of the model may be clearly determined prior to a model's formulation and operation. It was made clear that compromises must be reached with respect to the ability of a model to simulate reality and the amount of abstraction necessary to render it a convenient scientific tool.

The symposium dinner was held on the Tuesday evening and was followed by a stimulating discussion and slide display given by David Phillips (Atmospheric Environment Service) on the environment of Canada.

A recent number of Weather (Vol. 31, No. 2, February 1976) contains an amusing "irreverent revision" of the meteorological glossary. The "revision" has been prepared by K.B. Slone and some examples are:

Anticyclone - a term to describe a centre of low pressure which continues to deepen in spite of predictions to the contrary.

Hadley Cell - place of confinement for failed forecasters.

Wilting Point - half an hour after starting work.

St. Elmo's Fire - an early form of storage heater.

John Lewis participated in the annual meeting of the Association of American Geographers in New York, April 11-14, 1976, and in the University of Guelph Annual Symposium, April 20-21, 1976, which this year was combined with the 1976 meeting of the Friends of Climatology. In New York he collaborated with Carol Jenner of the Institute of Arctic and Alpine Research in Boulder, Colorado, in presenting a paper entitled "A Review of Applications in Urban Land-use Climatology". At Guelph he gave a paper entitled "Verification and Calibration of an Urban Surface Climate Simulation Model".

The World Meteorological Organization held a symposium at Asheville, North Carolina from 3-7 November, 1975, on the subject of "Meteorology as Related to Urban and Regional Land-use Planning". The meeting was attended by some 40 delegates, mostly from the United States and Canada, but including a number of persons from Europe and elsewhere. The symposium consisted af a series of invited main lectures together with contributions from other persons. The Canadian contributor to the main lectures was T.R. Oke (University of British Columbia) who gave a comprehensive review paper on the subject of "Inadvertent Modification of the City Atmosphere and the Prospects for Planned Urban Climates". Among the contributions from other Canadian sources were "Use of Meteorology in Canadian Land-use Planning" by B.F. Findlay (Atmospheric Environment Service) and "Bright Sunshine Hours and Atmospheric Particulate Matter" by D. Milton and A.J.W. Catchpole (University of Manitoba). B.J. Garnier (McGill University) attended the symposium and read a paper prepared by J.E. Lewis, S.I. Outcalt, and R.W. Pease on "Urban Surface Thermal Response Associated with Land-use".

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