Mental processes and disorders: A neurobehavioral perspective in human biometeorology

by M. A. Persinger

Sudbury Algoma Hospital, Sudbury (Ontario P3EIX3, Canada)

Summary. Research concerning the complex relation between weather and psychological processes has emphasized three important issues: methodological problems, the determination of the major behavioral factors, and the isolation of neurobiological mechanisms. This paper reviews the current status of each issue. Weather changes are most frequently associated with behaviors that are the endpoints of inferred psychological processes that include mood, subclinical pain, anxiety, and the correlates of schedule shifts. Learning and conditioning appear to mediate a powerful influence over weather-related responses. This may explain the large individual variability in these behaviors. The most well-known group effects associated with weather changes involve psychiatric populations. Clinical subpopulations may respond in different ways to different aspects of the same weather system as well as to different types of air masses. Likely neurobiological mechanisms through which meteorogenic stimuli may mediate whole organismic effects include the locus coeruleal and limbic systems. Expected psychobiological consequences are examined in detail. The magnitude and temporal-spatial characteristics of weather effects indicate they are the subject matter of behavioral epidemiology.
Key words. Weather; cognitive processes; sympathetic; psychopathology; emotion or mood; brain.

Introduction

Month after month, air masses move over populations of people. Responses are displayed; some of them are learned, others are not. Although these behaviors should be conspicuous as epidemiological phenomena, their transient nature masks the strength of their significance. This paper reviews the major, known effects of weather and its changes upon human behavior with special emphasis upon the neurobiological mechanisms. Detailed reviews of the literature can be found in *The Weather Matrix and Human Behavior*[26] and S. W. Tromp's classic work: *Medical Biometeorology*[40].

1. Weather as stimuli

From a behavioral perspective, 'weather' is a construct that attributes a false singularity to aggregates of physical and chemical stimuli. A stimulus is defined here as any environmental event whose presentation is systematically correlated over time with the occurrence of a behavior. A stimulus may exist for several hours or days; it may even have ceased before the display of the behavior.

Classifications of air masses are dominated by dichotomous labels that reflect the temperature (warm versus cold) or barometric pressure (high versus low). However, no two air masses are the same; even though a series of air masses may be called 'warm', their rate of approach, duration and magnitude of stimulus elements are different. A further distinction is made between air masses and their interfaces: fronts. It is important because air masses can become stable stimuli to which behaviors can habituate. Fronts involve changes that can be so rapid that the concept of *rate of change* becomes relevant.

1.1 Stimulus elements: Temperature, humidity, barometric pressure, windspeed and precipitation are classic variables that discriminate air masses. Factor analysis verifies the interdependence between these variables over time. Other weather-related variables include audible and nonaudible (infrasound) phononic energy, alterations in electrostatic fields, and ions (positive and negative; small and large). ELF (extremely low frequency, 10 Hz–1 kHz) and VLF (very low frequency, 10 kHz–100 kHz) fields[24], particularly those pulsed within the ELF range, are common but complicated correlates of changing weather. Secondary variables include soil gases that can be released by decreases in barometric pressure or organic constituents (allergins) that can be carried by the wind. Man-made factors, such as pollutants, are important local factors[32]. Each variable can be a potent behavioral stimulus.

1.2 Confounding variables. Geophysical phenomena are superimposed upon meteorological conditions; they can interact with the contemporary stimuli and contribute to later weather changes. Many geophysical phenomena have life-times (1–5 days) that are similar to those of the troposphere. Both the consequences of solar flares and of geomagnetic storms deserve special attention. In fact, all of the behaviors that have been associated with weather changes have also been correlated repeatedly with geomagnetic activity[26].

1.3 Weather matrix. The term weather matrix[26] is both preferred and more accurate since the components can sometimes interact to evoke synergistic effects. An example is the marked intensification of arthritic complaints when there is a simultaneous decrease in barometric pressure and increase in humidity[15]. Secondly, there may be *stimulus substitution.* This means that multitudes of different stimuli may produce a similar change in behavior. However, only one of these stimuli are required to produce the small but maximum effect. The presence of more than one of these stimuli does not substantially add to the effect.

1.4 Methods of analyses. Attempts to grabble with this complex problem usually begin with bivariate analyses whereby a single behavioral measure is correlated with a single weather stimulus. This technique, although appealing intuitively, does not control for changes in other behaviors (in addition to the one measured) or for the contribution of other weather stimuli to which the chosen weather variable is correlated. These problems have been attenuated by careful use of multivariate techniques, such as multiple regression or discriminant analyses. Preference for a 'dichotomous' solution can be preserved when weather *factors* are compared with behavioral *factors*[5]. Since weather implicitly involves change in meteorogenic stimuli over time, the second technical problem has been the isolation of the optimal temporal windows. Time frames that are too short, such as hours, may fragment the phenomena into a plethora of confusing elements. Increments that are too long, such as months, over-include different air masses as if they were the same event. Since responses to weather are invariably transient in nature, the latter intervals merely 'average out' the effect. Daily or weekly increments of analysis have been selected most frequently; usually they involve fixed intervals of analysis. The advantage of this approach is the methodological simplicity. Its primary disadvantage is that the actual phenomena of air masses display a temporal elasticity. They may exist over an area for one to three or more days. Lebowitz[19] states that the majority of abnormal days (high or low temperature) occur usually within four days of each other, but the duration is variable.

1.5 Stimulus parameters. The behavioral efficacy of an air mass is related to the interstimulus interval (the time between air masses), the duration of the air mass (how long it remains within the behavioral locus) and the amplitude of the change (relative to the previous two to three weeks). The mathematics for these analyses are cumbersome, and have not been expressed in easily available computer software. Weather phase analysis preserves both daily indices and the properties of the air masses. In the method of Ungeheuer[41] each day can be given a score with respect to its biotrophic potential. The 'same' weather phase is assumed to influence behavior in the 'same' way regardless of individual or seasonal differences.

1.6 Seasonal versus weather effects. Behavioral variations associated with season and weather are nonchalantly grouped by popular writers under the same conceptual rubric. Although season and weather share obvious tropospheric sources, there are important differences[34]. The most crucial are the duration and amplitude of the stimulus profiles. Seasonal variations are dominated by 1) subtle and gradual shifts in the relative distribution of positive and negative stimuli, 2) stimulus redundancy (and hence satiation, boredom), 3) the consequences of coerced hypoactivity (in the winter), and 4) the facilitation of anxiety. These features have been discussed elsewhere[28] and will not be included in this paper.

2. Weather-related behaviors

The behaviors that are influenced by weather are pervasive; however their characteristics are diffuse. Whereas many medical and psychiatric ailments are differentiated by their specific symptoms and particular etiologies, weather-related behaviors are remarkably mundane. They are primarily exacerbations, in either intensity or frequency, of the ongoing behaviors of the individual. Discrimination of both the occurrence and the magnitude of these changes is determined by the method of analysis. Time-dependent artifacts in response magnitude or type may also mask (or artificially create) biometeorological phenomena[35].

2.1 Types of behavior. Behavioral biometeorological studies have dealt with the observable endpoints of inferred psychoneurological processes. They can be seen as two forms: verbal complaints and aversive social consequences. Verbal complaints involve tiredness, discontent (with the world or self), restlessness or interrupted sleep, failure to concentrate (particularly on new information), general apprehension (fidgetiness or anxiety), irritable aggression, depression, forgetfulness, chest pains, vertigo, and visual flickering (black spots in front of the eyes). Aversive social consequences have included discrete events such as increased numbers of school absences, traffic deaths, industrial accidents, suicides, and homicides. Certain weather phases and parturition have been associated numerous times[9].

The apparent aversive nature of weather-related behaviors is conspicuous; however, it is an artifact of reporting. Aversive (affective) stimuli are just more likely to disrupt psychological processes and to require some attribution of cause. Aversive behavioral endpoints, such as accidents, have significant social and economic impact as well as efficient social networks for detection and recording. Weather may generate positive affective and production behaviors as well; however, their consequences are rarely recorded or are attributed to other sources.

2.2 Magnitude of weather effects. The relative potency of weather effects is usually described in terms of 1) the percentage change in the behavior over the baseline or 2) the amount of explained variance in a temporal stream of behavior. Both measures indicate that weather explains no more than 10% to 20%[2] of the variance (equivalent to r values of about 0.30–0.45). This variability includes the contribution of the obstructive effects of weather (rain or snow) to accident risk. Although trivial by traditional criteria, a factor that accommodates 10% of the variance in any social behavior has powerful economic and epidemiological consequences.

The magnitude of the effect is based upon group averages and generally ignores catastrophic days, extreme weather conditions (that are usually infrequent) and potentially enhanced sensitivity by clinical subgroups. It also ignores the results of analyses that allow combinations of weather variables, lagged up to several days before, to enter the equation. For example, between 30% to 60% of the variance (multiple r = 0.60–0.80) in daily, self-rating reports of 'mood' have been shown to be accommodated by 4–5, (time) lagged meteorological or geomagnetic variables[25,27]. The precise combinations of variables were specific to individuals but could predict responses outside of the period from which the equations were generated. Inclusion of weather, pollution, and seasonal variables accommodates 50% of the variance in family disturbances according to Rotton and Frey[32].

2.3 Weather responsiveness. The early work of Faust[10, 11] and his colleagues is representative of questionnaire studies that sample self-evaluations of weather responsiveness. According to this series of studies, involving thousands of subjects, one out of every three to four persons report sensitivity. People (such as schizophrenic patients) who have aberrant labels for their internal processes report little weather sensitivity (although they may still respond to weather changes). Sensitivity was reported at all age groups but peaked in adolescence and between the ages of 40 and 50 years. Females reported more sensitivity than males. Very sensitive people especially depressive and neurotic females, stated they could detect weather changes three to four days before the changes occurred; sensitive males reported early detection by only a few hours.

2.4 Lag effects. The occurrence of a maximum meteorotrophic effect hours to days after a significant weather change has theoretical and empirical support[40]. Both the latency of the response and the magnitude appear related to the interstimulus interval, duration and magnitude of the previous weather conditions. In several studies involving self-ratings, we[22, 25, 27] have found that the most important meteorological variables are those that occur one to three days before the daily rating. This suggests that attribution of mood to the weather on the day of the experience may be contaminated by other psychological factors.

2.5 Relevant biological responses. Three major classes of medical or biological complaints that are relevant to psychological processes have been frequently correlated with weather. They can be described as transient dysfunctions in vascular flow (peripheral or central), fluid balance and hormonal activity. No doubt they are also interrelated. Specifically, these effects include: migraine headaches, heart rate, blood pressure, myocardial infarction, stroke, blood clotting (in lungs and legs), joint swelling, glaucoma pains, premenstrual distress (exacerbation of), thyroid activity, skin conductivity, and epileptic episodes.

2.6 Classic warm air/cold air behaviors. Influxes of cold air (usually high pressure) have been associated with general sympathetic stimulation. Enhanced feelings of mood and ambulation are frequent. Increased urination, more severe kidney pains, peripheral circulatory complaints, and some types of headaches also occur. Influxes of warm air masses are associated with more water retention, restlessness, irritability, rashes of various accidents (without obvious obstruction features), and complications of hemorrhaging. These symptoms are traditionally considered indicative of parasympathetic activity[26]. There are few available analyses that differentiate the interactions between weather phases and time of year. Besançon et al.[3] found that 2885 suicide attempts within a population of 1.5 million people in a sector of Paris occurred with influxes of warm air during the spring but with influxes of cold air during the autumn.
The effects of air masses depend upon their absolute properties with respect to the general climate; there may also be geographical differences. One well-studied area is Switzerland, where weather is influenced by the Alps. Neuwirth and Faust[23] state that the strongest biometeorological effects occur on the forward side of low pressure areas. During the intrusion of warm air masses, depressive disorders are exacerbated and heart and circulatory conditions deteriorate. There are also disruptions in sleep and increases in severity of asthma, myocardial infarction and infectious diseases. The backside of low pressure air masses, coupled with cold air, enhances irritability. According to Neuwirth and Faust[23], the connection between warm weather conditions and accidents, poisonings and violent crimes is so clear that a type of biotrophic risk index is published.

2.7 Weather effects and psychopathology. The psychiatric population has been popular for meteorological studies for a variety of reasons. First, the occurrence of abnormal behaviors are more easily discriminated than simply the increase in frequency or duration of normal behaviors. Secondly, the occurrence of these behaviors usually recruits a social network that leads to the registration of their occurrence, such as admission. Third, the ward is a more or less controlled environment in which daily measurements can be taken.
Certainly the most compelling work concerning weather and psychiatric disorders has been presented by Faust and Neuwirth[23], and their colleagues. One remarkable study, involving a retrospective case approach, evaluated the weather conditions at the time of the admission of approximately 18,000 persons over a 13-year period to a clinic in Switzerland. The researchers used the weather-phase methods of Ungeheuer[41] and the daily dynamic criteria of Delbert to discern about 10 major weather conditions. Unfortunately the results of the study were presented as chi-square analyses with p-values set at 0.01, so that the absolute strength of the effect cannot be easily determined.
In this area and for this period, schizophrenic patients of all categories were sensitive (symptoms worsened) during the approach of warm fronts. Hebephrenics, in addition, responded to cold air changes. Using the criteria of weather dynamics, schizophrenics worsened when warm air advection occurred at great heights at the leading edge of low pressure areas. Neuwirth and Faust concluded that schizophrenic admission rates increased during the passage of a warm front that was sandwiched between two high pressure (cold) air masses.
Depressive patients showed variable responses depending upon the type of disorder. Endogenous depressives reacted to warm and cold air changes. Neurotic depressives reacted more to warm weather, particularly if they lived in the highlands on the northside of the Alps. Anxiety neurosis or panic attacks were exacerbated during cold air changes. Patients with anxiety neurosis reacted to periods of atmospheric lability; these conditions are correlated with the generation of ELF fields and frequently lead to thunderstorms.
Faust's work emphasizes two points that are applicable to normal and abnormal behaviors. First, the greater the differentation of weather phases according to meteorologically relevant gestalts (e.g., phases), the more discriminable the specific reactions of particular disorders. Sec-

ond, some disorders may be influenced by the local geography within which the population is located.

A representative cross-sectional and longitudinal study was reported by Chlopocka-Wozniak and Strzyzewski[6] in Poland. They observed at total of 94 patients who met one of the following diagnostic criteria: endogenous depression, acute depression, manic-depression, or psychogenic depression. Indices of mood, activity, vegetative (autonomic) symptomatology and sleep disturbances were reported by patients and rated by staff observers. Classic meteorological parameters as well as meteorotrophic days were compared.

Because data for the onset of symptoms were not reliable, admission dates were used as indicators. Endogenous depression patients were admitted at statistically significant greater proportions (78%) on meteorotrophic days than other diagnostic categories. During a 36-day observation period per patient (relatively short for meteorological studies), weather changes were significantly correlated with autonomic complaints from manic-depressives, but not from endogenous depressives. The greatest number of complaints occurred (in 95% of the patients) during days when winds blew form the southwest and northwest. Vegetative symptoms increased with increased windspeed.

Despite concurrent medication, which tends to dampen autonomic (or detection of autonomic) lability, all patients reported weather-related symptoms. The most frequent symptoms were headaches, nervousness, and irritability; the least frequent complaints were shortness of breath, menstrual disturbances, and diarrhea. Depressed patients and manic depressive patients described the greatest numbers of these complaints. Depressed patients were also plagued by sleep disturbances shortly after rain and the movement of cold fronts. This pattern was evident for forms of both endogenous and psychogenic (neurotic) depression.

No competent review of the effects of weather upon psychopathology could be completed without reference to the seminal works of Solco Tromp. In a methodologically precocious study for its time, Tromp[39] collected evaluations of 'motoric restlessness' and 'general frame of mind' for institutionalized patients from several diagnostic categories. The measures were determined four times per day; intensity of restlessness involved clear, objective criteria. All data were collected by experienced psychiatrists and nurses from seven different institutes that were located throughout The Netherlands.

Tromp reasoned that the rapidly changing weather conditions through the year within The Netherlands made it particularly favorable for the study; in addition there was a climate boundary between the eastern and western portions of the country. Tromp patiently graphed the daily 'restlessness' and 'ill-tempered' scores for approximately 250 patients who were evaluated four times daily for two years (1956–1958). His most convincing results involved a heterogeneous group of approximately 100 schizophrenic patients.

Tromp found that the influx of warm continental or tropical marine or warm marine air (that caused a gradual rise in atmospheric temperature) was associated with increased unrest in schizophrenic patients, particularly those located along the coast. Influx of cold continental or polar air masses had the reverse effect. Cold *front* passages during periods of warm air mass flow over Western Europe evoked a temporary decrease in restlessness; warm front passages during a period of cold air mass dominance were correlated with a temporary increase in restlessness during normal periods of quiet.

The effects of these weather conditions on restlessness were exacerbated if the specific air mass conditions occurred during periods with intense atmospheric disturbances such as very active depressions moving over the country in conjunction with strong winds, heavy rains, snowstorms or thunderstorms. However, these extreme conditions were not effective unless they were associated with the primary meteorological factors noted in the last paragraph. Tromp made two other observations that have been replicated: 1) the influences of the influx of cold and warm air masses were entirely different during different periods of the year and 2) female patients seemed to show greater responsiveness to weather changes than male patients.

Unfortunately Tromp did not have access to the software for multivariate analyses. However he did observe that seasonal and pseudoseasonal variations in restlessness and 'general mood' were significant sources of variance. They could mask or distort the contributions of daily variations in weather. Finally Tromp emphasized a procedure that has been ignored in many contemporary statistical studies. He selected particular periods of extreme variations in weather, with the implicit assumption that they might evoke qualitatively different behavioral profiles than those associated with more stable periods.

3. *Psychological factors*

Direct measurements of weather effects upon psychological processes are limited from the onset since they must be inferred on the bases of behavioral (verbal) or physiological measures. Nonetheless many researchers allude to these elusive psychological factors. The most common studied processes involve mood, schedule changes and pain-anxiety. They are strongly influenced by individual differences in learning history and autonomic responsiveness.

3.1 Mood. Mood is a complicated hypothetical construct; it is correlated with autonomic symptoms, changes in the central monoaminergic systems and endocrine activity. The major distinction between mood and emotion is duration; mood refers to longer periods of affective tone that may last for hours to days. Quasi-periodicities of 3–9 weeks have been known for decades; recent spectral analyses of healthy volunteers have verified these observations[22,44,45]. The most reliable overt measure of one type of mood dimension: depression-euphoria, is ambulation: lethargy to hyperactivity.

Both the report and experience of mood are almost totally dependent upon language[42,43]. Davitz[8] could discriminate twelve clusters of emotional responses (descriptors in parentheses). They were: activation (warmth, excitement), hypoactivation (drained, hollow, sluggish), hyperactivation (heart pounds, blood pressure feels high), moving towards (preference to touch, to be close physically), moving away (be alone, draw back, aimlessness), moving against (impulse to strike, explosive, clenched fists), comfort (sense of well-being, overall warmth, security), discomfort (heart seems to ache, no appetite, heaviness in chest, can't smile), tension (tightness across neck, wound-up inside, ready to snap), enhancement (feel taller, stronger, bigger, higher intellectual function), incompetence (regret, nothing goes right, self-blame), and inadequacy (unable to cope, vulnerable, helpless).

Systematic measurements of these clusters or some variant of them on a daily bases and as a function of weather changes have not been reported in the literature. However the logical overt endpoints of these processes dominate the literature. Domestic disputes or assaults are expected consequences of processes associated with irritability (moving away) or tension. Suicide and self-inflicted wounds are expected endpoints of incompetence. Some endpoints, such as traffic accidents, could be consequences of more than one type of process. Both inadequate vigilance, due to hypoactivation, or enhanced hostility could contribute to multiple accidents while incompetence might prevail in single car accidents that contain suicidal components[17].

3.2 Schedule shifts. Changes in weather disrupt daily behavioral patterns. This can range from simple physical impediments, such as changing the work routine because of rain to avoiding the excess of heat by remaining indoors. Shifts in schedules, even small ones, have profound (although transient), effects on both physiological and psychological stability. These perturbations may continue for hours to days, before they dampen. These changes alter immunological competence and endocrine activity. In the case of the former, the consequences of this disruption may be only evident days to weeks later. Changes in weather are correlated with alterations in sleep patterns[6,23]. It is not clear whether they are consequences of the day before or direct stimulation from concomitant weather stimuli. There appears to be a continuum of severity that ranges from restless sleep to sleep disruption to multiple awakenings; these episodes influence the behavior of the next day or two. Adverse nights are often characterized by reduced amounts of slow wave sleep or delta sleep and shifts (increases) in dream (REM) periods.

The behavioral changes have 'jet lag' or shift work profiles. Failures in vigilance, increased constipation, and general irritability are more likely. Many of the subclinical symptoms are reminiscent of those associated with ACTH elevations and the antecedents of the common cold. They increase the likelihood of behaviors that lead to accidents or social unpleasantness. Tolerance to circadian disruptions may be related to the individual variation of body temperature. People with greater endogeneous temperature variation display greater tolerance to schedule shifts than do people with flatter and more consistent variations[31].

3.3 Pain-anxiety. Anxiety is a subjective experience characterized by a disruption of ongoing behaviors (inability to think, stuttering, blanks in concentration), and feelings of impending doom or apprehension. It can be a conditioned anticipation of aversive events. Severe forms are called anxiety or panic attacks. When they occur, there are concomitant symptoms of light headiness, tachycardia, depersonalization, choking sensations, and numbness or tingling in the extremities. Panic attacks have occurred in about 10% of patients seen by cardiologists and can be evoked by the infusion of lactate (the normal consequences of heavy muscular exercise). Recently, this condition has been shown to be associated with asymmetric blood flow through the parahippocampal gyrus[30], an area associated with vigilance.

Pain is a multisourced experience that is exacerbated by anxiety or the expectancy of aversive stimuli. Many weather-related symptoms that are correlated with pain are also prone to placebo treatment, a factor that has probably influenced opinion about weather complaints. Circulating opiates influence detection thresholds of pain[37]; decreases in their levels may enhance the signals of *normal* visceral processes that can be interpreted as increased pain by people who score highly on introversion tests or as enhanced discomfort by those who score highly on neurotic scales. Alterations in sleep patterns also influence circulating opioid levels.

3.4 Learning and conditioning. Two types of learning are important here. The first is the consequence of serial presentations, whereby the organism is exposed to more or less the same sequence of meteorotrophic stimuli over months or years. When a certain pattern is presented, the person learns to anticipate the next series of events. For complex patterns, there is a prepotency of stimulus elements. The organism learns to respond to one element of the complex. The discrimination does not require awareness.

The second type of learning involves the fundamental, phylogenetically prevalent paradigm: classical conditioning. In this instance, one or more components of the weather matrix act as unconditioned stimuli (UCS) that evoke unconditioned responses within the person. Classic candidates for unconditioned stimuli, because of their well-known physiological effects, are changes in temperature and perhaps barometric pressure. Any stimulus that precedes or is temporally contiguous with such stimuli can become conditioned stimuli. They will elicit responses that are very similar to those that are evoked by the UCS. The direction of the effect depends upon the consequences of the UCS.

The role of classical conditioning in meteorotrophic responses has received little attention. However, the paradigm is certainly applicable since large numbers of people are passively exposed to weather; they cannot escape. Considering the duration of UCS candidates (that exist in the order of hours to days) antecedent stimuli that precede these UCS by up to 12 h might become conditioned stimuli. This issue is particularly relevant in light of the well-known tendency for weather sensitive people to report changes several hours before the passage of a warm or cold air mass[40].

The role of learning in meteorotrophic responses not only alters one's perspective on mechanism, but makes the well-known (and often perplexing) individual variability of weather responses an *expected* feature. Whereas ELF fields[24] for example, have been argued to evoke weather responses because of their intrinsic properties, the classical conditioning model asserts that the efficacy of these fields is due to their frequent tendency to precede the arrival of fronts. The type of response that might be generated by these fields would depend upon which component of the weather air mass (temperature, barometric pressure) is an unconditioned stimulus for the *individual* and the type of response (positive or negative) that is elicited by the stimulus.

3.5. Weather sensitive people and autonomic lability
There should be clinical subgroups who share similar meteorotrophic profiles to more or less similar weather conditions; these patterns have been reported. The similarities would be based upon shared histories of exposure to particular weather patterns in conjuction with personality and autonomic characteristics.
Traditionally, weather sensitivity was also based upon dichotomous systems. There were W (warm) air mass responders and K (cold) air mass responders. With recent emphasis on the autonomic nervous system, two dimensional schemes have been developed; one dimension emphasizes the relative degree of sympathetic and parasympathetic dominance[20]. The other dimension evaluates activity and ranges from stable to labile. Presumably each individual can be placed in this two-dimensional grid.
Although every individual passes through stages of relative parasympathetic 'dominance' each day, Gellhorn and Loofbourrow[12] assert that 8% of the population are clearly parasympathetically dominant, 8% are sympathetically dominant and the rest are mixed. Introversion-extraversion, a psychological trait that would influence the threshold for detection of visceral (autonomic) changes, is a third factor. Weather sensitivity is expected among labile, introverted individuals; the type of weather to which they respond would depend on the type of dominance.

4. Detection of weather changes: a multitude of mechanisms

Researchers who prefer to study mechanisms rather than effects suffer sensory overload when exposed to behavioral biometeorology. The hypotheses for the detection of weather (changes) involve physical mechanisms while the dependent measures are biological or behavioral. These mechanisms have been discussed elsewhere[26]. There is also the complex problem of how these *physical* changes, from temperature, electromagnetic fields, ions or barometric pressure, cascade to the level of whole organismic responses.
There are many functional interfaces between weather stimuli and the body that could mediate their effects. Only a few are briefly considered. Changes in gas or ion concentrations stimulate the olfactory tract; it has direct connections to the amygdala. Because all of the blood of the body passes through the lungs about every 30 s, this interface could respond to physical and chemical properties of the air.
Direct visual stimulation from light intensity influences autonomic activity; changes in light duration, intensity or phase can also influence diurnal features of pineal melatonin, an important temporal coordinator of endocrine activity[36]. Wind noise is a consistent, often irritating index of frontal passages[18]. Its second-to-second variation inhibits habituation. ELF electromagnetic fields are often generated by areas of turbulence. They penetrate buildings and organisms as well as arrive hours before the passage of an air mass. Baroreceptors near the carotid sinus could mediate alterations in atmospheric pressure. The thermosensory mesh of the body communicates to the brain through direct and indirect pathways. At effective skin temperatures near 33 °C cold and warm receptors are continuously active, but no conscious temperature sensations are reported. The preoptic, anterior hypothalamic region is the central thermoregulator whose cells show linear and nonlinear responses to blood temperature. Changes as small as 1 °C, well within the normal diurnal variation, evoke conspicuous changes. Some cells show narrow-band windows of response. This means that different neuronal consequences could follow small changes in central temperature but might be masked or altered by larger changes[14].
Cold and warm air evoke changes in blood flow within the skin but the mechanisms vary with body part. Whereas blood flow through the extremities (hands, feet, ears, lips, and nose) are controlled by noradrenergic fibers, flow through the trunk and proximal limbs is cholinergic via the release of bradykinins from sweat glands. The head and brow share other mechanisms. Hence different portions of the body could stimulate or be stimulated by different neurochemical mechanisms that might alter the consequence changes.
One final mechanism is a temporal property. Most periodic systems are sensitive to driving by resonance interaction. In man, the strongest periodicity is the 24-h circadian rhythm. By chance, the rates of change and slope of a few air masses should be similar to those of daily rhythms; phase-locking might occur. These special air masses would be more effective at disrupting (driving) circadian variations than similar air masses that were moving at slower velocities.

5. Neural mechanisms

Despite the multiple points of interaction between the weather elements or aggregates and the human body, there should be central mechanisms through which the behaviors are displayed. On the basis of contemporary knowledge, the two most likely sites of action involve the major central noradrenergic (locus ceruleus) and cholinergic (vagal complex) nuclei of the brain stem and their forebrain limbic referents.

5.1 The locus ceruleus: The locus ceruleus (LC) is the major aggregate of noradrenergic (NA) neurons in the central nervous system[1]. It is a component of an archipelago of NA neurons that are scattered through the rostral medulla and pons. The LC has cholinergic components and reciprocal connections to the vagal complex and to the serotonergic cells of the median raphe; the latter are most well-known for control of deep (slow wave) sleep. The locus ceruleus contains in the order of 10,000 cells in man, yet NA fibers are the source of more than half of the NA in the entire brain. Several, nonmedulated pathways have been distinguished[7].Two of these compose major forebrain components. One (the ventral bundle) projects to the paraventricular and supraoptic nuclei of the hypo-

thalamus. These two neurosecretory nuclei synthesize vasopressin (ADH) and oxytocin, respectively. Vasopressin influences water retention while oxytocin contributes to uterine contraction (associated with parturition). One form of vasopressin has been shown to influence memory consolidation.
The second afferent system (dorsal) to the forebrain innervates the hippocampus (and related structures) and the cerebral cortex. Norepinephrine fibers in the hippocampus contribute to long-term potentiation, a process instrumental to memory consolidation[16]. These fibers also distribute to blood vessels and hence contribute to blood flow. Tissue necrosis within the hippocampal area, due to a variety of traumatic, vascular or nutritional deficits, results in a hyperinnervation by NA fibers. Increased release of NA in these sensitized areas can evoke vasospasms that precipitate both complex partial and convulsive epileptic phenomena[1].
Norepinephrine fibers are distributed in a laminar pattern within the cortex, although their ramifications distribute to all layers. There, multiple varicosities appose neurons and blood vessels alike. This unique distribution allows fibers from just a few thousand brain stem neurons to affect millions of cortical neurons. It predisposes large numbers of neurons to be effected simultaneously; this contributes to both consciousness and vigilance.

5.1.1 Weather-relevant properties. The locus ceruleus is most known for its control of REM (or dream sleep) and the reciprocal connections with the serotonergic containing median raphe cells that control slow wave sleep. The LC influences cardiovascular function, presumably by NA fibers to the pacemaker, and has a well-documented effect on micturition. In human beings, electrical stimulation of the locus ceruleus is associated with panic attacks, death, and fear[30]. Glassman[13] and his colleagues suggest that people learn to discriminate small elevations of NA activity as cues for impending dysphoria – a condition that would generate restlessness, irritability, and anxiety.
The LC is highly capillarized; the density is surpassed only by the two neurosecretory hypothalamic nuclei. In addition, the interface between the vasculature and LC neurons is relatively thin. This makes the LC very sensitive to small changes in blood chemistry and temperature. LC cell bodies contain alpha 2 (autoreceptors) noradrenergic receptors while their postsynaptic connections are primarily beta-adrenergic. LC soma contain receptors for GABA (a presumed mechanism that mediates the effects of anxiolytic drugs), acetylchloine, barbituates, and the opiates[29]. In fact, the LC has one of the highest densities of opiate receptors. Considering the role of pain-related symptoms in meteorotrophic behaviors, this factor is not irrelevant.
Cold distress, in the rat, elevates tyrosine hydroxylase (TH), the rate limiting enzyme for NA synthesis in both central and peripheral NA neurons[1]. Painful stimuli can also increase both NA turnover and TH activity within the LC. Interestingly, LC neurons can be sensitized such that subsequent distress leads to further NA release. Blood platelets contain NA receptors; their stimulation facilitates clotting through the reduction of the ferric component of heme.

There appears to be a reciprocal relationship between LC, NA levels and the activity and the levels of ACTH and circulating corticosteroids. Conditions or drugs that elevate ACTH, decrease NA activity. However, this may follow a period of transient but excessive NA increase, associated with activation and alertness. Gradual increases in NA activity evoke craving (and irritability, restlessness) in people addicted to cigarettes, opiates and alcohol; the craving can be reduced by clonidine. One of the most compelling correlates of depletion of brain stem NA (and serotonin) is endogenous depression and suicide; depressed patients also show elevated ACTH releasing factors in the cerebral spinal fluid[46]. Excessive elevations of NA are thought to be common correlates of excessive euphoria and hyperactivity: mania.

5.1.2 A brief scenario. Stimulation of the LC would affect endogenously depressed and schizophrenic patients, but by different mechanisms. Since acute schizophrenia is associated with hypofrontal blood flow and it is affected by LC-derived NA fibers, attenuation in flow could exacerbate symptoms. Warm fronts might contribute to this by decreasing the activity of NA neurons. On the other hand, endogeneous depression might be worsened by cold fronts or any process that encouraged quick NA turnover or relative depletion in the brain stem. The weather-related depression should be preceded by increased REM periods in these patients. Interestingly, inhibition of REM in some depressed patients improves their symptoms.
For neurotic depressives or those prone to panic attacks, the cold front-stimulated, sympathetic dominance could also alter blood flow and evoke anxiety. This should be more evident, following motor activity-induced lactic acid elevations, in people with asymmetric blood flow in the temporal lobe. Epileptic patients with temporal lobe foci would also respond to the alterations in vasculature flow through sensitized hippocampal and amygdaloid tissues. Lowered NA levels at terminals in target organs such as the heart and bronchial muscles (lungs) could facilitate tachycardia and heart failure on the one hand and asthmatic attacks on the other. Alteration in cardiac NA during depressive episodes could increase numbers of 'sudden death' cases, particularly during sleep. Recondite changes evoked by the influx of air masses could predispose the person to cardiac failure when mechanical effects (shovelling snow) were superimposed.
Alteration in light duration (cloudiness) or seasonal interactions (wavelengths) would modulate a baseline upon which weather-evoked behaviors occurred. Stimulation of retinohypothalamic pathways, via the paraventricular nuclei, could influence the sympathetic stimulation of pineal melatonin: the temporal coordinator of hormonal activity[36]. Since melatonin synthesis is dominated by NA activity of beta-adrenergic receptors in the pineal gland, sympathomimetic changes could disrupt this function. There would also be susceptible periods such as pubescence and preovulation.

5.2 The vagal complex. The central vagal complex, primarily the dorsal efferent nucleus, nucleus ambiguus, and glossopharyngeal components, is a popular single site of action. Approximately 80% of all the fibers that constitute the parasympathetic nervous system are contained with the vagus nerves. Their specific innervation of organs allows more discriminating activation or inhibition. The full range of vagotonic activity is accomplished at stimulation frequencies of less than 10 Hz. Because of the rich reciprocal relationship between the vagal and sympathetic system, stimulation in one is often followed by overshoots in the other.

5.3 The limbic system. The limbic system is a collection of primarily subcortical telencephalic structures that are correlated with emotional experiences; their cell membranes also share distinct proteins as defined by immunoproperties. The major structures are the amygdala, hippocampus, hypothalamus, and (provisionally) nucleus accumbens.

The amygdala is associated with the attribution of affect: pleasure (reward) and pain (punishment) to experiences. Electrical stimulation evokes experiences of meaningfulness and deepened affect; some of its nuclei control aggressive and fear displays. MacLean asserts that the amygdala is associated with self-preservation[21]. The amygdala is innervated by NA and particularly serotonergic fibers. Its electrical activity is especially sensitive to blood temperature. The amygdala and the hippocampus are the most electrically labile structures of the brain. The amygdala is prone to electrical seizures and can learn by brief, very intermittent electrical stimulations, to display nonconvulsive seizure activity. Psychological correlates of these brief nonconvulsive ictal events include strong emotional ideation, such as sex and aggression. The experiences would be incorporated into the ongoing stream of behavior.

The hippocampus is involved with memory and affective connotation. Because of the peculiar geometry of the hippocampal vasculature, this tissue is prone to ischemic effects from small, local alterations in blood flow. Statistical alterations in memory retrieval or consolidation follow. Although the major structural bases of memory is related to cortical columns, the index for the retrieval appears to be hippocampal[38]. Changes in optimal function alter spatial, semantic and other complex memories. This is complicated by its influence on vigilance; hippocampal activity is correlated with daydreaming and hypnogogic imagery.

The ventral striatum, of which the nucleus accumbens (a traditional septal nucleus) is a major contributor, is involved with the inhibition of irrelevant movements and ideation. Stimulation of this area disinhibits conditioned, inhibited behaviors. Thus, irrelevant responses (free association) and repressed behaviors (aggressive ideation and impulses) have access to cognition or expression. This area, its dorsal connections and the prefrontal cortex, are heavily innervated by brain stem dopaminergic fibers.

The hypothalamus receives information from all of these structures. The hypothalamus is the major integrator of emotional expression. Anticipation of aversive events (anxiety) can inhibit hypothalamic function, particularly eating, via frontocorticohypothalamic pathways. Because the hypothalamus synthesizes releasing factors for all of the major hormones, slight stimulation can induce endocrine desynchrony. Finally, recent evidence demonstrates that NA fibers within the hypothalamus are instrumental in influencing immunological capacity of splenic lymphocytes[4].

5.3.1 A brief scenario. Alterations in blood flow due to the passage of warm or cold air masses could elevate aggressive impulses and ideation through amygdaloid activity; daydreaming and periods of decreased vigilance would involve hippocampal changes. Odd or peculiar thinking would involve the ventral striatum. These changes would have profound psychological impact but only be detected by overt endpoints (e.g., accidents). For populations who display *chronic* dysfunctions in these areas (such as psychiatric patients or people who are prone to inadequate frontal cortical inhibition), challenge from sudden weather changes would be potent triggers of 'unsocial' behaviors. They are normally subject to the greatest inhibition.

Because of the electrical lability of hippocampal and amygdaloid tissue, direct stimulation by ELF fields could influence vigilance and emotional behaviors. The contribution of these fields to obvious convulsive or dissociated (decreased vigilance) states, is likely[33]. Special hot, ion containing winds, a well-known serotonergic stimulus, could overstimulate amygdaloid neurons. Aggressive ideation could be followed by suicidal impulses. Because NA mediates inhibitory effects on immunorelated hypothalamic neurons, maintained stimulation (sympathetic) might reduce the immunocompetence of the organism by influencing receptor densities on splenic lymphocytes that dominate the system for several days to weeks.

6. Biometeorological research and psychoneurological process: sources of slow progress

Despite strong theoretical and recent empirical evidence that weather has powerful, though transient effects on psychoneurological processes, relatively little serious attention has been given to biometeorology. Five major factors may be responsible.

6.1 Situation-specific weather profiles. Precise evaluations demonstrate that weather profiles vary between areas. Switzerland and southern Germany display moderate seasonal variations. Fronts and air masses constitute a substantial portion of the yearly variation in temperature. During some periods, turbulent processes that lead to thunderstorms occur almost on a daily basis. Northern Ontario (Canada) shows much greater seasonal variability in temperature; the variance in temperature from movements of air masses is small, except during the spring. True turbulence may be exceptional and air masses may pass less than once per week. Consequently, unlike many other sciences, basic patterns from one context cannot be easily applied to another.

6.2 Multivariate analyses. Because of both the complexity of the weather stimuli and the processes they affect, multivariate analyses that incorporate time lag operations with elastic options are essential. These techniques are often seen as antithetical to the bivariate approach that is favored by many researchers in other disciplines. Many opinions about multivariate analyses have been molded by anachronistic concepts about the limits of these procedures.

6.3 Ubiquity, diffuseness and transcience. The basic phenomena of behavioral biometeorology, for both independent and dependent variables, challenge the nature of human perception and thought. They are optimal for highly resolved and discrete elements. Weather effects should be conspicuous epidemiological phenomena; however, they are transient and produce multiple outcomes. Thus despite the global significance of weather effects, their potency escapes traditional analyses.

6.4 Social networks. There are no appropriate social networks to record weather-relevant behaviors. Government records utilized monthly or weekly tabulations. Although local psychiatric institutions maintain daily admission data and traffic agencies store daily accident reports, there are few central agencies to coordinate data integration. When there are, local variations in weather (which are often phase lagged), are ignored.

6.5 Inappropriate training. Because of the exponential increase in technical details, disciplines are becoming more specialized. This has produced monumental progress in science. However, phenomena whose elaboration is orthogonal to this mainstream, are ignored. Biometeorology requires an integrator scientist who is competent in many physical and behavioral areas, yet does not attempt to imitate the role of the specialist. Traditional pedagogy does not emphasize the development of these individuals.

1 Amaral, D. G., and Sinnamon, H. M., The locus coeruleus: neurobiology of a central noradrenergic nucleus, Prog. Neurobiol. *9* (1977) 147–196.

2 Banziger, G., and Owens, K., Geophysical variables and behavior: II. Weather factors as predictors of local social indicators of maladaptation in two non-urban areas. Psychol. Rep. *43* (1978) 427–434.

3 Besançon, F., Ricome, H., Pezzi-Girault, D., and Chaptal, E., Circonstances météorologiques des infarctus du myocarde, des accidents vasculaires cérébraux et des tentatives de suicide. Sem. Hôp. Paris *57* (1981) 1609–1611.

4 Besedovsky, H. O., del Rey, A., Sorkin, E., da Prada, M., and Keller, H. H., Immunoregulation mediated by the sympathetic nervous system. Cell Immun. *48* (1979) 346–355.

5 Briere, J., Downs, A., and Spensley, J., Summer in the city: urban weather conditions and psychiatric emergency-room visits. J. abnorm. soc. Psychol. *92* (1982) 77–80.

6 Chlopocka-Wozniak, M., and Strzyzewski, W., The influence of biometeorological factors on the occurrence of depressive phases. Psychiat. Pol. *13* (1979) 471–478.

7 Cooper, J. R., Bloom, F. E., and Roth, R. H., The Biochemical Basis of Neuropharmacology. Oxford, New York 1982.

8 Davtiz, J. R., The Language of Emotion. Academic Press, New York 1969.

9 Driscoll, D. M., and Merker, D. G., A search for associations between weather and onset of human parturition. Int. J. Biomet. *28* (1984) 211–224.

10 Faust, V. V., Wiedmann, M., and Wehner, W., The influence of meteorological factors on children and youths: a 10% selection of 16,000 pupils and apprentices in Basel City, Switzerland. Acta paedeopsychiat. *44* (1974) 150–156.

11 Faust, V., and Hole, G., Meteorologisch bedingte Schlafstörungen bei psychiatrischen Patienten. Psychiat. clin. *5* (1972) 265–288.

12 Gellhorn, E., and Loofbourrow, G., Emotions and Emotional Disorders: A Neurophysiological Approach. Harper and Row, New York 1963.

13 Glassman, A. H., Jackson, W. K., Walsh, B. T., Roose, S. P., and Rosenfeld, B., Cigarette craving, smoking withdrawal, and clonidine. Science *226* (1984) 864–866.

14 Hensel, H., Neural processes in thermoregulation. Physiol. Rev. *53* (1973) 948–1017.

15 Hollander, J. L., Environment and musculoskeletal diseases. Arch. envir. Hlth *6* (1963) 527–536.

16 Hopkins, W. F., and Johnston, D., Frequency-dependent noradrenergic modulation of long-term potentiation in the hippocampus. Science *226* (1984) 350–352.

17 Krantz, P., Differences between single- and multiple-automobile fatal accidents. Accid. Anal. Prev. *11* (1979) 225–236.

18 Large, W. A., and Johnson, F. N., Psychiatric diagnosis on acute admission related to prevailing weather conditions. Psychiat. clin. *13* (1980) 90–95.

19 Lebowitz, M. D., A comparative analysis of the stimulus-response relationship between mortality and air pollution-weather. Envir. Res. *6* (1973) 106–118.

20 Ludwig, H. W., A hypothesis concerning the absorption mechanism of atmospherics in the nervous system. Int. J. Biomet. *12* (1968) 93–98.

21 MacLean, P. D., The limbic brain in relation to the psychoses, in: Physiological Correlates of Emotion, pp. 129–146. Ed. P. Black. Academic Press, New York 1970.

22 Makarec, K., and Persinger, M. A., Weather, individual periodicities and self-reports over a six-month winter period (1986) submitted.

23 Neuwirth, R., and Faust, V., Neue medizinmeteorologische Ergebnisse an psychisch Kranken. Münch. med. Wschr. *117* (1975) 431–436.

24 Persinger, M. A., (Ed.), ELF and VLF Electromagnetic Field Effects. Plenum Press, New York 1975.

25 Persinger, M. A., Lag responses in mood reports to changes in the weather matrix. Int. J. Biomet. *19* (1975) 108–114.

26 Persinger, M. A., The Weather Matrix and Human Behavior. Praeger, New York 1980.

27 Persinger, M. A., and Levesque, B. F., Geophysical variables and behavior: XII. The weather matrix accommodates large portions of variance of measured daily mood. Perc. Mot. Skills *57* (1983) 868–870.

28 Persinger, M. A., Winter blahs and spring irritability: the chronic but subtle behavioral operations. Percept. Mot. Skills *57* (1983) 496–498.

29 Redman, D. E., Alterations in function of the nucleus locus coeruleus: a possible model for studies of anxiety, in: Animal Models in Psychiatry and Neurology, pp. 293–305. Eds I. Hanin and E. Usdin. Pergamon Press, New York 1977.

30 Reiman, E. M., Raichle, M. F., Butler, F. K., Herscovitch, P., and Robins, E., A focal brain abnormality in panic disorder, a severe form of anxiety. Nature *310* (1984) 683–685.

32 Rotton, J., and Frey, J., Air pollution, weather, and violent crimes: concomitant time-series analysis of archival data. J. Personality soc. Psych. (1986) in press.

33 Ruhenstroth-Bauer, G., Baumer, H., Kugler, J., Spatz, R., Soenning, W., and Filipiak, B., Epilepsy and weather: a significant correlation between the onset of epileptic seizures and specific atmospheric – a pilot study. Int. J. Biomet. *28* (1984) 333–340.

34 Sarto, A., Le ciclonosi mentali. Osp. Psichiat. *47* (1979) 240–262.

35 Stebbings, J. H., Panel studies of acute health effects on air pollution. II. A methodologic study of linear regression analysis of asthma panel data. Envir. Res. *17* (1978) 10–32.

36 Tamarkin, L., Baird, C. J., and Almeida, O. F. X., Melatonin: a coordinating signal for mammalian reproduction? Science *227* (1985) 714–720.

37 Terman, G. W., Shavit, Y., Lewis, J. W., Cannon, J. T., and Liebeskind, J. C., Intrinsic mechanisms of pain inhibition: activation by stress. Science *226* (1984) 1270–1277.

38 Teyler, T. J., and DiScenna, P., The topological anatomy of the hippocampus: a clue to its function. Brain Res. Bull. *12* (1984) 711–719.

39 Tromp, S. W., Biometeorological Analyses of Daily and Monthly Variations in Restlessness and Ill-temperedness of Mental Patients in the Western Part of The Netherlands. Bioclimatological Research Centre, Leiden 1959.

40 Tromp, S. W., Medical Biometeorology. Elsevier, New York 1963.

41 Ungeheuer, H., Das menschliche Befinden bei verschiedenen Wettertypen. Therapiewoche *7* (1957) 1–4.

42 Wessman, A. E., and Ricks, D. F., Mood and Personality. Holt, Rinehart and Winston, New York 1966.

43 Whissell, C. M., Self-ratings of mood and emotion: predictors of between-word variance. Percept. Mot. Skills *58* (1984) 299–306.

44 Whitton, J. L., Kramer, P., and Eastwood, R., Weather and infradian rhythms in self-reports of health, sleep and mood measures. J. psychosom. Res. *26* (1982) 231–235.

45 Whitton, J. L., Periodicities in self-reports of health, sleep and mood variables. J. psychosom. Res. *22* (1978) 111–115.

46 Wilk, S., Cerebrospinal fluid levels of 5-hydroxyindolacetic acid in psychiatric patients: a critical assessment, in: Serotonin and Behavior, pp. 483–497. Eds J. Barchas and E. Usdin. New York 1973.

47 Thanks to Dr M. Moroz for the translation of the Polish articles and to Dr H. Falter for the translation of the German articles.

Please address all correspondence to: Dr. M. A. Persinger, Children's Mental Health Centre Sudbury Algoma Hospital, Sudbury, Ontario Canada P3E 1X3.

0014-4754/87/010039-10$1.50 + 0.20/0
© Birkhäuser Verlag Basel, 1987

The influence of seasonal atmospheric factors on human reproduction

by T. Miura

Department of Hygiene, Teikyo University School of Medicine, Kaga, Itabashi-ku, Tokyo 173 (Japan)

Key words. Epidemiology; human reproduction; infertility; infection; season of birth; sex ratio; twin-birth.

1. Introduction

In most animal species, the breeding season is firmly set at a particular season specific for each species of animal at the time which is favorable for bringing up their young. It is an established fact that the seasonally changing length of daylight is the most crucial factor in determining the onset of breeding and the pineal is known to be the major site of regulation of the exact circannual photoperiodicity.

In nature, the change of daylight length is decisively related to the change of atmospheric temperature with some time lag and thus is a co-determinant for the characteristics of the seasons. In some animals photoperiodism may be one of the most temperature-sensitive factors in the physiological responses. Hence, changes in atmospheric temperature are also essential factors in determining the time of breeding. In some districts, rainfall is another critical factor which determines the quantity of available plant food for wild animals and thus regulates their reproductive capacity.

In man, the seasonality of birth or conception is not so marked as in wild and domestic animals. However, it is well-known that, in general, babies are born most frequently in the early spring season. In other words, conception occurs most frequently during the period April-June. This phenomenon has been so widely observed in most European countries and in Japan, where vital statistics were available, that it was considered to be a kind of basic rhythm in animal reproduction including man. This type of birth pattern was called by Huntington[26] a 'basic animal rhythm'. The causes of this phenomenon of animal rhythm were quite naturally considered to be the effects of seasonal or solar and atmospheric factors on the comfort and vigor of man[1,6,8,20,26,43–45,49,65,77].

Atmospheric pressure has little effect on the reproductive capacity of animals and man, except in some extreme examples at very high altitude in the Andes[49,63]. On the other hand, the seasonal variation in atmospheric pressure is so small at any given location that it seems likely to be too insignificant to cause any seasonal effects on the reproductive system of man.

Apart from this biological-comfort hypothesis, socio-cultural factors have been proposed as causes for seasonal birth distribution. The rainy season, for instance, might increase or decrease conception in man possibly by changing the content of drinking water[39], by increasing indoor life[61] or by causing stress, for example the fear of damage to crops owing to too much rain[47]. The seasons of festivities[5,26,60,62]; social class[2,6,29,64,83,85]; agricultural patterns[69], and race or ethnic differences[7,34,50] might also be factors in the variations in seasonality of births. However, in many instances, every explanation involving these factors as the causes or mechanisms of the observed phenomena failed to convince us[36]. Some biological factors such as maternal age or birth order are also found to be related to the birth seasonality[67,73]. Other investigators suspect other, unknown biological factors[15].

Atmospheric factors which affect the reproductive capacity of man and animals include not only the physical factors, light and heat, but also chemical and biological ones. Among the chemical factors, besides humidity or water vapor, CO_2 is also known to fluctuate seasonally owing to the changing magnitude of photosynthesis of green plants, and to the anthropogenic fuel combustion. The seasonal variation of the atmospheric CO_2 concentration, however, is not known to affect the reproductive capacity of animals. Other chemical or inorganic components of the atmosphere, including air pollutants[38], have rarely been considered to have effects on reproductive capacity.

It is apparent that seasonal variations in the biosphere, or the food available in nature, may affect the reproductive capacity of animals and man. The microbiosphere composed of pollen of plants, spores of fungi and microbes may also change seasonally and some of these microbiospheric organisms can be suspended in the air and may play a role as part of the atmospheric factors which influence the biological functions causing the seasonality in the reproductive capacity of animals and man. All these factors are closely interrelated and it seems impossible to differentiate the effect of each factor.

Many bacterial infections are known to cause abortions in animals. Therefore, it is very likely that the recognized seasonality of prenatal pathology[32] or spontaneous abortions[48,80] could be caused by seasonal epidemics of certain infectious agents.