Howard E. Daugherty
University of Georgia

Climate and Ecology in Latin America

Introduction

The fields of climatology which are relevant to a consideration of the interrelationships between climate and ecology are 1) macroclimatology which includes descriptive, dynamic, and energy balance climatology, 2) bioclimatology or microclimatology, and 3) climatic change and weather modification.

Macroclimatology

The lack of extensive, reliable and comparable data seriously limits research in macroclimatology in Latin America. The distribution of meteorologic observing sites throughout most of Latin America is closely related to the distribution of human population. Thus, extensive land areas are largely unobserved meteorologically, including the tropical lowlands of the Amazon basin and the Caribbean coastal zone of Central America, the desert and steppe areas of Patagonia and northern Mexico, and the higher elevations of the major mountain chains.

Meteorologic observation of adjacent marine areas, which have a pronounced influence on terrestrial climates, is largely restricted to discontinuous observations aboard ships which transverse only a small portion of the oceanic sectors which encompass Latin America. It should be noted that such observations are not monitoring conditions at or near the air-sea interface, but are measuring on-deck conditions highly modified by the vessel itself.

The meteorologic network of El Salvador, which has one of the better programs of weather observation, illustrates many of the inherent problems of data collection in Latin America. Most of the observing sites in El Salvador are concentrated in a narrow zone through the south central portion of the country which encompasses only about one-fifth of the total national territory but which includes over one-half of the total population. Furthermore, most of the stations are located between 400 and 750 meters of elevation, an altitudinal range which excludes a large portion of the country. There is the additional problem that most observing sites are located in valley bottoms in or near settlements or airports. Thus, many of the observations are in reality measuring only a series of largely unrelated microclimates created by man rather than regional macroclimatic characteristics. There is no systematic observation of the adjacent oceanic area.

Precipitation is the most frequently observed climatic parameter throughout Latin America. However, Precipitation measurements are particularly susceptible to error. The summation of errors of a standard rain gage, for example, may be as high as 30 to 40 percent (Rusin, 1969). The amount of error increases with increasing rainfall intensity (Lamb and Pharo, 198). Thus, the degree of error is particularly high in many areas of Latin America which experience high rainfall intensity, such as the A and B climatic zones.

Measurements of relative humidity in Latin America are of questionable accuracy because of the instrumentation used -- generally hair hygrographs or sling psychrometers which are not particularly sensitive instruments. The hair hygrograph is particularly inaccurate in areas of high absolute humidity (such as A climatic regions) where the average error is 15 to 17 percent (Read, 1968). Observations of other humidity parameters such as vapor pressure deficit and specific humidity are rarely made.

Although air temperature is measured at numerous localities with a reasonable degree of accuracy, the reported monthly and annual means are not particularly important data except for descriptive climatology.

Data on wind direction and velocity are critically insufficient. The adequate observation of wind parameters in urban areas (where most weather stations are located) requires a profile of measurements taken at three levels and in rural areas at two levels. Such profiles are lacking for most of Latin America.

Other important macroclimatic parameters such as atmospheric pressure, evaporation, cloudiness and radiation parameters are infrequently measured, largely because of the lack of more sophisticated instrumentation and trained personnel.

The time-depth of meteorologic observation varies considerably from country to country, station to station, and parameter to parameter, With the exception of precipitation, the continuous measurement of standard climatic parameters at the same site is generally limited to less than 20 years and rarely exceeds 40 years.

Interpretation of such short-range data is clearly limited and generally obscures short-term weather cycles and longer-range climatic change.

Meteorologic observation in Latin America is hindered by a number of other problems which are common in many parts of the world, viz., the lack of standardization of observing station construction, instrumentation and exposure. Shelters are variously roofed with wood, aluminum or palm thatch. Many are located near buildings, others in more open areas, and some are placed under tree cover for protection. In addition, instruments are placed at various heights above the ground. As a result, few stations conform to specifications established by the World Meteorological Organization. Furthermore, a given parameter is frequently measured by different types of instruments (with varying degrees of accuracy) at different stations. Finally, the observing sites are often moved without a proper notation made in the record.

The above factors add up to minimize the validity and comparability of existing data and to severely restrict their utility for research purposes in climatology. The data are generally sufficient only for broad climatic generalizations and regional descriptions which do not require a high degree of precision.

Examples of past research in descriptive climatology in Latin America based on existing data include Portig's study (1965) on Central American rainfall, Wallen's research (1955, 1956) on precipitation patterns in Mexico, Blume's work (1962) in Caribbean climatology, Sternberg's analysis (1956) of the "drought polygon" in northeast Brazil, and Lauer's comparative analysis (1952) of the dry season in South America and Africa. 0ther regional studies which might be mentioned are those by Trojer (1959) , Serra (1963), Cleare (1961), Cavacanti Bernardes (1952), Prohaska (196 1961b), and Lydolf (1957). Other descriptive studies are noted in Par important research review of Latin American geography (1964). Various Latin American geographical and meteorological journals (such as Revista Geográfica, Revista Brasileira de Geografía and Meteoros contain regional climatic studies. In addition there are climatic atlases for several American countries, such as Brazil (Serra, 1955).

The Köppen climatic system can only be applied in a highly genera fashion to large parts of Latin America. The placement of climatic boundaries and isolines often reflects the whim of the cartographer rather climatic reality (Bennett, 1967). Eidt (1968) has discovered that some of the Köppen symbols are not applicable as such to portions of the tropics and require substantial modification and reinterpretation (e.g., portion of the lower and middle Andes of Colombia and Ecuador have been redesignated Aws, Asw, Cws,and Csw and a small portion of the Brazilian coast has been reclassified As).

The delimitation of the "humid tropics" has proved to be a particularly evasive problem (e.g., Fosberg and Garnier, 1961; Gauss and Legris, 1963; Garnier, 1965). A recent reevaluation of data by Chang (1968) considerably reduced the areal extent of the Af c1imatic type, although admitting that the data are two sparse in South America for an accurate limitation. The problem of delimiting the humid tropics is a particular important one for ecology and agronomy and is discussed further in the following section on bioclimatology.

The intricate topography and climatic zonation in the highland areas of Latin America have posed difficult problems for the climatologist. Although research by Troll (1952, 1959, 1968), Lauer (1959), Prohaska (1961c) and Bates (1948) has contributed greatly to an understanding the climatic and ecologic complexity and diversity of the highland are clearly much research remains to be done. The concept of "undifferentiated highland climates" should be discarded by geographers and others and the real research problems should be identified and attacked.

The paucity and inadequacy of surface data have limited research dynamic climatology in Latin America. Riehl's work (1954, 1962) include the most comprehensive treatment of tropical atmospheric circulation (which affects virtually all of Latin America). Boffi's study (1949) the effects of the Andes on atmospheric circulation and work by Schwerdtfeger and Martin (1964) have contributed toward an understand of circulatory patterns in South America.

Studies on the influence of regional circulation on surface phenomena include Riehl's research (1947) on the relationship between subtropical upper air flow and summer precipitation maxima in Central America Lahey's analysis (1958) of the dynamic aspects of the dry zone of nor South America and the southern Caribbean, and Nimer's study (1964) on relationship between circulation and drought in northeast Brazil.

Research by Riehl (194S), Hosler (1956) and Wallace (1969) has clarified many of the problems of the dynamics of easterly waves.

Other important studies in dynamic climatology which can be mentioned include those by Gutnick (1958), Serra (1941), Serra and Ratisbonna (J 1960), Simpson (1947), Portig (1959) and Quinn and Burt (1970).

Meteorologic investigation initiated during the International Geophysical Year 1957-58 has greatly increased the understanding of the complexity of southern circulatory systems, particularly in the data-sparse areas of the southern oceans (World Meteorological Organization, 1962; Loon, 1965, 1967; Taljaard, 1967, and references).

Satellite cloud photography has increased the qualitative understanding of tropical circulation by permitting the daily observation of the location and evolution of the subtropical jet, analysis of the location, structure and seasonal changes of tropical cloud bands, and detection and tracking of tropical storms (Oliver and Anderson, 1969).

Photography from geostationary satellites has permitted the continual observation of the dynamics of individual storms (Soumi, et al., 1969). Photography has also been used from the ground and air to observe cloud and rain systems in Costa Rica (Dingle, 1969).

In spite of its important contributions, satellite photography has major limitations. Climatic phenomena (such as atmospheric circulation) generally must be inferred from the nature and distribution of clouds. The utility of satellite photographs in cloud-free areas is obviously limited. Furthermore satellites have limited capability of measuring interface phenomena.

Upper air circulation influences surface weather phenomena and thus has some relevance for ecology. The following sources are intended as an introduction to the literature on upper air circulation affecting Latin America: Colon (1963), Ebdon (1963), Troup (1961), Tucker (1965) and Veryard and Ebdon (1961).

The role of Latin America and adjacent marine areas in the global energy balance is poorly understood. Most of the information has been gained through satellite observations (with extremely limited ground control and surface observation) and the utilization of theoretical energy models. Studies which have contributed to an understanding of atmospheric energy and moisture transfers in the Latin American area (largely in the tropical portions) include those by Riehl and Malkus (1957, 1958), Quinn and Burt (1967, 1968), Hastenrath (1966a, 1966b) and Raschke and Bandeen (19700). Recent measurements from satellites and surface stations indicate that more solar radiation is absorbed in tropical regions than previously believed (Haar and Hanson, 1969) – evidence which tends to invalidate many of the earlier energy balance estimates for the tropics, e.g., those by Budyko (1956).

In order to alleviate the problems of macroclimatic data deficiency, there is a clear need for a more extensive observational network throughout Latin America, particularly in the more sparsely populated areas (which are increasingly being subjected to resettlement plans and agricultural expansion). Instrument accuracy needs to be improved.[3] There is also a critical need for standardization of shelter construction, instrumentation and analytical procedures in order to increase the reliability and comparability of data.

Better use of existing data could also be made. Greater attention could be focused on frequencies, durations, intensities and extremes of climatic phenomena with less attention given to the standard use of monthly and annual means and the Gregorian calendar. Generally, the raw climatic data are available from the various national meteorological services in Latin America (listed in WMO's 1965 world directory of meteorological services).

Some of the problems of data deficiency may be alleviated by the World Weather Watch (WWW), the Global Atmospheric Research Program (GARP), the Barbados Oceanographic Meteorological Experiment (BOMEX) and the establishment of the Caribbean Meteorological Institute.

The objectives of WWW are atmospheric observation on a global scale and the establishment of worldwide telecommunications and computer centers to transmit and process data rapidly for forecasting and research. GARP is an international research program designed to increase an understanding of atmospheric circulation in order to aid weather prediction and modification (Malone, 1968).

BOMEX was a set of more than 80 atmospheric and oceanographic experiments conducted in an extensive area northeast of South America in May-July 1969 (Kuettner and Holland, 1969). The major objective was the observation of energy fluxes at the air-sea interface–a major meteorological and climatological problem.

The Caribbean Meteorological Institute was established in Barbados in 1967 to provide training and research in instrumentation, climatology, agrometeorology, hydrometeorology and aerology (Smedley, 1968).

Satellites will probably remain the only source of data for many of the remote areas of Latin America for several years and perhaps decades. The increasing refinement and sophistication of satellite systems offer considerably greater potential in the future for the observation and measurement of climatic phenomena throughout the region (see Lahey's paper in this volume). The greatest contribution of satellite observations has been and will continue to be to provide a better understanding of atmospheric dynamics and a more refined basis for numerical forecasting.

Other possibilities for resolving the problems of data deficiency in Latin America are the use of lasers, acoustic radars, LIDAR (light radar) and automatic weather stations (such as AMOS III-70).

Bioclimatology

Standard weather data have even more serious limitations for research in bioclimatology–the field of study which treats those microclimatic phenomena which are directly interrelated with biological phenomena. Standard observation stations are not strategically located with reference to the natural structure of ecosystems; rather the observations are generally made above a grass surface in open and disturbed sites. The data collected from such sites are rarely applicable to biogeographical and ecological problems such as the distributions of plans and animals, the nature of animal habitats, biological productivity and ecological energetics (energy flows and transformations within ecosystems).

Air temperature measured at the standard observational level of one and one-half meters, for example, is not a particularly important biological datum. Numerous measurements (see Lowry, 1967, pp. 4-11 for summary) have documented the enormous lapse rates which occur within the first two meters of the ground, particularly within a few millimeters of the surface–the interface to which most biological life is exposed. In a study of the environmental conditions of the alpine zone of Mt. Orizaba, Swan (1952) found little relationship between standard air temperature and the environmental temperatures of lizard and field mice habitats. A more precise measure of the true heat load on an organism than air temperature is the "test body" temperature (the actual temperature of an organism) in relation to the ambient temperature.

The utility of standard precipitation data (particularly the reported means) for biogeography is similarly limited. The degree of measurement error with standard rain gauges has already been mentioned. In a study on the relationship between precipitation and the distribution of vegetation in northern Mexico, Shreve (1944) pointed out the deficiencies of standard rainfall data and concluded that:

so closely are contrasting communities of plants interwoven that general climatic data are manifestly of only remote relation to the controlling conditions for such communities (p. 105).

Measurement of the amount of precipitation available for utilization by plants and animals is particularly complex within forest environments because of the high variability of interception by the canopy, evaporation from leaf surfaces, and the random nature of trunk flow and leaf drip. Read (1968) observed that the amount of rainfall on the ground beneath a tropical forest varied by a factor of two within a distance of only four meters and that trunk flow from similar trees varied during a single storm from one-half inch to 118 inches within a distance of 50 feet.

Standard wind data are largely irrelevant for ecological problems. Standard observations are not made within ecosystems and vertical profiles of wind structure are lacking. Wind profiles constructed by Hales (1949) within and above a forest in Panama illustrate the high variability of wind speed and direction along the vertical. Read (1968) has shown that ventilation (however slight) is the critical factor governing evaporation within a tropical forest. The measurement of such slight but important air movement (+ 1 kt) poses a difficult problem in instrumentation.

Standard relative humidity data give little indication of evaporation and heat and moisture stresses on organisms. Swan (1952) has shown, for example, that evaporation in a tropical highland environment may be intense even when relative humidity exceeds 90 percent. A more meaningful measure of the moisture content of the air and of heat and moisture stress than relative humidity is vapor pressure deficit (which can be calculated from air temperature and relative humidity data).

In sum, standard weather observations are largely irrelevant for biological and ecological problems and provide little insight into the energy conditions at the earth-atmosphere interface -- the key element of bioclimatology. Thus, research in bioclimatology and the related fields of ecology and biogeography must rely on a distinct data base. Such a data base, however, is extremely limited throughout Latin America. Attempts to measure the vertical structure of standard climatic parameters have been short-term, haphazard and areally scattered. The systematic observation of energy and moisture balance parameters such as solar and thermal radiation, albedo, evaporation, and the fluxes of latent heat, sensible heat and soil heat has only recently begun at a few localities in spite of their importance in biology, agriculture and meteorology. Observations of parameters which are particularly important in agronomy such as evapotranspiration, soil temperature, net photosynthesis, and carbon dioxide exchange are almost nonexistent.

In spite of data limitations, there have been attempts to construct "bioclimatic systems" utilizing standard weather data. One example is the well-known Holdridge system which attempts to delimit "natural life zones" (which are plant formations only) on the basis of simple temperature and precipitation data (Holdridge, 1947, 1959, 1960, 1962a; Tosi, 1964; Tosi and Voertman, 1964). Among the major limitations of this system are the following:

1) The use of mean values ignores the important ecologic laws of minimum and the maximum which were formulated as early as 1840 (Brown 1942; Taylor, 1934; Shelford, 1952).

2) The parameter "mean annual biotemperature," which is derived taking the annual mean of daily (or monthly) means of temperature abo 0°C., has little if any biogeographical or ecological significance.

3) The use of mean annual precipitation ignores the importance of soil moisture and short- and long-term variations of precipitation in determining biogeographical distributions. For example, the distribution of evergreen forest in coastal El Salvador is related to the moisture retention capacity of the soil rather than to annual precipitation characteristics (Daugherty, 1969).

4) Temperature and evaporation data are insufficient to support assumption that potential evapotranspiration (a critical element of the system) is constant along any given isotherm, much less along an isoline of mean annual "biotemperature." The critical role of net radiation the determination of potential evapotranspiration is ignored, as well other important determinants such as wind velocity and surface characteristics (particularly the temperature of the evaporating surface).

5) The influence of man on vegetation is totally ignored in the system -- a

particularly severe limitation in Middle America where most of vegetation has been greatly modified by human activities.

In spite of these limitations, the Holdridge system has been applied to many parts of Latin America, e.g., Nicaragua (Holdridge, 1962b) an Peru (Tosi, 1960).

Earlier attempts were made to apply the "life zone concept" to part of Latin America, e.g., Panama (Goldman, 1920). Mexico (Goldman and 1945), and El Salvador (Dickey and van Rossem, 1938). However, the delimitation of life zones in these studies relies more on elevation than on observed climatic characteristics and is, therefore, highly generalize and of limited utility.

Another "climatic" system is Plath's (1967) classification (and mapping) of potential land use types in the Central American republics Panama based on elevation and length of the dry season.

Troll (1952, 1959, 1968) and Lauer (1956, 1959) have worked extensively with the altitudinal zonation of climate and related vegetation patterns in various parts of Latin America, particularly in the tropics. Daubenmire (1954) has examined the general location of timberline in highlands of the Western Hemisphere in relation to climatic factors. Beaman (1962) has done detailed work on the timberline of Popocatepetl and Ixtacihuatl in Mexico. Although there is an interplay of a host variables which determines the location of timberline, the deficiency heat appears to be the principal controlling factor.

Such studies of vertical zonation have been limited by the lack climatic data from many coastal and highland areas, particularly those above the tree line. Swan (1952) has shown the ecological and biogeographical importance of surface temperature, soil temperature, sunlight and cloudiness in the alpine zone of Orizaba in Mexico. observation such factors is grossly limited in Latin America.

Swan (1967) has done an interesting study relating the distribution of lizards and salamanders in the aeolian region of Orizaba (beyond the limit of flowering plants) to the distribution of wind-blown insects. The presence of lizards, in turn, explains the presence of several predators, e.g., sparrow hawk, raven and rattlesnake in the zone characterized by an absence of flowering plants.

Wagner (1962) has done an important study of the influence of man on the zonation of vegetation in Chiapas -- a research theme which deserves greater attention in Latin America.

The Thornthwaite moisture balance system (1948), which is based on potential evapotranspiration and which has been used for water management problems, has been applied to various parts of Latin America, e.g., Argentina (Burgos and Vidal, 195l). This system, however, has several limitations. The assumption that mean temperatures and potential evapotranspiration are directly correlated is unsupported by empirical data. Chang (1961) has shown that the Thornthwaite computation of potential evapotranspiration is inaccurate, particularly in the tropics where measured values are often twice the calculated values. In addition, the assumption that an excess of rainfall during the wet season compensates for a deficit during the dry season is biologically invalid.

Many of these systems have been used for planning and development purposes (e.g., Holdridge, 1962b; Plath, 1967). Clearly there is a critical need for the innovation of bioclimatic models which have more relevance for biological distributions, crop plant tolerances, and agricultural development in general. However, such innovation must await the initiation of the collection of data which are biologically relevant.

The knowledge of the vertical structure of climatic parameters within different ecosystems in Latin America is grossly limited. An important source of forest microclimatic data is Schulz's work (1960) on rainforest ecology in Surinam, which included the measurement and analysis of the vertical structure of light, atmospheric humidity, evaporation, air temperature and soil temperature. Richards (1952) has summarized much of the knowledge of tropical forest microclimate.

Short-term observations of air temperature, relative humidity, evaporation and vapor pressure deficit were made by Read (1968) at three levels within a forest during the rainy season in the Canal Zone. Although the utility of the study is limited by the short time-depth of observation and the failure to adequately describe the structural nature of the forest site, the profiles illustrate the microclimatic diversity of the various forest biotopes which is obscured by standard weather data. The study also provides some insight into the problems of methodology and instrumentation in the tropics.

Baynton et al. (1965) constructed air temperature profiles in and above a forest environment in northwestern Colombia which indicated that maximum daytime temperatures occur above the forest canopy, suggesting that the forest itself exerts a modifying influence on temperature.

Ashton (1958) measured light intensity for one day within a forest in the Santarem region of the lower Amazon. The observations correlated well with those from a similar environment in southern Nigeria (Evans, 1939).

Recent work by Bennett (1967) included some short-term observations of air temperature and relative humidity in forests and adjacent cleared areas in Panama which clearly illustrate the impact of man on microclimate

The measurement of the microclimates of animal habitats has been almost totally ignored by investigators. Jackson (1953) measured the temperature and relative humidity of army ant bivouacs and ambient habitats in Panama. Swan (1952) collected intriguing microclimatic data on lizard and field mice habitats on the upper slopes of Orizaba. The microclimatic structure of habitats is clearly an important field of investigation which deserves further study. The classification of animal habit in Honduras by Carr (1950) could provide a framework for such study.

Earlier studies in various parts of Latin America which included microclimatic observations are those by McLean (1919) and Freise (1936) in southern Brazil, Davis and Richards (1933, 1934) and Carter (1934) in Guyana, Hales (1949) in Panama, and Bates (1948) in Colombia. Frequent reference is made in contemporary literature to Allee's early observations (1926a, 1926b) in Panama -- a reflection of the degree to which more recent data are lacking.

There is a critical need for the measurement of energy and moisture balances of the various ecosystems of Latin America. Although certain energy and moisture parameters are measured at a few stations, there has been no systems approach to the surface observation of the energy balance with the exception of a recently initiated program in Barbados (Garnier, 1968) which has limited relevance to other areas. Indeed, no standard systems methodology has yet been devised for the measurement and analysis of energy and moisture balance parameters. This lack of energy/ moisture systems data from Latin America precludes a precise understanding of many ecological problems such as energetics and biogeographical distributions, adaptations and tolerances. The lack of surface data also hinders an understanding of the importance of the lower latitudes in larger scale atmospheric transfers of heat and moisture.

A major ecologic Problem in Latin America is the delimitation of tropical ecosystems and the analysis of their structure (physical, chemical and biological characteristics) and function (productivity, energetics and succession/stabilization). Such information is desirable no only from a purely scientific point of view but would enhance certain economic development plans as well, such as human resettlement and agricultural expansion into more sparsely inhabited regions (viz., the humid tropics). Many tropical crops, for example, require a short dry season for maturation and are thus more suitable for Am and Aw climatic region than for Af climates (Chang, 1963). The reduced cloud cover during the dry season (and hence increased solar radiation) also increases net photosynthesis (organic production or yield). Chang (1970) has pointed out that a small increase of mean annual temperature (induced in the tropic by the persistently high night-time temperatures) reduces net photosynthesis. Consequently crops which are productive in highland C and D climatic zones generally yield less when extended into lowland areas of A climate. Thus, a more accurate delimitation of the Af/ Am/Aw and A/C climatic boundaries is essential for the proper evaluation of agricultural expansion and potential productivity in the tropics. The success of agricultural expansion depends upon the proper evaluation of climatic as we as other resources. An important research task is the determination of optimal crops for given climatic regions.

More extensive and precise observation of solar radiation -- the key factor governing photosynthesis -- is essential for estimating potential productivity in the tropics. Chang (1970) has estimated that potential photosynthesis is during a four-month (high sun) growing season in the humid tropics is approximately two-thirds that of the middle latitudes. However, mean annual photosynthesis is higher in the tropics than in the middle latitudes and is higher in the highland tropics than in the lowland tropics. In addition Borden (1941) has shown that fertilization is most effective under conditions of high solar radiation and that the use of fertilizers is often uneconomical in areas of high cloudiness (such as the humid tropics). Thus, it is becoming increasingly apparent that agricultural production in the tropics could best be increased through the intensification of agriculture in the highlands (by double cropping, irrigation and fertilization) rather than by expansion into the lowlands. It may be that the ecologic functions of the tropical lowland forests most beneficial to man are not agricultural, but rather the provisions of animal habitats and the stabilization of watersheds and regional hydrologic cycles. The determination of optimal ecologic functions is a pressing research task of the ecologist and would aid the proper management and utilization of ecosystems, in Latin America.

In addition to tropical ecosystems, there is a critical need for the study of the distribution, structure and function of the other major ecosystems of Latin America, such as the mixed forests, dry environments, extra-tropical grasslands, estuaries and adjacent coastal systems, and the myriad of highland environments. A systems approach appears to offer the most fruitful and productive research technique. The role of the bioclimatologist in ecosystems research is clear: the observation and analysis of microclimatic parameters which are ecologically and biologically relevant. Ideally systems research would be conducted at at least one permanent study site in each major ecosystem. Such sites should be equipped for the continual measurement of: 1) the vertical gradients of air temperature, soil temperature, moisture, and wind, 2) the energy balance (solar and thermal radiation, albedo and the fluxes of latent heat, sensible heat and soil heat), and 3) the moisture balance (precipitation, evaporation, absorption and runoff). Study sites should also have the instrument capability for shorter-term observation of the component biotopes (or microenvironments) which comprise the ecosystem.

The data thus collected would be applicable to a host of research problems in ecology (such as energetics), biogeography (plant and animal distributions and the nature of habitats), agronomy (crop tolerances, ranges and productivity), and energy systems (local, regional and global). Such data would contribute greatly to an understanding of the overall structure and function of ecosystems -- an understanding which is vital for the formulation of alternative strategies for ecosystem utilization -- a basic problem in human ecology. Many of the research techniques and tools of bioclimatology and ecology have been field tested; critically lacking are operational systems for observation and analysis.

The establishment of research stations with systems research capability could be done through the International Biological Program, the World Meteorological Organization, the Organization for Tropical Studies or a similar consortium of universities (with each university having the research responsibility for a different ecosystem), Only through the concerted and cooperative efforts of scientists from several disciplines can the major ecologic research problems of Latin America be resolved.

There are other problems in bioclimatology which deserve attention. The study of animal habitats, for example, includes the human habitat. Yet, the bioclimatology of individual dwelling types and of the total urban environment are untouched fields of inquiry in Latin America. Although casual observations indicate that air pollution is critical in many Latin American cities, little is known of the nature and distribution of the problem nor of its biological significance. That widespread burning associated with agriculture may constitute a significant rural pollution problem with implications for human health has not been considered.

Human physiological climatology (the physiological response of man to climate) has received little attention in Latin America (with the exception of a few studies on the relation between altitude and human physiology). There are no data to substantiate the glib statements frequently encountered in the literature about the direct relationship between climate and human phenotypes. Nor are there data to support the idea of "climatic adversity" in the humid tropics. Man, after all, underwent much of his evolutionary history within the African tropics (Leakey, 1960).The entire realm of phenotypic implications of Bergmann's and Allen's rules needs to be reworked. The Mexican lizard *Sceloporus micro-lepidotus*, which ranges from the tropical lowlands to nearly 16,000 fee on Mt. Orizaba (Swan, 1952), might provide a good case study for testing the relationship between phenotype and climatic stress.

Climatic change and weather modification

An ecological approach is increasingly being employed to attack major problems of New World prehistory such as the extinction of Pleistocene animals, the subsistence characteristics of early peoples, the origin of agriculture, and the rise (and fall) of urbanism and civilization. Examples of this research approach in Latin America include studies by Sanders and Price (1968), Coe and Flannery (1964), and Flannery (1966) on Mesoameri Byers (1967) on Tehuacan; Cowgill et al. (1966) in northern Guatemala and Coe and Flannery (1967) in south coastal Guatemala.

These and other studies point up the lack of significant climatic data from the late Quaternary in Middle and South America which are necessary if meaningful reconstructions of past environments are to be made.

Earlier studies on palynology and climatic change were done in central Mexico by Deevey (1944), Hutchinson, Patrick and Deevey (1956), Se (1952), and Sears and Clisby (1955). These studies, however, have limited utility as interpretive tools of climatic change because the time-depth of the pollen cores is limited and unsupported by radiocarbon dating, and the interpretation of the cores relies heavily on the genus Pious as a climatic indicator.

More significant pollen research has been done in Guatemala and El Salvador (Tsukada and Deevey, 1968) which indicated that major vegetation change has occurred during the last 4000 years (the maximum time-depth of the cores), but due to human interference with vegetation rather than climatic change.

Important paleoclimatic research has been done in highland Costa Rica by Martin (1964) which indicated a significant displacement of climatic zones during the Wisconsin glacial maximum and a synchronization of late Pleistocene climatic events in Costa Rica with those of norther North America and Europe.

In South America, paleoclimatic research by Hammen (1961, 1966) and Hammen and Gonzales (1960a, 1960b) has been outstanding. Their research in the Colombian Andes indicated a decrease of mean annual temperature by as much as 12°C. during the Wisconsin maximum, a correlation with the known climatic changes of North America and Europe, and the occurrence of a postglacial warm period --the only evidence from the lower latitudes in the New World that such a period occurred.

Pollen cores with a maximum time-depth of 14,000 years have been analyzed from the savanna areas of northern South America (Wijmstra and Hammen, 1966). The pollen profiles indicated the predominance of a closed savanna woodland during the late glacial period followed by a more open herbaceous savanna, particularly since ca. 3000 D.P., which the investigators attributed to felling and burning by man.

Other paleoclimatic research includes studies by Wilhelmy (1952) on South America in general, Wilhelmy (1954) on the dry zone of northern South America, Hammen (1963) in coastal Guyana, Laeyendecker-Roosenbarg (1966) in northwestern Surinam, Czajka (1955) in Argentina, Auer (1958) in southern South America, Heusser (1960) in Chile.

These studies have contributed significantly to an understanding of the nature of late Quaternary environments in Middle and South America. it should be clear, however, that the research efforts to date have had severe spatial and time-depth limitations. Thus, future research should be directed toward greater pollen sampling of the numerous lake, bog and coastal sites throughout Latin America with the purpose of extending the areal and temporal limits of late Quaternary climatology. Such research would provide greater insight into the environmental evolution of Latin America during the period of human occupance[5] and would contribute toward a solution of major problems of New World prehistory. Such research, particularly palynological analyses focusing on the evidence for human disturbance of vegetation (such as the abundance of chenopods and amaranths, Compositae, Gramineae, Zea, and carbon fragments) would also enhance an understanding of the nature and degree of ecologic alteration by early human populations. Comparative analyses of Quaternary environmental change in various parts of Latin America would also provide some insight into the controversial ecological concept of diversity and stability of ecosystems. Finally, paleoclimatic research in the American tropics -- where little is known of Quaternary climatic phenomena -- would contribute to the theoretical basis of Pleistocene climatic change.

Contemporary climatic change has obvious implications for agricultural productivity, planning, and biogeographical distributions. Portig (1958, 1965) has analyzed the rainfall variability of San Salvador for eleven-year periods from 1912 to 1961. He has concluded that there has been a significant change in the annual distribution of rainfall which he believes may be due to a worldwide displacement of climatic zones. Although Portig presents interesting data, this conclusion based on the analysis of data from a single station (with all of the inherent difficulties of standard weather data) may be premature.

Long-term fluctuations of rainfall in Mexico have been attributed to the periodic strengthening and displacement of the subtropical high pressure cells (Wallen, 1956). Permanent changes in precipitation patterns have not been detected.

According to Schwerdtfeger and Vasino (1954), rainfall has increased in parts of Argentina due to agricultural expansion which has reduced runoff. This interpretation, however, has been challenged on numerous grounds.

The degree to which human activities (agriculture, industry, vegetatation removal, water impoundment, etc.) have altered regional climatic characteristics in Latin America has not received research attention. Portig (1968) and Feininger (1968) have called attention to the possible detrimental influence of widespread forest removal on regional precipitation patterns in South America. Research is needed to evaluate the potential climatic (and economic) impact of forest clearance necessity by certain development plans such as agricultural expansion or wide timber exploitation.

The degree to which fire-induced haze associated with agriculture may have altered temperature and precipitation patterns may be significant. Indeed, many aboriginal societies have folk beliefs concerning fire-induced precipitation which may have some scientific foundation (Sternberg, 1968).

Weather modification research, which has obvious implications for economic development, has been extremely limited in Latin America, particularly in the tropical terrestrial portions. Most research (e.g. Project STORMFURY) has been directed toward the dynamics of hurricanes and their modification. The results indicate that hurricane intensity can be suppressed by seeding with freezing nuclei (Gentry, 1969, 1970). Related research indicates that certain tropical convective clouds can be increased in height through seeding, and a numerical model for the prediction of the growth of clouds under natural and seeded condition has been constructed (Simpson, Brier, and Simpson, 1967).

Cloud seeding has been carried out in the northern Peruvian Andes since 1951 with the purpose of ensuring a more reliable water supply lowland irrigated cane fields (Howell, 1965). The results indicate that rainfall has increased by an estimated eight to fifteen per cent. The area under irrigation has expanded, due in part to the success of the seeding experiments. The results may be biased, however, because of loosely controlled nature of the experiments.

Considerable research clearly remains to be done on the potential of cloud seeding and other techniques of weather modification and their relevance to economic development. Attention should also be directed to the effects of weather modification in a given area on weather phenomena outside the control area. Northern Middle America, for example, receives a significant portion of its rainfall from disturbances associated with hurricanes several hundreds of miles away in the Caribbean. It is not known to what extent rainfall in Middle America would be reduced as a result of deliberate hurricane suppression in the Caribbean. Research should also be directed to the effects of severe weather phenomena, such as hurricanes or extreme "nortes," and to the economic and other benefits of suppression of such events.

Vogt (1966) has called attention to the possible impact of weather modification on the cultural patterns of tribal societies, including the Zinacantecos of Chiapas, and noted the lack of research on this problem.

The water balance has been significantly altered through the impoundment of water and the use of irrigation in large parts of Latin America e.g., northwest Mexico. Research should be focused on the climatic effects of such alteration and on the advisability of further alteration in other areas. Sternberg (1956), for example, has pointed out the dangers of the misuse of irrigation systems and alterations of the water balance in northeast Brazil.

All international development plans should be designed to include a series of post-audits to assess the climatic and other ecologic impacts of development projects. Such assessment has been grossly neglected in the past and partially accounts for the failure of some projects.

Summary and conclusions

In view of the inadequacy of existing data for climatological research in Latin America, the following research directives are suggested for the future:

1) The extension and standardization of observing networks and instrumentation to enable a more precise description and interpretation of regional climatic phenomena and to provide a more solid climatological framework for agricultural feasibility studies.

2) The development of bioclimatological methodology and operational systems of observation applicable to the tropical ecosystems of Latin America and the innovation of bioclimatic models which are relevant to biology, agronomy and planning.

3) The initiation of microclimatic and energy/moisture balance research as part of an overall program of ecosystem analysis in Latin America in order to resolve fundamental problems in ecology, biogeography, and atmospheric energy and moisture transfers. Such research would alleviate the basic problem of data deficiency from the earth-atmosphere interface -- the vertical zone most important for ecology and biogeography.

4) Research focused on climatic change within the broader spectrum of environmental evolution and in relation to major problems of New World prehistory.

5) Research on weather modification (induced and inadvertent) and its potential

impact (beneficial and detrimental) on agricultural development.

Such research would promote a greater understanding of the interrelationships of climate, ecology, and man in Latin America and would contribute to a more sound ecologic framework for developmental planning.

The most feasible and potentially productive avenues for increasing the output of research are through the strengthening of interdisciplinary graduate training in climatology and ecology (which is woefully lacking in American universities) and the establishment of permanent research stations in Latin America for ecosystem analysis.

Notes

1. Although there are published climatic records for some Latin American cities which date back into the last century, rarely were the observations made at the same site and with comparable instrumentation and methodology.

2. Many of the problems of instrument precision and data reliability and comparability were discussed at the American Meteorological Society Symposium on Meteorological Observation and Instrumentation (February 10-14, 1969, Washington, D.C.). Abstracts of the papers appeared in the Bulletin of the American Meteorological Society, Vol. 49, pp. 1109-1129 (November, 1968). For additional comments the reader is also referred to Beekman (1967).

3. Alaka (1969) has shown that in areas with a low density of observing stations, a greater accuracy of data is achieved by doubling the network density rather than by doubling instrument accuracy.

4. Alaka (1969) has shown that in areas with a low density of period of lower temperature which has continued to the present is known to have occurred in various parts of the middle and higher latitude (e.g., Deevey and Flint, 1957).

5. Recent reviews of the evidence pertinent to dating early man in Latin America suggest a minimum time-depth of human occupance of 20,000 to 40,000 years in Mesoamerica and 10,000 to 20,000 years in southern Central America and South America (Bennett, 1968; Daugherty, 1969).

REFERENCES CITED

Alaka, M. A. "Theoretical and Practical Considerations for Network Design." Paper presented at the Symposium on Meteorological Observation and Instrumentation of the American Meteorological Society, Washington, D.C., February 10-14, 1969.

Allee, W. C. "Measurement of Environmental Factors in the Tropical Rain-Forest of Panama." *Ecology*, Vol. 7 (1926a), pp. 273-302.

_____. "Distribution of Animals in a Tropical Rain-Forest with Relation to Environmental Factors." *Ecology*, Vol. 7 (1926b), pp. 445-468.

Ashton, P. S., "Light Intensity Measurements in Rain Forest Near Santarem, Brazil." *Journal of Ecology*, Vol. 46 (1958), pp. 65-70.

Auer, Vaino. "The Pleistocene of Fuego-Patagonia. Part II, The History of the Flora and Vegetation." *Annales Academiae Scientiarum Fennicae (Helsinki)*. Series A, III GeologyGeography, Vol. 50 (1958), pp. 1239.

Bates, Marston. "Climate and Vegetation in the Villavicencio Region of Eastern Colombia." *The Geographical Review*, Vol. 38 (1948), pp. 555-574.

Baynton, H. W., P. Hamilton and J. Worth. "Temperature Structure In and Above a Tropical Forest." *Quarterly Journal of the Royal Meteorological Society*, Vol. 91 (1965), pp. 225-232.

Beaman, J. H. "The Timberlines of Ixtaccihuatl and Popocatepetl, Mexico." *Ecology*, Vol. 43 (1962), pp. 377-385.

Beckman, John C. "On the Need for Standardization of Instruments, Calibration, and Related Terminology." *Bulletin of the American Meteorological Society*, Vol. 48 (1967), pp. 704-705.

Bennett, Charles F. "A Review of Ecological Research in Middle America." *Latin American Research Review*, Vol. 2 (1967), pp. 3-27.

_____. "Human Influences on the Zoogeography of Panama." *Ibero-Americana*, Vol. 51 (1968), 112 pp.

Blume, Helmut. "Beitrage zur Klimatologie Westindiens." *Erdkunde,* Vol. 16 (1962), pp. 271-289.

Boffi, Jorge Alberto. "Effect of the Andes Mountains on the General Circulation Over the Southern Part of South America." *Bulletin of the American Meteorological Society*, Vol. 30 (1949), pp. 242-247.

Borden, R. J. "Cane Growth Studies. Factors Which Influence Yields and Composition of Sugar Cane." *Hawaiian Planters' Record*, Vol. 48 (1941), pp. 241-263.

Browne, Charles A. "Leibig and the Law of the Minimum. Leibig and After Leibig." *American Association for the Advancement of Science Publication No. 16* (1942), pp. 71-82.

Budyko, M. I. *The Heat Balance of the Earth's Surface* (Washington: U.S. Department of Commerce, Office of Technical Services, Translation PB131692, 1986).

Burgos, J. J. and A. L. Vidal. "The Climates of the Argentine Republic According to the New Thornthwaite Classification." *Annals of the Association of American Geographers*, Vol. 41 (1951), pp. 237-263.

Byers, Douglas S. (ed.). The Prehistory of the Tehuacan Valley. Vol. I, *Environment and Subsistence.* (Austin: University of Texas Press, 1967), 331 pp.

Carr, Archie F. "Outline for a Classification of Animal Habitats in Honduras." *Bulletin of the American Museum of Natural History*, Vol. 94 (1950), pp. 569-594.

Carter, G. S. "Reports of the Cambridge Expedition to British Guiana, 1933. Illumination in the Rain Forest at Ground Level." *Journal of the Linnean Society (Zoology)*, Vol. 38 (1934), pp. 579-589.

Cavacanti, Bernardes, Lisia Maria. "Tipos de Clima do Estado do Rio de Janeiro." *Revista Brasileira de Geografía*, Vol. 14 (1952), pp. S7 80.

Chang, Jen-hu. "Microclimate of Sugar Cane." *Hawaiian Planters' Record*, Vol. 56 (1961), pp. 195223.

_____. "The Role of Climatology in the Hawaiian Sugar-Cane Industry: An Example of Applied Agricultural Climatology in the Tropics." *Pacific Science*, Vol.

17 (1963), pp. 379-397.

_____. "The Agricultural Potential of the Humid Tropics." *The Geographical Review*, Vol. 58 (1968), pp. 333-361.

_____. "Potential Photosynthesis and Crop Productivity." *Annals of the Association of American Geographers*, Vol. 60 (1970), pp. 92

Cleare, L. D. "The Climate of British Guiana." *Guyana Department of Agriculture Rice Storage Investigation Publication (Georgetown)*, No. 1 (1961).

Coe, Michael D. and Kent V. Flannery. "Microenvironments and Mesoamerican Prehistory." *Science*, Vol. 143 (1964), pp. 650-654.

_____. "Early Cultures and Human Ecology in South Coastal Guatemala." *Smithsonian Contributions to Anthropogy*, Vol. 3 (1967), 136 pp.

Colon, Jose A. "Development of Tropical Cyclones in Relation to Circulation Patterns at the 200-Millibar Level." *Monthly Weather Review*, Vol. 91 (1963), pp. 329-336.

Cowgill, Ursula M., et al. "The History of Lake Petenxil, A Small Lake in Northern Guatemala." *Memoirs of the Connecticut Academy of Arts and Science*, Vol. 17 (19676), 12-6 pp.

Czajka, W. "Rezente und Pleistozaene Verbreitung und Typen des Periglazialen Denudationszyklus in Argentinien." *Acta Geografica*, Vol. 14 (1955), pp. 121-140.

Daubenmire, R. F. "Alpine Timberlines in the Americas and Their Interpretation." *Butler University Botanical Studies*, Vol. 11 (1954), 119-136.

Daugherty, Howard E. "Man-Induced Ecologic Change in El Salvador. Unpublished Ph.D. dissertation, University of California, los Angeles (1969), 248 pp.

Davidson, Ben. "The Barbados Oceanographic and Meteorologic Experiment." *Bulletin of the American Meteorological Society*, Vol. 49 (1968), pp. 928-934.

Davis, I. A. and P. W. Richards. "The Vegetation of Moraballi Creek, Briitish Guiana; An Ecological Study of a Limited Area of Tropical Rain Forest." Part I, *Journal of Ecology*, Vol. 21 (1933), pp. 350-384; Part II, *Journal of Ecology*, Vol. 22

(1934) pp. 106-155.

Deevey, Edward S. "Pollen Analysis and Mexican Archeology: An Attempt to Apply the Method." *American Antiquity*, Vol. 10 (1944), pp. 135-147.

_____. and Richard F. Flint. "The Postglacial Hypsithermal interval." *Science*, Vol. 125 (1957), pp. 182-184.

Dickey, D. R., and A. J. van Rossem. "The Birds of El Salvador." *Fieldiana: Zoology*, Vol. 23(1938), 609 pp.

Dingle, A. Nelson. *"OTS Pilot Study #69-27, Brief of progress as of 27 August 1969*, (1969). Mimeographed report.

Ebdon, R. A. "The Tropical Stratospheric Wind Fluctuation." *Weather*, Vol. 18 (1963), pp. 2-7.

Eidt, R. C. "The Climatology of South America," in *Biogeography and Ecology in South America*, ed. by E. J. Fittkau et al. (The Hague: Dr. W. Junk N. V. Publishers, 1968), pp. 54-81.

Evans, G. C. "Ecological Studies on Rain Forest in Southern Nigeria." *Journal of Ecology*, Vol. 27 (1939), pp. 436-482.

Feininger, Thomas. "Less Rain in Latin America (Letters to the Editor)." *Science*, Vol. 160 (1968), pp. 13-14.

Flannery, Kent V. "The Postglacial 'Readaptation' as Viewed from Mesoamerica." *American Antiquity*, Vol. 31 (1966), pp. 800-805.

Fosberg, F. R. and B. Garnier. "Delimitation of the Humid Tropics." *Geographical Review*, Vol. 51 (1961), pp. 333-342.

Freise, F. "Das Binnenklima van Urwaldern in Subtropischen Brasilien." *Petermanns Geographische Mitteilungen*, Vol. 82 (1936), pp. 301-307.

Garnier, B. J., "The Problem of Delimiting the Humid Tropics." *The Geographical Review*, Vol. 55 (1965), pp. 595-596.

_____. "The McGill University Climatology Programme in Barbados." *Bulletin of the American Meteorological Society*, Vol. 49 (1968), Gauss, H. and P. Legris. "La Delimitation des Zones Tropicales Humides." *Annales de Geographie*, Vol. 72 (1963), pp. 513-528.

Gentry, R. Cecil. "Project STORMFURY." *Bulletin of the American Meteorological Society*, Vol. 50 (1969), pp. 404-409.

_____. "Hurricane Debbie Modification Experiments, August 1969." *Science*, Vol. 168 (1970), pp. 473-475.

Goldman, Edward A. "Mammals of Panama." S*mithsonian Miscellaneous Collections*, No. 5, Vol. 29 (1920), 309 pp.

Gutnick, Murray. "Climatology of the Trade-Wind Inversion in the Caribbean." *Bulletin of the American Meteorological Society*, Vol. 39 (1958), pp. 410-420.

Haar, T. H. Vonder and K. J. Hanson. "Absorption of Solar Radiation in Tropical Regions." *Journal of Atmospheric Sciences*, Vol. 26 (1969), pp. 652-655.

Hales, W. B., "Micrometeorology in the Tropics." *Bulletin of the American Meteorological Society*, Vol. 30 (1949), pp. 124-137.

Hammen, Thomas van der. "The Quaternary Climatic Changes of Northern South America." *Annals of the New York Academy of Science*, Vol. 95 (1961), pp. 676-683.

_____. "A Palynological Study on the Quaternary of British Guiana." *Leidse Geologische Mededelingen (Leyden)*, Vol. 29 (1963), pp. 125-180.

_____. "The Pliocene and Quanternary of the Sabana de Bogota (the Tilata and Sabana formations)." *Geologische-mijnbouwkindig (Leyden)*. Vol. 45 (1966), pp. 102-109.

Hammen, Thomas van der and E. Gonzales. "Upper Pleistocene and Holocene Climate and Vegetation of the Sabana de Bogotá." *Leidse Geogogische Mededelingen (Leyden)*, Vol. 25 (1960a), pp. 261-315.

_____. "Holocene and Late-glacial Climate and Vegetation of the Páramo de Palacio." *Geologische-mijnbouwkundig (Leyden)*, Vol. 39 (1960b), pp. 337-345.

Hastenrath, Stephan. "On the General Circulation and Energy Budget in the Area of the Central American Seas." *Journal of Applied Atmospheric Sciences*, Vol. 23 (1966a), pp. 694-712.

_____. "The Flux of Atmospheric Water Vapor Over the Caribbean Sea and the Gulf of Mexico." *Journal of Applied Meteorology*, Vol. 5 (1966b), pp. 778-788.

Heusser, C. J., "Late Pleistocene Environments of the Laguna de San Rafael Area, Chile." *The Geographical Review*, Vol. 50 (1960), pp. 555-577.

Holdridge, Leslie R. "Determination of World Plant Formations from Simple Climatic Data." *Science*, Vol. 105 (1947), pp. 367-368.

_____. "Simple Method for Determining Evapotranspiration from Temperature Data." *Science*, Vol. 130 (1959), p. 572.

_____. "Evapotranspiration." *Science*, Vol. 131 (1960), pp. 1260-1262.

_____. "The Determination of Atmospheric Water Movement." *Ecology*, Vol. 43 (1962a), pp. 1-9.

_____. *Mapa Ecológico de Nicaragua*. (Managua: U.S. Agency for International Development, 1902D).

Hosler, Charles R. "A Study of Easterly Waves in the Gulf of Mexico." *Bulletin of the American Meteorological Society*, Vol. 37 (1956), pp. 101-107.

Howell, Wallace E. "Twelve Years of Cloud Seeding in the Andes of Northern Peru." *Journal of Applied Meteorology*, Vol. 4 (1965), pp. 693-700.

Hutchinson, G. E.; Ruth Patrick; and Edward S. Deevey. "Sediments of Lake Pátzcuaro, Michoacán, Mexico." *Bulletin of the Geological Society of America,* Vol. 67 (1956), pp. 1491-1504.

Jackson, W. B. "Microelimatic Factors in Army Ant Behavior and Ecology." *American Philosophical Society Yearbook*, Vol. 1952 (1953), pp. 157-161.

Kuettner, Joachim P. and Joshua Holland. "The BOMEX Project." *Bulletin of the American Meteorological Society*, Vol. 50 (1969), pp. 394-402.

Laeyendecker, Roosenburg, D. M. "A Palynological Investigation of Some Archeologically Interesting Sections in Northwestern Suriname." *Leidse Geologische*

Mededelingen (Leyden), Vol. 38 (1966), pp. 49-70.

Lahey, J. F. "On the Origin of the Dry Climate in Northern South America and the Southern Caribbean." *University of Wisconsin Department of Meteorology Scientific Report, No. 10*, AFCRCTN-58-218 (1958).

Lamb, Robert C. and James A. Pharo, "Standardizing Meteorological Instrument Testing." *Bulletin of the American Meteorological Society*, Vol. 48 (1967), pp. 707-708.

Lauer, Wilhelm. "Humide und Aride Jahreszeiten in Afrika und Südamerika und Ihre Beziehungen zu den Vegetationsgurteln." *Bonner Geographische Abhandlungen*, Vol. 9 (1952), pp. 15-98.

_____. "Vegetation, Landnutzung und Agrapotential in El Salvador." *Schriften des Geographischen Instituts der Universitat Kiel*, Vol. 16, No. 1 (1956), 98 pp.

_____. “Klimatische und Pflanzengeographische Grundzuge Zentral-amerikas." *Erdkunde*, Vol. 13 (1959), pp. 344-354.

Leakey, L. S. B. "The Origin of the Genus Homo," in *The Evolution of Man. Vol. II, Evolution After Darwin*, edited by Sol Tax (Chicago: University of Chicago Press, 1960), pp. 17-56.

Lowry, William P. *Weather and Life*. (Corvallis: Oregon State University Book Stores, 1967).

Loon, H. van. 17A Climatological Study of the Atmospheric Circulation in the Southern Hemisphere During the IGY," Part I, *Journal of Applied Meteorology*, Vol. 4 (1965), pp. 479-491; Part II, *Journal of Applied Meteorology*, Vol. 6 (1967), pp. 803-813.

Lydolf, P. "A Comparative Analysis of Dry Western Littorals.” *Annals of the Association of American Geographers*, Vol. 47 (1957), pp. 213-230.

Malone, Thomas F. "New Dimensions of International Cooperation in Weather Analysis and Prediction." *Bulletin of the American Meteorological Society*, Vol. 49 (1968), pp. 1134-1140.

Martin, Paul S. "Paleoclimatology and a Tropical Pollen Profile." *IV International Congress of the Quaternary* (Warsaw, 1961), Report, Vol. 2 (1964), pp. 319-323.

McLean, R. C. "Studies in the Ecology of Tropical Rain-Forest with Special Reference to the Forests of South Brazil." *Journal of Ecology* Vol. 7 (1919), pp. 15-54, 121-172.

Nimer, E. "Circuiacao Atmosferica de Nordeste e Suas Consequencias--O Fenomeno des Secas." *Revista Brasileira de Geografía*, Vol. 26 (l964), pp. 141-157.

Oliver, Vincent J. and Ralph K. Anderson. "Circulation in the Tropics as Revealed by Satellite Data." *Bulletin of the American Meteorological Society*, Vol. 50 (1969), pp. 702-707.

Parsons, James J. "The Contribution of Geography to Latin American Studies" in *Social Science Research in Latin America*, edited by Charles Wagley (New York: Columbia University Press, 1964), pp. 33-85.

Plath, C. V. *Uso Potencial de la Tierra*. Six parts. (Rome: Food and Agricultural Organization, 1967).

Portig, W. H. "Klimapendelungen in San Salvador, Mittelamerika." *Annalen der Meteorologie*, Vol. 8 (1958), pp. 143-148.

_____. "Air Masses in Central America." *Bulletin of the American Meteorological Society*, Vol. 40 (1959), pp. 301-304.

_____. "Central American Rainfall." *Geographical Review*, Vol. 55 (1965), pp. 68-90.

_____. "Latin America- Dangers to Rainfall." *Science* (Letters the Editor), Vol. 159 (1968), p. 376.

Prohaska, Frederico. "El Problema de las Sequias en la Region Semiárida Pampeana y la Sequia Actual." *Instituto de Suelos y Agrotecnia* (Argentina) Publicación No. 71 (1961a).

_____ "Las Características de las Precipitaciones en la Región Semiárida Pampeana." *Instituto de Suelos y Agrotecnia (Argentina) Publicación, No. 72* (1961b).

_____. "Algunos Aspectos del Clima de la Alta Cordillera y de la Puna Argentina." *Boletin de Estudios Geográficos (Argentina)*. Vol. 8 (1961c), pp. 21-30.

Quinn, W. H. and W. V. Burt. "Weather and Solar Radiation Reception in the Equatorial Trough." *Journal of Applied Meteorology*, Vol. 6 (1967), pp. 988-993.

_____. "Incoming Solar Radiation Over the Tropic Pacific." *Nature*, Vol. 217, (1968), pp. 149-150

_____. "Prediction of Abnormally Heavy Precipitation Over the Equatorial Pacific Dry Zone." *Journal of Applied Meteorology*, Vol. 9 (1970), pp. 20-28.

Raschke, E. and W. R. Bandeen. "The Radiation Balance of the Planet Earth and Radiation Measurements of the Satellite Nimbus II," *Journal of Applied Meteorology*, Vol. 9 (1970), pp. 215-238.

Read, Robert G. "Evaporative Power in a Tropical Forest of the Panama Canal Zone." *Journal of Applied Meteorology*, Vol. 7 (1968), pp. 417-424.

Richards, P. W. *The Tropical Rainforest, an Ecological Study.* (Cambridge: Cambridge University Press, 1952), 450 pp.

Riehl, Herbert. "Waves in the Easterlies and the Polar Front in the Tropics," *University of Chicago Department of Meteorology Miscellaneous Reports No. 17* (1945).

_____. "Subtropical Flow Patterns in Summer." *University of Chicago Department of Meteorology Miscellaneous Reports, No. 22* (1947).

_____. *Tropical Meteorology* (New York: McGraw-Hill, 1954), 392 pp.

_____. "General Atmospheric Circulation of the Tropics," *Colorado State University Atmospheric Science Technical Paper No. 19* (1962).

Riehl, Herbert and J. S. Malkus. "On the Heat Balance and Maintenance of Circulation in the Trades." *Quarterly Journal of the Royal Meteorological Society*, Vol. 83 (1957), pp. 21-29.

_____ "On the Heat Balance in the Equatorial Trough Zone." *Geophysica (Helsinki)*, Vol. 6 (1958), pp. 503-538.

Rusin, N. P. "Sensor Development for Precipitation Measuring." Paper presented at the Symposium on Meteorological Observation and Instrumentation of the American Meteorological Society, Washington, D.C., February 10-14, 1969.

Sanders, William T. and Barbara J. Price. *Mesoamerica; The Evolution of Civilization* (New York: Random House, 1968), 266 pp.

Schulz, J. P. *Ecological Studies on Rainforest in Northern Suriname.* (Amsterdam: North-Holland Publishers, 1960).

Schwerdtfeger, W. and D. W. Martin. "The Zonal Flow of the Free Atmosphere Between 10° N and 80° S in the South American Sector." *Journal of Applied Meteorology*, Vol. 3 (1964), pp. 726-733.

Schwerdtfeger, W. and C. J. Vasino. "La Variación Secular de las Precipitaciones en el Este y Centro de la República Argentina." *Meteoros*, Vol. 4 (1954), pp. 174-193.

Sears, Paul B. "Palynology in Southern North America. Part I, Archeological Horizons in the Basins of Mexico." *Bulletin of the Geological Society of America*, Vol, 63 (1952), pp. 241-254.

Sears, Paul B. and K. H. Clisby. "Palynology in Southern North America part IV, Pleistocene Climate in Mexico." *Bulletin of the Geological Society of America*, Vol. 66 (1955), pp. 521-530,

Serra, Adalberto. "The General Circulation Over South America." *Bulletin of the American Meteorological Society*, Vol. 22 (1941), pp. 173-178.

_____. *Atlas Climatologico do Brasil.* (Rio de Janeiro: Conselho Nacional de Geografia e Servicio de Meteorologia, 1955).

_____. "Clima da America do Sul." *Revista Geográfica*, Vol. 33 (1963), pp. 93-126.

Serra, Adalberto and Leandro Ratisbonna. "As Massas de ar da America do Sul." (la Parte), *Revista Geográfica*, Vol. 25 (1959), pp. 67-129; (2a Parte), *Revista Geográfica*, Vol. 26 (1960), pp. 41-71.

Shelford, Victor E. "Paired Factors and Master Factors in Environmenta Relations," *Illinois Academy of Science Transactions*, Vol. 45 (1952), pp. 155-160.

Shreve, Forrest. "Rainfall of Northern Mexico." *Ecology*, Vol. 25 (194 pp. 105-133.

Simpson, R. H. "Synoptic Aspects of the Intertropical Convergence Near Central and South America." *Bulletin of the American Meteorologic Society*, Vol. 28 (1947), pp. 335-346.

Simpson, Joanne, Glenn W. Brier, and R. H. Simpson. "Stormfury Cumulus Seeding Experiment 1965: Statistical Analysis and Main Results." *Journal of Atmospheric Sciences*, Vol. 24 (1967), pp. 508-521.

Smedley, David. "The Caribbean Meteorological Institute--a UNDP/WM0 Project for the Improvement of Caribbean Meteorological Services. *Bulletin of the American Meteorological Society*, Vol. 49 (1968), pp. 653-655.

Soumi, V. E., et al. “1968 Hurricane Watch Experiment." *16mm Film Report NASA 69-812.* (Prepared for National Aeronautics and Space Administration, Washington, D.C., 1969).

Sternberg, Hilgard O'Reilly. "Geography's Contribution to the Better Use of Resources," in *Future of Arid Lands*, edited by G. F. White, American Association for the Advancement of Science Publication, Vol. (1956), pp. 200-220.

_____. "Man and Environmental Change in South America," in *Biogeography and Ecology in South America*, edited by E. J. Fittkau, et al. (The Hague: Dr. W. Junk N. V. Publishers, 1968), pp. 413-44S.

Swan, Lawrence W. "Some Environmental Conditions Influencing Life at High Altitudes," *Ecology*, Vol. 33 (1952), pp. 109-111.

_____. "Alpine and Aeolian Regions of the World," in *Arctic and Alpine Environments*, edited by H. E. Wright and W. H. Osburn (Bloomington: Indiana University Press, 1967), pp. 29-54.

Taljaard, J. J. "Development, Distribution and Movement of Cyclones and Anticyclones in the Southern Hemisphere During the IGY." *Journal of Applied Meteorology*, Vol. 6 (1967), pp. 973-987.

Taylor, W. P. "Significance of Extreme or Intermittent Conditions in Distributions of Species and Management of Natuial Resources, with a Restatement of Leibig's Law of the Minimum." *Ecology*, Vol. 15 (1934), pp. 374-379.

Thornthwaite, C. W. "An Approach Toward a Rational Classification of Climate." *The Geographical Review*, Vol. 38 (1948), pp. 55-94.

Tosi, Joseph A., Jr. "Zonas de I Vida Natural en el Perű." *Instituto Interamericano de*

Ciencias Agrícolas de la O.E.A. Boletín Ténico, No. 5 (1960), 271 pp.

_____."Climatic Control of Terrestrial Ecosystems: A Report on the Holdridge Model." *Economic Geography*, Vol. 40 (1964), pp. 173-181.

Tosi, Joseph A., Jr. and Robert F. Voertman. "Some Environmental Factors in the Economic Development of the Tropics." *Economic Geography*, Vol. 40 (1964), pp. 189-285.

Trojer, H. "Fundamentos Para una Zonificación Meteorológico y Climatológico del Trópico y Especialmente de Colombia." *Cenicafé* , Vol.10 (1959), pp. 289-373.

Troll, Carl. "Die Localwinde der Tropengebirge und ihr Einfluss auf Niederschlag und Vegetation." *Bonner Geographische Abhandlungen*, Vol- 9 (1952), pp. 124-182.

_____. "Die ropischen Gebirge. Ihre Dreidimensionale Klimatische und Planzengeographische Gliederung. *Bonner Geographische Abhandlungen*, Vol. 25 (1959).

_____. "The Cordilleras of Tropical America. Aspects of Climatic, Phytogeographical and Agrarian Ecology," in *Geo-Ecology of the Mountainous Regions of the Tropical Americas*, edited by C. Troll, Colloquium Geographicum (Bonn), Vol. 9 (1968), pp. 15-56.

Troup, A. J. "Variations in 200-millibar Flow in the Tropics." *Meteorological Magazine*, Vol. 90 (1961), pp. 162-167.

Tsukada, Matsuo and Edward S. Deevey. "Pollen Analyses from Four Lakes in the Southern Mayan Area of Guatemala and El Salvador," in *Quaternary Paleoecology*, edited by H. E. Wright and E. J. Cushing (New Haven: Yale University Press, 1968), pp. 303-331.

Tucker, G. B. "The Equatorial Tropospheric Wind Regime." *Quarterly Journal of the Royal Meteorological Society*, Vol. 91 (1965), pp. 140-150.

Veryard, R. and R. A. Ebdon. "Fluctuations in Tropical Stratospheric Winds," *Meteorological Magazine*, Vol. 90 (1961), pp. 125-143.

Vogt, Evon Z. "Some Implications of Weather Modification for the Cultural Patterns of Tribal Societies," in *Human Dimensions of Weather Modification*, edited by

W. R. Derrick Sewell, University of Chicago Department of Geography Research Paper, No. 105 (1966), pp. 373-392.

Wagner, Philip L. "Natural and Artificial Zonation in a Vegetation Cover Chiapas, Mexico." *The Geographical Review*, Vol. 52 (1962), pp. 253-274.

Wallace, John M. "Some Recent Developments in the Study of Tropical Wave Disturbances." *Bulletin of the American Meteorological Society*, Vol 50 (1969), pp. 792-799.

Wallén, C. C. "Characteristics of Precipitation in Mexico." *Geografiska Annaler*, Vol. 37 (1955), pp. 51-85.

_____. "Fluctuations and Variability in Mexican Rainfall," in *Future of Arid Lands*, edited by G. F. White, American Association for the Advancement of Science Publication, Vol. 43 (1956), pp. 141-155.

Wijmstra, T. A. and Thomas van der Hammen. "Palynological Data on the History of Tropical Savannas in Northern South America." *Leidse Geologische Mededelingen (Leyden)*, Vol. 38 (1966), pp. 71-90.

Wilhelmy, Herbert. "Die eiszeitliche und nacheiszeitliche Verschiebung der Klima- und Vegetationszonen in Sudamerika." *Tagungsberichte und Wissenschaftliche Abhandlungen des Deutschen Geographentages*(Frankfurt) (1952), pp. 121-127.

_____. "Die Klimamorphologische und Pflanzengeographische Gliederung des Trockengebietes am Nordrand Sudamerikas Seit Dem Pleistozean." *Die Erde*, Vol. 6 (1954), pp. 244-273.

World Meteorological Organization, *Catalogue of IGY/IGC Meteorological Data* (Geneva: World Meteorological Organization, 1962).

_____. *Meteorological Services of the World* (Geneva: World Meteorological Organization, 1965).