PROCEEDINGS OF A CONFERENCE ON CLIMATOLOGY AND RELATED FIELDS IN THE CARIBBEAN, Mona, Jamaica, 1966

Held at Mona by the Division of Geography,
Department of Geology and Geography, University of the
West Indies.
In Association with the Scientific Research Council of
Jamaica.

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Editor
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EDITORIAL FOREWORD

Under the sponsorship of the Geography Division of the Geography and Geology Department, UWI, also the Scientific Research Council of Jamaica, a three-day conference on applied climatology was held at Mona from September 20th to 22nd 1966. Some thirty delegates attended, from Trinidad, Puerto Rico, Guadeloupe, Jamaica, Canada and the USA, in what is believed to be the first attempt in the Caribbean to bring together academicians, professional climatologists and interested laymen concerned with the application of climatological data and research to the problems of economic development and other facets of the emergent societies in the Caribbean.

The real need for a personal exchange of ideas and information, and a chance to establish contacts and to co-ordinate research endeavours, were the motivating forces which encouraged the conference organizers to bring their plans to fruition. It was felt too that the conference would assist the University, various Governmental agencies, the Scientific Research Council and overseas institutions to be better informed on past and current climatological research in the Caribbean area. Data collection at various levels of sophistication and through different types of instruments, the classification and statistical processing of resulting atmospheric measurements, the mapping and analysis of data, and their application to such activities as agriculture, forestry, building and engineering, these and other aspects of the science of climatology were considered appropriate topics for review and discussion at the conference.

New concepts in climatology.

As in virtually every other discipline in both the natural and the social sciences, there have been some remarkable conceptual developments in the field of climatology in recent years. While the all-pervasive nature of atmospheric environmental conditions has long been appreciated - the impact of the elements of weather and climate on, for example, landforms, vegetation, soils, agricultural land use, house design, road and bridge construction, etc. was recorded by Greek and Roman observers - investigations in the more recent past have become too heavily compartmentalized into specialized disciplines. This has tended to draw one's attention away from the essential unity and and inter-connectedness of the conditions of the natural environment. Today, environmental scientists are looking anew at the vital connections between their specialized areas of research and there is a "growing awareness that the sciences dealing with the physical environment are not a collection of separate and distinct fields of scientific interest, but rather a unified group of disciplines"[(1)].

Thus in the U.S.A. the time-honoured and familiar agency of the Weather Bureau has been replaced by a much larger and more embracive organization, the Environmental Science Services Administration (ESSA). The desirability of, and the prospects for, such a development for the countries of the Caribbean were also considered a legitimate topic for discussion at the UWI Climatological Conference.

The new emphasis on environmental climatology depends increasingly on a study of exchange processes. The outstanding change in climatology during the last decade has been a shift away from such parameters as temperature and relative humidity, and towards the measurement of fluxes. Climatologists have become concerned with the movements and transformation of energy in the atmospheric boundary layer, in the plant-cover and in the soil. "It is not air temperature that is *per se* significant; it is the heat exchange that occurs at the leaf, sea, soil or skin surface. Rainfall alone is not enough; we have to consider the evaporative losses also, again off leaf, sea, soil and skin.... Once we begin to ask the question - what, effectively, is climate as environment? - we find ourselves carried more and more deeply into most of the territories of the various environmental disciplines"(2). Thus the science of climate is a marvellously catholic study. It is the obvious cementing matrix for the environmental sciences.

The necessity of recognizing these new viewpoints in Anglo-American climatology and of assessing their significance to Caribbean environmental studies were further themes which could be traced throughout the conference programme at Mona.

The Conference Programme.

Some thirteen papers were delivered at the conference (see Table of Contents) and stimulated considerable discussion both during the formal sessions and in after-session conversations. Unfortunately, due to the limitations of the sound-recording system utilized during the Conference it has not been possible to include in the proceedings a record of the discussions which followed the presentation of each paper. At the same time the published texts of the papers incorporate come of the suggestions and recommendations raised by delegates in the course of the Conference.

Regrettably also, we have been unable to include a number of the illustrations (maps and figures) used by participants in support of the oral delivery of their papers, either because the manuscript maps were not forthcoming in the post-Conference period, or because we lacked technical assistance in having the illustrations reproduced.

Readers of the Proceedings who desire further information on a particular paper are invited to contact its author personally, at the address given below the title of the paper.

In addition to the delivery of papers at the Trade Union Education Centre - the venue for the Climatological Conference - an afternoon was devoted to an excursion to the Jamaica Sugar Manufacturers Association Research Laboratories at Mandeville, where conference delegates met with the Assistant Director (now Director), Mr. T. Chin-Loy, and talked with other members of the Laboratories on climatological factors in sugar production and pest control.

Recommendations

It would clearly be desirable if further Environmental Science symposia could be held in the Caribbean area, with as strong an interdisciplinarian emphasis as the conference sponsored at U.W.I. In a "summing up" session, it was recommended that a second gathering of environmental scientists be called for in 1968 in the Eastern Caribbean, and a planning committee of four members (with powers to co-opt) was elected to implement this recommendation:

1. John T. Connor, U.S. Secretary of Commerce (June, 1965).

2. F. Kenneth Hare, "The Concept of Climate," Geography, Vol. 51 (1966).

G. Smith (Chairman)
R. Calvesbert
C. Hewitt
D. Vickers

It was also proposed that support for the second conference be sollicited from such bodies as the Institute of Applied Meteorology (Barbados); the Institute of Caribbean Studies (Puerto Rico); the International Society of Biometeorology; the American Meteorological Society; the Royal Meteorological Society; the National Science Foundation (USA).

Acknowledgements

The organizers of the Climatological Conference and the editor of these Proceedings would like to acknowledge with sincere thanks the generous and enthusiastic response on the part of many to their plans for initiating the 1966 assembly of Caribbean climatologists and related scientists, and for publishing this permanent record of their contributions to the Conference.

It is neither feasible nor apposite to name the numerous individuals (in many different capacities) who contributed to the success of this academic venture. It is sufficient to record here our deep gratitude for their sustained interest and assistance.

The support of the Scientific Research Council and the University of the West Indies in publishing the Proceedings is also gratefully acknowledged.

Barry Floyd.

EXTRACT FROM PRE-CONFERENCE PUBLICITY IN "DAILY GLEANER."

An Irishman in the early seventeenth century - his name is now unknown - wrote of the problems of climate in the Caribbean, with its typical alternations of flood and drought:

> *"The winter only consisteth of great rains; it beginneth about August and lasteth until Christmas, in which time we have often land flood, which fall into several gullies that many lose their lives. Yet sometimes the year is less wet, according to the disposition of the heavens and of the planets; and as the sun approacheth or aboundeth with water and moisture. If the debauched lives of the people did not prevent nature, it would be a fertile and plentiful country..."*

Three hundred years later climatology still remains an important field of research in Caribbean lands. Indeed, in many ways it is at a rudimentary stage of development compared with the sophisticated work presently being carried out in the U.S.S.R., United States and European countries. Although we have progressed considerably since the days when all climatic variations were put down to the disposition of the heavens and of the planets, we are still only at a stage of basic data collection and analysis. With many of the big questions in tropical climatology, we have only just begun to collect the data that may ultimately provide the answers.

Our rudimentary climatology can undoubtedly be a handicap. A major scheme such as the proposed Yallahs Valley dam cannot conceivably be carried out without reference to rainfall, evaporation, prevalence of slumping and soil creep, hurricanes and a whole host of other factors. In the Yallahs Valley in 1909 rain fell in November at the rate of an inch an hour for a hundred continuous hours! How often must plans be made for that sort of rainfall?

In the absence of reliable detailed data careful research has had to be carried out. The sucrose content of sugar cane (and therefore its profitability), the juiciness of citrus, crop diseases, the design of our homes, soil erosion and conservation, the success of afforestation measures, all these and much else that is presently of great concern to dwellers in Caribbean countries are basically aspects of applied climatology. The well-being of thousands of farmers is related to wet and dry cycles of climate, and with long-term forecasting these are today not quite the frighteningly unpredictable phenomena which they once were. And West Indians need no reminding of the importance of hurricanes to their economies.

Among the organizations which are carrying out climatological or related research and which will be actively participating in the conference are the Environmental Science Services Administration, Puerto Rico and the United States; the Centre de Recherches agronomiques des Antilles et de la Guyane; the Bellairs Research Institute, Barbados; the Scientific Research Council, Jamaica; the Caribbean Meteorological Service; the Ministry of Agriculture and Lands, Jamaica; the Sugar Manufacturers Association Research Laboratories, Jamaica; the forestry Department, Jamaica; Howard Humphreys, consulting engineers to the Yallahs Valley Scheme; and departments of the University of the West Indies at Mona and St. Augustine.

L. Alan Eyre,
Conference Organizer.

EXTRACTS FROM SPEECHES

Welcome from Dr. Philip Sherlock (now Sir Philip Sherlock), Vice-Chancellor of the University of the West Indies.

Hon. Minister and Friends: I have the greatest possible pleasure on behalf of the University in welcoming you all. We welcome particularly those who come to us from other countries, the United States, from sister islands like Puerto Rico, and Trinidad and Tobago. I know that this meeting must mean a great deal to many of you and to many who are not here, but who have an abiding interest in the study of man's physical environment - a study that I once used to think was rather remote from our daily lives, and how all this has been changed by science!

In July I went to the University of Miami and talked for a few moments with some of the scientists in that quite remarkable unit which studies the weather - particularly of the Caribbean as well as parts of the United States. While I was there talking with them, they handed in the latest photographs that had been transmitted from Nimbus; it changes your whole concept of modern technology and science suddenly to realize that there is this constant and persistent activity in the extension of knowledge, going on all the time, ceaselessly, with a satellite placed in outer space transmitting pictures.

I saw the whole of the southern half of the United States with the cloud formations building up from California across to Florida and part of the Atlantic. And all this going on as a matter of routine! We in the West Indies cannot afford the costly instruments and equipment that modern science demands, but in all our research (and I am particularly glad for the help being given by the Scientific Research Council of Jamaica), we can at least do this. We can provide within the community an active, living centre of scholarship which doesn't seek to duplicate all the instrumental work of greater and richer powers, but which can take advantage of it and learn from it and contribute to it.

I was very impressed the other day when I discovered that Sweden has made tremendous use of modern technology, not by concentrating on discovering new things - only about 10% of its work is new - but by making use of the research work done by more advanced countries. Some 90% of its modern technology is founded on research work and effort in other countries. This whole business is universal, so that the fact that we are limited in resources does not mean at all that we should limit the extent to which we enter into the understanding of modern technology as in this particular field of climatology.

One last sentence. When I was at St. Augustine working there, I was always impressed by the devotion with which George Smith would collect data about the Trinidad weather and keep endless lists of statistics day after day. I think that this particular seminar must give him a great deal of encouragement and perhaps help him to feel that devoted work throughout the years does have value to the community as a whole.

It is a great pleasure to welcome you all, and, in particular, to welcome the Hon. Minister of Agriculture.

Opening Adress from the Hon. Minister of Agriculture, Mr. J.P. Gyles.

Mr. Chairman, Mr. Vice-Chancellor, Delegates to this Conference on Climatology, Ladies and Gentlemen: I am happy to join with you in this Opening Session of the Conference. Of recent times this island has been host to many conferences and seminars on matters of importance; some of international interest bring to us scholars and dignitaries from all parts of the world, some concerned with problems affecting the family of nations in the British Commonwealth, and some dealing with matters of purely local consequence in the Caribbean Area. Each occasion of this nature involves the bringing together of persons with learning and experience in various fields, and Jamaica inevitably benefits by their presence here.

The exchange of thought and experience which these meetings and discussions produce, the opportunities which arise for our local people to meet and talk with scholars and persons of responsibility from other countries, the valuable contacts, lasting friendships which develop - all these are dividends which we in Jamaica derive from having these meetings here.

We like to think that those who come from overseas to attend these conferences in Jamaica also reap some broadening of perspective, some pleasant or rewarding experience as a result of their visit to our country. I trust that this conference will be no exception in this respect. The subject of your deliberations is Climatology and related fields in the Caribbean. I must confess to a certain lack of precision in my own mind as to the definition of the science of climatology. I presume that what it involves essentially is a study of the various aspects of environment which determine what we laymen call "the weather". If this is at all close to the true definition, then I can assure you that I have a very personal and practical interest in the subject which you propose to examine professionally.

In addition to being Minister of Agriculture, I make my living as a farmer in a part of the country where irrigation is not at present available. In this respect I am in the same position as the vast majority of farmers in Jamaica, and indeed in the Caribbean Area as a whole. We have many problems, as those of you must know who in any way are concerned with agriculture, but perhaps our most difficult problem is the weather. Our success as producers is almost entirely dependent on good weather, and that good lady is so notoriously capricious that it has become a common-place part of communication in the English language to speak of the vagaries of the weather. With the exception of those few areas where artificial irrigation is possible, most of our agriculture is, so to speak, at the mercy of the weather. Our plans for seedtime are based on expectation of normal seasonal rain. Our plans for harvest depend on expectation of normal sunny weather. Any deviation from normal and the whole schedule is thrown out of gear. As you know, prolonged deviation from normal can result in famine and national disaster. To the farmer, therefore, and to agriculture as an element in our national life, weather is a most vital factor. But its importance is not confined to agriculture, nor to Jamaica, nor indeed to the Caribbean Area. Those of us who are familiar with the temperate regions of the world know to what extent life in those parts is conditioned by weather to a far greater degree than it is in this area. Indeed I think that even human conversation might languish in some countries were it not for the ever present subject of weather as a topic of general interest.

We travel today by aeroplane as freely as our fathers moved about on horse-back, that is why, Mr. Chairman, I have been able to travel around Jamaica as often as I do, in greater comfort, but at far greater cost that doesn't apply to me; I travel freely. And in this respect we have built up a huge industry to which weather is a matter of vital concern. Science and technology have fortunately enabled us to predict weather conditions with considerable accuracy and to communicate our predictions over long distances so that the forewarned may become forearmed. Our hurricane warning system in this region has been a great blessing which has enabled us to save countless human lives and vast damage to property.

There are also new techniques in which unfortunately our first experiments had recently to be postponed, which may enable us to dissipate tropical hurricanes before they can develop dangerous proportions. We all hope and pray that these efforts will eventually be successful.

The science of rain-making has made some progress and produced some amazing results. It is to be hoped that this particular endeavour will increase in precision so that rain can be produced not only when it is needed, but where it is needed. As an agricultural country this is, of course, a matter which is of great practical interest and importance to Jamaica. Weather, however, is merely an expression of climate, and the subject of your conference is Climatology. Climate and man is the subject of one of the Yearbooks published by the United States Department of Agriculture. "The struggle of man against climate has been continuous ever since his advent on this planet. The unceasing effort to modify his environment to suit his purpose. It is a battle which will never cease, but the struggle will undoubtedly be made easier as we come to understand more clearly the factors which determine and influence climate". This, as I understand it, is your quest. I trust that your deliberations and exchanges of thought during the next few days will take us some distance in this direction. It is a real pleasure on behalf of the Government of Jamaica to welcome you all. I hope that your stay will be pleasant and profitable and that you will return whenever it is possible. I have great pleasure in declaring this Conference open.

SURVEY PAPERS

Statements on established Observational and Research Programmes, and Basic Problems.

THE AVAILABILITY OF CLIMATOLOGICAL INFORMATION FOR THE CARIBBEAN AREA

by

David Smedley, Chief
Foreign Branch
Environmental Data Service
Environmental Science Services Administration
Washington, D.C., U.S.A.

In preparing to discuss the availability of climatological information for the Caribbean area I have found it advisable to divide my comments into two separate sections. In the first I shall discuss the subject in a rather general way, looking at several aspects of the problem beginning with an analysis of WHY the existence of climatological information should be of importance. Following that, I shall consider the question of WHAT the availability picture is at the moment and then WHERE can we find the reasons for the situation being as it exists today. Finally the all important consideration of HOW we can improve the situation will be discussed, together with some thoughts on WHEN we can hope to accomplish our overall aims.

The second major part of my talk will describe the operation of the Environmental Science Services Administration, Environmental Data Service's program in climatology in the Caribbean area.

Economically, climate may be an asset or a liability. Proper recognition and exploitation of the favorable aspects of the climate of any locality can result in monetary gains while identification and consideration of its unfavorable aspects can reduce losses. In a like manner, the climate has much to do with our day to day living, the occupations we pursue, our forms of recreation and our physical and mental well-being. A large segment of our commercial enterprise is engaged in treating our indoor environment so as to make it more enjoyable, more comfortable and more conducive to productive endeavour. I refer here to the heating, refrigerating, ventilating and air conditioning industry. These same branches of engineering are also engaged in providing better facilities for the transportation of perishable commodities, thus decreasing spoilage and reducing financial losses as well as lowering the cost of foodstuffs in the local markets.

One of the most lucrative industries, if I may call it that, in the Caribbean area is tourism. In many areas it is responsible for a high percentage of the dollar income. This is due to a large extent to the favorable climate. It is cooler and more comfortable in the summer and warmer in the winter than it is in the majority of the areas from which these tourists come. There has been a marked tendency, in recent years, for the tourist season to last twelve months rather than only five or six.

Certainly agriculture is extremely sensitive to the climate as is well illustrated by the disastrous aftermath to a period of drought. In many of the Caribbean countries and islands agricultural products form the bulk of the export items which are so important to the economy of this area. I am sure that each of you can remember at least one such instance of crop failure and resulting economic and physical distress. I note that several papers to be delivered here during this Conference will discuss this general topic. Increased agro-climatological research into the inter-relationships between climate and agriculture would be most helpful in the development of new crop varieties and agricultural practices which would result in higher yields and, as a result, increased export ability.

In each of these situations, an intimate knowledge of at least the climatic normals, their probable variations and possible extremes, is necessary if we are to make our climate work for us more effectively or to lessen the impact of its less desirable aspects. We need to do all we can to obtain a better understanding of the basic meteorological processes in the tropics. A World Meteorological Organization Technical Note, No. 62 PROBLEMS OF TROPICAL METEOROLOGY, by M. A. Alaka in 1964 surveyed the general field of tropical meteorology and pointed out many areas where much additional research effort is sorely needed before we can fully understand what happens and, even more important, why it happens.

I have pointed out here that there are two basic needs for climatological information. One is practical and economic in nature and is concerned with the field of applied meteorology in its attempts to help us to improve our lot in life. The other is quite scientific in nature and concerns the problem of basic meteorological research. Each is of extreme importance in its own right. Each is worthy of all the support we are able to give it.

Let us analyze, for a moment, the picture as it exists today. Are all of the data we need readily available to us? Are we able to answer in a satisfactory manner the questions which are put to us? Are we in a position where we are able to sit back complacently and feel that we, as climatologists, have done all we can to supply all the information concerning the climate of the Caribbean area for which we are asked?

The answer is NO! There is still a great deal of work which needs to be done. The time has not yet come when we can feel satisfied. We must constantly strive to improve our product, to provide it in the form, quantity and degree of sophistication required. We must be ever vigilant to search out new requirements, to make our product worthwhile and to justify the money it costs each year to retrieve and process the meteorological data for climatological purposes.

Before we can furnish the climatological material in the form in which it is required we should have a sound understanding of the problem which faces the potential user. What is required here is a "well travelled bridge" between the meteorologist and the user. Too frequently this bridge has broken down - that is, the meteorologist and the user do not communicate their ideas properly with a consequent breakdown that results in failure to do the best job possible in providing the right information in the proper form. The traffic that should travel over this bridge should not consist merely of raw information in the form of mean values or normals, or even frequency distributions wrapped up in scientific terminology which may well be meaningless to the user and subject to incorrect interpretation on his part. What is required is a real interchange of data, terminology and ideas. The climatologist has a responsibility to try to understand and appreciate the user's problem before he attempts to provide an answer.

I would like here to mention a few examples of occasions when the proper use of climatological counselling would have helped to save valuable dollars or to avert extensive remodeling. There is the one instance when a shipping company decided to build a new pier. Proceeding without first seeking climatological assistance they went ahead and built the pier. After they brought their first ship in to dock, they learned to their dismay that during the day the wind blew with such a force that it was impossible to bring the ship away from the pier, and it was necessary to devise additional procedures, costly ones at that, in order to solve their problem.

I might cite another case where a large office building was being built. In designing the air conditioning equipment to be installed, climatic factors were not considered in full. As a result the equipment which was installed was far too big, far more costly than was necessary. Each month the operating costs were more than they should have been.

Then there was the case where a large combination office building and factory was being built. For asthetic purposes, without consideration of the prevailing wind direction, the black-top parking lot was placed in the back of the building, away from the eyes of passers-by. Unfortunately, the side of the building on which the lot was placed was the upwind side. When the sun hit the black top it heated it up to extremely high temperatures and the prevailing wind blew this hot air right into the building making it unbearable. The original plans had not called for air-conditioning the entire building, but now it had to be done at great cost. This could have been avoided. I could go on all day recounting this sort of experience but time does not permit.

How often have you had a construction engineer come to you with a request for rainfall intensity information on which to base his decision as to what size sewer pipes to use so as to avoid unnecessary flooding, or possibly to use in designing the size of the cistern to install to catch the most valuable rainwater in areas of little or no underground water supply? I have had such a request during the past few months and found it necessary to recommend the use of data for an area more than a thousand miles away simply because the data were not available for any location closer than that to the site for which the data were required.

Have you ever had a visit from an air-conditioning engineer who needed information concerning the frequency distributions of dry and wet bulb temperatures to use in planning for the proper size equipment or, possibly, in determining whether the installation was necessary at all? These data are extremely scarce in the Caribbean area. Did you ever have a need for reliable, observed, cloud cover information over the interior of an island for use in selecting the optimum time of day and time of year for conducting aerial photographic reconnaissance for mapping purposes or for use in road construction? I am quite certain that these problems have faced you at one time or another in the past. How many of them have you been able to answer in a really satisfactory manner? Not very many I would imagine. Moreover, as you are no doubt aware, many of the countries and islands in the Caribbean area are making a determined effort to attract industrial enterprise in an effort to bolster their economy. Prospective investors require a great deal of information so that they may make a sound evaluation of the problems they are likely to face. Unfavorable climate, if not detected until after the fact, could be disastrous. We should be able to give them the help they need.

Following a similar line of approach, let us look at the demands placed upon us from the purely scientific point of view. There can be no doubt that the success of many research projects hinges to a large extent on both the quantity and quality of the climatological information available. Here we find, once again, that the information available to us is inadequate. I am quite certain that many potentially fruitful research project plans have been permitted to wither on the vine simply because the information required either was never collected or, even if it had been, the time and cost involved in locating it and preparing it for use were prohibitive.

There are a number of reasons why these data are not at our fingertips when we need them. Primary on the list of reasons is the fact that the observations were, plain and simply, never taken. The network of stations for which these data are available, even in raw form, is basically inadequate. Also high on the list of reasons for our failure to be able to provide the information is that even though the observation may have been taken, they have never been summarized in the proper form, if at all, or, possibly, not published in any form at all.

I believe that we will be able to understand some of the reasons for our difficulties in providing climatological data if we take a look at the area which I am speaking about when I discuss the "Caribbean Area". I consider the Caribbean area to include not only the individual islands in the Greater and Lesser Antilles, but also the Bahamas, all of Central America portions of Mexico, and those portions of South America which border on the Caribbean Sea, primarily Colombia, Venezuela, Guyana, Surinam and French Guiana. Some eighteen individual meteorological services are involved in meteorological operations, including the taking of climatological observations. There are varying practices with respect to observations, the number of observations taken daily, and even in the number of elements observed. In many cases metric units are used while in others inches of rainfall and Fahrenheit degrees are used. Certainly, publication policies are quite different, not only in the density of the networks of stations for which data are published but also in the frequency of publication and the degree of sophistication of the material published. The networks of stations are nowhere completely adequate but in some areas the situation is in need of greater expansion than it is in others.

One reason for the wide disparity in practice from one service to another is financial. Certainly not every service has the same financial resources on which to draw for climatological purposes. This is only one reason for our failure to be able to provide satisfactory service to those who come to us for assistance but it is not, in my estimation, necessarily the predominant reason. I do not think that we, as climatologists, have done a satisfactory job of selling ourselves and the benefits which may be derived from the enlightened utilization of the product which we are able to provide. We have not sold the authorities who control the purse strings on the economic potential which may be derived from proper consideration of the climate. We have not been active enough in pointing out forcefully how we are able to help all aspects of the economy. Certainly, from an aviation standpoint, this has been done to the degree that for aviation forecasting at least a satisfactory network is in existence. Likewise, hurricanes in this area have been well recognized as potential enemies and the various meteorological services in the area have for years banded together, with periodic meetings of the Eastern Caribbean Hurricane Committee held to discuss items of mutual interest. These two groups, the aviation interests and the hurricane interests have sold themselves adequately and as a result, the financial support needed has been made available. We, as climatologists, have been travelling along, here in the Caribbean, on the shirttails of the aviation and hurricane interests; as a result, we have had to be satisfied, to a large extent, with the networks, observations and practices which, while they may be sufficient for the purpose for which they were intended, are inadequate for climatological purposes.

In this day of automation we would expect that the use of punch card equipment and electronic computers would make our job easier to do. In some cases this has been true, but these cases are all too few and far between for us to be complacent. These mechanical and electronic tools are fine, but only if there is sufficient information to feed into them. We cannot hope to get more out of them than we put into them. The better and more complete and more accurate the raw material, in this case the basic observational data, the better our finished product will be. In the Caribbean area, to a large extent, there is not sufficient information readily available at the present time for us to use these new tools to their best advantage.

You may say there are plenty of stations for which data are in the archives. This may be true to a certain extent, but when there is a need for this information, how readily can it be assembled? For the most part these data are not available in a single location. They are scattered all over the Caribbean, in the offices of the various meteorological services and, to make things worse, there is also quite a bit of information reposing in the files of individual private or commercial sources or at agricultural stations. Not only is there relatively little information available concerning the extent of this type of information but attempts to locate it when needed are often subject to frustrating delays which are frequently sufficient to doom a project to failure when the time available is not sufficient to permit lengthy waiting periods. Have you ever written to potential sources for information and then begun to suspect that your letter had been assigned for delivery to a seagoing turtle without a sense of direction? If your need is for information covering a large area crossing the domains of several meteorological services how often have you had adequate response from several sources and either inadequate response or none at all from others, thus leaving large gaps in your data? We have had this experience all too frequently.

I have outlined what I consider to be some of the outstanding problems in climatology in the Caribbean area today. It is certain that we will not find answers to any of them overnight, and to some of them maybe never. However, there is one method of approach that cannot help but bear fruit. In general there is not sufficient awareness of the potential value of climatic intelligence, if I may call it that. As suggested earlier it is up to us to promote our own product, to educate the potential user to the fact that he does have a problem that can be helped by intelligent use of climatological information. We must prove to him that this type of information can be converted into dollars and cents (or should I say pounds and shillings)?

Once this has been done, the second phase of our work is only beginning. There are networks to be expanded to provide us with the density of reports we need. There are additional elements to be added to the list of those already observed. Improved capability to process the data which will be collected should be provided for. It would behoove us to make an approach to the question of whether or not it would be feasible and economically sound to provide for a central processing facility for the Caribbean area. Possibly such a center would require the inclusion of the South American meteorological services to make it sufficiently large an operation to be economically sound. This type of enterprise has already been suggested in deliberations of the World Meteorological Organization.

Perhaps if we do a proper selling job *now* our work in the future will be a little easier, and we will be able to do a better job of providing the information which is requested from us in the manner and degree of completeness which our professional pride tells us we should be able to do. We should encourage a greater degree of co-operation between the various meteorological services in the Caribbean area in climatological matters, similar to that which is already enjoyed in aeronautical and tropical storm matters. It is up to us to do this. It will never happen if we sit back complacently and wait for someone else to do it for us.

Now let us take a look at what the Environmental Data Service of the Environmental Science Services Administration has done to help to alleviate some of the problems which I have discussed above. I do not mean to hold up what we have done as a model for all to follow. There are many roads that lead to the same destination and it is impossible to say that any one path is necessarily better than any other.

In developing our program we took into consideration the fact that there are varying degrees of requirements as well as varying approaches to be considered in seeking the proper manner of fulfilling them. Never send a boy on a man's errand and, conversely, do not send a man on a boy's errand. For efficiency and economy of operation it is important to see that each request is handled at the proper level within the organization so as to avoid either failing to give sufficient attention to problems that are quite difficult or of having a highly paid scientist spend his valuable time dealing with a problem that could be handled quite satisfactorily by a clerk.

Many types of request are received. There is the one from the woman who wants to know whether a sweater would be necessary on a vacation trip. Then there is the one requiring high level consultation, complicated statistical analysis and specialized computer processing before a solution is found. Obviously each of these requests requires different handling.

For requests of a simpler nature, we have provided a series of publications. Some of these are periodic in nature and contain day-by-day and month-by-month information on the various meteorological elements which we have learned, by experience, are those most called for. Other publications summarize the most used elements, and vary from providing simple mean values or maps to more complex frequency distributions. I do not think it necessary to dwell at length on these. It will suffice to say that both surface and upper air data are included throughout the Caribbean area with, naturally, primary emphasis being placed on Puerto Rico and the U.S. Virgin Islands, both of which have stations directly operated by our own service.

These publications are available for inspection at the Weather Bureau offices located in most of the principal cities in the United States, in San Juan, Puerto Rico, and for those who have a recurring need for them, are available by subscription through the Government Printing Office at a nominal cost.

There are of course requests which are not adequately satisfied by merely providing publications. These involve problems where the requester himself does not have sufficient "know-how" to enable him to select the proper information to use in making his decision. He is in need of counsel. Problems of this type begin with those that, after consultation, can still be handled by supplying already published material together with instructions as to their interpretation and proper use. An example of this type would be the one received from a manufacturer who plans to open a new factory and requires information to use in designing his physical plant. The building is to be a long narrow one and he wants to orient it so as to make the most efficient use of the prevailing wind for the comfort of the occupants. The wind is also important in considering the location of the stack which will emit certain noxious effluents, and for determining the proper site for the parking lot. Wet and dry bulb temperature distributions are needed to properly design an air conditioning plant and rainfall intensity information is necessary for selection of the proper size storm sewer pipes. I am certain that you can all envision many similar problems. At the upper range of request are those which are so complex in nature that published information is not available and procedures have not yet been established to solve them. In other words, high level consultation is required before a solution can be found.

In order to provide assistance in solving these more complex problems we have made provision to have professional help available in several locations to provide limited consultation service. In each state there is a State Climatologist, a professional meteorologist who is an expert on the climate in his area, familiar with the sources and location of climatological information. He works closely with the various Federal and State agencies in his area and is responsible for developing a program to provide the maximum climatological service possible. In the Caribbean area we have the Commonwealth Climatologist who is based in San Juan, Puerto Rico. His basic area of responsibility includes Puerto Rico and the Virgin Islands but his location in the middle of the Caribbean area dictates that he also concern himself with the climatology of the surrounding countries and islands.

In addition to the man-on-the-spot we have two other locations where professional assistance is available. In the headquarters office of the Environmental Data Service in Washington, D.C., the Foreign Branch maintains limited resources in the form of summarized information for all foreign areas of the World, including the Caribbean area. Naturally the completeness of this information varies greatly from place to place. These files are supplemented by the vast resources of the Atmospheric Sciences Library located in the same building and readily available to the staff of the Foreign Branch.

Located in Asheville, North Carolina, is the National Weather Records Center which is the final repository of all of the meteorological data collected. Both United States data and foreign data are stored there; many are placed on punch cards or magnetic tape and are available for use in special programs designed to solve the more intricate statistical problems. Professional assistance in selecting the proper information and method of preparation is also available here.

As I have described, we have a program designed to help solve many types of problems. The provision of professional consultant service helps us to cross the bridge to the user so that we may be able to appreciate his problem and to provide the best assistance. We have found that there is no substitute for personal consultation in solving climatological problems. There is less opportunity for misunderstanding. We do not profess to have all the answers. We have not yet managed to solve all of the problems outlined in the first part of my discussion, but the search for new and better methods of providing the information and assistance required is a continuing one.

The question of how we obtain the data for our own stations is an interesting one. Obviously it would be financially impossible to have complete round-the-clock observation stations equipped with instruments of all types at each desirable site. In Puerto Rico there are about one hundred stations and in the Virgin Islands there are in the neighborhood of thirty. As I have discussed in the first part of my paper, the aviation interests carry quite a bit of weight in the decision as to what observation locations are necessary for their purposes. In Puerto Rico and the Virgin Islands we have one first order Weather Bureau Airport Station, two military airfields which take round the clock observations and two airport meteorological stations which are operated by the Federal Aviation Agency. There is one second order station for aviation purposes and two Supplementary Aviation Weather Reporting Stations operated on an as-necessary basis by one of the local airlines. This gives us a basic network satisfactory for aviation purposes but nowhere near complete enough for climatological purposes. This basic network is also used for the hurricane warning service, but even here it is not complete enough, so there is a supplementary network of stations that are active only during time of emergency and which, for all practical purposes, are of no value climatologically. As a result, in order to provide us with the density of stations necessary for our purposes it has been found expedient to establish a further network of co-operative stations whose observations supplement those of the basic network. Generally speaking only temperature and precipitation observations are taken.

It is appropriate to say a few words at this time about the co-operative observers. As the name implies, these observers receive no pay for their services. The Weather Bureau supplies the instrumental equipment and the necessary observational forms while the observers donate the use of their property on which the instruments are installed and take one observation daily, either in the early morning or in the late afternoon or early evening. By using this co-operative arrangement to obtain our observations we are able to obtain a much better sampling of the climate both for scientific and applied purposes than we would be able to if we were required to pay an observer at each observational site.

Because there is only one observation of maximum and minimum temperature each day, it becomes necessary for us to compute daily and monthly mean temperatures by averaging the maximum and minimum readings. We feel, however, that the benefits gained in having a denser network of stations outweigh the loss in accuracy in the mean temperature which results from the method of computation used.

We feel that these co-operative observers are performing a most worthwhile service to their country, and the data they provide to us are used many times over in research projects and in other more immediately recognized activities such as the building of roads, planning of the size of storm sewers, determining the requirement for heating of air-conditioners and the like. We have established a program of providing them with official recognition of their services through the formal presentation of honorary awards, the Thomas Jefferson and the John Campanius Holm awards, and also through the medium of congratulatory letters from the President of the United States or the Secretary of Commerce for observers with exceedingly long periods of service. There are many who have been active in this program for more than fifty years. Length of service pins are also awarded to them at intervals, beginning at ten years, as a token of our gratitude for their assistance. The majority of these co-operative observers have a deep feeling of accomplishment in this service to their country and to their fellow citizens and have been found to be extremely reliable.

This is as far as we have been able to go, within the resources available to us, in providing for the collection of climatological data, all of which are published in one form or another in one or more of the series of publications already described. The Agricultural Experiment Station of the University of Puerto Rico has installed additional equipment to suit its own particular requirements and has made its data available to us for publication in our series.

I have now discussed the arrangements we have made to provide assistance to those requiring it in the solution of problems that are climatologically oriented, and have spoken about the source for the domestic material which is published in our publications. As I indicated, several of our series contain information for other countries and islands in the Caribbean area.

Several of our publications have been sponsored by the World Meteorological Organization, and the interested members have been urged to co-operate by furnishing the necessary information to be included. This has worked out quite well and the results have been most gratifying although occasionally there are periods when delays on the part of one or more of the co-operators are responsible for delays in publication.These publications which are international in nature have been undertaken in an effort to provide relatively current information covering a large homogeneous geographical area so as to satisfy the most immediate needs of the users until the various meteorological services are able to provide more complete publication.

Our efforts to solve the problems discussed earlier in the paper have been successful to a certain extent. There are still gaps in our own networks and still other problems remaining to be solved. There is hope that, in the future, with greater co-operation in climatology on the part of all of the eighteen meteorological services involved, we will be able to satisfy more and more of our shortcomings. Time will tell.

In the meantime it is important that we continue to do all we can to increase our understanding of the various applications of climatological information, to help to increase the traffic over the "well travelled bridge" between the meteorologist and the user of our product. For it is only by interchange of ideas that we will be able to do an efficient and effective job of fulfilling our responsibility.

McGILL's CLIMATOLOGICAL OBSERVATIONAL AND RESEARCH PROGRAMME IN THE CARIBBEAN AND GUYANA.

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The Department of Geography maintains climatological stations in both Barbados and Guyana. These were developed through the energy and enterprise of Professor Theo Hills. Although not primarily interested in climatology he naturally recognised the importance to geographical research in general of having observation stations. Consequently, he made use of his opportunities for research in these territories to establish the stations and subsequently to maintain them under considerable difficulties.

Climatological Research in Barbados.

In 1957 Professor Hills approached the government of Barbados for the lease of 5 acres of land for climatological research with particular emphasis on agro-climatology. His negotiations were successful and a 50-year lease at a peppercorn rental was obtained on these five acres of land in Waterford. The site is one mile from Bridgetown on the western side of the island where the valley opens out towards the western coast. The station is 120 feet above sea level and was originally a part of Codrington Agricultural Research Station. Observations started at Waterford in March 1959 with Ivan Smith a native Barbadian and McGill Ph.D. candidate in charge.

To begin with, the following observations were taken: dry and wet bulb temperatures; maximum and minimum temperatures; rainfall and evapotranspiration made from three Thornthwaite Evapotranspirometers. Six months later a simple evaporation pan and disk atmometers were added. In January 1960, soil temperature readings at 2,4 and 8-inch depths were begun, as was the observation of grass minimum temperatures. Later an American Class A pan was added to the station together with a totalizing anemometer and a bare soil evapotranspirometer. By the end of 1960 radiation measurements were being made, first at Combermere School, later to be transferred to the Brace Experiment Station, eight miles away. Additional observations included wind direction from March 1961 and a Bellani atmometer in June of the same year. These observations comprise those which have been conducted from their various points of installation to mid-1966. After Ivan Smith left Barbados in July 1962 various graduate students of the department have been in charge of observations and from July 1965 the chief observer has been Victor Gibbs who has operated with the assistance of David Holford, both of whom were under the General supervision of Mr. Colin Hudson. Mr. Gibbs is attached to the Ministry of Agriculture in Barbados. This Ministry has at all times been extremely interested in and helpful with respect to the work of the station.

Closely connected with the particular observation at Waterford has been a series of radiation observations taken at various sites in the island as part of David Tout's research programme. These have been made by silicon cells linked to an ampere-hour meter.

From March 1959 the data collected on the island have been published in mimeographed form at three-monthly intervals.

The following theses on climatological topics have been completed:

Smith, S. I.	Climatic Control of Distribution and Cultivation of Sugar Cane. Ph.D.
Rouse, Wayne	The Moisture Balance of Barbados and its Influence upon Sugar Cane Yield. M.Sc.
Chia, L.	Albedo Measurements of Various Surfaces in Barbados. M.Sc.
Oguntoyinbo, J.	Rainfall Variability on Barbados and its Influence on Sugar Cane Yields. M.Sc.
Oyelese, J.	The Distribution of Food Crops in Barbados. M.A.
Tout, D.	The Inter Relationships of Solar Radiation in Tropical Latitudes. Ph.D. Not yet submitted.

These are six of eighteen theses that students of the Department of Geography have written on Barbadian topics.

In addition, a report including the Rouse thesis and a special report by D. Watts on 'Energy Relationships at Waterford, 1961' are now in print.

Other work conducted since 1958 includes: advice to plantations on irrigation water control; establishment of a small irrigation control station on St. Lucia on behalf of U.S. Aid and the St. Lucia Government; co-operation with C. Hudson, then of the Barbados Irrigation Board, in short-term observational programmes.

In the past two months arrangements to expand the climatology work in Barbados have been made. The Waterford site is undergoing reorganization with a view to developing it for three purposes.

1. As one of a chain of micro-climatological stations being established from Knob Lake (Sub-Arctic Quebec) to Guyana as part of the graduate teaching and research programme in micro-climatology in the Department of Geography.
2. To provide a definitive place on the island for experimental work in agro-climatology. The five acres leased by the Barbados Government are ideal for the purpose especially as they are so near to the Codrington Agricultural Station.
3. To provide a base station as part of a wider network of observation sites being developed on the island in co-operation with interested government departments and the recently founded Institute of Tropical Climatology.

Climatological Research in Guyana

The Climatological Programme is conducted as one phase of the McGill University Savanna Research Project.

The climatological programme must be considered in the light of the major objective of the Savanna Project, which is to investigate the nature and origin of the Rupununi and Rio Branco savanna landscapes. The major objective of the Climatological Programme is to investigate the climatic factor in the savanna landscape.

The significance of climate is being assessed at two levels: micro and macro. These investigations have two major objectives:

1. To provide the data necessary for the complete description and explanation of soil water conditions in both savanna and forest associations.
2. To assist in the determination of whether or not the savanna is self-perpetuating.

Micro stations have been established at five locations within a two-mile radius of St. Ignatius under different vegetation, slope and aspect conditions. The data measured and computed twice daily are: maximum and minimum temperatures, wet and dry bulb temperatures, soil temperatures at 3, 6 and 9 inches, grass minimum temperature, rainfall, evapotranspiration, and water table readings. Other micro data are measured and computed at the main climatological compound at St. Ignatius, and are listed below.

The major objective of the macroclimatological investigations of the climatological programme is to provide a complete description and explanation of the climatology of the Rupununi and Rio Branco regions. Concurrently an attempt is being made to determine the nature of the relationship between types of savvanna and rainforest climatic characteristics. In pursuit of the major objective, the following has been achieved:

1. Instrumentation allowing for the measurement of the climatic data listed in Appendix 1.
2. Limited instrumentation, more particularly rain gauges at selected locations in both the Northern and Southern Rupununi.
3. The collection of all data available from various sources representing observations made at several locations, for varying periods, between 1900 and 1966.
4. The analysis of daily weather charts covering the Amazonion-Guiana region.
5. The following theses have been completed:

   Eden, M. **The Savanna Ecosystem.** M.Sc.

   Frost, D. **The Climatology of the Rupununi Savannas.** B.A. Hons.

   Frost, D. **The Climate of the Rupununi Savannas** - a study in ecological climatology. M.Sc.

6. Publication of annual climatic statements. (Data as published in Appendix 1).

In addition, climatological observations are being maintained in conjunction with geomorphological and hydrological investigations.

The future calls for the continuation and expansion of the observational programme, more intensive investigations of the water and energy balance of both the forest and savanna environments and micro. studies within the varied vegetation associations of the region.

APPENDIX 1.

CLIMATIC DATA, ST. IGNATIUS, RUPUNUNI, GUYANA.

A. **Standard Meteorological Parameters**

1. Daily maximum and minimum temperatures.
2. Wet and Dry-bulb temperatures at 0800 hr. and 1400 hr.
3. Sunshine hours.
4. Rainfall (in cms.).
5. Wind measured at 3 ft. height (in m.p.h.).

B. **Agrometeorological Parameters**

1. Solar maximum temperature.
2. Grass minimum temperature.
3. Soil temperatures at 3 in., 6 in., 9 in., 12 in., and 48 in. depths taken at 0800 hr. and 1400 hr. (in ^{o}F).

C. **Evaporation Measurements**

1. Evaporation pans:
   a. 22 inches diameter.
   b. 48 inches diameter.
2. Lysimeters (three).
3. Robertson disc atmometor.
4. Thornthwaite potential evapotranspiration (computed).

D. **Radiation Measurements** - direct and diffuse.

AGRO-CLIMATOLOGY IN THE FRENCH ANTILLES.

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et de la Guyane, Guadeloupe.

The Agro-Climatological Section of the Centre de Recherches agronomiques des Antilles et de la Guyane functions as an out-station, in a tropical environment, of the Department of Agro-Climatology in the Institut National de la Recherche Agronomique (I.N.R.A. - France).

In addition to the accumulation of basic climatic data, the Section seeks to apply in its area research carried out in other places by French bioclimatologists. The aim of its work is to apply in the Caribbean region as economically as possible new ideas concerning the relationships between plant and ecology and develop new possibilities which may lead to increased crop yields.

The discipline of bioclimatology may be said to have come into being only in 1965 and it does not yet claim to have obtained a great number results. We are going to confine ourselves to a rapid review of its principal actual directions of activity, which one may subdivide into four principal division, as follows:

A. Basic climatological data
B. Instrumentation problems
C. The study of microclimates
D. The study of water-plant relationships.

A. Basic Climatological Data

A.1. We do not intend to spend time considering those parameters which for the most part consist of meteorological elements: soil and air temperatures, humidity, rainfall, wind, insulation, evaporation, global radiation. The installations and the observations are made in conformity with the recommendations of the World Meteorological Organization.

A.2. Measurement of potential evapotranspiration (ETP) is carried out by means of seven Thornthwaite-type evapotranspirometers set up in Pangola grass *(Digitaria decumbens)*. The vegetation is maintained, as in a circle of 200 square meters, at a height of at least 10 cms.

B. Some Instrumentation Problems

Studies are undertaken with the aim of putting at the disposal of farmers a simple apparatus, derived from more sophisticated equipment, and secondly in order to permit a more exact approach to data which is fundamental to research.

B.1. One approach adopted is to compare the values of evaporation obtained from the Piche evaporometer and the class A tank with the values of ETP measured. See A.2. In particular the Piche evaporometer, placed in certain conditions and taking account of certain climatic factors, ought to give the ETP with a precision requisite to the desired scale: field, region, etc.

B.2. Similarly, comparison of measured ETP and ETP calculated from different formulas is undertaken.

B.3. Another approach is to measure the temperature of the soil with different types of apparatus: L-shaped thermometer, capillary tube probe, resistance probe, thermocouples. These should explain certain anomalies found in this type of measurement and contribute to the determination of the most suitable instrument.

B.4. Finally, difficulties encountered in the establishment of the hydrological balance by means of evapotranspirometers, especially in periods of high pluviosity, have led us to consider the problem of rainfall measurement. The question is to determine if in a tropical region with prolonged and intense rainfall the quantity of water collected in the classic rainfall gauge is the same as that falling on a homogeneously vegetated surface. We do not pretend that this is not an arduous and lengthy task.

C. Study of Microclimates

Everyone knows the extreme variety of climatic conditions in the Antilles within very restricted geographical zones. The considerable biogeographical variations which result from these justify, within the framework of agronomy, studies of microclimates which may lead to their exploitation on a rational agricultural basis. This is why we study microclimates.

C.1. Study of microclimates, at the scale of the island, necessitates the establishment of observation stations in different geographic regions in collaboration with the Meteorological Service. Other than rainfall (already fairly well known), observation of wind and evaporation form the principal aim. These two last elements appear to have a predominant influence on agricultural production in a tropical environment.

C.2. Study of microclimates, with agricultural development principally in view, emphasises in particular exposure to the wind and ought to allow a better appreciation of the role of this element in the agricultural exploitation of each area of land and its most suitable land use.

C.3. The problem of habitat, particularly in relation to livestock management, has led us to study optimal comfort levels by simple measurement of temperature and evaporation (Piche evaporometer).

C.4. Finally, the problems posed by opening new land for cultivation, like zoological problems, necessitate a better knowledge of the atmospheric environment of the forest. Hence the establishment of observation stations in the forest areas has been carried out, the accent being on the differences existing in the radiational and hydrological balance between clearing and forest.

D. The Study of Water-Plant Relationships

It is known that the efficiency of photosynthesis and, in consequence, the productivity of a particular crop is bound up with among other things absorption of food and water by the plant structure. Our experiments, based on the theoretical results obtained in temperate countries and, in particular, on the studies carried out as a team by the scientists of the Departement de Bioclimatologie at the Institut National de la Recherche Agronomique (I.N.R.A.), aim at reducing the 'demand' for water represented by the potential evapotranspiration, which itself is ultimately bound up with other climatic factors. The problem is to reduce this 'demand' to the level of 'supply' which the plant is capable of assuming the nature of its physiology, the soil reserves being regularly reconstituted by irrigation. The methods employed ought to reduce the consumption of water by agriculture on a world scale and ensure a better use of vital water.

The actual practical applications are oriented in three directions:

D.1. The lowering of instantaneous ETP by the application of frequent spraying during tay (overhead irrigation), the total amount being the same as in classical irrigation. In this way the environment is so modified that the water requirements are lowered without changing the plant, and energy equilibrium maintained.

D.2. We also seek to lower ETP by reducing the energy put at the disposal of the plant by global radiation. The problem of artificial shade (films or screens or plastic coverings) or natural shade (crop associations practised over a long period by traditional agriculture, but which need rationalizing) is studied.

D.3. Finally, we seek to reduce ETP by lowering the advection energy due to the wind. We are thus approaching the problem of natural and artificial windbreaks which seems a particularly important one in islands constantly brushed by the regular flow of the trade winds. Provided that there is prior control of water it would seem highly likely that the rational use of techniques of windbreaks ought to give encouraging results in the field of raising crop yields of many traditional branches of agriculture.

The programme we have outlined may seem vast and ambitious. We insist on the fact,however that it is a natural outcome of ideas put forward by the research workers of the Department of Agro-Climatology of I.N.R.A.

We hope to be able in the near future to present some preliminary results which we anticipate will be our modest contribution to the efforts of research workers in the Caribbean towards a better comprehension of the tropical environment and the promotion of agriculture in our regions.

(Translated by L. Alan Eyre, assisted by Dr. Gertrude Buscher.)

PAPERS ON RAINFALL, WATER SURPLUS AND WATER DEFICIT etc.

THE CONCEPT OF WATER SURPLUS AND WATER DEFICIT AND ITS USEFULNESS IN CARIBBEAN CLIMATOLOGY

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Sebastian: What a strange drowsiness possesses them?
Antonio : It is the quality o' the climate.

The Tempest

The Basic Problem

There are two matters of great concern to the geographer who likes to flatter himself that he is a "pure" as distinct from an "applied" climatologist - one is the problem of definition or classification of a climate and the other is climatic change. The not-so-eager schoolboy must have a slick and easily memorised label to pin on this climate or that: here is "hot and wet", there is "desert", and over there is that old favourite of the external examiner "tropical savanna". In his search for the "quality of the climate", as Shakespeare's Antonio called it, the geographer has often appeared to have a very mixed and imprecise collection of terms in his classificatory repertoire. Some terms are locational (e.g. Mediterranean), some vegetational (e.g. savanna) and all lack in precision what they possess in empirical flexibility. Tropical climates and Caribbean climates have, in particular, many qualities other than the drowsiness which Sebastian complained of and which those of us who are teachers know to be indeed its most characteristic quality. But there is still a need for these to be more precisely quantified before analysis is very meaningful.

In the tropics where temperature is chiefly a function of altitude, it is precipitation which is the chief demarcator of spatial zonation. The commonest and simplest measures of this factor utilise raw monthly rainfall data and, as in Harold Wood's recent classic analysis of the climate of northern Haiti, categorise a month as wet, moist or dry. The principal drawback to this, of course, is the fact that it is effective precipitation which matters, but so complex are the measures of this, that the climatologist seeking regional or global classifications may be forgiven if he becomes frightened at the battery of class A pans, elbowed soil thermometers and rows of Thornthwaite evapotranspirometers. These are absolutely essential to micro-climatic study and to the precise demands of the climatologist who has to set himself to the problems of a specific area or applied field. In any case no network of this kind of sophisticated data as yet exists in the tropics. The macro-climatologist attempting broad classification in the tropics needs a middle-of-the road technique which will give good empirical results with the very limited basic data available to him.

Since Thornthwaite many and varied have been the attempts to provide the data needed by the classifying climatologist and each no doubt has its merits. Most of them are based on the concept of water surplus and water deficit. In his attempts to find a suitable base from which to erect a more satisfactory classification of tropical climates than those presently available the author of this paper has found a system based on a rather complex but empirically successful manipulation of temperature and humidity (measured or estimated) developed by the Department of Geography and Meteorology of the University of Kansas to be the most useful tool available. Research workers there have tested their formula for water balance against a wide range of temperate and tropical crops with excellent results on the macro scale, Geographers at Kansas have been engaged upon a classification of climate on a national scale and preliminary results seem to suggest its usefulness in our region. The preliminary and tentative map of the climates of the United States seems to have so far delighted a number of agro-geographers as well as debunked a number of old traditions (such as the classification of the Seattle area as "British" type). The purpose of this paper is not to add yet another complex formula but to offer two examples of how the concept of water surplus and water balance can be used as a cartographic aid in:

(a) the analysis of the statics of climate (classification)
(b) the analysis of the dynamics of climate (climatic change).

An Analysis of the Statics of Climate (Jamaica)

Using the tables supplied by George F. Jenks of Kansas, and his graphic method of presentation, an attempt has been made to elucidate Caribbean climates. A very simple example from Jamaica is shown. [*Wall maps and charts were displayed. Ed.*] It reveals a number of interesting features:

(1) the well-known but puzzling ineffectiveness of the May rains in the Kingston area is apparent. Climatologically only the October rains provide a water surplus in the south east area of Jamaica.

(2) The area of Jamaica with 'dry-season' maximum and 'wet-season minimum is illustrated.

(3) The length and severity of the water deficit period in the south west would be even more clearly shown if more stations had been plotted.

(4) The potential danger of the "little dry season" in July and August can be seen at a number of stations. The slightly higher temperature in these months compared with the January-March dry season makes water deficit potentially more severe. Farmers throughout Jamaica fear a July drought more than any other.

Using this type of analysis classification of tropical climates according to two basic parameters appears useful.

High
Altitude
TEMPERATURE

Sea Level

No Surplus — No deficit

WATER SURPLUS AND DEFICIT

More detailed factors such as one peak or two peak surplus, one or two dry seasons, months of occurence of surplus or dificit and severity of deficit may be introduced. Represented graphically the length and intensity of the dry seasons are visually apparent.

An Analysis of the Dynamics of Climate (Nassau, Bahamas).

The chart of Nassau [*displayed*] indicates the utility of the concept of water surplus and water deficit in the elucidation of climatic dynamics and secular change. It is a plausible view that the longer the series of observations which can be used to calculate a norm or mean the more reliable it is as an index of definition or classification of the climate of any location. Annual variations are of course increasingly smoothed out the longer the period used to obtain the mean, but at the same time the longer the period used the more likely it is that highly significant long-term secular changes will be masked by the mean.

Assuming for the present that a period of water surplus may be broadly defined as 'wet season' conditions and water deficit as 'dry season', the climate of Nassau on the basis of long-term means can be considered to have a seasonal climate consisting of a dry season with one minimum and a wet season with two maxima. But that basic simplicity is in reality a potential snare, especially for short and even medium term planning such as is required for most governmental purposes.

Of the fifty five-year means shown on the chart from 1905-1909 to 1955-1960 seventeen did not have two maxima. As many as six consecutive sets of five-year means, as during the second half of the '30's, did not show two maxima, and the monthly position and magnitude of the two maxima were very different in the '20's from what they were in the '40's and '50's. During the twelve years from the beginning of the records in 1905 to 1918 the running means indicated a consistent and pronounced June maximum, in fact the five-year mean 1909-1913 shows a single maximum for the year in June. Then followed a long period with an October maximum, followed in turn by an interesting period in the late '20's with an extremely pronounced seasonality and a high September maximum. In the '30's June and July maxima appear, to be replaced in the '40's and '50's by a long period of October maxima again.

The first two decades of this century were characterised by a distinct water surplus early in the wet season, but in the third and fourth decades this feature was absent; people at this time, recollecting the heavy May and June rains of their youth, were correct in their assertion that these early rains had 'failed' over these decades.

There have been times during the present century, especially during the '30's and '40's, when Nassau has barely had a water surplus at all even during the months of the average "wet season". Water is used for much else besides agriculture and if Nassau's tourist boom of the last fifteen years had begun ten years earlier water shortage problems may well have been critical. As it is, the possibility of a turndown in total water surpluses may on theoretical grounds be expected in the coming decade and might lead to difficulty in the future.

The behaviour of the "little dry season" between the two mean wet season maxima shows very considerable secular variation. As in Jamaica this is a feature of great importance since it is liable to occur at a time of maximum water need. All five-year means in the '50's indicate that it occurred then merely as a lowering of water surpluses, but at earlier periods very real deficits occurred. Very broadly the running means of the "little dry season" show the following:

1905-1910	Surplus
1911-1925	Deficit
1926-1930	Surplus
1931-1942	Deficit often very severe
1943-1960	Surplus often considerable.

These changes are of sufficient intensity and length to be categorised as climatic rather than meteorological.

The writer has studied the possibility of co-relating these variations in Nassau with other climatic phenomena during the period and it appears that the closest co-relation is with the temperature of the Gulf Stream surface waters; slightly less pronounced but still important is that with the expansion and contraction of the Inter-tropical Convergence Zone which bears in turn a complex relationship to the expansion and contraction of the cold polar 'high' and is reflected in varying patterns in the general circulation.

The two periods of water surplus coincided with observed maxima in the Gulf Stream temperatures and the high deficit periods with minima. (Brown 1963, Rodenwald 1963). Maximum expansion of the ITCZ during the present century is supposed to have occurred during the decade of the '40's (Lamb 1966) and the'50's up to 1955. Warm tropical air masses reached high latitudes more frequently in the early fifties (Mitchell 1963). Somewhere about 1960 most authorities agree a definite observable deterioriation of climate began in temperate latitudes. There is spectacular evidence of glacial advance and greater snow cover on Mt. Rainier in Washington where tourist camps are becoming unusable and ice caves permanently closed over. On theoretical grounds this should be expected to produce long term secular reduction in water surpluses and greater frequency of drought in areas in the western sub-tropics and the Caribbean area, exemplified by such stations as Nassau. It is possible that we may be entering a drying period throughout our region.

One final point. At the risk of being heretical, it is suggested that we abandon the idea that a mean or norm must always be a straight horizontal line. Over several decades or even centuries a norm may be a rising line, a slope of calculable gradient representing a long-term secular change. After all, we live in days of relativity and climatologists may do well to join the fashion.

A NOMOGRAM FOR ESTIMATING SOIL MOISTURE DEFICITS

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Introduction

Measurement of the amount of water in soil has been undertaken in many different ways. Thus, Marshall (1959) lists fifteen different principles on which methods have been based, most having disadvantages. Absorbent blocks, whose electrical impedence is measured, give spurious readings in saline soils, and suffer from hysteresis. Neutron probes are expensive and inaccurate when used in the top few inches of soil. Probably the most accurate, and that against which all others are ultimately calibrated, is the gravimetric method, in which the moisture content of soil samples is determined by drying in an oven.

Another method which has many advantages is that in which soil moisture is estimated from climatological data. This assumes that both water entering and leaving the soil can be measured. Once certain physical parameters of the soil and plant are known, the difference gives the required value. No instruments are needed apart from those normally found in a meteorological station. The method is thus inexpensive. If climatological records have been preserved, it is possible to estimate soil moisture status retrospectively. Although no other method has this advantage, it has not been widely used, and its accuracy is not well known.

The purpose of this paper is to present a nomogram which eliminates calculation, and to show that, in an example with a permanent grass cover of *Axonopus compressus*, good agreement was obtained between estimated and measured values of soil moisture deficit. In this context, "soil moisture deficit" is defined as the amount of water, with dimensions of length, needed to bring a defined layer of soil from its present moisture content up to field capacity. The minimum moisture deficit is thus zero at field capacity, increasing to a maximum determined by soil and plant parameters.

Potential evapotranspiration rate

The amount of water used in unit time by green, actively-growing vegetation, completely covering the soil surface, with a non-limiting moisture supply is the potential evapotranspiration rate. It is possible to measure this quantity in the field, and it is probable that it is dependent only on the climate (Sanderson, 1948; Schofield and Penman, 1948; Mather, 1954). Assuming this is correct, many formulas have been proposed to estimate the potential evapotranspiration rate from climatological parameters. Probably the best known are those of Penman (1948) and Thornthwaite (1948), though there are at least ten other methods which have been devised for particular conditions.

Such formulas almost invariably neglect one or more of the parameters known to influence the potential evapotranspiration rate. Perhaps the method proposed by Penman is based on the soundest physical foundation, since it includes the parameters of wind speed, relative humidity, temperature and incident solar radiation. Even so, it basically measures potential evaporation from an extended open-water surface, relying on empirically-derived conversion factors to convert these values to potential evapotranspiration figures. There are other considerations ignored in the Penman formula which result in lack of agreement between estimated and measured rates in some circumstances. To obtain a formula which would always be completely accurate is probably impossible. Even if such a formula could be devised, it would be so complex that a computer would be needed to solve it. When potential evapotranspiration rates are required to estimate irrigation needs, such accuracy is not necessary. Methods of applying water in the field and of measuring rainfall are crude, so there is little point in estimating the amount of water very accurately. It is therefore permissible to use one of the simpler methods which have been proposed for estimating potential evapotranspiration.

In many parts of the world, although it is difficult to obtain figures of such climatological parameters as wind speed, relative humidity or solar radiation, it is usually possible to find mean air temperatures and rainfall. A formula for potential evapotranspiration must therefore be chosen which requires only mean air temperature. One of the simplest is that of Holdridge (1962).

$$P.E. = 0.16T \qquad (1)$$

where P.E. = daily potential evapotranspiration in millimeters
T = mean air temperature in degrees Centigrade.

TABLES

Table 1 - Potential evapotranspiration, St. Augustine, Trinidad

	Mean Measured P.E. (mm)	Mean Calculated P.E. (mm)	Mean Rainfall (mm)
Jan.	105	123	58
Feb.	101	121	30
Mar.	138	128	22
Apr.	162	132	47
May.	162	133	108
Jun.	159	130	224
Jul.	130	130	220
Aug.	145	132	214
Sep.	138	133	164
Oct.	133	133	148
Nov.	133	130	177
Dec.	112	127	122
Year	1618	1552	1534

Table 1 compares the monthly mean values of potential evapotranspiration at St. Augustine, Trinidad, West Indies, as measured by four Thornthwaite-type units during a period of eleven years with values estimated by equation 1. Mean rainfall figures are also given. Agreement between the two methods is fairly good.

Estimating soil moisture status is most important in the dry part of the year when irrigation may be needed. In Trinidad, this is during the months of January to May, inclusive. For these months, Table 1 shows that "Holdridge" values may be corrected to "measured" values by multiplying by a factor, S, varying from 0.83 in February to 1.23 in April. It seems reasonable to assume that similar factors could be obtained for other parts of the world.

The variation of actual evapotranspiration with soil moisture deficit

Conflicting views have been held for many years about how actual evapotranspiration depends on soil moisture. If F = actual evapotranspiration/potential evapotranspiration, and if F is plotted against soil moisture deficit, then two points are known. The first is at a moisture deficit of zero, where F will be unity, since at field capacity water is not limiting to growth. The second known point is at a deficit equivalent to wilting point, when all the available water has been removed. F will then be either zero or very small. However, the form of the curve between these two points is a matter of dispute.

Lowry (1959) concluded that three of four types of curve considered were mutually supporting, representing special cases of the same process; the fourth was considered contradictory. Linacre (1963), in an excellent review of the whole subject, considers that a crop will lose water at the potential rate only as long as this rate is less than the "maximum evapotranspiration rate". He defines the "maximum evapotranspiration rate", or "potential intake rate", rather loosely as the rate at which a plant can extract water from a soil of certain dryness in a climate of high evaporative demand, i.e. a high potential evapotranspiration rate. He considers that the potential intake rate depends on soil and plant characteristics. Linacre does not suggest a value for a "high evaporative demand". In Trinidad, the maximum dry season potential evapotranspiration rate is about 5.5 mm per day. This might be considered a high demand rate, and may explain why Smith (1959) found that F could be assumed to vary linearly with soil moisture deficit. Compared with the high evaporative demand, the potential intake rate was probably low.

Denmead and Shaw (1962) have given curves in which F is plotted against soil moisture for various rates of potential evapotranspiration. At high rates, their curves show an almost linear relation, except for a small portion near field capacity. Unfortunately, the plotted curves of Denmead and Shaw do not indicate the variability of the results about the means, so that it is not possible to state with certainty that the shapes are exactly as given. Nevertheless, there is other evidence (Halstead, 1954 and Lowry, *loc. cit.*) that, in certain circumstances, there is an approximately linear relation between F and the soil moisture deficit.

The estimation of soil moisture deficit

If it be assumed that potential evapotranspiration can be estimated from records of mean air temperature, and that the F ratio varies linearly with soil moisture deficit, the process of estimating the deficit may be represented by Figure 1 [*displayed*].

Consider soil growing plants whose roots penetrate to an effective depth of L mm. Let the available moisture down to this depth be C mm. If A is the apparent specific gravity of the soil, Y the field capacity and Z the wilting point (both in percent dry weight) we have:-

$$C = AL(Y-Z)x10^{-2}. \quad (2)$$

Consider a period during which the potential evapotranspiration is P mm, and during which R mm of rain falls. If the initial moisture deficit at the start of the period is D_0 mm, the deficit at the end of period, D_1 mm, will be (D_0-R)mm plus an amount due to the evapotranspiration. This latter will be P multiplied by a factor F, but an immediate difficulty arises. At what point on the graph must F be taken?

If it be assumed that all the rain falls at the start of the period, then the value of F is that corresponding to a deficit of (D_0-R). If this value is F_1,

$$D_1 = D_0 - R + F_1 P. \quad (3)$$

With a linear F- moisture deficit curve, it is easy to show that

$$F = 1 - D/C. \quad (4)$$

And therefore

$$D_1 = D_0 - R + P\ (C+R-D_0)/C. \quad (5)$$

If

$$X_1 = D_1 - D_0,$$

then

$$X_1 = P(C+R-D_0)/C-R. \quad (6)$$

On the other hand, if all the rain falls at the end of the period, by similar reasoning it may be shown that

$$X_2 = P(1-D_0/C)-R. \quad (7)$$

Equations 6 and 7 are not strictly accurate, since F has been assumed to be constant. In fact, the soil is continuously drying out (in the absence of rain), so that a better value would be the mean of the "start" and "finish" values of F.

The number of ways in which the rain might fall during the chosen period is infinite, and each case considered would give a different result. However, there is a third simple possibility which may be considered. That is the case in which the rain falls continuously throughout, and the value of F also varies continuously. Without giving a mathematical proof, it may be shown that the final deficit obtained in this way is the same as the case in which all the rain falls at the end of the period.

From equations 6 and 7, it may be shown that

$$X_1 - X_2 = PR/C \quad (8)$$

Considering an example in which C = 200 mm and P = 4 mm per day, $X_1-X_2 = 0.02R$. Taking a high value of rainfall for one day of 100 mm, $X_1-X_2 = 2$ mm. Thus, for a period of one day, the difference between the estimates by the two methods is small.

For a period of one week, with the same value of C, a total rainfall of 200 mm, and P = 28 mm, X_1-X_2 = 28 mm. For a monthly interval between estimations, with C = 200 mm, P = 120 mm and R = 200 mm, X_1-X_2 = 120 mm. Thus, it is obvious that the shorter the period between estimations, the less the difference between final deficits computed in alternative ways.

If the distribution of rainfall within a period is unknown, a formula of which equations 6 and 7 are examples must be chosen. In the above illustrations, for daily determinations both formulas give almost the same result, and they are not seriously different for weekly determinations. Monthly periods are, however, too long, unless either the rainfall is very small or C is very large. From this point of view, daily determinations are superior.

On the other hand, estimates of potential evapotranspiration are more likely to be accurate if they are made for periods of several days or weeks. Most formulas relate to periods of one month, the reason being partly because there are phase shifts between air temperature, humidity, evaporation and solar radiation. In the tropics these shifts are likely to be smaller than in higher latitudes.

Bearing these considerations in mind, it was decided that estimates should be made on a weekly basis, and that of the formulas derived, as equation 7, is simpler, it should be used.

The nomogram

It was considered that a nomogram combining equations 1, 2 and 7 would be useful. Since temperature records in Trinidad are available in degrees Fahrenheit, an appropriate correction was made, giving the following expression for X, the difference between initial and final deficits in millimeters:

$$X = S(1-D_0/C)\ (0.623T-20)-R. \qquad (9)$$

Where S = a factor to correct "Holdridge" estimates of potential evapotranspiration to "measured" values

D_0 = initial soil moisture deficit, mm

C = available water held in the rooting zone, mm, and defined by equation 2

T = mean weekly air temperature, ^oF

R = weekly total rainfall, mm.

The nomogram given in Figure 2 [*displayed*] covers the contingencies that:

(a) the mean weekly temperature varies between 60^{o}F and 90^{o}F

(b) the available water in the root zone varies between 50 and 200 mm

(c) the total weekly rainfall varies between 0 and 200 mm and

(d) "S" varies between 0 and 1.5.

The method of use is as follows. Starting with a known initial deficit (which may conveniently be after a period of heavy rain, when the deficit is assumed to be zero) a straight-edge is laid between this value and the value determined for C, the available moisture in the rooting zone. At the interception on the pivot line α, the straight-edge is connected to the mean weekly temperature on the "T" scale, to intercept the

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extend downwards, an allowance can be made by letting "C" progressively increase. The "S" scale can be used to correct for incomplete plant cover.

One factor which has not yet been mentioned is run-off from the soil surface. In the dry season in Trinidad, on the level soil of this experiment, it is believed that little rain is lost in this way. This is not true of the rain falling in December or May. No figure is available of the infiltration capacity of the soil with vegetation, but when bare it is of the order of 30 mm per hour. Rainfall intensity measurements in December, 1958, showed that almost half the total amount fell at rates greater than 20 mm per hour. Twenty millimeters represents the mean intensity for periods up to an hour. Peak intensities were certainly greater than this, and some run-off is therefore to be expected. Observation confirms this. If allowance were to be made for this by reducing the value of "R", the estimated moisture deficit curves would tend to be raised, especially at the beginning and end of the dry season. The agreement with the "measured" curve would then be improved.

If it could be demonstrated that equally good results could be obtained with different conditions of soil, climate and vegetation, the nomogram would be valuable in predicting irrigation needs. It requires little more than the ability to read a rain-gauge, a thermometer and a scale.

An unsuccessful attempt was made to obtain comparable data from other parts of the world to test the nomogram under different conditions, because the relevant information was not available. So that the data used here may be available to others, the "measured" moisture deficits are given in Table 2, together with weekly rainfall totals and mean weekly temperature.

Table 2 - Measured soil moisture deficits, weekly rainfall totals and mean weekly temperatures, St. Augustine, Trinidad.

Vegetation - Savanna grass (*Axonopus compressus*)

Soil type - St. Augustine sandy loam

Field Capacity - 29%

Wilting point - 9%

Mean apparent specific gravity in root zone - 1.44

Mean root depth - 460 mm

Soil moisture deficits given are means of 16 samples

Moisture deficit limits are twice the standard errors of the means

Year	Week ending	Moisture deficit mm	Rainfall mm	Mean Temperature °F
1957	Dec. 3	26 ± 13	32	79
	Dec. 10	25 ± 11	22	77
	Dec. 17	1 ± 9	96	78

Year	Week ending	Moisture deficit mm	Rainfall mm	Mean Temperature ^oF
	Dec. 23	11 ± 11	34	78
	Dec. 31	0 ± 11	24	79
1958	Jan. 7	11 ± 10	39	79
	Jan. 15	27 ± 8	5	78
	Jan. 21	32 ± 7	16	77
	Jan. 28	56 ± 8	0	77
	Feb. 4	73 ± 5	0	77
	Feb. 12	78 ± 5	1	78
1958	Feb. 19	59 ± 8	18	78
	Feb. 25	84 ± 6	1	78
	Mar. 4	83 ± 6	13	79
	Mar. 11	107 ± 4	0	81
	Mar. 18	124 ± 4	0	81
	Mar. 25	121 ± 1	0	80
	Apr. 1	130 ± 1	0	83
	Apr. 9	128 ± 6	6	83
	Apr. 15	117 ± 6	21	81
	Apr. 23	134 ± 5	0	83
	Apr. 29	122 ± 4	8	82
	May 6	28 ± 11	205	80
	May 13	26 ± 14	34	81
	May 20	11 ± 11	82	81
	May 27	18 ± 10	37	81
1958	Dec. 2	10 ± 7	98	78
	Dec. 9	12 ± 9	17	77
	Dec. 16	17 ± 0	24	78
	Dec. 22	23 ± 9	19	78
	Dec. 30	31 ± 10	11	78
1959	Jan. 2	53 ± 8	6	77
	Jan. 13	67 ± 8	4	78
	Jan. 20	61 ± 8	19	78
	Jan. 27	79 ± 10	5	77

Year	Week ending	Moisture deficit mm	Rainfall mm	Mean Temperature °F
	Feb. 4	82 ± 4	5	78
	Feb. 11	84 ± 5	4	78
	Feb. 17	89 ± 10	1	76
	Feb. 24	109 ± 3	3	77
	Mar. 3	115 ± 5	3	78
	Mar. 10	119 ± 3	13	78
1959	Mar. 17	134 ± 8	1	80
	Mar. 24	127 ± 2	0	79
	Mar. 31	134 ± 3	0	79
	Apr. 7	132 ± 6	0	81
	Apr. 14	149 ± 5	6	80
	Apr. 22	138 ± 4	0	82
	Apr. 28	132 ± 4	0	82
	May 5	148 ± 3	4	82
	May 12	150 ± 3	0	82
	May 19	146 ± 3	0	82
	May 27	75 ± 9	37	81
1959	Dec. 2	9 ± 7	50	78
	Dec. 8	7 ± 8	21	77
	Dec. 14	28 ± 11	26	78
	Dec. 21	30 ± 7	11	78
	Dec. 29	36 ± 7	13	79
1960	Jan. 6	63 ± 14	6	77
	Jan. 13	59 ± 3	15	77
	Jan. 19	59 ± 9	8	78
	Jan. 26	81 ± 6	2	76
	Feb. 2	99 ± 4	1	77
	Feb. 9	98 ± 1	1	77
	Feb. 16	105 ± 3	4	77
	Feb. 22	105 ± 7	0	78
	Mar. 2	109 ± 5	7	78
	Mar. 8	125 ± 5	1	78

Year	Week ending	Moisture deficit mm	Rainfall mm	Mean Temperature ^oF
	Mar. 16	134 ± 2	4	79
	Mar. 22	140 ± 5	3	78
	Mar. 28	134 ± 6	5	79
	Mar. 4	137 ± 3	8	90
1960	Apr. 12	104 ± 7	42	79
	Apr. 20	130 ± 3	2	80
	Apr. 26	73 ± 9	48	80
	May 3	103 ± 4	6	81
	May 10	121 ± 5	7	81
	May 19	94 ± 6	16	81
	May 26	131 ± 6	2	81
	May 31	113 ± 10	13	81
1960	Dec. 6	19 ± 7	25	80
	Dec. 13	15 ± 10	89	78
	Dec. 20	26 ± 7	5	77
	Dec. 29	38 ± 7	12	77
1961	Jan. 3	34 ± 12	6	77
	Jan. 10	58 ± 5	2	77
	Jan. 17	66 ± 7	5	77
	Jan. 25	29 ± 9	51	77
	Feb. 1	59 ± 11	8	76
	Feb. 7	63 ± 12	2	76
	Feb. 15	87 ± 7	1	76
	Feb. 21	96 ± 6	0	78
	Feb. 28	80 ± 6	9	77
	Mar. 6	107 ± 3	2	78
	Mar. 13	108 ± 7	1	77
	Mar. 20	117 ± 6	0	78
	Mar. 27	92 ± 9	18	79
	Apr. 5	122 ± 3	4	80
	Apr. 10	127 ± 4	1	79
	Apr. 17	134 ± 4	2	81

Year	Week ending	Moisture deficit mm	Rainfall mm	Mean Temperature °F
	Apr. 24	136 ± 3	0	81
	May 3	144 ± 3	2	80
1961	May 8	142 ± 4	0	83
	May 15	155 ± 4	1	81
	May 25	128 ± 7	13	82
	May 29	142 ± 2	0	83
1961	Dec. 4	23 ± 6	60	79
	Dec. 11	30 ± 9	9	79
	Dec. 18	28 ± 11	21	77
	Dec. 28	61 ± 7	3	77
1962	Jan. 3	65 ± 12	5	77
	Jan. 8	78 ± 6	5	77
	Jan. 15	55 ± 7	18	77
	Jan. 22	69 ± 4	5	77
	Jan. 29	83 ± 5	2	76
	Feb. 5	75 ± 8	18	75
	Feb. 12	90 ± 6	2	77
	Feb. 19	84 ± 4	13	77
	Feb. 26	82 ± 6	10	77
	Mar. 7	95 ± 5	9	78
	Mar. 12	105 ± 7	0	79
	Mar. 19	123 ± 2	0	78
	Mar. 26	125 ± 7	0	79
	Apr. 2	122 ± 9	5	80
	Apr. 9	132 ± 3	7	80
	Apr. 16	136 ± 2	0	80
	Apr. 24	148 ± 3	0	82
	Apr. 30	142 ± 5	5	81
	May 7	92 ± 9	50	82
	May 14	124 ± 5	4	81
	May 21	130 ± 3	4	82
	May 28	127 ± 4	14	82

Year	Week ending	Moisture deficit mm	Rainfall mm	Mean Temperature °F
1962	Dec. 3	23 ± 8	52	78
	Dec. 10	40 ± 9	15	79
	Dec. 17	22 ± 10	28	77
	Dec. 31	31 ± 7	42	78
1963	Jan. 7	20 ± 11	31	79
	Jan. 14	38 ± 9	6	78
	Jan. 21	34 ± 12	22	76
	Jan. 28	50 ± 11	3	78
	Feb. 4	57 ± 9	3	77
	Feb. 11	81 ± 8	0	79
	Feb. 18	82 ± 6	7	78
	Feb. 28	90 ± 7	11	78
	Mar. 4	90 ± 6	3	80
	Mar. 11	101 ± 6	2	79
	Mar. 18	101 ± 6	13	78
	Mar. 25	113 ± 6	1	79
	Apr. 1	121 ± 4	0	79
	Apr. 8	125 ± 4	5	79
	Apr. 17	124 ± 3	6	80
	Apr. 22	119 ± 5	3	80
	Apr. 29	95 ± 6	54	80
	May 6	94 ± 5	12	80
	May 13	46 ± 9	52	79
	May 20	26 ± 8	117	80
	May 27	37 ± 6	26	80

* Because of holidays, etc. periods are not always exactly seven days.

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THE CLIMATOLOGY OF METEOROLOGICAL DROUGHT IN PUERTO RICO

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Drought climatology has always been a challenge to the environmental scientist. Whether he approaches the problem as a meteorologist, as a hydrologist, or from the viewpoint of the climatologist or the geographer; his task, to say the least is beset with numerous pitfalls. As all of us, who at one time or another have dealt with the drought concept, know; it is rather an "evasive beast". It is elusive to define. It is often elusive to detect until its damaging effects appear and it is certainly most elusive to analyze in quantitative measure of intensity and frequency. It is the purpose of this presentation first to briefly summarize a method recently developed by Mr. Wayne C. Palmer at the Laboratory of Climatology, Environmental Data Service, Washington, D.C., for the evaluation of drought as a meteorological anomaly, and second to illustrate some of the results of this approach in developing a drought climatology for Puerto Rico.

The basis for the first part of this discussion is Weather Bureau Research Paper No. 45, "Meteorological Drought", by Wayne Palmer, and I am further indebted to Mr. Palmer for arranging for the machine computation of the drought evaluations for Puerto Rico to be presented later.

It is interesting to note that this technique, originally developed on the basis of mid-continental data, has a definite application in drought evaluation for our own Caribbean area. I believe that we would all agree that droughts have had a most significant impact on the economies of our islands, an impact perhaps second only to the more spectacular tolls that are taken by our tropical storms. Still fresh in our memories is the general rainfall deficiency throughout the Caribbean during 1964 and 1965. The ramifications of this drought are still reflected at many locations in terms of water supply problems and degraded agricultural performance.

At this point it would be well to further qualify our meaning of the term "drought" and more specifically - "meteorological drought". As Palmer points out, "drought means different things to different people depending on their specific interest". In this discussion we refer to Palmer's concept of *meteorological* drought as differentiated, for example, from agricultural drought, hydrological drought, or other drought aspects. This concept treats drought as a meteorological anomaly characterized by prolonged and abnormal moisture deficiency. Drought severity is considered a function of moisture demand as well as moisture supply. A climatic analysis system can then be applied which is dependent on the duration and magnitude of this deficiency and may be further developed into a quantitative index which permits both time and space comparisons of drought severity.

There are decided advantages in approaching the problem from the standpoint of a meteorological phenomenon. The complications of biological response inherent in the aspects of agricultural drought, or the stream flow-water table-runoff factors of hydrological drought, are purposely avoided. Palmer treats drought severity as a function of accumulated weighted differences between actual precipitation and the precipitation requirement or demand appropriate for the area under study. This requirement depends on the carryover of previous rainfall as well as on evapotranspiration, moisture recharge and runoff rates that would be climatically appropriate for the particular time and place being studied. The *average* requirement is for normal rainfall, but individual periods may require much above or much below normal rainfall, depending on the character of the preceding weather and the temperature of the period in question. It is precisely the built-in climatic adjustment factor of the method which appears to allow its broad application to climatic regimes outside those of the continental United States. In his Research Paper No. 45, Palmer makes some reservations for the method when applied in humid areas with small water storage capability. Under this restriction the full extent of the abnormal wetness or dryness of the climatc cannot be fully taken into account and there is no chance for cumulative weather to build up to an extreme wet or extreme dry or drought condition. We were concerned about this problem when applying the method to the south coast of Puerto Rico. However, by using a water holding capacity value of 6 inches in the soil, slightly larger than actual, we found what appear to be reasonable results in that area, with very logical index variations throughout the 35-year period studied. Therefore, based on our experience with the method it would seem that, with care in using a reasonable water storage capability for the soil in the area under study, there appear to be no limitations to the method in the Caribbean.

It is not the intent of this presentation to describe in detail the procedures for computing Palmer's drought index data. This information is available in Research Paper No. 45. However, in order that the data to be presented for Puerto Rico are better understood, I would like at this point to briefly outline the basic steps involved.

1. Carry out a hydrologic accounting by months for a long series of years. This is performed using a 2 - layer system of soil moisture distribution. The upper layer or "surface" soil is roughly of the plow layer depth and is assumed to hold one inch of water at field capacity. This amount is assumed to be depleted at the potential rate as determined by Thornthwaite and Mather. Any deficiency in this layer must be satisfied before rainfall begins to recharge the "underlying" soil. (The soil is assumed to be at full field capacity at the beginning of the analysis). The lower soil depth, holding the remainder of the total available water capacity, loses its moisture only when there is no water remaining in the surface layer. In this case, the rate of evapotranspiration is assumed to be proportional to the available moisture in the underlying soil. It is further assumed that runoff occurs only after both layers reach field capacity. The water balance accounting also includes a monthly determination of the following factors:

a. Potential recharge, PR - the amount of moisture required to bring the soil to field capacity.

b. Potential loss, PL - the amount of moisture removed from the soil if rainfall is zero.

c. Potential runoff, PRO - the amount of runoff, RO, that would occur if potential evapotranspiration were zero, and rainfall equalled available capacity, W, of the soil. Thus PRO=W-PR.

2. The following mean values for each of the 12 calendar months of a long series of years are obtained:

a. Potential Evapotranspiration, PE

b. Evapotranspiration, ET

c. Potential recharge, PR

d. Recharge to the soil, R

e. Potential loss, PL

f. Loss from the soil, L

g. Potential runoff, PRO

h. Computed runoff, RO

i. Precipitation, P

j. Constant, K. These monthly K-values are graphically determined as an empirical function of moisture demand, moisture supply and the absolute magnitude of the differences between actual precipitation and the computed precipitation requirement. The purpose of the use of this factor is to establish comparability between different climatic areas.

3. The long term data are then reworked to compute the "moisture anomaly index", Z, for each month where:

$$(1) \qquad Z_i = K_j \left[P_i - \left(\frac{\overline{ET}_j}{\overline{PE}_j} PE_i + \frac{\overline{R}_j}{\overline{PR}_j} PR_i + \frac{\overline{RO}_j}{\overline{PRO}_j} PRO_i - \frac{\overline{L}_j}{\overline{PL}_j} PL_i \right) \right]$$

i a particular month in a series of months

j one of the 12 calendar months

Note: The parenthetical expression represents the climatologically appropriate precipitation for time and place being studied.

4. The derived values of Z are then used to compute drought severity, X, by the equation:

$$X_i = X_{i-1} + \frac{Z_i}{3.0} - .103X_{i-1}$$

The values of X range from about 6.0 (extremely wet) to -6.0 (extreme drought) as shown in the following table of classes for wet and dry periods:

TABLE 1. CLASSES FOR WET AND DRY PERIODS

Monthly value	Class
3. 4.00	extremely wet
3.00 to 3.99	very wet
2.00 to 2.99	moderately wet
1.00 to 1.99	slightly wet
.50 to .99	incipient wet spell
.49 to - .49	near normal
- .50 to - .99	incipient drought
- 1.00 to -1.99	mild drought
- 2.00 to -2.99	moderate drought
- 3.00 to -3.99	severe drought
-4.00	extreme drought

5. The end of each drought period is determined by computing moisture received *as a percentage of the amount required to end the drought by equation $P_e = 100\ V/Q$. Only when $P_e = 100\%$ is the drought period terminated.

$V = \Sigma U$ from the time U became positive until the current month, and $U_i = Z_i + 0.15$

U= the amount of wetness effective in ending a drought

$Q_i = V_{i-1} - 2.691X_{i-1} - 1.50$

The question of course arises, just what significance do the drought severity classes have in terms of drought effects on the economy? Palmer points out that "One can, as a rule of thumb, regard incipient drought as corresponding to a sort of dry spell in which the need for rain becomes definitely apparent. Extreme drought on the other hand, is a very serious situation which results from many months, or even years of abnormally dry weather. Very rarely, if ever, would one find drought reaching extreme severity in less than four months. During extreme drought crop yields are ordinarily so low that the crop is considered to be unprofitable; industries and municipalities may face the need for rationing water and the local and regional economy begins to become disrupted. So extreme drought is not merely an inconvenience, it is essentially a disaster". This drought classification was finally reached in most sections of Puerto Rico by late 1964 and early 1965 and the effects were remarkably parallel to those described a moment ago. Minor crops were of bad quality and in short supply, irrigation in the south coast was reduced to 25 percent of normal, south coast cattle areas were hard hit with water supply trucked in from the north and grain and molasses shipped in from the States; many cattle still died in the fields. Generation of electricity by hydroelectric plants dropped to 5 percent of the total with thermoelectric plants providing 95 percent of the power. By March 1965 the San Juan metropolitan area went on daily water rationing while other areas had been on a tight ration basis months previous to this. Ground water levels along the south coast dropped 4 to 10 feet in unpumped areas and more in pumped areas. Recognition that the disaster stage was being reached in many sections of the island came when the President declared these zones official disaster areas for the purpose of providing federal funds for relief measures. It was obvious that the drought intensity in Puerto Rico had made the full progression from the inconvenience stage to disaster proportions.

A brief description of the rainfall regime in Puerto Rico may be in order at this point before looking further at drought statistics. The shape of the island is roughly rectangular, 110 miles long and about 40 wide. It lies directly in the path of the easterly trade winds. There is a main divide running roughly east-west across the island. From this divide there is a gradual descent from about 3000 feet to a north coastal plain and a more abrupt descent to a narrower coastal plain to the south. El Yunque reaches 3,448 feet in the east and Cerro de Punta goes to 4,389 feet in the south-central section. Naturally, topography plays an important role in the formation and distribution of rainfall in Puerto Rico, as it does in all Caribbean islands. The annual rainfall variations are typical of those throughout the Great Antilles chain - a reflection of the large scale interplay between the northward surge of tropical easterly trade current and the northerly retreat of the polar front in summer (with its accompanying increase in convection and air mass instability), versus the southward surge of the westerlies in winter, with their typical "nortes" as the old timers call them. Puerto Rico receives most of its rain, almost two thirds the annual amount, during the period May to November. The rainiest months are May and September. The wintertime "dry" period lasts usually from December to April. Mean annual rainfall totals vary from about 180 inches in El Yunque to 37 inches in the south coastal section (Figure 1). Based primarily on the rainfall distribution, Puerto Rico is divided into six climatic divisions. Table 2 presents the normal annual rainfall amounts for these areas in inches and compares 1964 in terms of inches of departure from the normal and percent negative departure from normal.

TABLE 2

	1964	Normal	Departure	Percent Dep.
North Coastal Division	49.0	64.0	-15.0	-23
South Coastal Division	22.2	37.8	-15.6	-41
Northers Slopes Division	47.6	66.6	-19.0	-29
Southern Slopes Division	47.2	67.8	-20.6	-30
Eastern Interior Division	58.3	85.9	-27.6	-32
Western Interior Division	64.9	86.4	-21.5	-25
Puerto Rico Average	48.2	68.1	-19.9	-30

The islandwide distribution of percent negative departure from the annual normal rainfall amount is seen in Figure 2 for the period January 1964 thru March 1965. It is evident that the south coastal area had the most serious deficiency. This was centralized at about the midpoint of the south coast strip in the Coamo area, where a deficit of 65 percent from normal was built up by the end of 1964. By March 1965, the peak period of this drought, these departures had increased another 3 to 5 percent.

TABLE 3: Puerto Rico Drought Summary

PLACE: North Coast PERIOD: January 1931 - June 1966

	START		END		SEVERITY			NUMBER OF MONTHS					
	MO	YR	MO	YR	MAX	MO	YR	INC	MILD	MOD	SEV	EXT	SUM
1	8	33	11	34	-2.90	8	34	2	7	7	0	0	16
2	6	35	9	35	-1.36	7	35	1	3	0	0	0	4
3	1	36	4	36	-3.13	4	36	0	1	2	1	0	4
4	3	37	1	38	-3.04	6	37	0	4	6	1	0	11
5	6	39	9	39	-2.07	9	39	0	2	2	0	0	4
6	8	40	3	41	-3.65	2	41	0	1	4	3	0	8
7	2	42	3	42	-1.50	3	42	0	2	0	0	0	2
8	11	43	5	44	-3.57	5	44	0	1	3	3	0	7
9	12	45	10	48	-4.68	8	47	0	8	19	4	4	35
10	5	49	6	49	-1.50	6	49	0	2	0	0	0	2
11	3	51	5	51	-1.26	3	51	1	2	0	0	0	3
12	1	53	11	53	-3.02	11	53	0	4	6	1	0	11
13	12	54	4	55	-2.00	2	55	0	4	1	0	0	5
14	3	57	3	58	-3.82	10	57	0	1	2	10	0	13
15	3	59	3	59	-1.37	3	59	0	1	0	0	0	1
16	7	59	7	60	-2.90	1	60	0	5	8	0	0	13
17	11	60	11	60	-1.00	11	60	0	1	0	0	0	1
18	5	61	9	61	-1.80	9	61	1	4	0	0	0	5
19	7	62	11	62	-3.30	11	62	0	2	2	1	0	5
20	7	63	12	65	-6.16	3	65	1	4	2	5	11	22
					NUMBER OF MONTHS			6	59	64	29	15	172
					PERCENT			1	14	15	7	4	40

If we now turn to the application of Palmer's drought index method to tracing the course of this most intense drought in the island's history we find the story clearly depicted in quantitative terms - when did the drought start? How intense did it become? How long did it last? And finally we may turn to a long period of years to determine the climatology of droughts in Puerto Rico in terms of frequency, duration and intensity.

Figure 3 presents in graphical form the build up of the drought starting in 1963 in two different rainfall regimes of the island, the south coast where the highest rainfall deficiency existed and the north coast where, although the deficiency was slightly less marked, it held a higher significance in terms of drought intensity. This is to be ex-

TABLE 4: Puerto Rico Drought Summary

PLACE: South Coast PERIOD: January 1931 - June 1966

	START		END		SEVERITY				NUMBER OF MONTHS				
	MO	YR	MO	YR	MAX	MO	YR	INC	MILD	MOD	SEV	EXT	SUM
1	7	34	1	35	-2.50	11	34	1	2	4	0	0	7
2	11	35	4	36	-2.83	4	36	0	2	4	0	0	6
3	11	36	11	36	-1.09	11	36	0	1	0	0	0	1
4	6	37	7	37	-1.58	7	37	0	2	0	0	0	2
5	1	38	10	38	-2.70	10	38	0	5	5	0	0	10
6	5	39	9	40	-2.95	9	39	0	5	12	0	0	17
7	5	41	9	42	-3.28	12	41	0	3	9	5	0	17
8	2	45	4	45	-1.41	2	45	0	3	0	0	0	3
9	10	45	6	48	-5.25	5	48	0	5	5	10	13	33
10	7	50	9	50	-2.09	9	50	0	2	1	0	0	3
11	11	51	3	52	-2.12	3	52	0	4	1	0	0	5
12	2	53	7	53	-2.06	6	53	0	5	1	0	0	6
13	5	54	8	54	-1.48	8	54	0	4	0	0	0	4
14	5	55	3	56	-2.18	11	55	0	8	3	0	0	11
15	6	57	3	58	-2.86	3	58	0	3	7	0	0	10
16	12	58	12	59	-2.89	12	59	0	9	4	0	0	13
17	6	61	7	61	-1.18	6	61	0	2	0	0	0	2
18	6	63	7	63	-1.68	7	63	0	2	0	0	0	2
19	3	64	-	--	-4.80	10	65	0	2	4	14	7	27
					NUMBER OF MONTHS			1	69	60	29	20	179
					PERCENT			-	16	14	7	5	42

pected when we recall that the index has built into it relative climatic adjustment factors or coefficients previously discussed. Palmer points out that on a relative basis an area which does not have as high a water storage capability as an adjoining area is probably not as affected by prolonged dry weather as the area with the higher storage capability. On a relative basis this is true because the favored area is accustomed to and expects an adequate supply of water at all times. If the supply cannot meet the demand, a serious disruption in the economy takes place Whereas, in the drier area, operations are geared to the fact that water shortages are to be expected. Therefore, while the drought may become apparent sooner in the area of little moisture carry over capability, it will never reach the peak severity that will eventually occur in the more favored area. By the middle of 1963 when both zones surpassed the

Table 5: Puerto Rico Drought Summary

PLACE Northern Slopes PERIOD: January 1931 - June 1966

	START		END		SEVERITY			NUMBER OF MONTHS					
	MO	YR	MO	YR	MAX	MO	YR	INC	MILD	MOD	SEV	EXT	SUM
1	1	34	1	34	-1.13	1	34	0	1	0	0	0	1
2	5	34	9	34	-1.62	6	34	0	5	0	0	0	5
3	2	36	4	36	-2.75	4	36	0	2	1	0	0	3
4	3	37	1	38	-4.43	1	38	0	2	3	2	4	11
5	5	38	5	38	-1.19	5	38	0	1	0	0	0	1
6	10	38	10	38	-1.04	10	38	0	1	0	0	0	1
7	6	39	7	39	-1.33	9	39	0	2	0	0	0	2
8	8	40	3	42	-2.97	2	41	3	12	5	0	0	20
9	11	43	5	44	-2.27	4	44	0	4	3	0	0	7
10	10	45	8	48	-4.78	8	47	0	5	14	11	5	35
11	5	49	6	49	-1.38	6	49	0	1	0	0	0	1
12	6	50	7	50	-1.75	7	50	0	1	0	0	0	1
13	3	51	3	51	-1.35	3	51	0	1	0	0	0	1
14	1	53	11	53	-3.85	11	53	0	3	4	4	0	11
15	12	54	5	55	-2.54	4	55	0	2	4	0	0	6
16	11	56	10	57	-3.59	10	57	2	3	1	6	0	12
17	11	58	2	60	-3.05	1,2	60	0	8	6	2	0	16
18	11	60	11	60	-1.08	11	60	0	1	0	0	0	1
19	5	61	10	61	-2.28	9	61	0	4	2	0	0	6
20	9	62	11	62	-2.15	11	62	0	2	1	0	0	3
21	10	63	10	63	-1.05	10	63	0	1	0	0	0	1
22	12	63	12	65	-5.15	3	65	0	2	4	4	7	17
					NUMBER OF MONTHS			5	64	48	29	16	162
							PERCENT	1	15	11	7	4	38

incipient drought stage, the north coast continued to surpass the south coast in intensity till heavy May and December rains in 1965 brought an end to the drought in all areas except the southern slopes and coastal divisions. In these areas the drought continued fluctuating around the severe intensity level and only because there is sufficient water supply for irrigation purposes from replenished storage areas as well as slightly better rainfall distribution have further serious economic disruptions not occurred. Reports we have received from the various areas on the island concerning pasturage and other crop conditions appear to

Table 6: Puerto Rico Drought Summary

PLACE: Southern Slopes PERIOD: January 1931 - June 1966

	START		END		SEVERITY			NUMBER OF MONTHS					
	MO	YR	MO	YR	MAX	MO	YR	INC	MILD	MOD	SEV	EXT	SUM
1	10	34	11	34	-1.84	11	34	0	2	0	0	0	2
2	7	35	4	36	-2.60	4	36	3	6	1	0	0	10
3	5	37	10	37	-2.28	7	37	0	5	1	0	0	6
4	12	37	10	38	-2.27	10	38	0	9	2	0	0	11
5	6	39	9	40	-2.45	10	39	2	8	6	0	0	16
6	11	41	11	41	-1.16	11	41	0	1	0	0	0	1
7	10	42	10	42	-1.31	10	42	0	1	0	0	0	1
8	12	43	4	44	-3.00	4	44	0	3	1	1	0	5
9	11	44	3	45	-2.41	3	45	0	2	3	0	0	5
10	10	45	1	46	-1.38	11	45	0	4	0	0	0	4
11	8	46	9	46	-1.82	9	46	0	2	0	0	0	2
12	6	47	6	48	-4.21	5	48	0	1	3	6	3	13
13	7	50	7	51	-2.40	9	50	3	8	1	0	0	12
14	12	52	8	54	-3.07	5	53	2	4	14	1	0	21
15	1	55	1	56	-3.63	11	55	0	1	4	8	0	13
16	9	56	9	56	-1.41	9	56	0	1	0	0	0	1
17	3	57	3	58	-3.80	11	57	0	3	7	3	0	13
18	2	59	3	59	-1.38	3	59	0	2	0	0	0	2
19	9	59	11	59	-2.17	11	59	0	1	2	0	0	3
20	11	62	-	--	-6.07	3	65	0	9	14	8	13	44
					NUMBER OF MONTHS			10	73	59	27	16	185
					PERCENT			2	17	14	6	4	43

bear out the trend of the drought severity ratings throughout this critical period.

Finally, we should look back over a long term period to determine a climatology of meteorological drought in Puerto Rico based on Palmer's system. Tables 3 through 8 present the data for the six climatic divisions in the island.

Each drought period has been listed separately with the beginning date, the ending date, the maximum severity, and a breakdown of drought months by severity. A drought period is tabulated as having started when the index reaches at least -1.00 and includes all months in the series with a severity index of at least -0.50.

Table 7: Puerto Rico Drought Summary

PLACE: Eastern Interior PERIOD: January 1931 - June 1966

	START		END		SEVERITY			NUMBER OF MONTHS					
	MO	YR	MO	YR	MAX	MO	YR	INC	MILD	MOD	SEV	EXT	SUM
1	5	34	11	34	-2.59	11	34	0	5	2	0	0	7
2	4	36	4	36	-1.61	4	36	0	1	0	0	0	1
3	5	37	1	38	-3.07	7	37	0	1	7	1	0	9
4	5	38	5	38	-1.21	5	38	0	1	0	0	0	1
5	6	39	10	39	-2.15	9	39	0	2	3	0	0	5
6	8	40	9	40	-2.12	9	40	0	1	1	0	0	2
7	3	41	4	41	-1.23	4	41	0	2	0	0	0	2
8	10	41	12	41	-1.62	12	41	0	3	0	0	0	3
9	9	42	10	42	-1.38	9	42	0	2	0	0	0	2
10	12	43	4	44	-2.08	4	44	0	4	1	0	0	5
11	11	45	5	48	-4.26	12	47	3	15	3	8	2	31
12	7	50	9	50	-1.49	9	50	1	2	0	0	0	3
13	2	51	12	51	-1.43	11	51	2	9	0	0	0	11
14	12	52	8	54	-3.13	11	53	0	3	16	2	0	21
15	12	54	1	56	-2.25	12	55	0	7	7	0	0	14
16	2	57	10	57	-3.48	10	57	0	2	6	1	0	9
17	4	58	4	58	-1.01	4	58	0	1	0	0	0	1
18	12	58	3	59	-1.87	3	59	0	4	0	0	0	4
19	8	59	2	60	-2.83	1	60	0	3	4	0	0	7
20	9	62	12	65	-4.14	3	65	1	9	5	12	5	32
					NUMBER OF MONTHS			7	77	55	24	7	170
						PERCENT		2	18	13	6	2	40

The south coast and southern slopes division are still experiencing drought and therefore the ending dates are not indicated. The number of months falling into each drought class are totalled and have been expressed as the percent of the total 426 months period from January 1931 thru June 1966. It appears significant that despite the differences in rainfall regimes in the six climatic divisions, the number of drought periods in each is about the same. Nearly a third of all months fall into the mild or moderate classification. Severe and extreme drought account for only 7 to 12 percent of drought occurrence with the western interior the lowest in these categories and the south coast the highest.

Palmer has noted that the full potential use of the drought index

Table 8: Puerto Rico Drought Summary

PLACE: Western Interior PERIOD: January 1931 - June 1966

	START		END		SEVERITY			NUMBER OF MONTHS					
	MO	YR	MO	YR	MAX	MO	YR	INC	MILD	MOD	SEV	EXT	SUM
1	1	31	1	31	-1.06	1	31	0	1	0	0	0	1
2	8	31	8	31	-1.20	8	31	0	1	0	0	0	1
3	2	32	4	32	-1.31	4	32	0	3	0	0	0	3
4	11	32	2	33	-2.02	2	33	1	2	1	0	0	4
5	9	33	12	33	-1.76	12	33	0	4	0	0	0	4
6	5	34	11	34	-2.58	10	34	0	3	4	0	0	7
7	4	35	4	36	-4.52	4	36	0	5	4	3	1	13
8	3	37	6	37	-1.40	6	37	2	2	0	0	0	4
9	12	40	10	41	-2.24	2	41	0	8	3	0	0	11
10	1	44	5	44	-2.89	5	44	0	3	2	0	0	5
11	6	45	5	49	-3.96	8	47	2	12	28	6	0	48
12	7	50	7	50	-1.15	7	50	0	1	0	0	0	1
13	11	52	9	53	-1.97	2	53	3	8	0	0	0	11
14	2	57	7	57	-4.52	7	57	0	1	2	2	1	6
15	11	58	10	59	-2.60	3	59	3	4	5	0	0	12
16	6	61	7	61	-2.77	7	61	0	1	2	0	0	3
17	3	62	5	62	-1.08	3	62	1	2	0	0	0	3
18	8	62	2	63	-2.73	12	62	0	3	4	0	0	7
19	10	63	12	65	-7.00	3	65	1	2	1	1	14	19
					NUMBER OF MONTHS			13	66	56	12	16	163
							PERCENT	3	16	13	3	4	38

values cannot be determined until they have been put into practical use. The data we have shown here for Puerto Rico are the minimum which can be developed from the method. There are many useful "side products" coming out of the analysis system. For example, Palmer points out that the "moisture departure" value, the difference in the actual precipitation and the computed "climatologically appropriate for the area concerned" precipitation represents the departure of the weather from the average moisture climate for that month and is probably more closely related to crop conditions. The ratio of the long term actual evapotranspiration to the long term potential evapotranspiration, or coefficient of evapotranspiration (ET/PE) is another factor forthcoming from the analysis. Palmer feels this should provide a reasonably good delineation of agricultural capabilities for various "systems" where a system represents a particular combination of precipitation, temperature and soil.

Recently an additional step was made when we began to receive the machine computer results of a weekly analysis for each division. This of course allows us to keep up with the status of current drought situations such as we have now on the south coast. We perhaps get a slightly more realistic measure on the weekly basis but for overall climatological purposes the differences are slight.

Palmer's method has given us a much stronger grasp on the climatology of meteorological drought in Puerto Rico and a means for taking the measure of one of the island's greatest weather scourges outside of the tropical storm. It is very likely that additional applications and interpretations of the results of this approach to drought analysis will be found. We plan to continue delving into these other potentialities for further application in our Caribbean area.

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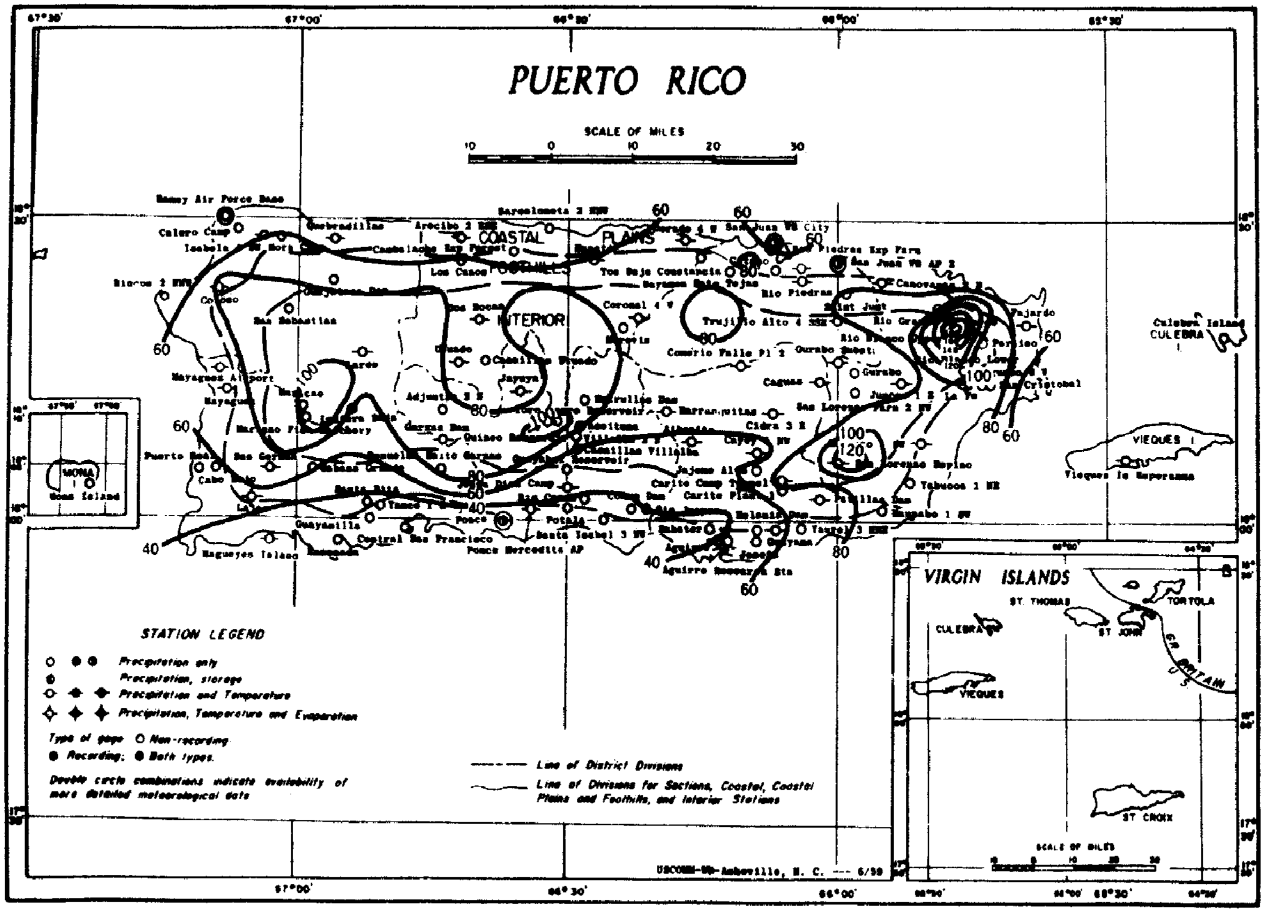
2. D.J. Fieldhouse and W.C. Palmer, **Meteorological and Agricultural Drought, The Climate of the Northeast,** Bulletin 353, University of Delaware, 1965

3. U. S. Weather Bureau, **Climatological Data - Puerto Rico and Virgin Islands,** Volume 11, No. 1, January 1965

4. U. S. Weather Bureau, **Climatological Data - Puerto Rico and Virgin Islands,** Volume 11, No. 3, March 1965

MEAN ANNUAL PRECIPITATION, INCHES



Based on period 1931-55

Isolines are drawn through points of approximately equal value. Caution should be used in interpolating on these maps, particularly in mountainous areas.

FIGURE 1

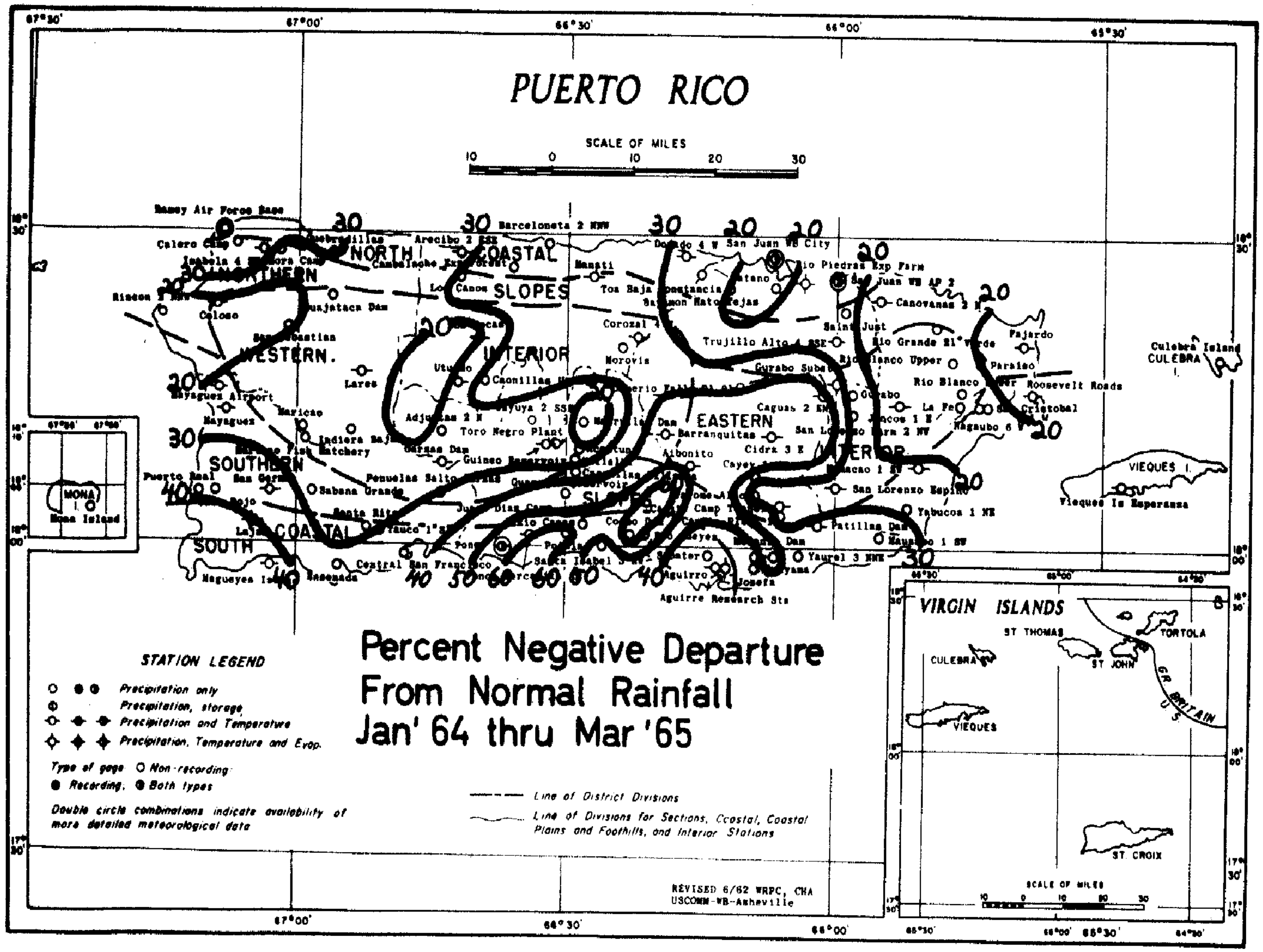

PUERTO RICO
SCALE OF MILES
Percent Negative Departure
From Normal Rainfall
Jan' 64 thru Mar '65
STATION LEGEND
Precipitation only
Precipitation, storage
Precipitation and Temperature
Precipitation, Temperature and Evap.
Type of gage O Non-recording
Recording. Both types
Double circle combinations indicate availability of more detailed meteorological data
Line of District Divisions
Line of Divisions for Sections, Coastal, Coastal Plains and Foothills, and Interior Stations
REVISED 6/62 WRPC, CHA
USCOMM-WB-Asheville
VIRGIN ISLANDS
ST THOMAS
ST JOHN
TORTOLA
CULEBRA
VIEQUES
ST CROIX
NORTH COASTAL
NORTHERN
SLOPES
WESTERN
INTERIOR
EASTERN
SOUTHERN
SOUTH COASTAL

FIGURE 2

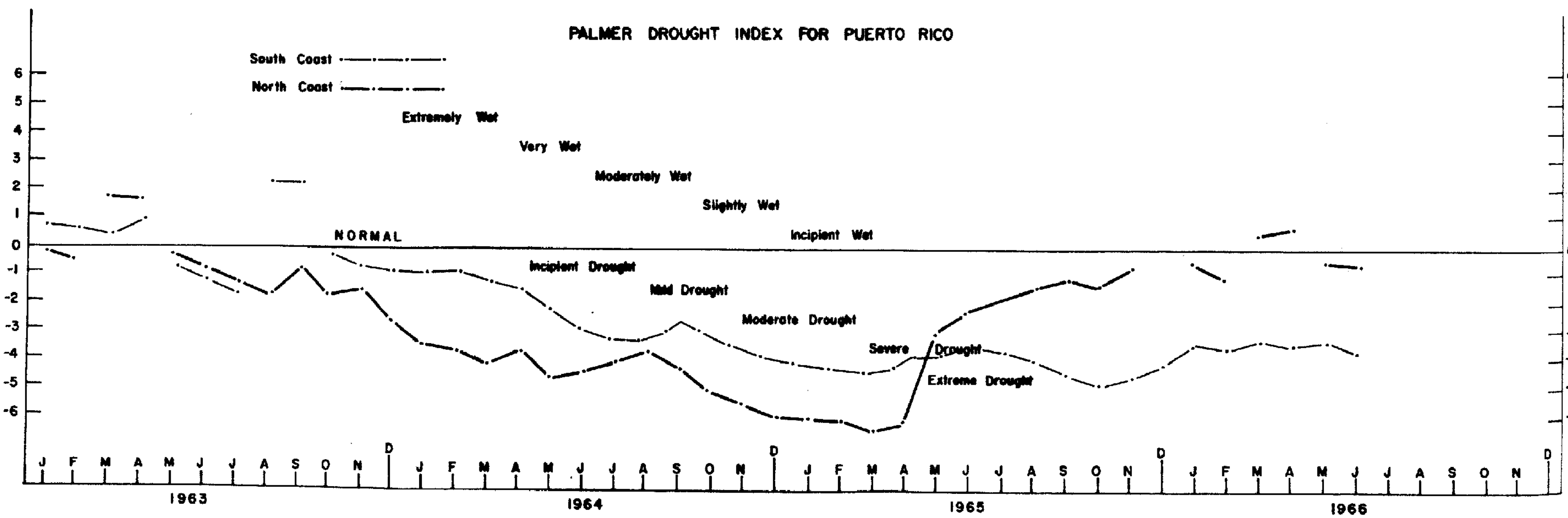


Figure 3

Note: Since positive and negative index values represent weather discontinuities (the beginning and ending of a different wet or dry spell) they cannot be joined across the zero line.

VERY HEAVY AND INTENSE RAINFALLS IN JAMAICA

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Introduction

The "91 year averages" of annual rainfall for 467 locations in Jamaica published in the 1961 Jamaica Weather Report (1) vary from 22.39 inches at Carredu, Trelawny to 303.99 inches at Bowden Pen, Portland and rainfall maps (2) prepared from these date show the spatial variation of the averages. Rainfall in Jamaica is also highly variable with respect to time. There were severe floods in October 1963 and a drought early in 1965. Heavy falls occur frequently and depth-area-duration analysis for a small watershed in the southeast yielded an estimate of nearly 18 inches for a maximum twentyfour hour rainfall averaged for the watershed (3).

2. Observed Very Heavy Rainfalls in Jamaica.

Extreme values of rainfall are of considerable importance, especially to hydrologists. Some observed very heavy rainfalls over periods ranging from two to four days are given in Table 1 which was prepared from data appearing in "The Rainfall of Jamaica from about 1870 to end of 1909"(4), the annual publications "Jamaica Weather Reports" and unpublished records. Although Jennings (5) included the 1909 observations at Silver Hill over periods of 2 to 8 days among "The World's Greatest Observed Point Rainfalls", no mention was made in his tables of the Radnor, Farm Hill or Moy Hall rainfalls which were according to Maxwell Hall (4) also observed during November 1909.

Table 1. - Observed Very Heavy Rainfalls in Jamaica over periods of 2-4 days.

Dates			Location	Depth (inches)	Period
12-14	May	1888	Boston, Portland	40.54 (c)	3 days
5- 8	Nov	1909	Silver Hill, St. Andrew	96.50 (b')	4 days
5- 7	Nov	1909	Silver Hill, St. Andrew	78.50 (b')	3 days
6- 9	Nov	1909	Farm Hill, St. Thomas	95.88 (b')	4 days
6- 9	Nov	1909	Moy Hall, St. Thomas	61.35 (b')	4 days
8-10	Nov	1909	Radnor, St. Thomas	77.40+ (b')	3 days
22-25	Jan	1960	Bowden Pen, Portland	109.79 (a)	4 days
22-24	Jan	1960	Bowden Pen, Portland	99.52 (a)	3 days
22-23	Jan	1960	Bowden Pen, Portland	82.11 (a)	2 days
22-24	Jan	1960	Mill Bank, Portland	55.18 (a)	3 days
22-23	Jan	1960	Mill Bank, Portland	48.42 (a)	2 days
5- 7	Oct	1963	Silver Hill, St. Andrew	60.00 (b)	3 days
5- 7	Oct	1963	Strawberry Hill, St. Andrew	48.16 (b)	3 days
5- 7	Oct	1963	Hermitage Res., St. Andrew	44.32 (b)	3 days
5- 6	Oct	1963	Hermitage Res., St. Andrew	39.38 (b)	2 days
5- 6	Oct	1963	Gordon Town, St. Andrew	35.10 (b)	2 days
5- 6	Oct	1963	Halfway Tree, St. Andrew	29.90 (b)	2 days
5- 6	Oct	1963	Strawberry Hill, St. Andrew	27.56 (b)	2 days
5- 6	Oct	1963	Harbour Head, Kingston	27.30 (b)	2 days
5- 6	Oct	1963	Jack's Hill, St. Andrew	27.00+ (b)	2 days

+ gauge overflowed

The 1960 Jamaica Weather Report shows that more than 16 inches of rainfall were observed at two other stations in Portland, Darley and Fellowship, on 23 January 1960. The details of the October 1963 Silver Hill observations have not been published and may not now be available. The two day rainfall at Harbour Head exceeds three times the "91 year average" for October and is more than half the annual average for that location. The 1888 observation was included in Table 1 since it was classified in the 1888 Jamaica Weather Report (1) as the heaviest rainfall yet reported in Jamaica.

Table 2. - Observed Very Heavy One-Day Rainfalls in Jamaica.

Dates			Location	Depth (inches)	
5	June	1868	Denbeigh, Clarendon	24.00	(c)
18	Aug.	1880	Cinchone, St. Andrew	20.00	(b)
14	May	1888	Boston, Portland	25.78	(c)
20	Feb.	1896	Cinnamon Hill, St. James	16.00+	(a)
25	May	1898	Cinchone, St. Andrew	28.66	(c)
6	Nov.	1909	Silver Hill, St. Andrew	30. 5	(b')
7	Nov.	1909	Farm Hill, St. Thomas	28.50	(b')
7	Nov.	1909	Silver Hill, St. Andrew	27.00	(b')
10	Nov.	1909	Radnor, St. Thomas	28.00+	(b')
29	Jun.	1917	Retreat, St. Mary	24.00	(c)
31	May	1919	Worthy Pk., St. Catherine	20.45	(c)
13	Mar.	1931	Shrewsbury, Portland	24.79	(a)
13	Mar.	1931	Paradise, Portland	23.65	(a)
1	Jul.	1933	Belle Plain, Clarendon	20.50	(b)
1	Jul.	1933	Mocho, Clarendon	20.95	(b)
15	Aug.	1933	Dallas Castle, St. Andrew	20.22	(b')
28	May	1936	Shooters Hill, Manchester	16.48+	(c)
23	Nov.	1937	Mill Bank, Portland	21.60	(a)
23	Nov.	1937	Castle Comfort, Portland	21.50	(a)
23	Nov.	1937	Greenvale, Portland	20.86	(a)
23	Nov.	1937	Balcarres, Portland	20.00	(a)
23	Nov.	1937	Moore Town, Portland	20.00	(a)
18	Nov.	1940	Greenvale, Portland	27.15	(a)
19	Nov.	1940	Balcarres, Portland	19.95	(a)
19	Nov.	1940	Mt. Holstien, Portland	19.58	(a)
19	Nov.	1940	Lennox, Portland	19.00+	(a)
30	May	1942	Port Antonio, Portland	21.12	(c)
30	May	1942	Passley Gardens, Portland	20.95	(c)
30	Mar.	1943	Balcarres, Portland	27.50	(a)
15	Oct.	1950	New Market, Westmoreland	18.62	(b)
15	Oct.	1950	Troja, St. Catherine	18.39	(b)
15	Oct.	1950	Langley, St. Andrew	17.04	(b)
15	Oct.	1950	Cedar Valley, St. Thomas	16.95	(b)
17	Aug.	1951	Palisadoes, Kingston	16.93+	(b)
2	Dec.	1959	Chepstowe, Portland	20.32	(a)
22	Jan.	1960	Bowden Pen, Portland	38.46	(a)
23	Jan.	1960	Bowden Pen, Portland	43.65	(a)
23	Jan.	1960	Mill Bank, Portland	39.41	(a)
5	Oct.	1963	Gordon Town, St. Andrew	20.00	(b)
6	Oct.	1963	Halfway Tree, St. Andrew	23.15	(b)
6	Oct.	1963	Hermitage Res., St. Andrew	22.35	(b)
6	Oct.	1963	Strawberry Hill, St. Andrew	21.24	(b)
6	Oct.	1963	Harbour Head, St. Andrew	19.10	(b)

+ Gauge overflowed.

Some very heavy one day rainfalls are contained in Table 2. As also in Table 1, the day is defined as the 24 hour period commencing at a specified time - usually 7 A.M. Some data for the heavy rainfalls of 15 October 1950 have been included since the four locations are in different parishes on the southern half of the island from Westmoreland in the extreme west to St. Thomas in the extreme east. Also included is the October 1963 rainfall at Harbour Head since this figure is approximately twice the average for October - the wettest month of the year. The report of 20.32 inches of rainfall at Chepstowe in 1959 seems open to question as it exceeds by far observations at neighbouring locations on that date.

3 Observed Intense Rainfalls in Jamaica

There are only a few recording raingauges on the island and most of these instruments were installed in recent years. Nevertheless, some information is available on intense rainfalls over periods of less than 24 hours. The data given in Table 3., it appears, were all obtained from

Table 3. - Intense Rainfalls in Jamaica.

Date			Location	Depth (inches)		Period	Duration (hours)
4	Jul.	1883	Kempshot, St.James	5.08	(c)	2pm/3pm	1
24	Jun.	1884	Cherry Gardens, St.Andrew	7.73	(c)	1pm/5pm	4
8- 9	May	1888	Port Antonio, Portland	11.00+	(c)	9pm/9am	12
8- 9	May	1888	Boston, Portland	18.09	(c)	10pm/1pm	15
14	May	1888	Boston, Portland	11.78	(c)	8am/8pm	12
14-15	May	1888	Boston, Portland	9.50	(c)	10pm/2.30am	4½
15	May	1888	Boston, Portland	4.50	(c)	2.30am/6am	3½
13	Jun.	1904	Irwin, St. James	8.00	(b')	7am/1pm	6
13	Jun.	1904	Fontabelle, Westmoreland	7.13+	(b')	5.30am/8.30am	3
12	May	1916	Plumb Point, Kingston	7,80+	(c)	(3pm)	¼
29	Jun.	1917	Retreat, Orange Bay, St.Mary	23.40	(c)	6am/6pm	12
29	Jun.	1917	Retreat, Orange Bay, St.Mary	10.75	(c)	9am/2pm	5
29	Jun.	1917	Retreat, Orange Bay, St.Mary	8.50	(c)	2pm/6pm	4
31	May	1919	Worthy Park, St.Catherine	20.43	(c)	-	19

+ gauge overflowed

observations using ordinary (non-recording) raingauges. The Plumb Point observation was included by Jennings (5) among the world record falls. The description of the weather (1) does not rule out the possibility of sea water instead of rainfall being measured, particularly in view of the comment that "the cloud-burst was followed by a small whirl-wind". The reported strong wind, if it occurred before the precipitation began, might well have been directly associated with a cumulonimbus cloud, but if coincident with the "downpour" would suggest the possibility of a water spout. There was marked instability as more than 14 inches of rainfall were observed on that day at two or three locations within 15 miles of Plumb Point.

Some rainfall intensity data for Palisadoes obtained from tilting siphon rainfall recorder charts, after adjustment to fit with check gauge readings, are given in Tables 4 and 5. Unfortunately the recording gauge at Palisadoes did not always operate satisfactorily, particularly during some of the heavy falls prior to 1964 and it is likely that some of the short period falls are greater than the estimates given in these Tables.

Table 4. - Maximum Rainfalls in Specified Periods - Palisadoes, January 1953 to July 1966

Duration Year	½hr.	1hr.	2hr.	3hr.	6hr.	12hr.	18hr.	24hr.
1953	0.66*	1.32	1.94	2.44	3.58	3.80	3.98	3.98
1954	1.04*	2.07	3.09	3.40	5.52	6.33	6.61	6.61
1955	0.95	1.51	1.70	2.36	2.49	2.50	3.64	3.69
1956	0.48*	0.96	1.51	1.76	2.47	3.82	6.62	8.64
1957	0.79	1.42	1.71	2.24	3.00	3.19	4.03	4.28
1958	1.27	1.63	2.02	2.39	3.02	5.20	5.49	6.81
1959	0.46	0.93	1.72	1.81	2.09	2.29	2.32	2.70
1960	0.59	1.08	1.77	2.23	3.87	4.02	4.10	5.38
1961	0.81	0.98	1.63	2.02	2.32	3.04	3.30	3.89
1962	0.63*	1.10	1.16	1.71	2.85	2.85	2.85	2.87
1963	1.38*	2.83	3.39	3.52	5.31	7.28	8.68	10.25
1964	0.72	0.87	0.92	1.14	1.35	1.96	2.08	2.10
1965	0.79	1.57	2.64	3.58	3.58	3.58	3.58	3.58
1966	1.14	1.41	1.99	2.45	3.04	4.68	4.83	5.96

* estimated

Table 5. - Frequency of occurence of rainfalls of specified intensities Palisadoes June 1946 to July 1966

Intensity Period	More than 50 ins. in ½hr.	More than 1 in. in 1hr.	More than 2 ins. in 6hrs.	More than 5 ins. in 24hrs.
1956	2	1	1	1
1957	4	3	4	-
1958	10	3	4	2
1959	2	-	-	-
1960	12	4	4	1
1961	4	4	1	-
1962	4	1	-	-
1963	3	2	2	1
1964#	2	-	-	-
1965	3	2	2	-
Jan. - Jul. 1966	2	2	2	1

\# Period 11 months only - excluding October.

June 1946 to May 1958 - more than 20mms. 1 hr.:59; more than 30mms. in 1 hr.: 22; more than 2 ins. in 5 hrs.: 23.

4. Associated Synoptic Scale Features.

The synoptic scale features associated with heavy or intense rainfall in Jamaica fall into three groups:

a.) frontal

b.) hurricane or b '.) incipient hurricane

c.) other features

On the basis of the available evidence, the categories into which the associated synoptic scale features appeared to fall are indicated in Tables 1 to 3. Incipient hurricanes have been taken to include tropical storms and incipient tropical storms which did not subsequently develop into hurricanes. In a number of cases the category to be assigned was uncertain. However, the main purpose of classification was to broadly indicate the relative frequencies. The November 1909 flood is attributed to an incipient hurricane although this may well be an oversimplifica-

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1962	0.63*	1.10	1.16	1.71	2.85	2.85	2.85	2.87
1963	1.38*	2.83	3.39	3.52	5.31	7.28	8.68	10.25
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1961	4	4	1	-
1962	4	1	-	-
1963	3	2	2	1
1964#	2	-	-	-
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Tables 1 to 3 indicate that many very heavy rainfalls in Jamaica and especially in the north eastern section have been frontal. The very heavy rainfalls to which category (a) was assigned all occurred in the months November to March. With the 1909 falls as outstanding exceptions most of the very heavy hurricane rains falls in the months of August and October, while most of the falls to which category (c) is assigned occurred in the month of May.

a.) Fronts
Cold Fronts, when approaching Jamaica are often observed to be attended by only light or moderate rainfall. The air mass to the north of the front is modified by the Gulf Stream and the Caribbean Sea and air mass differences across fronts when reaching Jamaica are invariably not marked. Aircraft reports indicate that unlike hurricanes in which cloud tops have been reported to reach 61,000 feet (6), the vertical development of clouds in the cold front near and over Jamaica do not often exceed 25,000 feet. Kirk (7) argues that recourse to the traditional concept of air masses can be avoided and that cold fronts should be considered as aspects of development.

He starts from the equation of motion, written in vector form, in isobaric coordinates

$$\frac{d\bar{V}}{dt} + f\bar{k} \times \bar{V} = -\bar{\nabla}\,\Phi$$

where $\bar{V}$ is velocity vector, Φ the geopotential, $\bar{K}$ a unit vertical vector and f the Coriolis parameter. He neglects the influence of the friction layer. For the latitude of Jamaica the Coriolis force is small and generally assumed to be negligible and it is suggested that, in the dynamical approach to the cold front over Jamaica, account should be taken of the effects of the friction layer and of orographic effects. In support it is pointed out that most of the heavy frontal rains in Jamaica are observed to occur in the north eastern and northern districts where orographic effects are strongest but that some intense rainfalls have been observed on the north coastal areas, where changes in surface effects are most marked.

b.) Hurricanes and incipient hurricanes,
Various aspects of hurricane rains have been discussed by Peterson and Molansky (8), Schoner and Molansky (9) and others and the last named researchers have noted that many of the heaviest falls have been from storms of less than hurricane intensity. Hurricane Flora of 1963 may be described as a wet hurricane. Additionally the very slow movement of the storm over a period of several days described by Dunn *et. al.* (10) provides the basis for an explanation of the persistence of heavy rainfall over most of eastern Jamaica during the period. Several other hurricanes have affected the island and tracks of all storms over the years 1971-1963 have been published in Technical Paper No.55 (11). Fowler (12) claimed that the centre of hurricane Charlie passed over the island and

reported that the gauge at Palisadoes overflowed because it became clogged with sand and small gravel, thus emphasizing one of the problems of measurement of rainfall in hurricane conditions.

c.) Other synoptic scale features.

Hurricanes or tropical storms very rarely form in or enter the Caribbean during May (11). Easterly waves occur less frequently and are usually less well formed in May than in later months. In May fronts usually cease to move southwards before reaching Jamaica and those reaching the island are invariably then very weak and ill-defined. Yet several very heavy rainfalls have been observed in Jamaica during May. It is suggested that the synoptic scale patterns associated with such falls involve the phasing of two or more features. Several heavy rainfalls have been observed to occur, especially in the month of May, in association with the phasing of a mid-tropospheric cold low or trough with other features which prior to phasing were relatively weak.

5. Summary

Several very heavy and intense rainfalls have occurred in Jamaica over the past hundred years. It is suggested that the main associated synoptic scale features are the cold front for north eastern and northern areas in November to March, the hurricane or incipient hurricane especially during August and October and phasing of two or more features during the month of May.

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THE HYDROLOGICAL INVESTIGATION OF THE RIVER YALLAHS CATCHMENT

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As Consulting Engineers to The Water Commission and The British Government, Howard Humphreys & Sons are currently investigating the water resources of Kingston and its surrounding Parishes in order to determine possible sources of water for supply to the city and nearby towns. At present three catchments, or watershed basins, are being studied in detail. Of these, possibly most attention is being given to The River Yallahs Catchment. This is because the area has many problems regarding the development of water resources resulting from its severe topography and climatic conditions.

The head waters of the River Yallahs are immediately to the south of the mountain chain known as the Blue Mountains. This ridge lies along the major axis of the eastern third of the island the peaks of which reach 6,500 to 7,400 feet above sea level. Ridges extending southwards from the main range flank the catchment to the east and west enclosing an area of 75 square miles.

The first proposals to utilise the Yallahs River to provide a supply for the Corporate Area of Kingston & St. Andrew, were made in the 1920's and some hydrological investigations and surveys were carried out at that time. Various suggestions have been made since then regarding possible methods of abstracting the water from the river. In an area where problems arise from steep rivers, seasonal river flow and high sediment concentrations, river intakes were ruled out because of the sediment problem and the Water Commission's proposal to construct a small dam was not favoured by the Government because of the need for irrigation water further down the valley. A large dam was in fact required which could provide adequate storage through the long dry season and allow for heavy sediment concentrations in the river.

In 1959 when reviewing the water requirements of Kingston, attention was again given to the River Yallahs in order to find a site for a future dam. Aerial photographic surveys suggested a possible dam site at Mahogany Vale, where there is a steep sided narrow gorge with a wide river basin upstream. Further investigations were necessary and subsequently studies of the geology, erosion and land settlement were undertaken together with investigation into the engineering feasibility and the hydrological characteristics of the area.

Hydrologically, the problem is to design a storage reservoir so that the demands for water can be supplied despite variations in river flow. Reservoirs that are built too large waste money and water; reservoirs built too small cannot do the job expected of them. Therefore the characteristics of climate, rainfall and runoff of the catchment area have had to be assessed in order to determine design criteria for the dam.

The design criteria for a river impounding scheme involve the evaluation of the following factors:

(a) The mean flow which is expected over an extended period of time.

(b) The minimum dependable flow.

(c) The frequency of occurrence and expected duration of drought periods.

(d) Long period trends in Climatic, Hydrological and Hydrogeological conditions.

Knowing these factors, a dam can be designed which is economically suitable for the supply of water which is demanded from it. Satisfying the project's efficiency is possibly the most important aspect of design, requiring an intensive hydrological and statistical analysis. The economic justification is determined by a comparison of the capitalised benefit of the Project against the estimated construction and maintenance costs. This being so the dam still has to be designed so that it is able to resist any flood discharge force to which it may reasonably be subjected within its economic life. Therefore, the maximum probable flow to develop in the catchment must also be evaluated and the spillway designed accordingly.

The first part of our work involved searching for historic data on rainfall amounts, rainfall intensities, evaporation and also on stream flow. Although rainfall records have been available since 1870 stream flow measurement started much more recently. Beginning in 1953 the Government Water Resources Section has been recording river discharge at six stations in the Yallahs Catchment. Unfortunately, some of these records have been discontinuous because of severe floods and indeed the important recording gauge at Mahogany Vale was washed away by the Flora hurricane flood in 1963.

Following the provision of funds by the Jamaican and British Governments near the end of last year, a programme of more intense measurement has been started by The Water Commission in conjunction with the Ground Water Research and Surveys team. Already twelve stations have been established with regular current meter calibration. These stations have been located to measure not only the discharge characteristics of streams into the dam catchment but also to measure irrigation requirements downstream of the dam and supplementary sources of water to be fed either into the reservoir or into the pipeline. The most important flow measuring station will be that at Mahogany Vale which will incorporate a weir of modern design capable of measuring discharges far higher than experienced during the 'Flora' storm. Two recorder houses will be installed upstream and downstream of the weir to record continuously the flow through the station. Already basic calculations are being carried out on the past records and comparison made with nearby catchments, showing consistencies with elevation and broad geological types. As time progresses more data will become available to supplement and, we hope, confirm our present calculations.

To obtain the more extreme conditions and the long term trends it has been necessary to correlate the runoff with the long period rainfall records. As already mentioned we have rainfall values from 1870 until the present day. Monthly rainfall values are available from 1871 at Hope and Hill Gardens, from 1893 at Easington and Hardwar Gap with several others extending back for more than 50 years. These stations were either maintained by public authorities or large plantations.Unfortunately not many of them have continuous records due not only to observers moving from their property but also due to the movement of records from one archive to another. Lack of suitable storage facilities has meant that the great majority of this information is now no longer available for study. Summaries of the data are fortunately available in the Jamaica Weather Report which gives monthly totals of rainfall at many of the stations together with the greatest daily fall at each station for each month and the date of its occurrence. The volumes of this report and other documents indicated that Jamaica is subjected to very high rainfalls. In fact, world record values have been recorded such as 7.8 inches in 15 minutes at Plumb Point. This gauge however, was located within 50 yards of the sea and the observer's description of the event suggests almost certainly that it was caused by a water spout. Apart from this value Jamaican falls for short periods are generally less than the world maxima. At periods of one to three days, falls in Jamaica approach world maxima and in periods of two to six days falls recorded at Silver Hill and Bowden Pen were world records until 1952 when they were exceeded by a storm at La Reunion. It is interesting to note that both Jamaica and La Reunion are located in the hurricane zone and that these record values were measured around 4,000 feet above sea level on steeply sloping valley sides.

Realising that much of the upper Yallahs catchment is above 4,000 ft. with steep slopes facing the south east and open to the prevailing track of hurricanes, it is not surprising that the resources of the British Meteorological Office were requested. Messrs. Helliwell & Singleton were asked to study the probable maximum precipitation for the dam catchment area and have recently produced a report, some of the details of which I am including here. Because of the lack of continuity of daily records the investigation has for the most part been theoretical. They approached the problem in several ways as follows:

(a) A study of historic falls for 24 hours, on as many occasions as possible followed by maximization of these falls for moisture content or moisture inflow as appropriate.

(b) A statistical analysis of daily maximum falls (mainly for erosion studies).

(c) Transposition of the maximum possible cloud-burst.

(d) A theoretical computation of the rainfall and rainfall time relations in a hurricane from which it should be possible to estimate the fraction of the maximized fall of 24 hours which could fall in short periods.

(e) Consideration of the various rainfall producing sequences of weather which have and which could occur.

Firstly using historical storm data, charts of mean annual rainfall for a ten year period were produced in which the available observations were analysed with careful regard to topography. Secondly, rainfall values for individual storms were plotted as percentages of the ten year mean. This method has two effect in that it removes topography where there is marked orographic effect and enables incorrect readings to be detected. After drawing Isopercentals, values of percentage rainfall were read off at a series of grid points to give actual storm rainfalls and subsequent storm isohyets. The storm rainfall was maximized having regard to the ratio of the amount of water vapour forming rainfall to the amount of water available to form precipitation. Thus the actual precipitation is increased in the ratio of the actual moisture charge to the maximum possible for that type of storm. A further analysis was done with the storm isohyets to produce depth area curves which were also maximized by multiplying the rainfall by the maximising moisture inflow index. Considering short period intense rainfalls, it is a pity that there have only been rainfall recorders around the coast of Jamaica. A lack of records inland can, of course, be overcome by a theoretical analysis of maximum probable thunderstorms. These are essentially very local phenomena except when there is an area of organized convergence such as the inter-tropical convergence zone, or an easterly wave. Because the Mahogany Vale Catchment has ridges of high ground to the East and West, thunderstorms forming in this area would have a tendency to remain stationary especially during the winter. Values of depth duration curves for probable maximum thunderstorms have been obtained for Puerto Rico and the Virgin Islands and have been translated to one-hour, three-hour and six-hour values for the Yallahs Catchment.

The methods of Gumbel were used to estimate the extreme rainfall for a number of return periods but outliers were found in the storm of 1909 which spoiled the reliability of such analysis.

As already mentioned, the Yallahs is open to the south-east and is therefore subjected to the onslaught of hurricanes. The hurricane model produced by the United States Weather Bureau is being used. Several computations were carried out in which rainfalls were computed at 20 points in the Yallahs area over a period of 60 hours. Some of the computations were to test the model against known falls and others were to examine the "worst" case for the catchment. The comparison between a maximum computed hurricane rainfall, produced by a storm moving northward at 5 miles per hour at 25 miles to the west of the catchment, and the P.M.P. values obtained by conventional maximization, proved them to be remarkable similar. From an examination of the records it would appear that almost any combination of thunderstorm, easterly wave, hurricane or tropical storm can occur. Mr. Helliwell has concluded, by using very different techniques which are quite independent, that a 24-hour hurricane rainfall over Mahogany Vale Catchment could attain values of up to about 60 inches at a point and 40 inches over the whole area.

In order to correlate such rainfall studies with stream-flow the future rainfall values will be most useful. Present rain gauges are being improved where possible and the new gauges have been installed.

In addition, six rainfall intensity recorders have been installed in the Yallahs Catchment which are sampling rainfall durations between 80-ft. and 4,020-ft. above sea level. These are located at climate stations which have been sited at Yallahs Valley Land Authority Agricultural Stations. The Authority's Chairman, Mr. Morrison, has not only provided land and the observers but also the equipment for two of the stations with a view to determining the climatic factors affecting crop growth and production. Choosing the sites for the network has been a compromise between the availability of observers and a distribution relating to elevation and aspect. Between the dam catchment extreme elevation of 7,400-ft. and 1,750-ft., there are four stations at elevations of 4,020, 3550, 3200 and 2130 feet above sea level. Downstream of the dam two stations are situated at 1,980-ft. and 80-ft. At these climatological stations daily records are taken of wind, speed, evaporation, rainfall, maximum and minimum temperatures, semi-diurnal measurements of humidity, wind direction and continuous records of rainfall intensity and sunshine duration. For hydrological interest the data is being collected to establish the water losses from evapotranspiration using either Penman's formula or associated methods and also to estimate the potential evaporation from the reservoir surface. Such information has not been available until now in Jamaica except at low elevations and although the stations are only a few months old, we are looking forward to obtaining interesting information concerning tropical climate at high altitudes. Already interesting diurnal variations have been detected resulting from different weather conditions involving wind, humidity and evaporation. The observers are keen and show an active interest in taking reliable readings of all the instruments at their stations. Much work has been entailed teaching them the procedure of maintenance and reading of the instruments but regular monthly data sheets are now being collected in our new filing system. A very promising hydrology team is now established, collating the new climate data as well as rainfall data from about 60 stations around Kingston, and stream flow measurements and records from a thirty mile radius. However, without the help of The Water Commission, the Jamaican Meteorological Service, the Yallahs Valley Land Authority, the Ground Water Research & Surveys and the Public Works Department, we would not have been able to carry out any hydrological work except for measuring rainfall in buckets.

PAPERS ON AGRO-CLIMATOLOGY

THE RELATIONSHIP BETWEEN RAINFALL VARIATION AND AGRICULTURAL PRODUCTION

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In areas where irrigation water is not available a knowledge of the rainfall characteristics is essential for the choice of crops for farmers to grow economically. Although fertile soils are available in any area a wrong choice of crop may not only bring financial embarrassment to farmers but also engenders a lack of confidence in the advisory services who have recommended the planting of these crops. There has been much discussion concerning the zoning of crops in Jamaica to facilitate not only supplying seeds, fertilizers etc. to farmers but also to make easier the collection and marketing of the produce.

In this exercise on zoning of crops we have used the 91 year average rainfall data published by the Meteorological Department and using the system of classification outlined by Mohr and Van Baren (1) produced a seasonal rainfall map of the island (Figure 1), from which one is able to deduce the most suitable crops for these zones.

Mohr and Van Baren from their studies of rainfall distribution not only in Indonesia but other tropical countries have concluded that 60 mm (2.36 inches) should be taken as the limit above which a month may be regarded as being more or less moist and beneath which a month may be considered more or less dry. Moderately moist months are considered to be those which have rainfall between 60 - 100 mm (2.34 - 3.90 inches) and wet months over 100mm (3.94 inches).

In using this system of classification the authors state that an important factor to be taken into consideration is whether the dry months are preceded or followed by moist months or wet months. In the first case the first of these dry months may be counted among those which are fully dry, in the latter event a residual effect is obtained from the preceding very wet season so that as far as the soil and vegetation are concerned the dry period really begins to take effect later. Similarly the effects of a drought period will be relieved earlier when the month which follows brings more than moderate rain (over 3.9 inches).

For example, three dry months and nine wet months mean a sharp but not prolonged dry period preceded and followed by heavy rain. If however two moist months precede the dry period and two follow it, the dry period will be felt more intensively by soils and vegetation. Accordingly the stations in Jamaica for which data over the 91 year period are available have been grouped as follows.

Zone 1.

This is a continuously wet area in which all stations show a surplus of rainfall over evaporation during practically the whole twelve months of the year. A random sample in this group is shown below.

Zone 1.

	Manchioneal	Fellowship	Caenwood	Bybrook	Enfield
Jan.	5.58	12.87	10.92	17.02	12.73
Feb.	5.08	9.99	7.96	12.02	7.99
Mar.	3.57	7.01	8.28	6.98	7.36
Apr.	6.66	9.63	6.30	7.35	8.91
May	12.72	16.57	12.28	10.30	11.05
Jun.	8.89	17.64	11.08	6.48	4.66
Jul.	6.25	6.19	9.75	5.54	4.27
Aug.	8.02	13.69	6.49	4.52	6.35
Sep.	10.74	13.06	7.38	7.88	6.65
Oct.	17.25	17.34	10.04	9.68	12.63
Nov.	14.61	25.05	13.56	15.95	24.50
Dec.	7.32	18.19	16.96	22.74	20.37
	106.69	167.23	121.00	126.46	127.47

Agricultural production in this zone is at no time limited to lack of rainfall and provided temperatures are within the limit of 80 - 90°F. crops selected should be those that do not require a dry season for the accumulation of reserve food before flowering. Bananas, cacao and coconuts are the first choice for this area.

Urquhart (2) states that cacao does best with a minimum rainfall of 3.5 - 4.0 inches of rain per month and cropping will under these conditions be distributed over the greater part of the year.

Physiological studies carried out at the Inter-American Cacao Centre in Costa Rica by Alvim (4) and others have shown that only a slight water deficit is sufficient to cause stomal closure of the cacao leaf and death of leaves occurs when it loses 25% of its water content as comprised to leaves of coffee which can lose over 40% of its water before permanent damage occurs. These workers have concluded that cacao is not a suitable crop for districts where there is a marked dry period.

In the case of bananas Simmonds (3) has found that bananas do best in areas with no growth check due to drought conditions. Total rainfall should be over 100 inches per annum and where rainfall is ample, bananas are in continual growth and produce fruit throughout the year. A dry season or low temperatures will cause growth to slow down and result in loss of production.

Murray and Lucie Smith (5) have shown that coconuts are particularly susceptible to drought periods and as a result of a marked dry season in Trinidad, yields of coconut trees fell from 100 nuts per year to between 60 - 70 nuts per tree for two successive years. Similar effects of a drought period are also reported in Ceylon.

Zone 2.

The rainfall data below illustrate that this area may be considered as one with a weak dry period in average years in that the soil does not really dry out except perhaps in the case of well drained loams and sandy soils.

In this area a great variety of crops may be recommended, as the crops recommended for Zone 1 will do well when rainfall is more than average for the year, and do poorly in drought years.

Citrus and coffee which are better suited for Zone 3 will do poorly when the dry season is not marked.

Zone 2.

	Highgate	Guy's Hill	Claremont	Cambridge	Knockalva
Jan.	4.47	6.36	5.78	2.27	2.44
Feb.	4.75	4.30	3.96	2.85	3.10
Mar.	2.35	3.54	3.01	4.40	4.60
Apr.	4.55	5.41	4.68	7.29	9.79
May	11.43	8.25	7.68	13.06	13.03
Jun.	6.45	5.91	4.94	10.56	7.10
Jul.	5.54	4.16	3.20	9.23	8.07
Aug.	7.77	5.65	1.98	11.29	10.78
Sep.	4.94	7.01	6.15	11.85	16
Oct.	8.59	9.60	8.63	12.34	.40
Nov.	5.00	7.71	11.06	5.70	5.56
Dec.	4.30	8.02	7.93	2.17	3.92
	70.4	75.90	72.00	93.01	90.95

With additional pasture and vegetables this is an ideal zone for mixed farming to include bananas, citrus, cacao, coconuts, coffee, pasture and vegetables.

Zone 3.

The following are rainfall data for some stations in this zone.

Zone 3.

	Morant Bay	Bog Walk	Alexandria	Frome	New Port	Mocho
Jan.	2.79	2.20	2.43	1.85	2.62	2.22
Feb.	1.88	1.77	2.38	2.16	2.67	2.03
Mar.	1.69	2.32	2.16	3.51	2.95	2.82
Apr.	2.94	4.43	3.87	7.23	4.55	5.07
May	7.79	8.90	7.11	12.45	7.94	8.29
Jun.	8.16	7.01	4.07	9.24	7.03	5.83
Jul.	5.41	6.00	2.92	6.99	4.11	4.28
Aug.	6.61	8.04	4.71	9.69	7.22	7.84
Sep.	9.20	6.86	6.02	9.46	8.39	8.91
Oct.	12.86	11.07	7.88	9.77	11.97	5.14
Nov.	7.44	5.37	5.98	5.38	6.29	6.05
Dec.	3.94	1.64	2.98	2.48	2.64	2.26
	70.71	65.61	52.51	80.21	68.38	60.74

Stations in this zone have a dry season that is marked during which time the soil will dry out quite thoroughly to a considerable depth. Sugar cane which requires a drought period for the ripening of the crop does well and provided that the temperature range is from 70 - 80°F. excellent crops of citrus, coffee etc. which require a period of growth cessation to allow the tree to accumulate reserve food before the differentiation of flower buds may be obtained.

In the case of citrus this rest period occurs during the mild winter months in Mediterranean and subtropical areas and the onset of flowering takes place with the rise in temperature in the Spring. In the tropics flowering depends on a pronounced drought period. Kassin (6) in Guinea mean annual temperature (73 - 80°) found that flowering took place 28 days after the first effective rains have fallen after a dry season which lasted from 92 - 160 days. Torrisi in Italy (7) also found that flowering begins earlier in trees that have been subjected to a greater degree of dessication. After flowering a monthly rainfall of 3.9 - 5.8 inches is necessary for proper setting and growth of the fruit. Any one who has worked with these crops over a period of years will sooner or later realize that the antagonism between the vegetative and reproductive phases is one of the most important reasons for poor crops in years, during which the drought period is broken early.

Zone 4.

In this area a prolonged dry season demonstrated by the rainfall data shown below, is the main cause of low agricultural production. Vegetables and tobacco are suitable short term crops for the rainy season.

Dry season crops such as cassava, sorghum, sisal are recommended as they can withstand drought and can occupy the land for the greater part of the year. Sisal thrives best where total rainfall does not exceed 50 inches per annum, and in Jamaica considerable losses are encountered when heavy rains fall due to root rots and fungus infection.

In this zone the mango also flourishes. Indian workers Gangally *et al* (8) find that the best mango varieties thrive in places where there is a hot dry season. Cloudy and rainy weather at blossoming interfere with pollination which is done by bees and flies, and also injure the stigma so that rainfall distribution has a definite influence on the bearing and quality of the fruit.

Zone 4.

	Falmouth	Cross Keys	Moneymusk	Old Harbour	Kingston
Jan.	3.22	1.04	0.58	1.96	1.06
Feb.	1.97	1.08	1.11	1.95	0.85
Mar.	1.72	0.72	1.31	2.17	0.60
Apr.	2.16	2.01	0.89	2.94	1.37
May.	4.35	6.50	4.42	5.77	5.14
Jun.	2.59	2.06	1.55	5.07	1.96
Jul.	1.50	1.83	2.97	4.71	2.37
Aug.	2.63	2.39	4.05	5.16	4.75
Sep.	3.46	9.96	7.73	6.08	5.37
Oct.	5.57	5.85	7.60	9.82	8.59
Nov.	5.46	6.77	1.72	4.88	2.45
Dec.	4.10	2.12	1.75	2.28	1.01
	38.73	42.33	35.68	52.79	35.52

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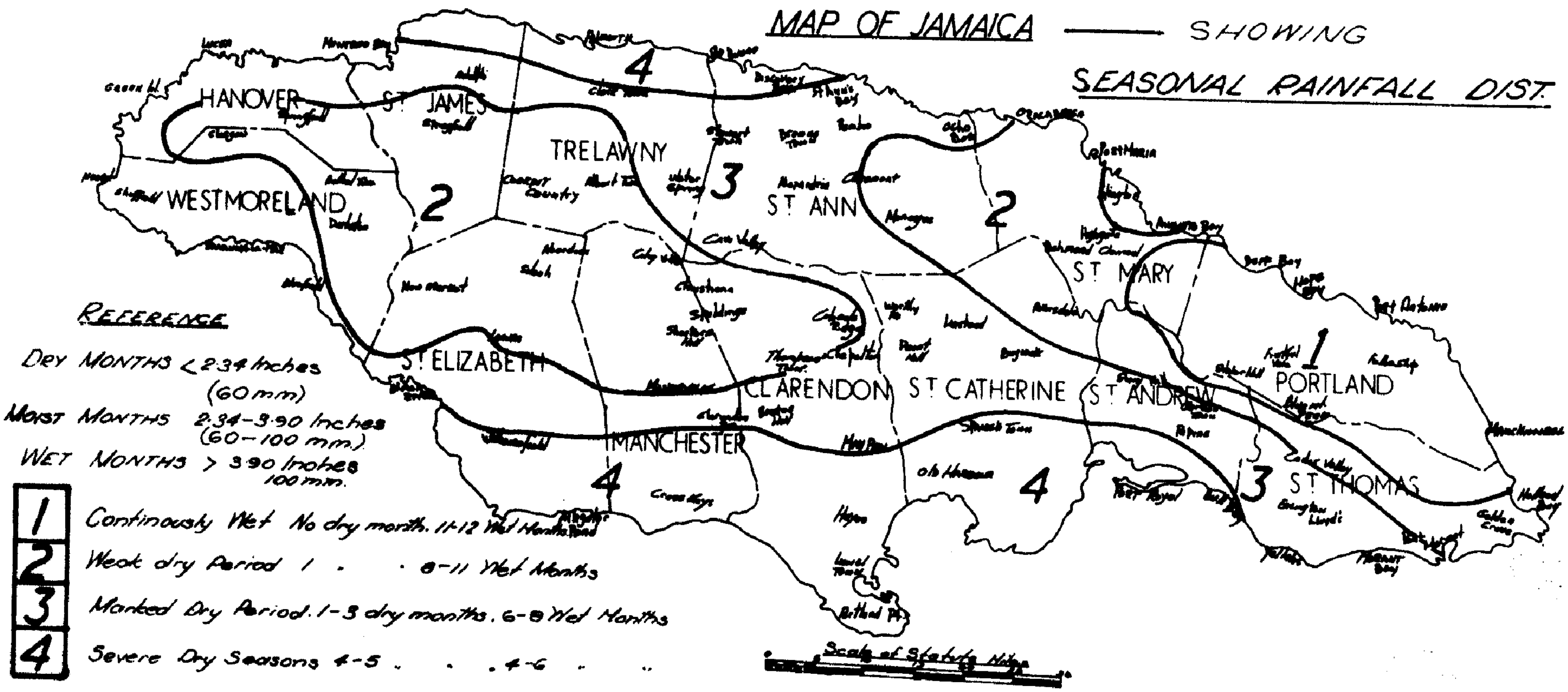
MAP OF JAMAICA —— SHOWING
SEASONAL RAINFALL DIST.
HANOVER
ST JAMES
TRELAWNY
WESTMORELAND
ST ANN
ST MARY
PORTLAND
ST ELIZABETH
CLARENDON
ST CATHERINE
ST ANDREW
MANCHESTER
ST THOMAS
REFERENCE
DRY MONTHS < 2.34 Inches (60 mm)
MOIST MONTHS 2.34–3.90 Inches (60–100 mm.)
WET MONTHS > 3.90 Inches 100 mm.
1 Continously Wet No dry month. 11-12 Wet Months
2 Weak dry Period 1 " " 8–11 Wet Months
3 Marked Dry Period. 1–3 dry months. 6–8 Wet Months
4 Severe Dry Seasons 4–5 " " " 4–6 " "
Scale of Statute Miles

INFLUENCE OF SHELTERBELTS ON MICRO—CLIMATE AND AGRICULTURE

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The use of shelter belts to create a local or micro climate has not been very prominent in this country although it is a regular feature of agricultural country-side of many other countries, mostly in the temperate regions. In Russia for example, research work started from the mid 19th Century when Graffe organized the planting of a belt of forest trees with the aim of combating drought and demonstrating the possibilities of afforestation in the extensive Steppe Regions of Russia. A great deal of work has since been done in that country and conclusions have been reached regarding the best type of shelter belt in terms of width, density, structure and distance between belts and resulting benefits to agriculture. In the U.S.A. much progress has been made during the present century and especially since the severe drought of 1934, in shelter belt planting for the rehabilitation of Prairie farm lands. Between 1934 and 1941, four million acres of farm lands were protected in the Northern Great Plains. Considerable shelter belt planting has also taken place in Denmark mostly on heath and sand dunes where severe wind damage had hitherto restricted the spread of agriculture.

Generally speaking the shelter belt in a given area influences a number of factors such as wind velocity, evaporation, temperature, radiation, precipitation from dew and soil moisture. The influence of a belt of forest trees on wind velocity is rather a complex study involving aerodynamics and meteorology and this is beyond the scope of this paper. It is accepted, however, that shelter belts reduce the speed of wind, and the final effect varies with the density and height of the belt of trees. When a windbreak is completely impenetrable to the wind practically the whole of the force of the wind is deflected upwards and over the barrier. According to Caborn, there is a certain amount of loss of kinetic energy due to collision of the air molecules with the barrier itself, or with the cushion of air which has developed on the windward side. This cushion or concentration of pressure causes the upward deflection of the air stream to take place at some distance in front of the barrier in much the same way as with a penetrable object. However, the pressure behind the barrier is low due to the fact that no wind can pass through the barrier to form a leeward air cushion. Consequently, a suction effect occurs and the air currents above the wind-break are drawn downwards, thereby causing intense turbulence to leeward. An impenetrable barrier therefore causes the wind to resume its normal velocity and pattern at a comparatively short distance from the obstacle. Although it is doubtful that even the most dense shelter belt can be considered impenetrable in the sense of a solid wall, it is certain that fairly intense turbulence takes place and is often responsible for the damage to crops on the leeward or protected side of a belt which is practically impenetrable to the wind. In the case of the barrier or belt which is partially penetrable there is a tendency for the streamline flow over the barrier to be re-established gradually and the sheltered area is correspondingly longer in extent.

Expressed in multiples of shelter belt height (h), the zone of wind velocity reduction on the leeward side of the belt may extend to about 40 or 50 h before normal flow is re-established. (Gloyne 1954). Effects at a distance of 100 h and more have been observed in Russia but this would appear to be unusual. In Denmark the wind conditions and the velocity of wind were examined behind 30 different hedges of various species of trees, different heights and different densities. A fairly open design gave a perceptible decrease of wind velocity up to a distance of 20 h while a dense hedge only decreased the wind velocity by 2% at the same distance. The dense hedge at a short distance of up to 4 times the height of the hedge (4h) gave a better shelter effect than the fairly open hedge but the effect was lost more quickly. The Danish experience therefore suggests that for practical planning of shelter belt planting it is preferable to use the very dense hedge when areas of crops which demand particularly good safeguarding are to be protected, orchards for instance, while for shelter belt planting on extensive areas the best effect is obtained by the planting of fairly open hedges suitably spaced at say, 20-30 times the height of the hedges.

Formerly it was the general opinion that several consecutive rows of hedges controlled the wind so that after it had passed a large system of shelter belts, its force would be brought down to a minimum. Measurements taken in Denmark show, however, that there is no question of such a complete control as the force of the wind is just as great when it blows against the last hedge as it was when meeting the first one. In other words one hedge will reduce the wind velocity only just as far as to the next one.

Different opinions have been expressed regarding the minimum wind speed reduction which should be considered significant. This must depend to a great extent on the wind speed prevailing in the unsheltered area and also on the critical velocity values above which soil erosion occurs or plant growth is inhibited. Under normal circumstances a 20 per cent wind reduction is considered by the Danes as the criteria of useful shelter. With high velocities a much smaller reduction than 20 per cent may be significant whilst with hurricane or near hurricane force winds the whole micro-climate is destroyed.

Evaporation:

The rate of evaporation depends on the velocity of the wind, the temperature and the relative humidity of the air. Bodroff (1936) who writes with special authority on conditions in the Russian Steppes, attaches great importance to the effect of windscreens on evaporation which he regards as the best index of a shelter belt's efficiency. There seems to be general agreement that, on the whole, evaporation is much less in the lee than the open. The influence of stands on evaporation, as stated by Bodroff, extends over a distance which in wind velocities of 2.5 to 3 metres per second in the open exceeds 60 times the height of the windscreen and which amounts to 100 times the height of the windscreen in wind velocities of 5 to 10 metres per second.

According to some investigations carried out in Japan in 1950, reductions may extend over a distance of from 20 to 25 h from the screen. At a distance of 1 h from the screen, evaporation amounted to 40 per cent of the value in the open, at a distance of 5 h it was 60 per cent and a distance of 10 h it was 80 per cent. Other investigations have shown that windscreens affect evaporation not only through their influence on temperature and radiation.

Radiation:

A windscreen influences radiation in the adjacent field, chiefly through its shading. This shading has a counterpart in the reflection of solar energy against that side of the screen which is facing the sun. Reflection causes an increase in the amount of energy wherever it is caught by the surface of the soil or by the soil cover. At the same time a windscreen intercepts sky radiation. The percentage of its interception rapidly decreases with increasing distance from the screen. Though a low sun creates long shadows, the effects of shading are really restricted to the zones nearest to the screen and, practically speaking the radiation on the greater part of the sheltered area is the same as the open.

Dewfall:

Dewfall appeared to be 21 per cent higher between screens than in the open in the summer in Russia and increased to 30 per cent in the winter. This may be due to the fact that dewfall is closely linked with minimum temperature – the lower the minimum temperature the more the dew.

Soil Moisture:

Soil moisture relationships in areas protected by shelter belts are a complex combination of the effects of tree belts on the various climatic factors including precipitation from rain or dew, evaporation, transpiration, atmospheric humidity, air and soil temperatures and solar radiation. The trees within shelter belts, particularly on the margins also effect soil moisture directly, the distance to which this influence extends depending on the spread of the root system of the trees. It has been observed that the horizontal transport of rain is decreased in the lee and thus more drops of rain can reach the surface of the ground. This is likely to have effect only in these countries where rainfall is light and would not apply to local conditions where heavy showers are the rule. Since windscreens have a strong influence on evaporation it is only natural that they should influence soil moisture. Studies in Russia indicate for instance, that over a definite period, the soil moisture on a sheltered strip of ground 10 to 12 h wide was 25 to 30 per cent higher than in the open. At 20 h from the screen the influence reached zero, and in the neighbourhood of the trees the moisture content of the soil was 20 per cent less than in the protected field. When soil moisture studies were made by Franken, Van Eimern and Harries (1954) in Hamburg in the wet summer of 1952, they found that the average values in the lee and in the open were not very great. The influence of the screen became clear, however during dry periods and in the area 120 to 180 metres from the screen the loss of moisture was much greater than near the screen.

Effects of Shelter Belts on Crops:

Many writers have mentioned the higher crop yields which are to be observed in sheltered areas, the agricultural prosperity which is associated with regions sheltered by trees and the decline in productivity which follows upon the removal of such shelter. In order to obtain information regarding the economic value of shelter belts in raising the productivity of exposed regions, America, Denmark and Russia carried out quantitative investigations of crop yields during the earlier part of this century.

Generally, there is a decrease in the yield of arable crops within a narrow strip bordering the shelter belt due mainly to root competition and shading. This strip is not normally more than half the shelter belt height in width, whilst increased yields extend as far as 12 h on the leeward side. Oat yields in Russia increased by 25 to 28 per cent due to shelter provided by a 5-row shelter belt. Hay yields in protected areas were 100-300 per cent greater than those in the open Steppe. In Denmark certain crops showed percentage increases as follows:

Beet root	-	23.2
Cabbage	-	13.4
Turnips	-	6.5
Potatoes	-	16.9
Grass and Clover	-	24.1

On the exposed site, where shelter belts gave protection, potatoes have yielded a 21-24 per cent greater outturn in Germany and it has been concluded that if shelter belts take up to 5 per cent of the cultivated area,there is a 15 per cent gain if one reckons only a 20 per cent yield due to shelter belts. Yields ranging from 37 to 60 per cent have been recorded for tomatoes and beans in the U.S.A.

In Grenada shelter belts have been used in cocoa plantations and their use is spreading to other crops as well. In one particularly bad area near the capital city, the wind velocity is so high that over head shade is used to supplement shelter belts. This practice is also common in hilly areas.

Very little use has been made of shelter belts in this country. Perhaps the only serious work is to be found at the Orange River Agricultural Station, in the parish of St. Mary where Topper is attempting to show the effect of shelter belt planting on cocoa production in the area. Figures on yield will not be available for some time yet but there has been an obvious improvement in the health and vigour of the crop in the sheltered zone. The problem here however,is that in this hilly country there is much difficulty experienced in attempting to forecast the velocity and direction of the wind and this makes the design of the shelter belt a very tricky problem indeed. Topper is using single lines of trees, mostly of the mango variety with an aralia bush hedge.

From casual observations in pastures in the plains of Clarendon it seems that shelter planting is improving soil moisture relationships. This in turn is reducing the periodicity of watering and also increasing yields over a longer period from grass.

Discussion:

To the local farmer, the problem of shelter belts is first and foremost an economic one. He will, almost as soon as the subject is introduced ask whether shelter is really worthwhile and if it does in fact help his cattle, his crops, his vegetables or his fruit. These questions cannot be answered from information gathered from other countries such as those mentioned earlier. The answers will have to come from our own experiences and trials in this region. From the knowledge available however there does seem to be merit in undertaking experiments to determine some of the answers as soon as possible. The need is even more immediate when one considers that the agricultural policy of the country is aiming at rapid increases in production and general improvement in the standard of living of the farming community. As far as increased production is concerned, only in beef, pork, poultry and Irish potatoes has there been noticeable increases in Jamaica. The level of production in the dairy industry which has considerable potential in Jamaica both in terms of production and market possibilities has remained static for the last 10 years. As far as export crops are concerned, except for sugar and citrus, the position is little better.

It is suggested that the judicious use of shelter belts may in fact be one of the answers to this problem of achieving the objective of increased production - an objective which is so clearly stated in the nation's Five Year Development Plan.

Perhaps in closing I may quote in full item 5 of the Report of Technical Commission IX on Forest Influences to the 6th World Forestry Congress held in Spain in June of this year.

> " *5. The Congress took note that, in modern farming, the tractor is hungry for land and that wind is becoming more important in crop and animal production and farm life. Farmers (and foresters, too) are generally unaware of the influences and values of shelter belts. The Congress recognized the need for extension work in this field and also emphasized that shelter belt planning should be a part of general land use planning. Shelter belts should be considered a fixed investment in the production of agricultural crops, and crop losses close to the belt weighed against the increased field yields and the additional value of the belt for timber production and its other important influences.*

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PAPERS ON CLIMATE AND BUILDING DESIGNS

DESIGN FOR COMFORT IN TROPICAL ENVIRONMENT

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The late Dr. McCulloch in his book **Your Health in the Caribbean** writes that *Tropical environments place extra stress and strains on the human being, and it is necessary that we should understand them. To know their hazards is to be able to guard against them. We cannot change our climate, but we can modify the effects upon ourselves.*

To study how the macro-climate effects man's comfort in his self-created physical environment and to advise on how mal-effects can be circumvented or modified by design and mode of construction of buildings is the very exercise of climate studies within a building research organisation.

In the past, knowledge about climate: how it works and how to build for optional comfort and economy, was accumulated over generations. Shaped by masterbuilders it became general heritage which, blended with the local peculiarities, resulted the world over in regional architectural expressions of remarkable strength and functional sense. Although building in Jamaica may not have been particularly successful in creating a language of its own, such features as the 'Cooler' and the louvred wooden facades which are found in pre-war buildings in Jamaica are typical of this development.

Looking at the buildings being put up today in Jamaica this general heritage seems gone. Some of the reasons for this are obvious.

The enormous increase in pressure on the building sector has forced an industrialisation which has given us all possibilities of building faster, better and cheaper. Industrialisation, however, has introduced in rapid succession new materials and ways of construction for which no skilled labour force has been established and no tradition is available as guidance. Moreover almost every building is today being put up to a strictly economic brief which rarely leaves consideration for a thorough study of the functional requirements the building is going to satisfy. And the trouble is that the functional requirements have undergone radical changes too.

Climate and our daily life

Talking about design for comfort: a new design brief must be built up based on data and research. The tradition which guided us before is gone, and we cannot rely on common sense to replace it, because as I shall presently show, common sense is not what governs our behaviour in daily life in regard to climate anyhow. Other things come first in our considerations: social status, habits, "taste", costs etc.

Taking three issues which all are vital for our well-being, I shall try to expose the gap which exists between our actual behaviour and the behaviour common sense should have taught us to be the more sensible one. As speaker on behalf of common sense I shall be quoting Dr. McCulloch.

McCulloch, W.E. - Your Health in the Caribbean - Kingston 1955, Pioneer Press. 149pp.

Clothes: Dr. McCulloch says that in a coastal tropical climate *we should have as much of the skin exposed as possible for evaporation of sweat and that we therefore should wear open shirts with short sleeves. Coats should be avoided. Shorts are the only hygenic garment for use in hot weather.* Compare this with the attire worn by Jamaican men as soon as they get outside their homes 'on business': coat,shirt with long sleeves and tie; or with the uniform of the policeman: long black trousers,heavy shoes and black cap.

Furniture: According to McCulloch, *one small point that is usually overlooked is the effect of overcrowding a room with furniture. This overcrowding serves to collect dust and insects; it impedes the free circulation of air that is so vital and by absorption of heat in the daytime it keeps our rooms much hotter than they need be.* Compare this with the heavy chairs and sofas sold today with soft upholstery covered with plastics,offering a perfect steam bath for the seated person. The weight of this furniture makes housework more strenuous and foils attempts to move furniture out on the terrace or into the garden, when that is the coolest place to be.

Work hours: McCulloch recommends *a straight day from 7.30 a.m. to 2.30 p.m. with only a short break. This will result in an increase of both comfort and productivity.* I have personally worked under similar climate conditions for three years having a work day from 7 to 2 without any break at all. This offers an escape from the time-and energy-consuming and traffic-creating lunch break, allows your morning commuting to take place at cooler hours, offers the chance of a real siesta and the possibility of using the coolest day light hours for recreation activities allowing for a real long siesta for shop employer. Shops can be held open during the cool hours of late afternoon and early evening to the convenience of everybody and to the stimulation of city life.

Compare this with the arrangement we have in Jamaica: a work day starting at 8 - 9 a.m. and ending at 4 - 5 in the afternoon packing all commuter traffic into a short interval morning and afternoon with resulting traffic congestion; a heavy lunch traffic at peak hours which upsets the service traffic and brings back the workers more exhausted than they left; no shops apart from supermarkets and pharmacies are open after 4.00 p.m. One ventures to say that it looks as if the system as it operates has been arranged for maximum discomfort.

How should we build?

All that has been said so far is in fact only common sense. Still, as it appears, common sense does not play a very important role in the organisation of our daily life. No wonder, therefore,that also our houses, the most complicated and expensive part of our surroundings, are showing serious deficiencies in regard to climatic considerations.

In the hot humid climate the prime object of design is to prevent the temperature of the interior rising above shade temperature and to provide air movement through the building and at all activity areas.

Our houses should be oriented away from the sun and so that they catch the prevailing winds, and what may be more important, catch the day and night breezes which are so well supplied in Jamaica. However,care should be given not to let the air be heated on its way to the house by heavy terraces, unshaded walls and windows which accumulate lots of heat. To counteract unnecessary transport of heat to the interior the cooling impact from evaporation from grass, trees and other foilage should be employed.

The construction of the house and all sunshading devices must be light as to prevent accumulation of heat which then is emitted at night by convection (air flow) and radiation. All outside surfaces should be light in colour and especially the roof must be as highly reflectant as possible without offering any glare to our neighbours. To avoid glare from the sky and from surrounding buildings careful consideration must be given in design and planting.

Analysis of climate dictated requirements

We have however a growing number of architects by whom better design principles may be introduced. But somebody, *in casu* Building Research, must provide the data and the 'know-how'.

The exact climatic conditions of the place where you build must be considered in the design all the way from the decision by the town planner over the sub-division of land, and the orientation and situation of the building on the site, to the actual shaping of the building. As usual, remedies to compensate for initial short-comings are costly and very often have undesired side effects. As an example I can mention the solid awnings which are used throughout Jamaica to compensate for lack of overhang to shade the windows. These awnings give shade - but only of the window and not of the lintel or surrounding wall as a roof overhang would do. However, they also give a critical reduction of air-movement. The cost of these awnings moreover is very high - for a living room with two to three windows it may run to more than the price of an air-conditioning unit.

There seems to be a lack of critical analysis. In want of a new tradition we seem to adopt British and North American standards unconditionally, although they do not suit our climate.

Tradition must be replaced by careful analysis of functional requirements and of data and 'know-how' about how to fulfil these requirements, data which enables the technologist to make his choice as a balance between economy and performance.

For we must of course appreciate the great economic problems facing a community wanting to develop its potential and at the same time trying to meet the growing demand of the individual which is bound to follow such development in a democratic society. But I cannot accept that this is a justification for lack of will to develop a building practice which is climatically suitable for Jamaica.

How can we accept that the basic rules of climate design for comfort are too expensive to implement before they are even defined and the cost calculated and put down on paper? Building Research has indeed here a very important role to play.

Building itself affects climate

By the way, I do not quite agree with Dr. McCulloch's statement, that we cannot change our climate. At least not without qualification. Man does not change the climate, and that in fact is a major cause of trouble. Man-made erosion has an important impact on local climate. And so does his urbanisation. To build great urban districts with its enmassement of buildings and covered surfaces deserve very careful studies of design and landscaping. Climate recordings before and after the building of Brasilia, the new capital of Brasil, are reported to reveal a rise in average temperature of several degrees.

Also the way the individual building is designed certainly affects the micro-climate. I have showed negative examples of this, but there are positive as well (some of the buildings in the University campus come to mind here). That is the very idea of the whole exercise of climate design research: *to turn deterioration of living conditions by ignorance into improvements based on mastership.*

Research Programme

For the Scientific Research Council, I have been reviewing the situation in building, in order to give advice on the most urgent needs for research. The Council is now based on this, contemplating the start of a Design Development Group which should build experimental dwellings and later on other types of buildings.

The group as designed will besides architect and engineer comprise a work operations planner and a climate physicist. The physicist will be responsible for the proper climatic conditioning of the designs. He will have to follow type designs up with studies in experimental buildings and will undertake such other studies which he finds necessary to establish sufficient 'know how' for advice to designers and builders.

Of special studies we have in mind so far can be mentioned a study of how various types of roof insulation will influence the temperatures in existing dwellings. Further we are contemplating comparative studies of comfort in dwellings of various constructions: some with concrete block walls and either aluminium roof or concrete slab roof and some of mainly timber construction. A small pilot study in this area was carried out by a student of the Geography Geology Department and although insufficient equipment was used the results obtained indicated that different climate conditions were offered. It is also the intention to repeat the study at different altitudes. For practical reasons like transport costs we tend to use timber in the hills and solid concrete on the plains while from an assessment of the problem of accumulation of heat in the walls one should think that it should rather be opposite. Studies at various altitudes will be able to guide us here. They will also tell us of some of the advantages of building and living in the mountains.

Climate influences productivity

Whether or not we are comfortable while at work means a lot to us - and to the productivity in our work. So do our possibilities of rest and sleep at home. Do not let us fool ourselves therefore. In modern society calling for high productivity, stamina towards heat and humidity in working places is no virtue. The development of sound design principles and economic ways of air-conditioning is as important to the well-being of each individual as it is vital to the prosperity of the country.

I have not discussed air-conditioning so far. Principles of design for air conditioned buildings are well established in hand-books and taught at engineering schools. In housing the ambition must be to make air condition unnecessary as far as possible, by selection of where to build, orientation, design, construction etc. However, at low altitude in the humid tropics, for all other buildings than homes air-conditioning is not only a future possibility, it is there already. The control of climate which can be exercised with air-conditioning offers a good possibility of studying the effect of good (or bad) climate on productivity, studies which give a kind of yardstick for what can be gained not only by air-conditioning but by better design in general.

From abroad we hear about surveys showing up to 50% increase of efficiency after installation of air conditioning and of 25% increase of mistakes in certain types of precision work in hot seasons as compared to winter conditions (non-air conditioned buildings). In the journal *Air Conditioning, Heating and Ventilation*, the *General Services Administration of the U.S.A.* in 1956 reported an increase of summer output of 9.5% measured over two years after air-conditioning was installed. We know little to assess those figures, however, and considering the importance of local attitudes etc. I think local surveys and experiments should be made before anything definite is concluded. I should personally like to see a comparative experiment with school classes - one in air-conditioned and one in normal accommodation - followed through the entire secondary school, this being the field where the biggest impact on the future of the country may eventually be achieved. A recent pilot study of office climate made by a student at the Department of Geography indicated that even in generally hot working places there is a noticeable reduction of work efficiency in areas with absolutely no ventilation. The same study also points to the usual psychological resistance against anything new, which has to be overcome. Air-conditioning was believed to cause constant colds, etc. among respondents *not* having access to it, an objection which was found non-existent where air-condition was already installed.

Homes may be air-conditioned in the future; some are already. I still think that the possibilities offered by design and by selection of better sites for building (see later) should be exploited first. However for a long time to come people will have to live on the plains in the bad houses we have built for them and for these a cheap system of air conditioning should be developed. But that is another story.

Where to build

You cannot change the macroclimate, but you can select it; and in few places in the world are you in a better position of doing so than in Jamaica. As it reads in Handbook of Jamaica: *From tropical temperatures at the coast the thermometer falls to 40° and 50°(F) on the top of the highest mountains and there is a dryness of atmosphere that renders the climate of the mountains of Jamaica particularly delightful and suitable to the most delicate constitution.*

It has been done before. Brasilia is one example. But of course we shall have to employ other building methods in the hills than we use on the plains. Although it may appear that the presently popular building systems are suitable on the mountains I would advocate climate studies and practical experiments before large scale operations are undertaken; - and I seriously mean large scale operations. Kingston has mountain slopes with almost ideal climate which can cater for a metropolis only 10 - 20 minutes away by cable train or monorail. In this context I think it is regrettable that the University where we now are was not built on a higher altitude like for instance on the top of Long Mountain (1500 feet), Dallas Mountain or behind Skyline Drive, all locations which are just as close to the city as Mona.

I started off by illustrating some probable psychological road blocks against progress in design for comfort. However, given the right guidance from Building Research, I do not myself believe that they are very serious impediments. Jamaica although still economically imbalanced has reached a level of development, of which it is a typical symptom that people start to recognise that things can be changed, that it pays off to define one's requirements. After central heating was introduced on the continent, it still took the British two generations to find out, that one could live without discomfort. And thus we now see the appreciation of discomfort disappear as a British national virtue. I do not think that it will take long before Jamaicans may have surpassed the British in their appreciation of the value of building for comfort. Most people will undoubtedly agree when I say that Jamaica has much better natural possibilities of achieving climatic comfort than has Britain.

I of course believe Building Research has an important role to play in this development. What is more, considering what little and scattered research has been done on climate design elsewhere I think that Building Research in Jamaica, if we are successful in getting the staff we want, and get our four-point programme of data collecting - analysis - design - full scale experiments rolling, very likely would be able to take on a pioneering role in this field.

A Jamaican architecture

Careful analysis of our objectives in the light again of climate data and of knowledge about how climate works in regard to building design has an important side-result: it not only automatically leads to functionally better buildings, but when the analysis comes in the hand of the talented it may also lead to a new concept of architecture. As a matter of fact I think that it is here more than anywhere else that the chance of developing a Jamaican identity in architecture is to be found. If we shall break through the foreign imitations in architecture it must be by establishing the data peculiar to our local scene. How else?

Illustrations

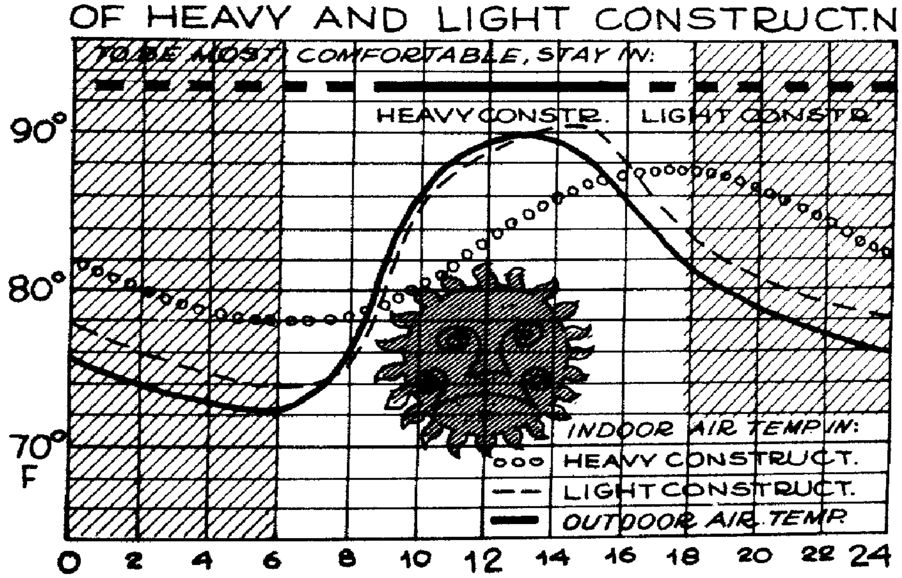
A series of seven figures is used to illustrate the major factors that must be taken into consideration in designing for comfort.

TIMELAG IN VARIOUS BUILD. MATERIALS

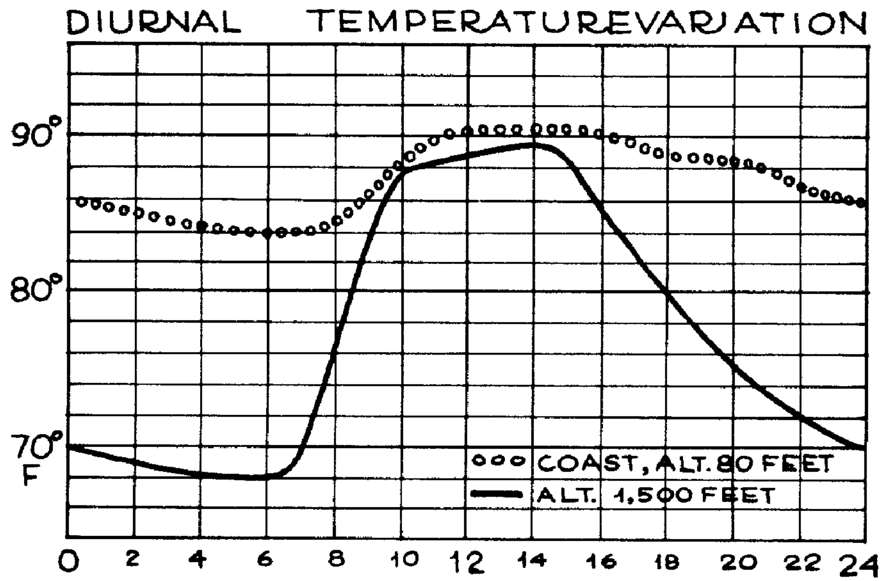
	THICK-NESS	U-VALUE Btu/SqFt/hr	TIMELAG HOURS
STONE	8"	0.67	5.5
	12"	0.55	8.0
SOLID CONCRETE	2"	0.98	1.1
	4"	0.84	2.5
	6"	0.74	3.8
SOLID RED BRICK	4"	0.60	2.3
	8"	0.41	5.5
	12"	0.31	8.5
TIMBER	½"	0.68	0.17
	1"	0.48	0.45
	2"	0.30	1.3
INSULATING BOARD	2"	0.14	0.77

1. **Overall heat transmission coefficient (U) and time lag in the rise or fall in temperature for different materials. The concrete roof used locally presents a time lag of approximately 2½ hours transferring by radiation the heat of midday to the interior of our houses around the time when the occupants return from work for a most necessary rest.**

DIURNAL TEMPERATURES IN HOUSES OF HEAVY AND LIGHT CONSTRUCT.N

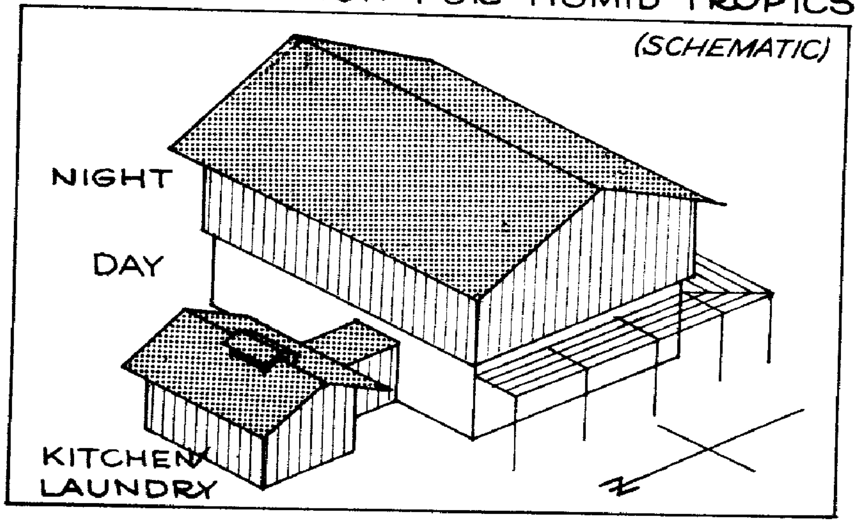


2. **Typified curves for indoor-air temperatures in houses of light and heavy construction (both left open for ventilation) at an altitude of 500 feet. Heavy constructions are adequate only up to 2-4 p.m. after which they become unnecessarily uncomfortable for the occupants and should therefore be used only for schools and work places. For evening and night use a light construction which more closely follows the outdoor temperature is to be preferred.**



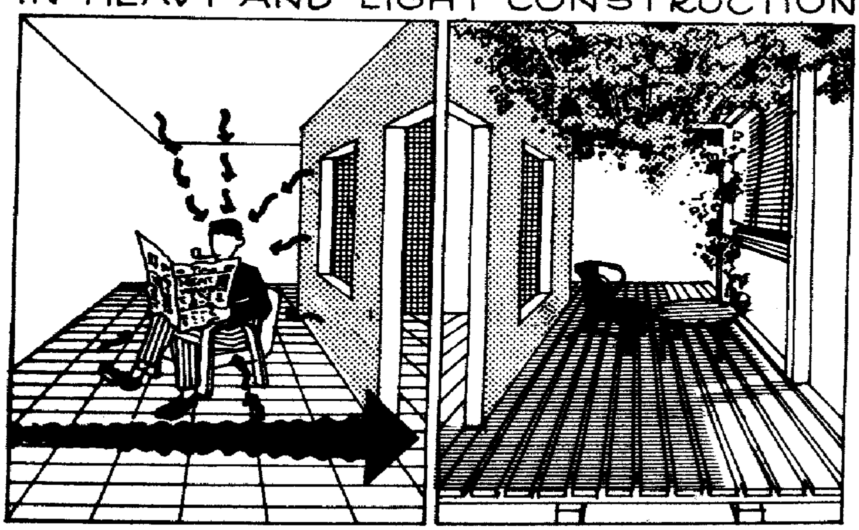
3. Diurnal temperature curves recorded same day at two stations near to Kingston, at the coast and at 1,500 feet above sea level. The curves illustrate the great differences in climate experienced in Jamaica within very short distances, and emphasises the need for an analysis of our various climates in relation to comfort criteria as a guidance for choice of building materials and ways of construction. In a hot humid climate the aim is to keep the indoor temperature from rising above the outdoor shade temperature. At the coast (dotted curve) this dictates a light construction with minimum of time lag, in order to exploit even the smallest drop in temperature. At higher level (solid curve) a light construction for evening quarters seems still to be required although some retainment of heat during the cooler nights may be desirable (can be obtained e.g. by using a tiled floor). At higher level (over 3000 feet) a heavy construction may prove advantageous for maximum comfort throughout. Studies to prove exactly how the building methods available in Jamaica reacts with regard to the comfort criteria at various altitudes will have to be carried out by building research.

CLIMATE DESIGN FOR HUMID TROPICS



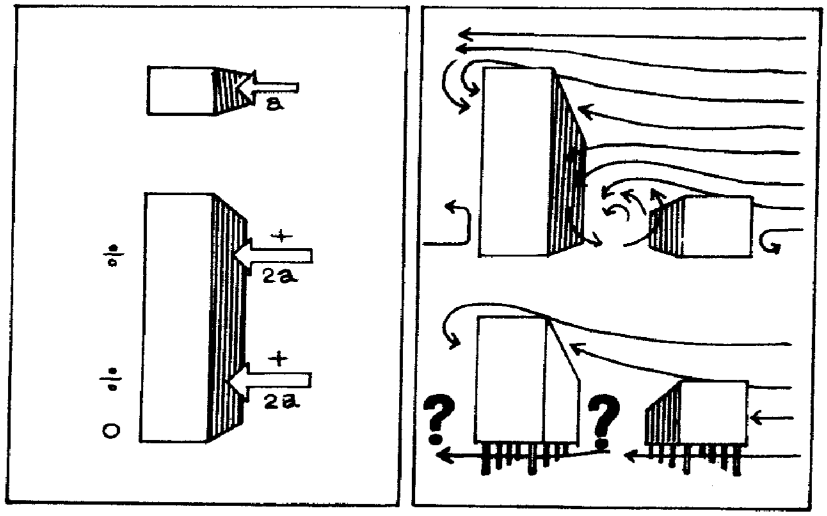
4. A house constructed with a view to day and night comfort: the night quarters on top are built of light materials which cool down quickly and at the same time protect the lower part (which is of heavier material) from the impact of the sun for maximum comfort during the day. Heat producing functions (kitchen work, washing) are placed in a separate building, of light material, provided with stack ventilation. Houses not very different from this were built in the old days. Examples are still seen in the country side and in older parts of the towns.

HEAT-ACCUMULATION AND -RERADIATION IN HEAVY AND LIGHT CONSTRUCTION



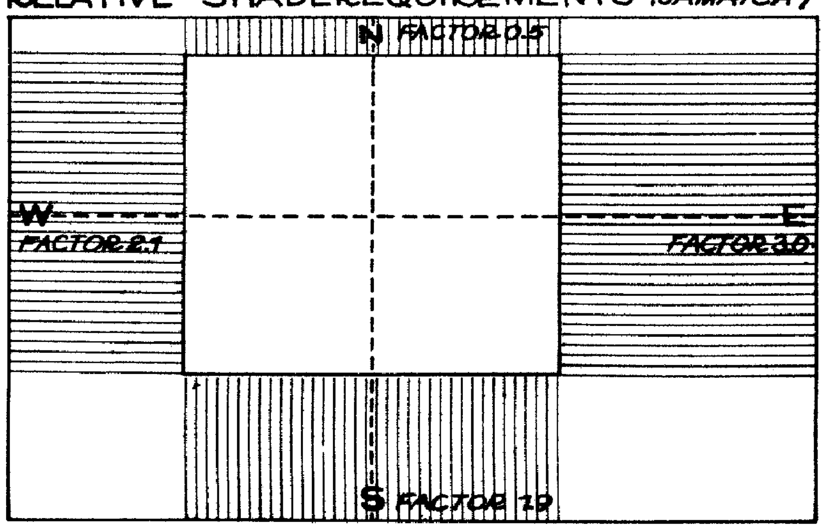
5. Heavy walls at roof (left) accumulate heat which is re-radiated to the residents in the late afternoon. A house of light construction (right) cools down quickly after sunset. Foilage does not accumulate heat, neither do rattan furniture and jalousies.

WIND SHAPES BUILDINGS -AND TOWNS



6. The wind is unwanted in cold and windy climates. In the humid tropics the wind, properly mastered by design and orientation, may be a blessing. The wind pressure on a tall building will at any place on this building be double the strength as on a low building. This explains why you want to get up in the heights in the tropics. On the other hand, tall buildings create negative air pressure to leeward and great pockets of still air. This is the reason why tall buildings must be carefully interrelated - in fact plans indicating heights and orientation should always be made for large sections of towns as entities. By raising the buildings on stilts free air movement may be preserved at ground level (winds are controlled by temperature differences - not air pressing toward cooler, shaded,areas; this can be utilized to strengthen the air movement).

RELATIVE SHADEREQUIREMENTS *(JAMAICA)*



7. The overhang needed to protect a vertical wall spacing either of the four main orientations (complete shade from 8 a.m. to 4 p.m.). The factors indicate the size of the overhang as multiple at the height of the wall. It is evident that north and south walls are the ones most easily protected.

HURRICANE PRECAUTIONS FOR TROPICAL BUILDINGS

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Research Council.

Mr. Chairman, Distinguished Visitors, Ladies and Gentlemen, it is a privilege to present this paper which may not have any new ideas for you but will no doubt stimulate interest to encourage others to follow some, if not all, of the suggestions put forward. This period could be regarded as the lighter side of the conference and if you look at your programme you will certainly appreciate this fact. The purpose of this paper, therefore, is to bring to attention ideas and practices which have been found to be useful and effective in preventing damage to property and loss of life by carrying out the instructions in respect of Hurricane Precautions for Tropical Buildings.

To the unenlightened climatology may be said to be the variations of the seasons due to vagaries of the weather. Some amount of concern is given to reports on rainy or sunny periods and how the recreational activities are interrupted. But from the point of view of the specialist such as you are, and working within the boundless limits of space, one must look on the wider horizon of many phases of the subject.Consequently the uninformed is made aware of conditions and it is our duty to take such precautions as will protect lives and minimize, if not reduce entirely, damage to property. This is a concentrated effort in the type of building and method of construction by which these ends are achieved.

The climate of tropical and sub-tropical areas is comparatively stable showing only slight seasonal changes. However, occasions of severe storms called hurricanes take place affecting houses from time to time. Origin of these hurricanes is generally in the Atlantic Ocean or Gulf of Mexico and the damage caused is not only due to the intensity of a particular hurricane but to the quality of workmanship and construction of buildings in the area as well as the lack of observance of warnings and precautions. Thus, although it is conceded that all damage cannot be eliminated yet it must also be agreed that a high percentage could have been avoided if ordinary everyday principles of sound building construction, such as the value of good foundations and the importance of ties between parts of the structure were observed.

It might be a good reminder to try and show the difference between a typhoon, tornado and hurricane as these form a group of disturbance sometimes confusing. The hurricane has been defined as a tropical storm with maximum sustained surface winds in its system of values of 73 m.p.h. and over. Thus the strength of the wind is the factor determining when any weather disturbance can be classified as a hurricane or not. The classical definition was given by the World Meteorological Organisation's Group on Tropical Meteorology for the Caribbean, Central America and Mexico at its meeting in May 1966, who recommended for adoption the following definition of a hurricane -

"In Region IV a hurricane is a severe, warm core type storm originated over tropical North Atlantic waters, the Caribbean Sea, the Gulf of Mexico or the Tropical Zone of the Eastern Pacific in the vicinity of the coast of Central America and Mexico with the following characteristics:

1) the air is revolving counter clockwise around a centre of low pressure;

2) somewhere in this primary circulation the surface wind speed, averaged over one minute, equals or exceeds 64 knots;

3) the centre of the circulation is normally recognized by an area of light winds, the eye of the hurricane;

4) the area associated with the hurricane with winds of 34 knots or higher will normally have a diameter of more than 50 km."

A tornado although physically possible in the tropics is very rare. It is essentially formed on land with an area of travel circumscribed by a diameter of few yards. It therefore bull-dozes its way over a narrow width and consequently the damage done is very heavy. On the other hand the size of hurricanes is of the order of miles thus presenting a major difference in its scale of movement. Consequently they affect wide areas with gradually decreasing damage. Furthermore, hurricanes are formed over the sea since they derive their source of energy from a warm atmosphere and require moisture to release the heat.

A typhoon is similar in character to a hurricane there being no basic difference in their movement. The only difference of note is area of formation - one in the Atlantic Ocean and the other in the Pacific Ocean. Thus the difference is rather in name rather than in scientific features.

Over and above all these observations hurricanes are generally accompanied by torrential rains thus causing heavy flooding of low lying lands making up-rooting of trees and overturning of shacks by the heavy winds a not too impossible task. Moving with a counter clockwise motion over an area of diameter of 80 miles and more they create a vortex or eye which moves calmly and slowly - 15 to 25 m.p.h. - relatively to the peripheral windspeed which may exceed 125 m.p.h.

The earliest recorded hurricane was in August 1689, and it is also recorded that "the English from their first settlement in 1665 to 1689, a space of 34 years were never affected with any of these terrible winds". Times when, between 1665 and 1885, hurricanes passed over or very close indeed to Jamaica as follows:

August 1689	27th August 1785
June 1692	20th October 1786
28th August 1712	12th October 1812
29th August 1714	1st August 1813
*28th August 1722	28th August 1813
22nd October 1726	*18th October 1815
*20th October 1744	*18th November 1818
2nd September 1751	3rd August 1832
31st August 1772	26th September 1837
*3rd October 1780	5th October 1844
*1st August 1781	*31st October 1874
30th July 1784	*18th August 1880

*Great hurricanes which caused widespread damage.

In Jamaica major floods are, most often, the direct results of hurricanes, tropical storms or possibly incipient tropical storms. In other cases floods occur most frequently in May and, primarily for the northern half of the island, November to March.

Major flooding or phenomenal rainfall not directly associated with hurricanes or tropical storms occurred during the following periods:

8-13th October 1879 (possibly due to a tropical storm)
early December 1885
6th June 1896 (possible due to an incipient hurricane
11-13th May 1916
31st January 1920
23rd-24th November 1937.

The hurricane season is regarded as from August to November and Table 1 gives a list of hurricanes (1886-1965) which passed near to, or actually hit, this island of Jamaica. Besides there are tropical storms which did not reach hurricane intensity and would have caused damage.

Table 1: Tropical Storms and Hurricanes with centre passing within 150 miles of Jamaica. Period 1886-1965.

Year	Minimum distance of centre from Jamaica	Direct hit track across island	Period
1886	90 miles SW		27th June
"	40 " NE		16th August
"	15 " W	E-NE (17th)	20th-21st August
"			17th-18th September
1887	15 miles W		17th May
"	150 miles SSW		23rd-24th July
"	60 " NE		6th August
"	100 " SSW		15th-16th September
"	120 " WNW		9th October
"	120 " NNE		11th-12th October
1889	70 " SW		14th-15th September
1894	90 " NNE (of most Northern pt.)		4th-5th October
1893	80 " W		5th-6th November
1894	120 " NNE		22nd-23rd September
1895	30 " S by W		24th-25th August
"		W-SW (19th)	18th-20th October
1896		S-SWW (25th)	25th-26th September
"	150 " NW of Wrn tip		4th July
1898		S-SSW (7th)	6th-8th October
"	20 " S		30th-31st October, 1st Nov.
1900	90 " N by E		2nd-4th September
1901	125 " SW		
"	80 " N by W		
1903		E-NW (11th)	11th-12th August
1904		Western tip	13th June
"	50 " W		13th-14th October

Year	Minimum distance of centre from Jamaica			Direct hit track across island	Period
1905	30	"	E		4th-6th October
1906	140	"	SW		20th-22nd September
"	100	"	S by W		13th-15th October
"	60	"	W by S		6th-7th November
1907	100	"	W by S		24th-25th June
1908	150	"	NE of East tip		28th-29th September
1909	20	miles	SW		16th-17th July
"	60	"	S by W		5th-7th August
"	40	"	NE		23rd-24th August
"	110	"	SW		15th-16th September
"	120	"	SW		7th-9th October
"	125	"	SE		10th-12th November
1910				E-Central-W	26th-27th August
"	10	"	N		8th-10th September
1911	35	"	N		24th-25th October
1912	80	"	SW		11th October
"				W-NW (18th)	17th-18th November
1915	15	"	N		12th-13th August
"	80	"	W by S		1st-2nd September
"	90	"	S by W		25th-26th September
1916				SE-Central-NW(15th)	15th-16th August
"	15	"	S by W		30th-31st August
"	60	"	S		12th-13th October
1917	35	"	N of NW coast		23rd-24th September
1918	55	"	SW		3rd-4th August
"	120	"	S by W		24th-25th August
1923	140	"	W		17th-18th October
1924				S by W-Wly by E	7th-8th November
1926	140	"	SW		3rd-4th October
1927	80	"	WNW		17th-18th October
1928				Southernmost tip(2nd)	2nd-3rd September
1930	140	"	N by E		4th-5th September
1931	140	"	S by W		13th-14th August
"	60	"	SSW		8th-9th September
"				E-Central-W	12th-13th September
1932				E-SE	28th-29th September
"	125	"	WNW		8th-9th November

Year	Minimum distance of centre from Jamaica	Direct hit track across island	Period
1933	55 " SW		1st-2nd July
"		N Coast (grazing)	16th-17th July
1933	20 miles SW		16th-17th July
"	80 " SW		19th-20th September
"	120 " W		2nd-3rd October
"		SW by S - NW by N	28th-30th October
1934		SE-Central-NW by N (20th)	20th-21st October
1935	35 " W		26th-27th September
"	40 " E		20th-24th October
"	45 " NW		
1938	40 " SW		11th-12th August
"	105 " SSW		23rd-24th August
1939	40 " N		1st-2nd November
1942	120 " SW		24th-25th September
"	20 " S		18th-19th September
"	60 " NE		13th October
1944		E-Central-W(20th)	20th-21st August
"	95 " S		26th-27th August
"	110 " W by N		13th-15th October
1947	40 " NW		20th September
1948	150 " E by S		22nd May
"	30 " W		18th September
1949		SW tip-NW	12th October
1950	40 " WNW		15th-16th October
1951	5 " S-SW		17th-18th August
1953	140 " NW		3rd October
1953	50 " S		23rd September
1954	100 " E by S		11th-12th October
1955	100 " NW by S		23rd August
"	90 " NW		14th-15th September
"	150 " SW		26th-27th September
1958	100 " NE		1st-2nd September
"	80 " NE		15th September
1963	115 " NE & 100 mls.NNW		(3rd-7th October)
1964	70 " NE		24th-25th August.

It will be noted that over a period of 80 years the centre of the hurricane was only 8 times over the island. On the other occasion nevertheless, the island was affected due to their proximity. Table 2 gives the observed frequency of North Atlantic hurricane occurrences from 1886-1963.

Table 2: Observed frequency of North Atlantic hurricane occurrences

Hurricanes, 1886-1900

No. of Storms	June	July	August	September	October	November	December-May
0	12	9	0	3	6	13	13
1	2	6	8	3	5	2	2
2	1	0	6	5	3	0	0
3	0	0	0	4	1	0	0
4	0	0	0	0	0	0	0
5	0	0	1	0	0	0	0

Hurricanes 1901-1963

No. of Storms	June	July	August	September	October	November	December-May
0	50	46	21	8	21	53	60
1	13	14	16	26	32	10	3
2	0	3	16	10	9	0	0
3	0	0	9	13	0	0	0
4	0	0	1	4	1	0	0
5	0	0	0	2	0	0	0

Tracking of tropical storms and consequently determining their positions are now being done primarily by observations from reconnaisance aircraft. This job becomes easier as the storms approach land and then radar control will take over. Thus it is not over-difficult to fix the eye or centre of the storm which is regarded as the point of lowest presure and because there is an extreme concentration of the heavy precipitation and strong winds near the centre of the hurricane every effort is made to track its centre as accurately as possible. It must be borne in mind that geographically a position-difference of as little as 25 miles may be very important in consideration of damage to life and property.

Since all this information is released within hours of a hurricane forming loss of life and damage to property can only be due to an attitude of complacency, of God will take care of us, or a disregard of warnings and advice or contempt for conforming to good and sound building practice. The following suggestions, therefore, are put forward for serious consideration and adaptation, if desired, firstly in respect of warnings etc., and secondly, in regard to building practices.

Warnings etc.

The precautions which are usually issued in the event of a hurricane warning for domestic attention so to speak can be outlined briefly as follows:

1. The availability of service organisations such as Red Cross, St. John's Ambulance, for casualties, displaced persons, etc.

2. Directions would be given for safeguarding ships, planes and any sea-going or air-borne vehicle.

3. Property owners would be advised to:

   (a) repair previous damage to shutters making sure they are strong enough to withstand the force of flying objects;

   (b) check for loose shingles, boards and other material which may be blown off;

   (c) batten up all buildings including sheds and lean-to additions;

   (d) cut down decayed trees and rotten limbs of trees which overhang or threaten to damage buildings;

   (e) store away such things as garbage tins, gas cylinders, loose lumber otherwise they will be carried by the wind to cause untold damage;

   (f) never try to make repairs from the outside of a house during the hurricane. If a door or window is blown out it would be better to open one on the other side of the building; and

   (g) clean up the premises as early as possible after the hurricane has passed.

4. Listening to radio or any means of public announcements should be regularly done.

Building Practices

FOOTINGS AND FOUNDATION WALLS

The design of footings and foundation walls is determined by soil conditions and if the site is sloping care should be taken to see that erosion of the soil does not cause subsidence and ultimate failure of the building. When a concrete structure is being considered the foundations are tied to the footings by hooked rods or by reinforcing bars which would extend to walls in corners, doors and window jambs. In the case of wooden buildings it will be necessary to fix sills to piers, foundation walls etc. by holding down bolts, strap bolts and such. By this means good resistance to uplift will be provided. (See sketches and photographs).

FLOORING

The flooring, that is floor boards and joists, should be securely fastened to the wooden sill which has previously been fixed to the foundation. Wooden joists when used with masonry construction are usually anchored to the wall with metal straps, twisted or otherwise.

WALLS AND UPRIGHTS

The roof and upper floors are supported by the exterior walls of a wood-frame structure. It must therefore be well braced against sway and lateral end thrust, two important considerations in hurricane resistant construction. In addition to withstanding the force of the wind the wall system serves as the link-up between footings and roof.

Ensuring good footings, piers and foundations is obviously not enough. Having used the reinforcement to tie the walls and/or blocks to the foundations a certain amount of safety is envisaged throughout the structure up to belt course for roof. In the case of wooden framing it is very important that the uprights be fixed to sills and plates. This is done by using U straps, knee or angles and since damage from hurricanes is likely to be worse in low lying areas adjoining the sea it would be advisable to specify galvanized material for this work.

ROOF FRAMING

If the roof is of reinforced concrete or similar construction there is no difficulty in fixing it to the walls which would normally be of reinforced concrete or blocks also. Weakness in this case lies in structural specification and workmanship.

On the other hand in the development of a hurricane resistant wood structure the most critically important details of construction are the fastenings for roof-to-wall connections. Loss of a whole roof or even part of it is generally the starting point for extensive and maybe total damage to the building. Resistance to forces on the windward side, provision against uplift on the leeward side and consideration of forces due to sway etc. of the walls must be taken into account so as to obviate or at least minimize damage.

There are many ways of fixing these fastenings. Besides those shown on the sheet there are the more elaborate and consequently expensive types. A metal strap can be used to tie rafter to plate and upright then nailing the ceiling joist to the rafter. The metal strap can be used to fix the joist to plate and upright then nailing the rafter to the joist. Double and single member plate connectors are commonly used. Besides these, the use of diagonals for rafters to ceiling joists and as cross ties or collar ties will help to strengthen the roofing system and provide good resistance to the onslaught of hurricanes.

ROOF COVERING

A last point which obviously is of paramount importance is the material with which the roof framing is covered, the quality of the material and the care with which it is laid. The roof covering is the first line of defence and if for instance shingles are poorly fixed and consequently are blown off or a material such as built-up roofing, asphalt shingles, tiles is badly and incompetently laid thus being lifted by the hurricane then the damage due to entry of water and even destruction of the whole roof and walls can be staggering. Worse, such damage almost without exception leads to loss of life.

This brief talk in no way covers all the details in which one can become involved when designing and constructing houses, buildings etc. to withstand hurricanes. The type of material used for external walls, sheathing and cladding are all factors against damage from wind action, flooding, floating and wind driven debris such as stones, tree branches and relatively small objects. The selection of a rugged exterior covering or the use of moveable shutters to protect glass windows are important factors of design.

It might be said that too much emphasis has been laid on timber framed structures. Experience has shown that:

(a) under severe hurricane attack structures built of timber throughout including cedar shingled roofs have suffered less damage than others;

(b) it is more economical to build in wood;

(c) control of quality of workmanship and material can be more easily exercised;

(d) an advantage of a timber framed structure is its ability to absorb shock and impact forces without failure due to the resilience of wood and the strength which is provided by the method of assembly and use of mechanical fasteners.

In conclusion, therefore, and in order that houses may be built to withstand hurricanes, the following simple but important factors should be observed:

1. Whatever is the type of material good constructional details and design are essential.
2. From experience gained and information available select proper material for use in the several sections of the building.
3. Insist on good standard nailing practices and carrying out of manufacturers' instructions especially with roof coverings.
4. Use special anchoring, metal straps and other forms of reinforcing the framework.
5. Observe the building regulations where they exist.
6. Carry out the warnings and advice given by your meteorological office when a hurricane is imminent.

It is hoped that these points will help to improve building practices and provide better structures which will resist hurricanes with minimum damage to life and property.

Acknowledgement

Deep appreciation is recorded for the help and advice given by Mr. Don Vickers of the Weather Bureau, Palisadoes Airport, Kingston, Jamaica in defining the difference between hurricanes and other tropical storms.

Recognition is also given for the opportunity to refer to and use photographs from:

U.S. Navy Weather Research Facility Task 12 "Improved Hurricane and Typhoon Forecasting Techniques".

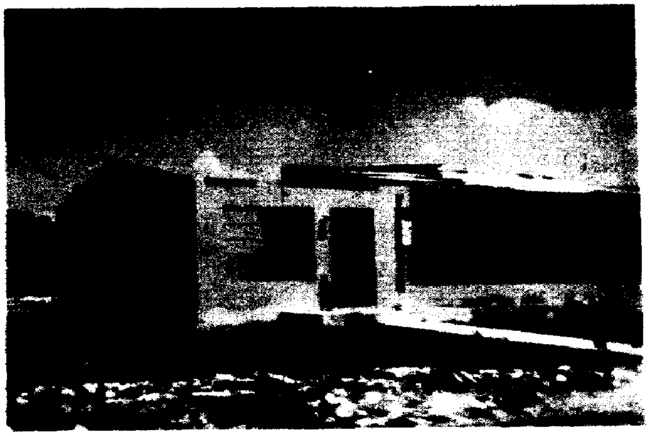
U.S. Forest Service Research Paper FPL 33 "Houses can resist Hurricanes".

World Meteorological Organisation, "Working Group on Tropical Meteorology for Caribbean, Central America and Mexico".

U.S. Department of Commerce, Weather Bureau Tropical Cyclones of the North Atlantic Ocean, Technical Paper No. 55.

Scientific Research Council - Technical Report 2/66, "Good Building Practice Prevents Hurricane Damage - A report on the effects of hurricane 'Betsy' on Nassau - 1965.

The pictures and engineering drawing appended to this paper were originally published in S.R.C. Technical Report 2/66 to which reference is made above.



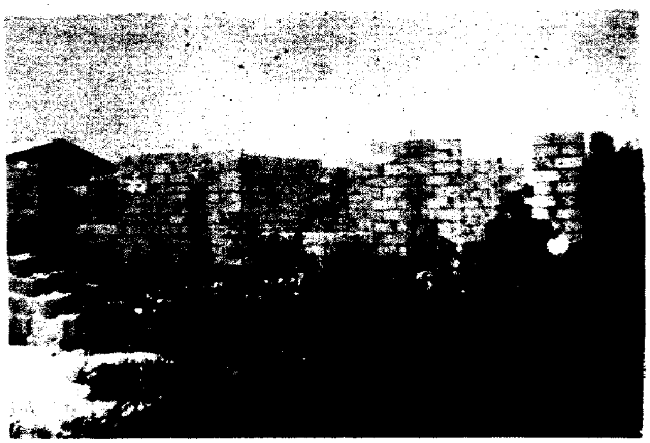
Roof lifted off. No holding down bolts or straps from rafter to plate to bolt. *Top left.*

House set on blocks. No damage because battened up. *Above.*

Note foundation is only an 8" block. An exception. *Left.*

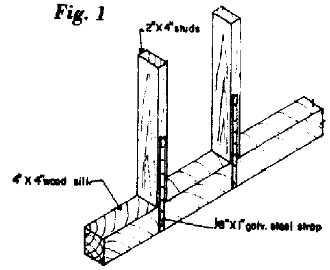
House in construction - Block walls not filled yet no damage. *Bottom left.*

House in construction - The damage to this building was caused from lumber blown against the wall. *Below.*



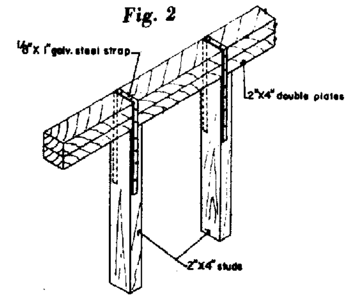
A series of photographs illustrating the effect of hurricane Betsy on buildings in Nassau was taken by the author. The pictures show the worst damage seen by the author and bear out the statements made in the report that (a) destruction could in nearly all cases be traced to careless construction (b) battening down helped save structures.

Fig. 1



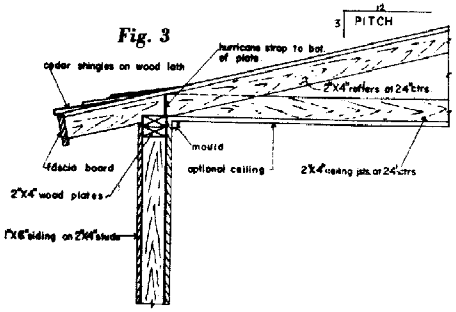
DETAIL scale 1" = 1'-0"
SHOWING FIXING OF STRAP ON STUD & SILL.

Fig. 2



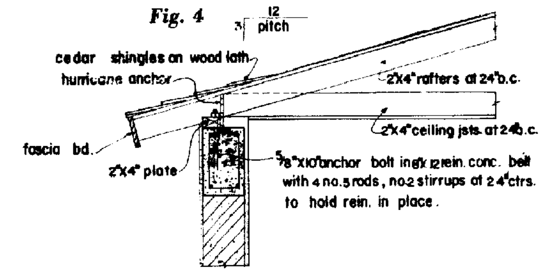
DETAIL scale 1" = 1'-0"
SHOWING POSITION OF STRAP ON STUD & PLATE

Fig. 3



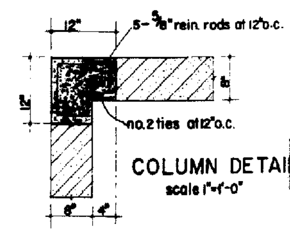
DETAIL A·A
scale 1" = 1'-0".

Fig. 4



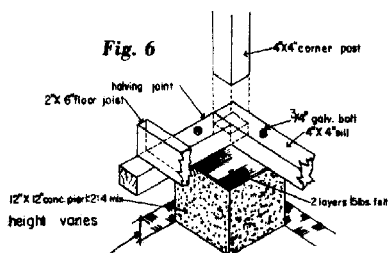
DETAIL A·A.
scale 1" = 1'-0".

Fig. 5



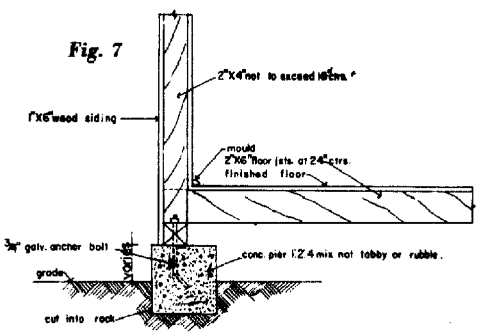
COLUMN DETAIL
scale 1" = 1'-0"

Fig. 6



DETAIL OF PIER
scale 1" = 1'-0"

Fig. 7



DETAIL C·C
scale 1" = 1'-0"

The engineering drawings were obtained through the courtesy of the Public Works Department, Bahamas, during a visit by the author to Nassau soon after Hurricane "Betsy" had struck. They are self-explanatory.

AN OVERVIEW

GENERAL TRENDS IN PURE AND APPLIED CLIMATOLOGY

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During the last few days we have seen and heard excellent examples of the general trends in pure and applied climatology. This conference has brought us all together to discuss very important problems.

I suppose the cause of this upsurge of interest has been that many more people are realising that there is such a thing as the environment. The old naturalist scientists of a couple of hundred years ago realized this, however, and came forward with very good ideas which have been lost in what I almost think of as the recent dark ages. If we went back to them we could get some remarkably useful clues. They had ideas as they were living with the environment. And so we now see a desire, especially in the universities and in the United States, to drop these ideas of geography, botany and meteorology and to speak of atmospheric sciences and environmental sciences, trying to get a whole team together but which succeeds only in getting confused because its members do not speak the same scientific language.

One part of the environment is the atmosphere, so that meteorologists have been drawn into the center of this. The term that is very often used is *biometeorology*, but this has different connotations in different countries. In some places it infers human aspects, simply the climate and human physiology; in others it has a wider connotation, the realm where the atmosphere and the biosphere meet, which leaves plenty of scope and an area so wide that you can cubbyhole almost anything under biometeorology. Bioclimatology, dealing as it does with longer periods of time, is perhaps a little easier to contain, for meteorology of any kind tends to be something of a transient thing. The old climatology consisted in taking a whole lot of numbers and saying, "The mean temperature at such and such a place is 80°F; The humidity is 70%". This was not really climatology, it was climography, and as such was just a descriptive thing. We did not try to get to the reasons for these things. But in the past decade or so, the emphasis even in climatic classification has been to make it practical, to get at the reasons why we have this climate or that; not simply that we get such and such numbers but *why* we get these numbers. In this way we are enabled to think of pure climatology as a science. A meteorologist was a very great one if he said, "Well, it is likely, maybe, possible, that it will rain today, if not here then somewhere else. That is the forecast". Now we are getting the meteorologist into a corner and saying, "Likely? How likely? You have to use terms of probability". And so the move in many countries now is to say, "There is a 30% chance of rain". Of course, you can still get away with this; you can say "I did not mean 30% of the time"! We have brought in statistics; this scares most people off and we have always got an escape hatch. But unfortunately we are going to have to bring it in, because we really have no alternative. We have to look at climatology logically and introduce numbers, percentages and probabilities, and it is quite simple to do so. We have plenty of climography - of information: we can group it, cut it, get numbers out of it and generally do various things with it and so make it into climatology.

It is how we interpret these final numbers, however, that is important. Take even one of the simple arithmetic means: how do we interpret it? Or consider this simple exercise in deduction: here you have parameters A + D, which lead to a third phenomenon I; B + D, which lead to a third phenomenon I; C + D, which lead to a third phenomenon I. A simple link-up between variables and the result. You will think automatically that D is the phenomenon which gives rise to I because it is the common factor and then dismiss it from your mind. But if this is rum + ginger, brandy + ginger, and whisky + ginger, you will have deduced that it is ginger that leads to intoxication! You see, we have to be very careful as odd probabilities have come up; A, B and C are all related to I but D is not. David Smedley in his paper shows how those tables with different variables must be dealt with; we have to look at them in terms of *probabilities*. If we say that station A has an average temperature of 60° for June, it could mean that it could go as low as 40° or as high as 85°. To know the probabilities that it will, we must know the distribution; then we can rule off a 90% probability or a 50% probability. When we look at the hydrological problems which Mr. Simpson introduced to us this morning, we are dealing with wider distribution, and if we say that we want to put in the 100% line then we have to have a very long arm which stretches out to infinity!

It is, then, interpretation which matters; we have to look at all these climatic elements, analyze and understand their distribution. A climatologist can do this at the desk, working away on his own, getting the information, integrating and analyzing it. But he *must* have the assistance of people working in the field to tell him what he should be doing. And we have seen in the last few days that it is double relationships which are often the most important, double variables, or *bivariants*. If we think about shelterbelts, then we will want to know something about wind speed and wind direction and how much they vary. We might not use the right combination to deal with some important applied problem if we are just sitting away in some little corner. We have to have the assistance of people who will tell us "we need to relate A and B". This is the trend in climatology, but it is patently obvious from complaints in the papers at this conference that we fall down badly in that we do not always measure the right things. We do not measure soil moisture in enough places. We have many complaints that we do not measure atmospheric charges. These are supposed to have a large influence on how we feel, on lung diseases, and on how our rheumatism is playing us up. So we have to be educated.

Let us look at the practical side of some of the work going on. I would like to refer to work at Texas A and M University in the applied field which began out in East Africa with a peanut scheme. If we take a rainfall map, even assuming that the isohyets are drawn on it with accuracy, this does not tell us the probability of getting something else at that place. Peanuts will grow marvellously in areas with 25 - 35" rain fall, so this area of Tanganyika was delineated and the peanuts put in there. What happened was that one year in four we had 40", the other three we had 15". At the end of the fiasco it cost nearly £1 a peanut! So the underlings were sacked and the hierarchy raised to the peerage. We have to know the probabilities, the chances in an area with 25" mean of getting 25" or more. It may often work out at one year in three. To know this, however, we must have sufficient data to compute the distribution.We have tackled this from various statistical aspects; it is also being done by the personnel of the Weather Bureau.

Another phenomenon concerning which we would like more information is the beginning and duration of the rainy season. We must first rather arbitrarily define the term rainy, taking 2" or 10" or whatever figure seems appropriate as the break point. This is what we did for a number of stations in East Africa: [*diagram displayed*] every five day period with rain according to a certain definition was made a white block and the rest were black; a time scale comprised the horizontal axis. The forty horizontal lines of blocks represent forty years of data, one for each year. In this area the rain usually began in March and ended in May and there were also November - December rains. But any one year might be quite different. We can either present this data in graphic form so that the kind of variation experienced can be visualized, or we can try and present it statistically. So we add the little squares vertically, compare white with black and reduce to a percentage,and so obtain a distribution index. We can then say that there is an 85% probability that the rains will begin between this and that date.

There is one frequency distribution curve which seems to hold up everywhere in the world. If you take the total number of rainy days, say over a 30 year period, and call this 100%, then rank these, starting with the smallest amount and plot how much contributes to the total, you will find that regardless of the synoptic patterns giving rise to the precipitation, 50% of the rainy days give only 10% of the rainfall. This curve can be used as a sort of heavy rain forecast.

Then we have the recently-developed analytic tool of harmonic analysts, the use of which enables the influence of individual factors to be separated out from the whole. If you believe, for example, that the ITC gives rise to rainfall, then the average movement of the zone can be calculated by this method. If it passes over a station and then at a later season returns, you can expect a double maximum; this can be analyzed in terms of time and amount. We utilized this method quite successfully with rainfall regimes in Central America. Two concepts are put to use here: the first is the *amplitude*. With 2" per month the amplitude would be zero,with 3" in some months and 30" in others it would be large. The amplitude gives us some idea of the intensity of the phenomenon. The other concept used is *phase angle:* this means the time at which the particular phenomenon reaches its maximum influence. In June, for example, the phase angle would be 180° - half of 360°. Finally, we test the honesty of the method and find out what part of the empirical pattern is left unexplained. We can then identify the odd areas where special factors apply.

What are the major fields for application of this quantitative climatology? I think we must put agriculture first. The agriculturalist wants the climatic data interpreted: he wants a graph, a nomogram, or a diagram of some sort – a kind of package deal. This we can provide if we know the problems. Another aspect associated with agriculture is climatic modification artificial creation of rain, frost prevention, reduction of evaporation, and shelter belts which must be put in the right place to work efficiently. But unfortunately, if anyone starts looking into the literature on these applications, confusion awaits him because he soon finds that while A has found out one thing, B with the same data has found out the absolute opposite. So he realizes that they are all fools and he must do it himself - so he joins the club! Part of this is due, however, to an aspect which has been so far hardly mentioned here - instrumentation. A thorny problem! I think that the meteorologist should be in a position to give advice on instrumentation, but usually he is not. He says, "Take a thermograph, take a thermometer, a whirling psychrometer". These things, however, just will not do for most micro-climatological and micro-meteorological investigations. We have to use other things, we could call them more sophisticated perhaps, such as thermocouples, thermistors, and so on. As they are not normally used in meteorological investigation, the meteorologist keeps away from them. But he *ought* to be able to advise on instrumentation and to say, for example "What you need to measure temperature in this case is a thermocouple inserted in a hypodermic needle. Then you can put it into the leaf". We need to know the snags and the accuracy; this is most important as a lot of our measurements are being taken with instruments which are not accurate.

Let us pass on to another application - building. We have had some very interesting papers on building. We have seen how factors like wind speed and radiation play a role in this. But where do you measure the wind? There are quite a few states in the U.S.A. which do not have any radiation measurements. The best networks of radiation stations are in South Africa and Austria. There are only four or five hundred radiation stations throughout the world. Since what we are really looking at in so many of our problems are heat balances and water balances, radiation is of key importance and we are impeded, because we do not have these measurements. Radiation gives us our pressure patterns, hence wind flows and consequently changes in humidity, the amount of moisture uptake into the air and its distribution. So many of these other data depend on radiation, measurements for which in some areas could be written on the back of a postage stamp.

Then there is human comfort and this business of comfort indices. A short while ago I was told that I had to review how many different ways there are of expressing the comfort of the environment on the human. I found more than twenty that are in general use and you can imagine the confusion when many of them have the same name. One of the favorites is 'equivalent temperature' and there are three different forms of this. There is no integration; we are all going on our own sweet way, and so we find confusion when we get together again as we are doing now.

What are we doing about this getting together? I think the society that is doing most is one which started just ten years ago, 'The International Society of Biometeorology'. We had our foundation meeting in Paris in 1956 and have held four congresses since, one of which I have just attended - in New Jersey, the first in the Western hemisphere. The membership of about 1,000 consists of scientists from all over the world even behind the Iron Curtain, who are interested in these applications which we have been considering here. They are from all interested disciplines and consequently we have the possibility of interchange of information. This is also kept up by the journal, 'The Journal of the International Society of Biometeorology'. We try to use the Society and the Journal as a sort of clearing-house of information. If a member requires help on a particular research problem, he can circulate the Society indicating his interest in, let us say, shelterbelts, and he is bound to get one or two responses – usually in foreign languages. You must, of course, put in equations and diagrams! At our meetings we are trying to get away from just presenting papers, and rather to get down to discussing common problems. It seems characteristic that people can only get money to attend a conference if they are going to present papers. Someone suggested – and it is a marvellous idea – that, for the first quarter of an hour, everybody gets up and reads his paper to satisfy his organisation and after that sits down and gets to work. It is only by discussion in coffee sessions that we really get at the real things.

Texas A and M University is interested in the organisation of tropical studies; about twelve universities, mainly in the U.S.A., are trying to develop a uniform program to interchange students and staff in the Caribbean region, Central and South America in important practical fields. The only aspect that is really well organized at present is biology. The only university with which we have a good interchange at present is the University of Costa Rica at San Jose. This is now being remedied; we hope that climatology will be the next aspect that will be developed, we hope with the University of the West Indies. Interchange for a reasonable period, two months or more, so that we can work together on practical aspects is what we need most.

There are many committees being formed all over the world to study these applied problems. The Weather Bureau, now ESSA, has quite a number of advisers around the U.S.A. We have two in Texas who work in liaison with people studying specific problems in the area of applied climatology. There is a tendency to draw more meteorologists and climatologists in these committees. Of our delegates here one is on a committee for the air-conditioning and refrigeration, and I am chairman of one for the Building Research Institute of America. The problems are being increasingly realized. Meanwhile in supplying the answers we have hardly begun. As in this conference, we are talking together. Ours is just a sample of a population which is asking questions. So let us all get confused together.