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TECHNICAL REPORT

EP-94

Canal Zone Analogs

ANALOGS OF CANAL ZONE CLIMATE

IN

SOUTH CENTRAL AFRICA AND MADAGASCAR

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Major General Andrew T. McNamara
The Quartermaster General
Washington 25, D.C.

Dear General McNamara:

This report, "Analog of Canal Zone Climate in South Central Africa and Madagascar," is the fifth of a series of studies comparing the climates of tropical areas with the climate of the Canal Zone.

The report presents information for military planners and test personnel on the extent to which the climates of Balboa Heights and Cristobal in the Canal Zone resemble those of South Central Africa and Madagascar. Thus it suggests the applicability to other tropical regions of the results of clothing and equipment tests conducted in the Canal Zone.

Sincerely yours,


C.G. CALLOWAY
Major General, USA
Commanding

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HEADQUARTERS QUARTERMASTER RESEARCH & ENGINEERING COMMAND, US ARMY
Quartermaster Research & Engineering Center
Natick, Massachusetts

ENVIRONMENTAL PROTECTION RESEARCH DIVISION

Technical Report
EP-94

Canal Zone Analogs V
ANALOGS OF CANAL ZONE CLIMATE
IN SOUTH CENTRAL AFRICA AND MADAGASCAR

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Geographer

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Prepared for the Environmental Analogs Project (8-97-10-004)
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July 1958

FOREWORD

A successful research, development, or training program requires a knowledge of the extent of environmental representativeness of test sites and training areas. The Quartermaster Corps, at the request of the Corps of Engineers, Waterways Experiment Station, under a directive from the U. S. Army General Staff, is developing a generalized comparative climatic picture of the wet tropics throughout the world by a series of tropical analog studies. The series parallels another already completed which presented comparisons between Yuma, Arizona, and the various desert regions of the Northern Hemisphere.

This is the fifth report of the tropical series. It compares the Canal Zone climate with that of South Central Africa and Madagascar, and by so doing provides a climatic reference for military planners and test personnel.

AUSTIN HENSCHEL, Ph.D.
Chief
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ABSTRACT

The climate of South Central Africa and Madagascar is compared with that of two localities in the Canal Zone: Balboa Heights, representing the drier, leeward, Pacific side of the Isthmus of Panama, and Cristobal, representing the wetter, windward, Atlantic side. Distribution of areas of analogy of pertinent climatic elements and combinations of these elements are shown on maps. The only area in South Central Africa that is analogous to either of the Canal Zone stations is the outer periphery of the Congo Basin, north of 7° S latitude and westward to the Atlantic Ocean; it is analogous to Balboa Heights. This analogous area does not have as much rainfall as Cristobal. Some of the higher areas which are analogous to Balboa Heights in precipitation are too cold for temperature analogy. The area of analogy for the mean temperature of the warmest month is much larger than the area of analogy for the mean temperature of the coldest month. The study area has greater mean daily ranges of temperature than the Canal Zone. An area in the most continental and equatorial part of the Congo Basin is not analogous because of too many wet months. For mean cloudiness of the wettest month and relative humidity of the driest month, analogy appears to exist between the Canal Zone and much of the study area, but not enough data are available to draw firm conclusions.

ANALOGS OF CANAL ZONE CLIMATE IN SOUTH CENTRAL AFRICA AND MADAGASCAR

1. Purpose and scope

This report is the fifth study of a series comparing the climate of Cristobal and Balboa Heights, Canal Zone, with other tropical regions of the world. These two stations were selected to represent respectively the climates of the Atlantic and Pacific portions of the Canal Zone. The environment of Cristobal is described in a previous report (Wiley and others, 1955).

No attempt has been made to provide a regional climatology of South Central Africa and Madagascar. Instead, the method has been to select certain climatic elements that are considered particularly significant and for each of these, to map the areas within the region considered closely analogous to either Balboa Heights or Cristobal. Some of the information presented on these maps of single climatic elements has been consolidated into two composite maps, one for each of the two Canal Zone stations, showing areas where there is a coincidence of analogy for up to four elements.

2. Delimitation and geography of South Central Africa and Madagascar

South Central Africa comprises that part of the African continent from the Equator south to $26^{\circ} 58'$ S latitude (near Vryburg, Union of South Africa), including the island of Madagascar (Figure 2). All areas in southern Africa which have climatic conditions analogous to the Canal Zone stations are north of this latitude.

a. Topography

This area is made up of 18 regions and many transitional sub-regions. They are: the Cameroons-Gabon Plateau, the Western Coastal Lowland, Angola Plateau, Congo Basin, Rift Valley System, Central African Plateau, Kenya Highlands, Somali Plateau, Eastern African Plateau, Kalahari Desert, Okovango Basin, Veld, Southern Rhodesian Plateau, East Coastal Hills, and Mozambique Lowland Plains. Also included are three regions on Madagascar: the Western Coastal Lowland, the Central Highland, and the Eastern Coastal Lowland.

The Cameroons-Gabon Plateau in French Equatorial Africa, forms the northwestern boundary of the Congo Basin. This low plateau, the southern extension of a larger system to the north and west, contains broad valleys of streams such as the Ogowe and the N'Goume. The maximum elevation of this part of the plateau is about 4,500 feet, and most of the area is above 2,000 feet.

The Western Coastal Lowland is a relatively narrow region with its greatest breadth to the north along the Ogowe and Congo River deltas. In the northern part, the lowland extends inland for nearly 150 miles. All of this area is below 1,000 feet in elevation, with occasional monadnocks in the north which are outliers of the Cameroons-Gabon Plateau. The rivers, except for the Congo, are relatively short and begin in the Angola or Cameroons-Gabon Plateaus. Most of this region is of low relief and without interruptions except in the north where the dissection of the Cameroons-Gabon Plateau is much greater than in the Angola Plateau.

The Angola Plateau forms the southern and southwestern peripheries of the Congo Basin. It is a large region and well drained, draining north to the Congo, west to the Atlantic, and southeast to the Ckovango Basin. Elevations within the plateau are in excess of 3,000 feet, with a nodal mountainous area of over 7,500 feet near Nova Lisboa. These mountains, which lie in the central part of the plateau, have a peak elevation of 8,563 feet. On the Atlantic side, the Angola Plateau rises about 25 miles from the coast. The streams flowing to the Atlantic are relatively swift; those flowing north to the Congo are broad and slow because they rise on a gradually rolling surface.

The Congo Basin is the largest region in South Central Africa. It occupies most of the Belgian Congo and parts of Angola and Northern Rhodesia. The dominant feature in this region is the Congo River and its many north-flowing tributaries. To the west, the river has cut deeply into the surrounding rocky rim of the basin. The eastern edge of the basin ends abruptly at the foot of the north-south trending escarpment of the volcanic Central African Plateau. In the south, the Congo Basin ascends gradually to the height of the Central African and Angola Plateaus which separate the drainage of the Congo and the Zambezi Rivers. Higher elevations occur in the southeast, north of Elizabethville in the Chine des Mitumba mountains, 5,000 feet in elevation. Swamps and poor drainage characterize the center of the basin, especially along the lower course of the Congo River.

The Rift Valley System has three major segments: the Great Rift, the Western Rift, and the Eastern Rift. The rifts are the most striking relief features in South Central Africa. The Western and Great Rifts are wide, deep, steep-sided, and occupied by large water bodies. The Western Rift has Lakes Edward, Kivu, and Tanganyika within its boundary, while the Great Rift contains Lake Nyasa and the Shire River, which flow south to the Zambezi River. The Eastern Rift is not as steep, has less relief, and is narrower than the other two rifts. Several small lakes occupy its floor, including Eyasi, Natron, and Magodi.

These rift valleys lie from 500 feet to more than 10,000 feet below the surrounding maze of mountain topography, the large block

mountains of the Kenya Highlands, the recent volcanic extrusions, and the few plateaus of Tanganyika.

The Central African Plateau lies east and north of the Angola Plateau and between the Eastern and Western Rifts. The most prominent feature of this high broad area of rolling surface is Lake Victoria. Almost all of this water body is south of the Equator between the Kenya Highlands and the Western Rift Valley. Gentle relief produces extensive swamps along several rivers and Lake Bangweulu, and the shore line of shallow Lake Victoria is constantly changing.

The Kenya Highlands are bisected by the Eastern Rift Valley. The major peaks in this region, Mt. Kilimanjaro (19,565 feet) and Mt. Kenya (17,040 feet), are the highest in Africa. Surrounding these peaks are table-top mountains, which have elevations in excess of 5,000 feet.

Only the southern edge of the Somali Plateau is within this analog study area. It consists of low, rolling, semidesert terrain which gradually descends to the coast of the Indian Ocean from an altitude of only 1,000 feet near the foothills of the Kenya Highlands.

The Eastern African Plateau is a lower southerly continuation of the Kenya Highlands, 3,000 to 6,000 feet in elevation. Several mountainous uplands modify the hill and valley landscape. This region is along the eastern edge of the Great Rift Valley and is situated in the territories of Tanganyika, Nyasaland, and Mozambique. The area along Lake Nyasa is extremely mountainous.

The Kalahari Desert lies between the Veld and the Okovango Basin in the southwest portion of this analog study area. Most of this region is arid, and inclines southeastward toward the Veld. Elevations in this region are between 2,500 and 4,000 feet, and much of the area is poorly drained.

The Okovango Basin is an ill-defined, shallow valley system at the headwaters of the Zambezi River. During the rainy season, the region is inundated by the tributaries of the Zambezi River. The rainfall varies from year to year to such extent that the maximum amount changes markedly from year to year.

In the extreme southern portion of the study area is located the Veld, a plateau nearly all of which is above 4,000 feet in elevation. The plateau is almost flat for large stretches, and in other places it is rolling with low, flat-topped hills rising from the surface. The Veld is drained mainly by the Limpopo and Olifants Rivers.

The Southern Rhodesian Plateau, which occupies most of Southern Rhodesia, is drained by the Zambezi River in the north, and the

Limpopo River in the south. The Plateau, mostly above 4,000 feet, is a surface of low relief, bordered on its eastern edge by a northwest-southeast trending highland which rises above 5,000 feet.

The East Coastal Hills, north of the Mozambique Lowland Plains, lie behind a very narrow coastal lowland. In the interior the land, mostly above 3,000 feet, is rugged like the Eastern African Plateau.

The southern part of this region is highly dissected, and expanses of land at altitudes of 1,500 feet to 3,000 feet are interrupted by many individual mountains of over 5,000 feet. The region is drained to the Indian Ocean by the Rufiji, Ruvuma, Rio Msalu, and the Rio Lurio. All of these rivers are relatively short. Their headwaters are in the Eastern African Plateau about 300 miles inland.

Southeast of the Southern Rhodesian Plateau is the Mozambique Lowland Plain which extends inland approximately 300 miles along the Zambezi River and almost the same distance along the Limpopo River. Most of this region is included in Mozambique. In general, it is less than 500 feet in elevation, and has relatively poor drainage. A large part of the plain, especially along the coast, is composed of alluvial deposits from the two great rivers, the Zambezi and the Limpopo. Many other smaller rivers drain directly into the Indian Ocean.

There are three main regions in Madagascar; the Eastern Coastal Lowland, the Central Highland, and the Western Coastal Lowland. The narrow Eastern Coastal Lowland, abutted abruptly in the west by steep highlands, is the smallest of the three major regions and the most homogeneous in physical composition. It is 750 miles long and less than 25 miles wide, and is flat, poorly drained, and sandy.

The Central Highland is composed of many sub-regions on a crystalline platform, including the Tsaratanana Massif, the Ankaratra Highland, and the Vohimaint Highland. The average elevation of the highland is about 7,000 feet, and the highest mountain rises to more than 9,400 feet. The western slope is gentle in comparison with the steep drop to the east. The major interior cities are found in basins on the platform. The Ankaratra Highland in the middle of the island is the core area of this region. Falls and rapids mark the end of the Central Highland, and several rivers cross the alluvial lowlands on the western slope of the highland. In the northwest, the edge of the highland is almost 100 miles from the coast.

The Western Coastal Lowland is a broad region marked by low-lying mountains and hills, especially in the southwest. In the north, the hills merge with an extensive broad lowland less than 600 feet in elevation. The extreme southwest portion of the island, in the lee of the southeast trade winds, is arid.

b. Climate

A January low pressure area centered in the Kalahari Desert, and a July low centered in the Libyan Desert and Nile Valley, in conjunction with the Southeast Trade Winds and the equatorial low pressure belt, produce the following conditions which modify the climate of South Central Africa:

- (1) The intertropical front running east-west within the Congo Basin all year, though it is north of the study area part of the year;
- (2) Prevailing south-southwest winds on the west coast paralleling the cold Benguela Current;
- (3) Prevailing southeast winds along the east coast somewhat influenced by the Asian monsoons;
- (4) Invasion of hot, dry air from the north during the northern summer.

The intertropical front migrates north and south of the Equator annually, producing two wet seasons for some stations within this migration zone.

The Benguela Current flows north along the South Atlantic Coast almost to the Equator. The cool, foggy seacoast and the nearly rainless desert of Southwest Africa are, in part, the result of the cold northward-flowing Benguela Current. The east-moving Guinea Current, with temperatures of over 80°F, brings excessive heat and humidity to the coast in the western equatorial portion of the study area.

Local orographic rainfall is found in the Kenya Highlands and the seaward slopes of eastern Madagascar. The east coast of Africa, on the lee side of Madagascar, is drier.

3. Climatic Summary of the Canal Zone

The Pacific portion of the Canal Zone, represented by Balboa Heights, has a moderately humid, tropical climate with a relatively dry season of four months (Fig. 1). The difference in mean monthly temperatures of the warmest and coldest months is only 2°F, and the range from the highest mean daily maximum (March and April, 90°F) to the lowest mean daily minimum (February, 71°F) is only 19°F. The mean annual temperature of 79°F is typical of equatorial areas. Precipitation, averaging 70 inches annually, is markedly seasonal. Two months, February and March, have less than 1 inch of rainfall, and 5 months have more than 8 inches. The dry season begins in December and ends in April. Rainfall during the remaining months is more than 7 inches; October and November both have more than 10 inches. Relative humidity is high from June through November. Cloudiness is at a maximum from

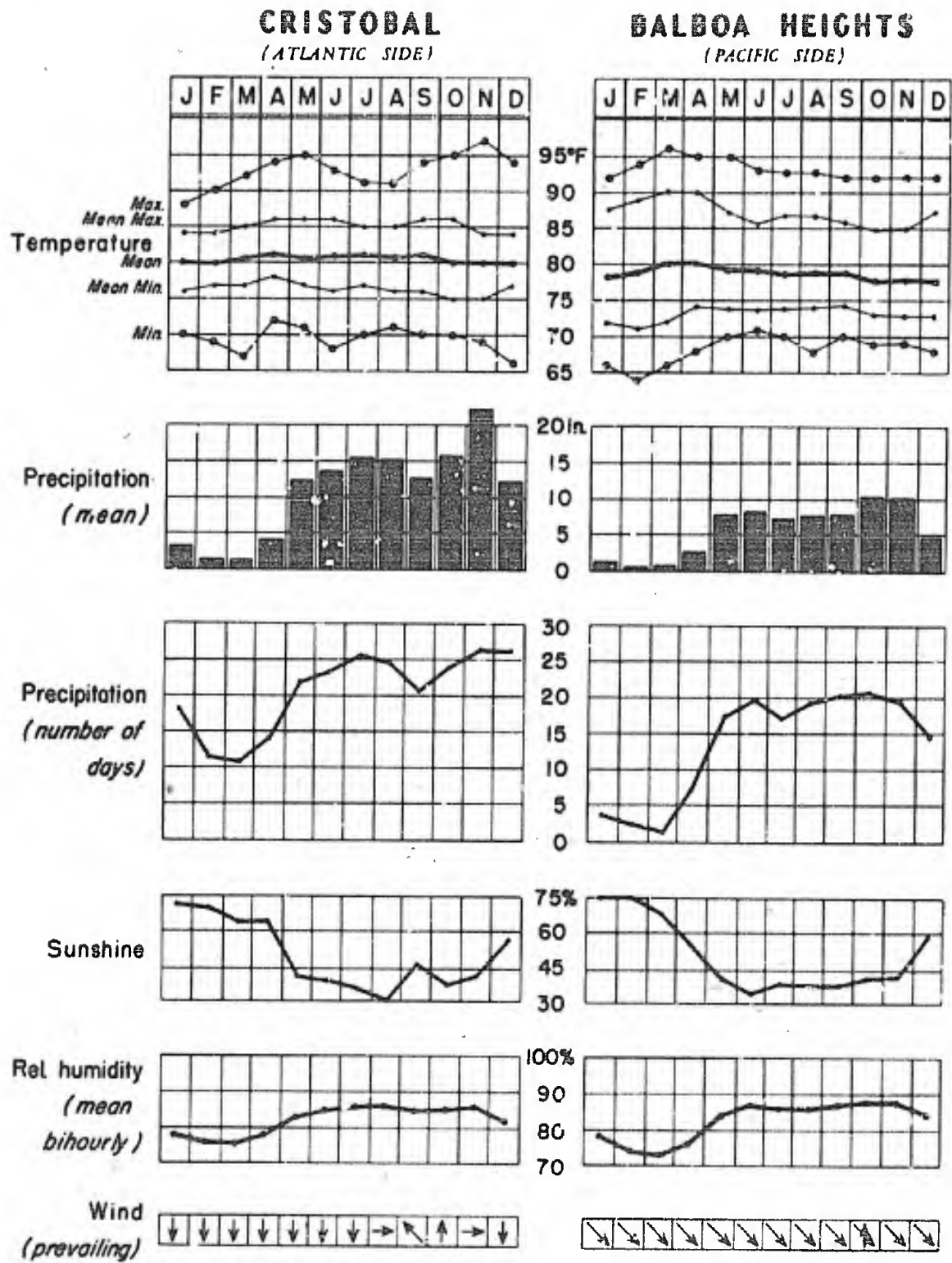


Figure 1. Climatic Summary of 2 Canal Zone stations

May through November, coinciding with the wet season; sky coverage averages about 8 tenths at Balboa Heights at that season. Wind speed, however, is greatest during the dry season; winds average 9 to 10 mph at Balboa Heights from January through April, but only about 5 to 6 mph in the other months. Southeastward toward the coast, there is a slight decrease in rainfall and an increase in temperature, as elevation drops to sea level from 118 feet at Balboa Heights.

The Atlantic portion of the Canal Zone, represented by Cristobal, has a wet-tropical climate (Fig. 1). The difference in mean temperatures of the warmest and coolest months is only 2°F, and the range from the highest mean daily maximum (April, May, June, September, and October, 86°F) to the lowest mean daily minimum (October and November, 75°F) is only 11°F. The mean annual temperature of 81°F is typical of equatorial areas. Precipitation averages 130 inches a year, and the monthly distribution is uneven. Although no month can be considered completely dry, 2 months have less than 2 inches of rainfall, while 8 months have more than 11 inches. The "dry" season at Cristobal begins in January (3.4 inches) and ends in April (4.1 inches). During the remaining months, average rainfall ranges from nearly 12, to more than 22 inches in November. Mean relative humidity is high in all months; the lowest mean value, 77 percent, occurs in both February and March. Cloud cover is greatest in July, 8 tenths, and least in February, 5.5 tenths. Mean wind speed is greatest in February and March (nearly 15 mph) and least in September (about 6 mph).

4. Criteria and methods

a. Climatic elements selected for study

As in the previous studies of this series, temperature, precipitation, humidity, cloud cover, and wind speed were the climatic elements considered most important to military activities. It was assumed that test authorities are more interested in stress periods (e.g., hottest and wettest) and annual fluctuations than in the data for specific calendar months. Accordingly, the warmest, coldest, wettest, and driest months of the year at each station were selected for study. The following specific combinations of element and month were studied:

- (1) Mean temperature of the warmest month
- (2) Mean daily maximum temperature of the warmest month
- (3) Mean temperature of the coldest month
- (4) Mean daily minimum temperature of the coldest month
- (5) Mean daily temperature range of the warmest month
- (6) Mean annual precipitation
- (7) Mean precipitation of the wettest month
- (8) Number of wet months
- (9) Relative humidity of the driest month
- (10) Mean cloud cover of the wettest month
- (11) Mean wind speed of the wettest month

b. "Analogous" and "semianalogous" ranges defined

Classes were established defining the ranges of values considered closely analogous to those for Balboa Heights and Cristobal. Fairly narrow limits of analogy were used to keep comparisons closely representative of the two reference stations. Table I lists the classes of analogy and semianalogy selected for each element. For temperature, a departure of 4 degrees (except where a mean was taken for the two reference stations) from the mean at the Canal Zone station was allowed for each analogy class, and an additional 4 degrees for semianalogy. For precipitation, departures of 15 inches of mean annual rainfall were considered analogous to Balboa Heights and an additional 15 inches for semianalogy. The mean annual rainfall of 70 inches at Balboa Heights is somewhat below that normally considered humid equatorial for a locality with a dry season; therefore, in this study the limits of analogy were set at 55 to 85 inches, differentiating it from most evergreen rain forest areas, on the upper margin, and savanna areas, on the lower margin. Cristobal, which has a tropical evergreen rain forest type of climate, has a mean annual rainfall of 130 inches. Departures of 30 inches of mean annual rainfall were considered analogous to Cristobal and an additional 30 inches was considered semianalogous. Departures of 5 percent in mean relative humidity, 1 tenth in amount of cloudiness, and 2 mph in wind speed were selected as ranges of analogy for these respective elements.

c. Explanation of maps

Values are shown for each station, with degree of analogy indicated by a symbol. Isopleths were drawn to show zones of close analogy, and these zones are shaded. Areas of semianalogy were not shaded but were indicated by placing the appropriate symbol on the map for stations having semianalogous conditions. From the separate maps showing analogous areas for each element, two composite maps were prepared (one for Balboa Heights and one for Cristobal) indicating regions where the following four single elements are analogous: mean temperature of the warmest month, mean temperature of the coldest month, mean annual precipitation, and number of wet months.

d. Limitations of data

The procedures as outlined have certain definite limitations in a climatic comparison of this sort. Foremost among these is the necessity, often encountered in climatology, of assuming climatic conditions in areas having few if any stations. A second limitation is that some elements, such as dew point, solar radiation, and visibility, which would have proved valuable as indicators of climatic analogy, were not included in this study because of the limited amount of data available. For certain elements, the number of stations reporting does not provide a representative picture. Consequently, isopleths were not drawn for the following: mean relative humidity for the driest month, mean cloudiness for the wettest month, or mean wind speed for the wettest month.

The assumption has been made that Balboa Heights and Cristobal are representative of the Pacific and Atlantic portions of the Canal Zone.

Data from some African Stations are not given in a form directly comparable to those from Balboa Heights and Cristobal. Where periods of record, hours of observation, or manner of observation differed, station records had to be interpolated in drawing the isopleths.

Values outside the limits of analogy or semianalogy were not analyzed, nor were combinations of climatic elements other than those involved in computing number of wet months.

The method of recording temperatures varies from country to country. Mean temperatures are usually determined by averaging the daily maximum and minimum temperature; however, at some stations in South Central Africa the means are obtained by averaging bi-hourly temperature observations, as at Balboa Heights and Cristobal. Experience has shown that the difference between mean temperatures derived in these different ways is seldom more than 1°F. Hours of observation of relative humidity, wind speed, and cloudiness vary widely throughout the study area.

5. Analysis of single-element maps

Individual maps showing analogous areas have been prepared for the climatic elements listed in paragraph 4a above, numbers 1 through 8. Maps of elements 9, 10, and 11 have been prepared showing only the values for individual stations, since the data were considered inadequate for delimiting analogous areas.

a. Mean Temperature, Warmest Month (Fig. 3)

As indicated in Table I, the analogous range of the mean temperature for the warmest month for both Balboa Heights and Cristobal is from 77° to 85°F. Most of the South Central Africa analog area is analogous to this 8°F range. In this study, the highest mean temperature for the warmest month, 88.2°F, is recorded in November at Feira, Mozambique. The lowest monthly mean temperature for the warmest month, 58.1°F, occurs at Equator, Kenya, located near the Equator at an altitude of 9,062 feet.

One large area too cool for analogy with the Canal Zone stations extends from the south Atlantic coast almost to the Indian Ocean. This area includes the Angola Plateau, the higher portions of the Central African Plateau, the Kenya Highlands, and most of the Eastern African Plateau. A second area too cool for analogy occupies most of the Southern Rhodesian Plateau. Only two areas are too hot for analogy with the Canal Zone stations: the Somali Plateau, and the valley of the Zambezi River from Wankie, Southern Rhodesia, east to Chamba, Mozambique. Most of Madagascar is analogous to the Canal Zone stations except for the higher areas of the Central Highland where it is too cool, and a single lowland station that records a mean temperature too high for analogy.

b. Mean Daily Maximum Temperature, Warmest Month (Fig. 4)

At Balboa Heights, the mean daily maximum temperature for the warmest month is 90°F , whereas at Cristobal it is 86°F . As ranges of analogy for the two stations are respectively 86° to 94°F and 82° to 90°F , there is a range of complete analogy for both stations from 86° to 90°F . In South Central Africa, approximately three-fourths of the area is analogous to one or the other of the two Canal Zone stations. The highest mean daily maximum temperature for the warmest month is at Feira, Mozambique, with a temperature of 100.8°F for November, and the lowest is at Mt. Nuza, Southern Rhodesia, with 65.4°F in January.

In this region, analogy with Balboa Heights is closely associated with the lowland areas, river valleys, and gently rolling topography; analogy with Cristobal is associated with the higher elevations, mountains, and areas of greater relief. Areas which are too cool for analogy are in the mountains, and the one large area too warm for analogy is located along the Zambezi River Valley from the Okovango Basin and Mongu, Northern Rhodesia, eastward to within approximately 25 miles of the Indian Ocean.

c. Mean Temperature, Coldest Month (Fig. 5)

Analogy for both Balboa Heights and Cristobal is 75° to 83°F for the mean temperature of the coldest month. For this 8°F range there is analogy in four main areas. One area is along the Ogowe and N'Goume River deltas and valleys on the Atlantic coast in French Equatorial Africa. This area lies in the Western Coastal Lowland and along the lower slopes of the Cameroons-Gabon Plateau. The second and largest area of analogy is in the central portion of the Congo Basin. The higher elevations of the Central African Plateau are the southern boundary of the analogous area. To the east, this analogous area is bounded by the foothills of the Western Rift. The third large area of analogy is a narrow zone along the Indian Ocean south from Alessandra, Kenya, almost to Ibo Island just off the coast of northern Mozambique. The inland border of this analogous area varies considerably and because of the thin network of stations, the boundary is almost totally extrapolated from topography and an analysis of other elements. In Madagascar, the northern half of the Western Lowland is analogous. A small area along the lower course of the Congo River and part of the valley of the Western Rift near Usumbura, Ruanda-Urundi, completes the analogous areas. The extremes in temperature shown on this map are from a low of 42.5°F in July at Belfast, Union of South Africa, to a high of 79.8°F in July at Garissa, Kenya.

d. Mean Daily Minimum Temperature, Coldest Month (Fig. 6)

The analogous range of the mean daily minimum temperature of the coldest month for Balboa Heights is from 67° to 75°F , and for Cristobal

the analogous temperatures are 71° to 79°F. Therefore, 71° to 75°F is analogous to both stations. For Balboa Heights, the analogous areas are approximately the same as those shown on the previous map (Fig. 5). The northwest analogous area, along the Atlantic, is largely confined to the lowland delta and an additional area of analogy is shown to the south along the Western Coastal Lowland at 4° S latitude. The core area of analogy in the Congo Basin is smaller than on the previous map. The eastern analogous area bordering the Indian Ocean spreads southward only to Kilwa, Tanganyika. In Madagascar, the analogous area is narrower than that shown in Figure 5.

There are only three stations analogous to Cristobal: Bolobo, Belgian Congo; Giumbo, Kenya; and Zanzibar on the island of Zanzibar; the latter has the highest temperature (72°F in August) of any station shown on the map. Vryburg, Union of South Africa, has the lowest mean minimum temperature, 30.7°F in July.

e. Mean Daily Temperature Range, Warmest Month (Fig. 7)

At Balboa Heights, the mean daily temperature range for the warmest month is 16°F, whereas it is 8°F at Cristobal. Temperatures within 4°F of these two means are considered closely analogous. The temperature ranges in the coastal lowlands on both the Atlantic and Indian Oceans are almost totally analogous. However, in the interior highlands and plateaus the temperature ranges are too great for analogy. Parts of the Central African Plateau, from the northern half of Lake Tanganyika to northern Lake Victoria, are analogous with Balboa Heights. Cristobal analogy appears only in isolated areas near the coast. On Madagascar, the northern half of the Eastern Coastal Lowland has low enough ranges to qualify for analogy with Cristobal. The extremes of temperature ranges on the map are Lobito, Angola, with 8.4°F and Mongu, Solwezi, and Mumbwa, Northern Rhodesia, all having temperature ranges of 34.4°F.

f. Mean Annual Precipitation (Fig. 8)

The range of analogy of mean annual precipitation is 55 to 85 inches for Balboa Heights, and 100 to 160 inches for Cristobal. There are two areas in South Central Africa which are analogous to Cristobal; the island of Nossi Be near the northwest coast of Madagascar, and the eastern coast of Madagascar from the Eate d'Antongil south to Farafangana. In eastern Madagascar, Soanierana, with an annual mean rainfall of 191 inches, is too wet for analogy.

The Central Highland of Madagascar is one of the controlling factors in the rainfall regime of the island. It is an abrupt barrier to the moist southeast trades, and most of the moisture is deposited on its windward slopes. There is a large area with precipitation analogous to Balboa Heights, covering the Cameroons-Gabon Plateau and the central portion of the Congo Basin. Along the Atlantic coast, the cold Benguela Current effectively limits excessive precipitation south of about 4° S latitude. One station south of this point, Mossamedes, Angola, has a

lower annual precipitation than any other station on the map, 2 inches. Air moving inland from the Guinea Current, which is warmer and moving from west to east, deposits up to 93 inches of rain annually on the heights of the Cameroons-Gabon Plateau. The annual rainfall diminishes to the south, except in the interior highlands, where there is another area of analogy to Balboa Heights.

The southeast trade winds and the Asian monsoon influence the precipitation regime of the east coast of South Africa. Generally, the rainfall decreases both to the south and to the north of the Mozambique Channel, where a small coastal area and several interior highlands are analogous to Balboa Heights. A local situation probably caused by the southeast winds moving over Lake Nyasa produces an analogous area in the western mountains of the Great Rift. Lake Victoria also is said to "make its own climate", and this is demonstrated by the areas of analogy with Balboa Heights which are found around its coast. Several other isolated mountain stations and the island of Zanzibar are the only other analogous areas.

g. Mean Precipitation, Wettest Month (Fig. 9)

Wettest month precipitation analogy with Balboa Heights is 8 to 14 inches; with Cristobal, 15 to 29 inches. Because of the seasonality of this element, a greater part of the study area is analogous to Balboa Heights or Cristobal for mean monthly precipitation of the wettest month than for mean annual precipitation (Fig. 8). Cristobal analogy is found only in isolated areas associated with heights and plateaus near the coast or other water bodies; analogous areas include part of the Cameroons-Gabon Plateau on the Atlantic side south of the Equator, the northwest heights of the Great Rift on Lake Nyasa, and a northwest-southeast band across the northern tip of Madagascar.

Most of the study area is analogous to Balboa Heights. However, three large areas too dry for analogy are enclosed by this analogous area. The analogy decreases to the south and disappears along the southwestern parts of Africa and Madagascar. The greatest monthly rainfall, 23.4 inches in April, is at Lyamungu, Tanganyika. Mossamedes, Angola, has the driest month, 0.9 inches in April.

h. Number of Wet Months (Fig. 10)

The definition used in this series of analogs for "wet month" is based on the Thornthwaite formula (Thornthwaite, 1931) in which higher temperatures must be associated with more precipitation in order for a month to be called humid. Mean monthly precipitation for any given mean monthly temperature must be at least as high as the values indicated below in order to be called wet.

<u>Mean monthly temperature (°F)</u>	<u>Mean monthly precipitation (in.)</u>
95	2.88
90	2.71
85	2.54
80	2.37
75	2.20
70	2.03
68	1.96

Wet months with mean monthly temperatures below 68°F are excluded from consideration as being nontropical.

Based on the above definition, the areas of analogy for Balboa Heights and Cristobal are 8 to 10 wet months and 9 to 11 wet months respectively. In South Central Africa, the greatest area of analogy is in the western part, and includes the Kasai River Basin. Three scattered areas on the Indian Ocean receive enough rainfall to be classified as analogous. On Madagascar, the interior of the Eastern Coastal Lowland and the windward slope of the Central Highland constitute areas of analogy.

The deep interior of the Congo Basin receives too much rainfall during all months for analogy with Cristobal. This is also true of the coastal segment of the Eastern Coastal Lowland of Madagascar which constantly receives precipitation from the moist southeast trade winds.

i. Relative Humidity, Driest Month (Fig. 11)

Mean relative humidities of 70 to 80 percent for Balboa Heights and 72 to 82 percent for Cristobal are considered analogous for the driest month. Isopleths for this map were not drawn because of the inconsistency of records for this climatic element. The eastern half of Africa and Madagascar are fairly well covered by the pattern of recording stations, but the variability in recording processes at these stations prevents exact comparison. It is obvious, however, that high humidities exist in approximately the same areas as high precipitation.

Of the stations of record, the lowest mean relative humidity for the driest month appears in June and July at Nova Lisboa, Angola, with 34 percent. Fort Hall, Kenya, Cabinda, Angola, and Port Francqui, Belgian Congo, have July mean humidities of 89 percent, the highest in the region.

j. Mean Cloudiness, Wettest Month (Fig. 12)

At both Balboa Heights and Cristobal, the mean cloudiness for the wettest month (November) is 7.6 tenths sky coverage. This element is inadequately observed, and observed by too many different methods at too many different hours of the day to be comparable. In general, the wettest areas tend to be the most cloudy, and the reported cloud amounts appear to be similar to those reported at Canal Zone stations.

k. Mean Wind Speed, Wettest Month (Fig. 13)

At Balboa Heights, the mean wind speed for the wettest month is 5.8 mph, and at Cristobal, it is 8 mph. Closely analogous areas would be 4 to 8 mph for Balboa Heights and 6 to 10 mph for Cristobal. With only 21 stations reporting this element, it is not possible to draw a pattern of analogy.

6. Analysis of composite maps (Figs. 14 and 15)

Two maps, Figure 14 for Balboa Heights and Figure 15 for Cristobal, are presented to show the extent of composite analogy within the study area with respect to the more important elements presented singly elsewhere. The elements for which areas of analogy are fully plotted on the composite maps are (1) the mean temperature of the warmest month, (2) the mean temperature of the coldest month, and (3) mean annual precipitation. Because of the importance of seasonality of precipitation in the tropics, areas which are analogous with respect to the number of wet months are also shown, but only where they occur within areas analogous with respect to the other three elements. This is done because full presentation of a fourth element would make the maps difficult to read.

There are only two areas of complete analogy for the four criteria on either map and these are both on the Balboa Heights map. The first of these areas includes the highlands and plateaus of the Cameroons-Gabon system. The other composite area of analogy is in the western and southern portions of the Congo Basin. The central portion of the Congo Basin has too many wet months for analogy. There is also an area of three-criteria analogy along the northwest coast of Madagascar. On the composite analogous area map of Cristobal, only two of the four climatic parameters were found to be analogous.

7. Tables of monthly values

Tables II through IX show the monthly means of the climatic elements for 22 key stations for the 12 months as well as the annual means. These stations were selected for length of reliable record and representativeness. No key stations are shown for the Somali Plateau, the Kalahari Desert, the Okovango Basin, or the Angola Plateau, because these regions are nonanalogous to most elements studied in this report. In each table, the mean values for Balboa Heights and Cristobal are shown for comparison. The tables reveal certain characteristics of climatic analogy which are not manifest in the maps.

TABLE I: CLIMATIC ELEMENTS AND CLASSES OF ANALOGY

Station index	Balboa Heights		Cristobal	
	Value at B.H. (mean)	Analogous (range)	Value at Cris. (mean)	Analogous (range)
TEMPERATURE (°F)				
Mean, warmest month*	80	77-85	82	77-85
				73-76 86-89
Mean daily maximum, warmest month	90	86-94	86	82-90
				78-81 91-94 71-74 84-87
Mean, coldest month*	78	75-83	80	75-83
Mean daily minimum, coldest month	71	67-75	75	71-79
				63-66 76-79 8-11 21-24
Mean daily range, warmest month	16	12-20	8	4-12
PRECIPITATION				
Mean annual (inches)	70	55-85	130	100-160
				70-99 161-190
Mean, wettest month (inches)	11	8-14	22	15-29
				8-14 30-36 7
Number of wet months	9	8-10	10	9-11
				12
RELATIVE HUMIDITY (%)				
Mean, driest month	75	70-80	77	72-82
				67-71 83-87
CLOUDINESS				
Mean, wettest month (tenths)	7.6	7.0-8.9	7.6	7.0-8.9
				6.0-6.9 9.0-10.0
WIND SPEED (mph)				
Mean, wettest month	5.8	4-8	8	6-10
				4-5 11-12

*See section 4b for explanation of ranges of analogy; sometimes a mean of the 2 reference stations is used.

TABLE II: STATIONS USED IN TABLES OF MONTHLY VALUES

<u>Stations</u>	<u>Elev. (ft)</u>	<u>Lat. (S)</u>	<u>Long. (E)</u>	<u>Period of Record (Yr)</u>		
				<u>Temp.</u>	<u>Prec.</u>	<u>Other</u>
BALBOA HEIGHTS (Canal Zone)	118	8°58'N	79°35'W	12-34	22-38	11-34
Beira (Mozambique)	54	19°50'	34°51'	37	27	18-20
Bosondongo (Belgian Congo)	1,558	0°39'	23°02'	10	10	*
Brazzaville (French Eq. Africa)	951	4°17'	15°16'	15	22	5-22
Broken Hill (Northern Rhodesia)	3,750	14°28'	28°27'	14	27	5-6
CRISTOBAL (Canal Zone)	36	9°25'N	79°52'W	7-32	8-60	3-41
Diego-Suarez (Madagascar)	98	12°17'	49°17'	27	27	2-4
Entebbe (Uganda)	3,842	0°05'N	32°29'	26	50	26
Farafangana (Madagascar)	10	22°50'	47°47'	27	27	5
Fort Johnston (Nyasaland)	1,263	14°31'	35°14'	5	14	6-8
Gandajika (Belgian Congo)	2,789	6°43'	23°59'	9	10	*
Johannesburg (Union of South Africa)	5,750	26°11'	28°03'	15	47	5-6
Livingstone (Northern Rhodesia)	3,090	17°50'	25°50'	22	26	5-6
Lourenço Marques (Mozambique)	194	25°58'	32°36'	31	31	27-32
Luanda (Angola)	151	8°49'	13°13'	30	58	19-58
Lulenga (Belgian Congo)	6,070	1°24'	29°22'	10	10	5
Mombasa (Kenya)	53	4°04'	39°42'	10	47	7
Mpika (Northern Rhodesia)	4,647	11°51'	31°27'	14	31	5
Nairobi (Kenya)	5,495	1°16'	36°50'	15	22	1-13
Porto Amelia (Mozambique)	197	13°06'	40°32'	7	6	6
Salisbury (Southern Rhodesia)	4,865	17°50'	31°01'	22	37	10-14
São Hill (Tanganyika)	6,500	8°20'	35°12'	5	12	5
Tabora (Tanganyika)	4,151	5°02'	32°49'	15	46	14-15
Tananarive (Madagascar)	4,511	18°55'	47°33'	27	26	4-26

*Period of record unknown

TABLE III: MEAN MONTHLY TEMPERATURE (°F)

<u>Stations</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>	<u>Yr</u>
BALBOA HEIGHTS	78	79	80	80	79	79	79	79	79	78	78	78	79
Beira	81	81	80	78	73	71	68	70	74	79	79	80	76
Bosondongo	78	78	78	77	77	77	77	78	78	78	78	78	78
Brazzaville	79	79	80	80	79	74	72	74	78	79	79	78	78
Broken Hill	72	72	71	69	65	61	62	65	72	78	77	73	70
CRISTOBAL	80	80	81	82	81	81	81	81	81	80	80	80	81
Diego-Suarez	81	80	81	81	80	78	76	76	77	78	80	80	79
Entebbe	72	72	72	71	71	70	69	69	70	71	71	71	71
Farafangana	80	80	79	77	72	69	69	70	72	75	78	79	75
Fort Johnston	80	78	79	76	72	68	69	70	77	82	83	81	76
Gandajika	76	77	77	77	77	75	74	76	77	77	76	76	76
Johannesburg	69	67	65	60	55	49	49	54	60	66	66	68	61
Livingstone	76	76	76	73	67	63	63	67	76	82	80	77	73
Lourenço Marques	78	79	77	74	70	66	66	67	70	73	75	77	73
Luanda	77	78	80	79	76	71	68	68	71	74	77	77	75
Lulenga	64	65	64	64	64	64	64	64	64	64	63	64	64
Mombasa	80	81	81	80	78	76	75	75	76	78	79	80	78
Mpika	69	70	69	68	65	61	60	63	70	74	74	70	67
Nairobi	66	67	68	67	65	63	60	62	64	67	66	65	65
Porto Amelia	81	81	80	79	77	75	74	74	76	78	80	80	78
Salisbury	70	69	70	66	61	57	56	60	66	70	71	70	66
São Hill	64	64	63	62	60	57	55	57	60	63	64	64	61
Tabora	72	73	73	72	72	70	70	72	76	78	76	73	73
Tananarive	70	70	69	67	63	59	58	59	63	67	69	69	65

TABLE IV: MEAN DAILY MAXIMUM TEMPERATURE (°F)

<u>Stations</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>	<u>Yr</u>
BALBOA HEIGHTS	88	89	90	90	87	86	87	87	86	85	85	87	87
Beira	89	89	87	86	82	79	77	79	82	87	87	88	84
Bosondongo	87	87	88	87	86	87	86	86	87	88	87	86	87
Brazzaville	88	89	91	91	88	84	82	85	89	89	88	87	88
Broken Hill	79	80	79	78	77	74	74	78	84	90	87	81	80
CRISTOBAL	84	84	85	86	86	86	85	85	86	86	84	84	85
Diego-Suarez	88	89	88	88	88	85	84	84	84	86	88	90	87
Entebbe	80	80	80	78	78	77	77	77	79	80	80	80	79
Farafangana	88	88	87	83	79	77	76	78	81	83	85	87	83
Fort Johnston	90	88	90	87	84	81	81	85	92	96	93	92	88
Gandajika	86	87	87	89	90	91	90	90	89	88	87	86	88
Johannesburg	80	78	75	72	66	61	61	67	73	78	78	80	72
Livingstone	87	87	86	86	82	78	79	83	92	96	92	88	86
Lourenço Marques	86	87	85	83	80	77	76	77	80	82	83	86	82
Luanda	85	85	86	85	83	78	74	74	76	80	82	83	81
Lulenga	74	75	74	75	75	75	75	75	74	73	73	73	74
Mombasa	86	86	87	84	82	80	79	79	81	83	84	85	83
Mpika	76	77	77	75	73	70	70	73	81	85	84	78	77
Nairobi	79	81	80	76	74	73	71	71	77	78	75	75	76
Porto Amelia	87	87	87	86	84	82	81	81	82	85	86	88	85
Salisbury	80	79	80	77	74	71	71	75	82	86	84	82	78
São Hill	72	73	72	70	69	68	66	68	72	75	75	73	71
Tabora	82	82	82	82	82	82	83	84	88	90	87	82	84
Tananarive	79	78	78	76	72	68	68	70	75	80	81	80	75

TABLE V: MEAN DAILY MINIMUM TEMPERATURE (°F)

<u>Stations</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>	<u>Yr</u>
BALBOA HEIGHTS	72	71	72	74	74	74	74	74	74	73	73	73	73
Beira	74	75	74	71	65	62	61	62	65	71	72	73	69
Bosondongo	69	68	69	68	68	68	68	69	69	69	69	69	69
Brazzaville	69	70	70	70	69	65	62	64	68	69	69	69	68
Broken Hill	64	65	64	59	54	49	49	53	59	66	67	64	59
CRISTOBAL	76	77	77	78	77	76	77	76	76	75	76	77	76
Diego-Suarez	75	75	75	75	74	71	69	69	70	72	74	75	73
Entebbe	63	64	64	64	64	63	62	61	62	63	63	63	62
Farafangana	74	73	72	69	65	61	61	61	64	65	70	72	67
Fort Johnston	70	68	69	65	61	56	57	55	63	67	73	69	64
Gandajika	66	67	67	65	64	59	59	62	65	66	65	65	64
Johannesburg	57	56	54	49	43	38	37	41	47	53	55	56	49
Livingstone	66	66	65	60	53	47	47	50	60	68	68	66	60
Lourenço Marques	71	71	69	65	60	56	55	57	61	64	67	69	64
Luanda	74	74	75	75	73	67	64	64	67	71	73	74	71
Lulenga	54	55	54	54	54	54	54	54	54	54	54	54	54
Mombasa	74	75	76	75	73	72	70	70	71	73	74	75	73
Mpika	62	62	62	60	56	52	51	53	59	63	64	62	59
Nairobi	53	53	56	57	56	53	51	52	52	55	56	54	54
Porto Amelia	75	74	73	73	70	68	67	67	69	71	74	75	70
Salisbury	59	59	58	54	47	42	42	45	51	55	58	59	52
São Hill	55	55	55	54	51	47	45	47	49	52	54	55	52
Tabora	63	64	63	63	61	59	58	60	64	66	66	64	63
Tananarive	61	61	60	58	54	50	48	48	51	54	58	60	55

TABLE VI: MEAN MONTHLY PRECIPITATION (inches)

<u>Stations</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>	<u>Yr</u>
BALBOA HEIGHTS	1.0	0.6	0.7	2.9	8.0	8.4	7.3	7.8	8.2	10.2	10.5	4.7	70.3
Beira	11.6	8.2	10.0	4.1	2.5	1.4	1.0	1.0	0.8	1.5	5.2	10.1	57.4
Bosondongo	4.7	5.7	6.8	6.7	5.2	5.3	3.3	6.7	7.5	8.4	10.3	6.6	77.2
Brazzaville	5.8	5.6	7.0	8.5	4.8	0.3	0.1	0.2	1.3	5.8	8.0	6.5	53.9
Broken Hill	7.7	7.3	4.2	0.5	0.2	T	T	T	T	0.5	3.8	8.9	33.2
CRISTOBAL	3.4	1.5	1.5	4.1	12.5	13.9	15.6	15.3	12.8	15.8	22.3	11.7	130.4
Diego-Suraz	9.6	9.5	7.8	2.1	0.3	0.4	0.2	0.3	0.3	0.2	0.7	7.3	38.7
Entebbe	2.6	3.6	6.1	10.2	9.3	4.9	3.2	2.8	3.0	3.9	5.1	4.6	59.3
Farafangana	10.7	15.8	15.7	10.4	8.7	6.3	8.8	5.3	4.8	4.4	5.6	10.9	107.4
Fort Johnston	8.7	8.1	5.2	1.8	0.3	0.1	T	T	0.1	1.2	2.0	6.3	34.0
Gandajika	6.4	4.1	7.3	7.8	1.2	0.1	0.3	0.9	4.3	5.2	8.0	8.9	54.5
Johannesburg	6.2	4.9	4.2	1.7	0.8	0.2	0.4	0.4	1.0	2.5	4.9	5.4	32.6
Livingstone	7.0	5.3	4.7	0.9	0.3	0.0	T	T	0.1	0.6	3.2	5.2	27.4
Lourenço Marques	5.4	5.5	5.0	1.7	1.1	0.5	0.6	0.4	1.1	2.0	3.1	4.7	31.1
Luanda	1.0	1.4	3.0	4.6	0.5	T	0.0	T	T	0.2	1.2	0.8	12.7
Lulenga	4.1	4.9	7.8	8.8	6.3	4.2	2.5	4.8	8.1	7.6	7.4	5.4	71.9
Mombasa	1.1	0.6	2.6	7.5	12.5	4.7	3.8	2.5	2.6	3.3	3.8	2.5	47.5
Mpika	10.3	9.6	7.9	1.6	0.2	T	T	T	T	0.3	3.3	9.8	43.0
Nairobi	1.6	2.1	5.0	7.7	5.5	1.7	0.6	1.1	1.0	2.4	4.2	2.5	35.4
Porto Amelia	6.3	7.5	7.6	5.4	0.7	0.2	0.4	0.1	0.1	0.6	0.5	4.3	33.7
Salisbury	7.4	6.4	4.5	1.0	0.5	0.1	T	0.1	0.3	1.1	3.6	5.9	30.0
São Hill	7.6	6.7	8.8	3.4	0.8	0.1	0.1	0.1	T	0.4	2.5	7.5	38.0
Tabora	4.9	5.1	6.8	5.2	1.2	0.1	0.0	T	0.3	0.6	4.2	6.7	35.1
Tananarive	12.0	11.5	7.5	2.0	0.6	0.3	0.2	0.3	0.6	2.5	4.8	11.4	53.7

TABLE VII: MEAN CLOUDINESS (tenths of sky covered)

<u>Stations</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>	<u>Yr</u>
BALBOA HEIGHTS	4.8	4.8	5.0	6.3	7.6	8.0	7.6	7.7	7.7	7.7	7.6	6.3	6.8
Beira	6.0	5.7	5.5	4.4	3.7	3.5	3.7	3.6	3.6	4.3	5.7	6.0	4.6
Bosondongo*	-	-	-	-	-	-	-	-	-	-	-	-	-
Brazzaville	6.0	6.0	6.0	6.0	5.7	4.2	4.7	4.4	4.9	5.7	6.0	6.0	5.5
Broken Hill	8.2	8.7	7.2	6.1	4.0	4.0	2.8	2.6	2.6	4.0	7.3	8.2	5.5
CRISTOBAL	5.9	5.5	5.8	6.4	7.8	7.9	8.0	7.6	7.1	7.4	7.6	6.8	7.0
Diego-Suarez	8.0	7.8	7.5	5.5	5.0	5.5	5.0	5.3	4.5	5.0	5.8	6.5	6.0
Entebbe	5.4	5.9	6.3	7.8	6.3	5.8	5.9	5.7	5.8	6.1	6.3	6.2	6.1
Farafangana*	-	-	-	-	-	-	-	-	-	-	-	-	-
Fort Johnston*	-	-	-	-	-	-	-	-	-	-	-	-	-
Ganda jika*	-	-	-	-	-	-	-	-	-	-	-	-	-
Johannesburg	5.9	6.1	5.2	3.0	2.1	2.0	1.3	1.0	2.7	3.6	4.8	5.7	3.6
Livingstone	7.4	7.1	6.2	4.8	3.4	2.6	1.6	1.2	2.2	4.0	6.8	7.6	4.6
Lourenço Marques	6.1	5.6	5.6	4.0	3.2	2.2	2.6	2.6	4.0	5.5	6.4	6.3	4.5
Luanda	6.4	6.2	6.8	7.1	5.5	5.0	5.5	6.0	5.9	6.2	6.5	6.6	6.1
Lulenga*	-	-	-	-	-	-	-	-	-	-	-	-	-
Mombasa	4.7	4.3	4.1	4.8	6.5	5.5	5.7	5.6	5.1	4.3	4.1	4.9	5.0
Mpika	7.6	7.8	6.6	5.8	3.4	2.9	1.9	1.8	1.8	2.4	5.3	7.0	4.5
Nairobi	4.1	4.1	5.1	6.3	6.5	6.4	6.3	6.6	5.8	6.5	7.1	5.9	5.9
Porto Amelia	7.0	7.3	7.0	6.0	3.4	4.2	4.3	4.2	3.9	3.8	4.3	6.3	5.1
Salisbury	7.1	6.6	5.4	3.6	3.2	1.7	1.4	1.6	1.5	2.1	5.1	6.2	3.8
São Hill	9.2	8.5	8.7	8.4	7.2	5.8	5.6	5.9	4.9	6.5	7.0	8.1	7.1
Tabora	7.3	7.4	7.4	7.3	6.1	4.2	2.8	3.4	4.4	5.9	6.8	7.2	5.8
Tananarive	8.0	8.0	7.8	6.8	6.0	6.3	6.0	5.5	5.3	5.0	6.5	8.0	6.6

* No data available

TABLE VIII: MEAN RELATIVE HUMIDITY (%)

<u>Stations</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>	<u>Yr</u>
BALBOA HEIGHTS	78	75	73	77	85	87	86	87	87	88	88	84	83
Beira	74	74	77	76	77	77	78	76	76	72	73	74	75
Bosondongo*	-	-	-	-	-	-	-	-	-	-	-	-	-
Brazzaville	83	81	82	81	82	81	79	75	73	78	82	83	80
Broken Hill	76	80	74	68	60	58	56	48	41	40	58	72	61
CRISTOBAL	78	77	77	79	83	85	86	86	85	85	86	82	82
Diego-Suarez	74	83	80	78	73	69	68	68	68	70	70	74	73
Entebbe	76	75	79	82	83	80	78	80	79	75	77	79	79
Farafangana	83	80	79	79	82	77	78	76	75	77	76	81	79
Fort Johnston*	-	-	-	-	-	-	-	-	-	-	-	-	-
Gandajika*	-	-	-	-	-	-	-	-	-	-	-	-	-
Johannesburg	72	76	72	60	52	50	48	40	46	50	63	68	58
Livingstone	69	68	64	56	50	50	50	43	36	32	46	63	52
Lourenço Marques	75	75	77	75	74	72	72	72	72	73	74	74	74
Luanda	80	78	80	83	83	83	84	86	83	82	82	82	82
Lulenga	81	80	83	86	85	82	81	81	83	86	84	83	83
Mombasa	72	69	71	75	81	77	77	77	75	73	71	73	74
Mpika	80	82	78	72	64	62	58	57	54	49	58	74	66
Nairobi	56	54	61	68	71	70	69	68	61	60	66	64	64
Porto Amelia	77	77	77	75	69	66	65	67	70	69	70	72	71
Salisbury	76	74	75	69	64	63	59	53	47	45	62	75	64
São Hill	83	80	84	82	79	70	72	72	62	58	66	76	74
Tabora	70	71	72	68	60	54	48	46	42	41	51	67	58
Tananarive	78	80	75	77	76	76	75	72	68	66	67	74	74

* No data available

TABLE IX: MEAN WIND SPEED (mph)

<u>Stations</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>	<u>Yr</u>
BALBOA HEIGHTS	8.8	10.1	10.3	8.8	6.1	5.4	5.9	5.9	5.6	6.3	5.8	6.4	7.1
Beira	11.4	12.0	11.4	10.9	9.9	9.3	9.5	11.2	12.2	13.4	13.0	11.9	11.3
Bosondongo*	-	-	-	-	-	-	-	-	-	-	-	-	-
Brazzaville*	-	-	-	-	-	-	-	-	-	-	-	-	-
Broken Hill	4.4	4.5	5.5	7.9	7.8	7.9	6.6	7.6	7.4	7.4	5.4	4.7	6.4
CRISTOBAL	14.0	15.0	15.0	12.0	8.0	7.0	8.0	8.0	6.0	7.0	8.0	12.0	10.0
Diego-Suarez*	-	-	-	-	-	-	-	-	-	-	-	-	-
Entebbe	3.0	3.0	4.0	3.1	2.9	3.0	3.0	3.0	4.0	4.0	3.0	3.0	3.2
Farafangana*	-	-	-	-	-	-	-	-	-	-	-	-	-
Fort Johnston*	-	-	-	-	-	-	-	-	-	-	-	-	-
Gandajika*	-	-	-	-	-	-	-	-	-	-	-	-	-
Johannesburg*	-	-	-	-	-	-	-	-	-	-	-	-	-
Livingstone	4.3	5.4	4.9	4.6	4.1	3.8	3.8	4.2	4.5	5.2	5.0	4.2	4.5
Lourenço Marques	11.0	10.5	10.1	9.4	9.6	9.7	9.9	10.8	11.8	12.1	11.8	10.9	10.6
Luanda	6.3	7.3	6.8	6.5	6.2	6.0	5.6	5.8	6.2	7.9	8.1	7.0	6.6
Lulenga*	-	-	-	-	-	-	-	-	-	-	-	-	-
Mombasa	2.6	2.4	2.7	5.0	3.0	3.4	2.9	3.3	3.8	3.1	3.4	3.4	2.7
Mpika	7.6	7.3	9.9	11.5	12.1	13.5	12.7	13.8	14.5	15.5	10.0	7.2	11.3
Nairobi*	-	-	-	-	-	-	-	-	-	-	-	-	-
Porto Amelia	2.2	2.1	1.7	3.0	3.6	5.2	6.2	6.3	4.5	3.5	3.9	3.1	3.8
Salisbury	5.0	4.8	5.3	5.1	5.2	5.6	5.8	6.4	7.0	7.8	6.0	5.6	5.8
São Hill*	-	-	-	-	-	-	-	-	-	-	-	-	-
Tabora*	-	-	-	-	-	-	-	-	-	-	-	-	-
Tananarive	5.4	5.4	4.5	4.3	4.3	4.5	4.7	5.1	5.1	4.7	4.5	4.5	4.9

*No data available

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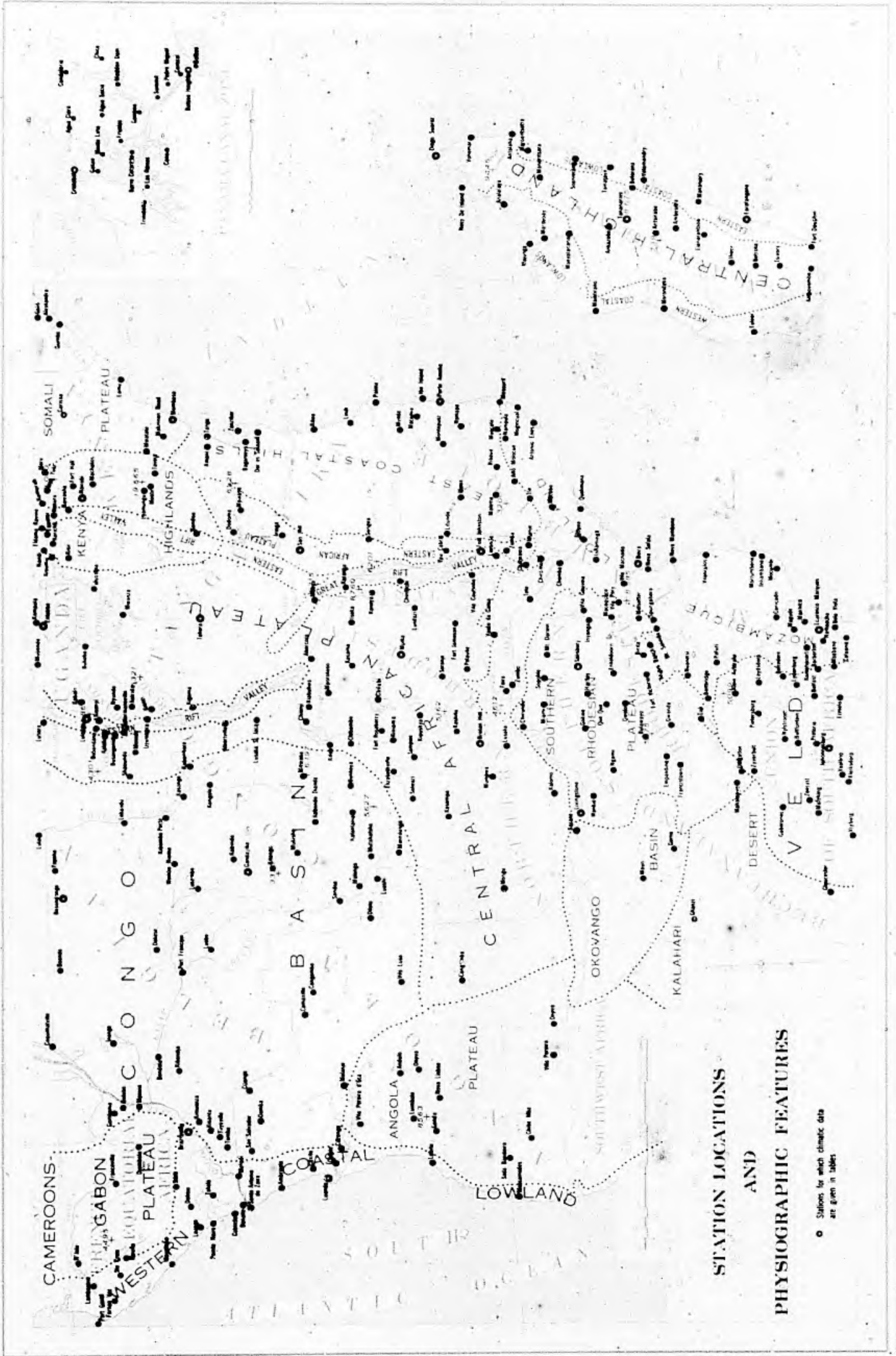
9. Acknowledgments

The final maps were drafted and printed by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Miss., from fair sheets prepared by the author.

10. Maps

Figure

- 2 Station Locations
- 3 Mean Temperature, Warmest Month
- 4 Mean Daily Maximum Temperature, Warmest Month
- 5 Mean Temperature, Coldest Month
- 6 Mean Daily Minimum Temperature, Coldest Month
- 7 Mean Daily Temperature Range, Warmest Month
- 8 Mean Annual Precipitation
- 9 Mean Precipitation, Wettest Month
- 10 Number of Wet Months
- 11 Relative Humidity, Driest Month
- 12 Mean Cloudiness, Wettest Month
- 13 Mean Wind Speed, Wettest Month
- 14 Composite of Analogous Areas - Balboa Heights
- 15 Composite of Analogous Areas - Cristobal



STATION LOCATIONS AND PHYSIOGRAPHIC FEATURES

○ Stations for which climatic data are given in tables

Figure 2

CLIMATIC ANALYSIS OF PANAMA CANAL ZONE, SOUTH CENTRAL AFRICA AND MADAGASCAR

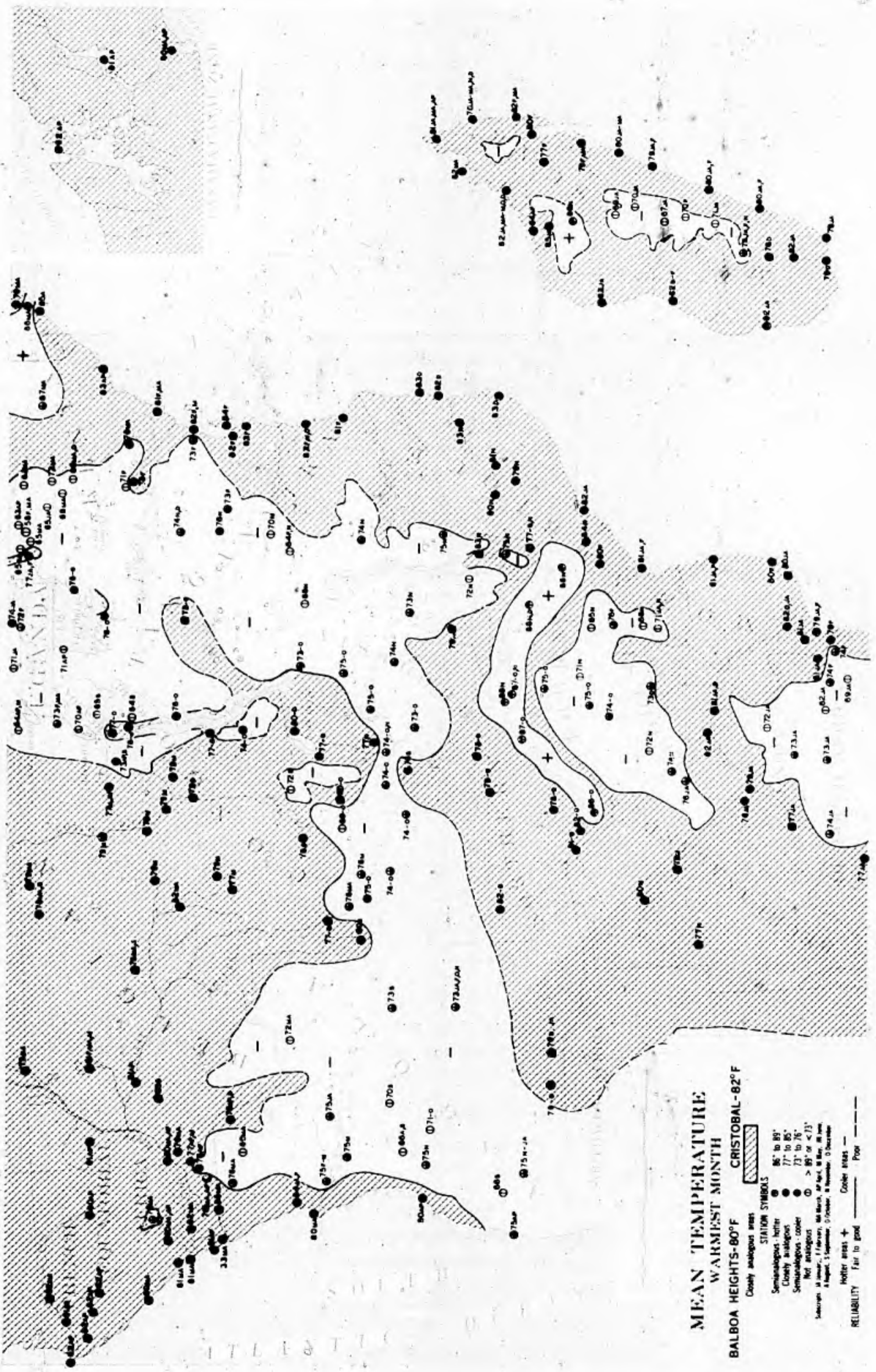


Figure 3

CLIMATIC ANALOGS OF PANAMA CANAL ZONE-SOUTH CENTRAL AFRICA AND MADAGASCAR

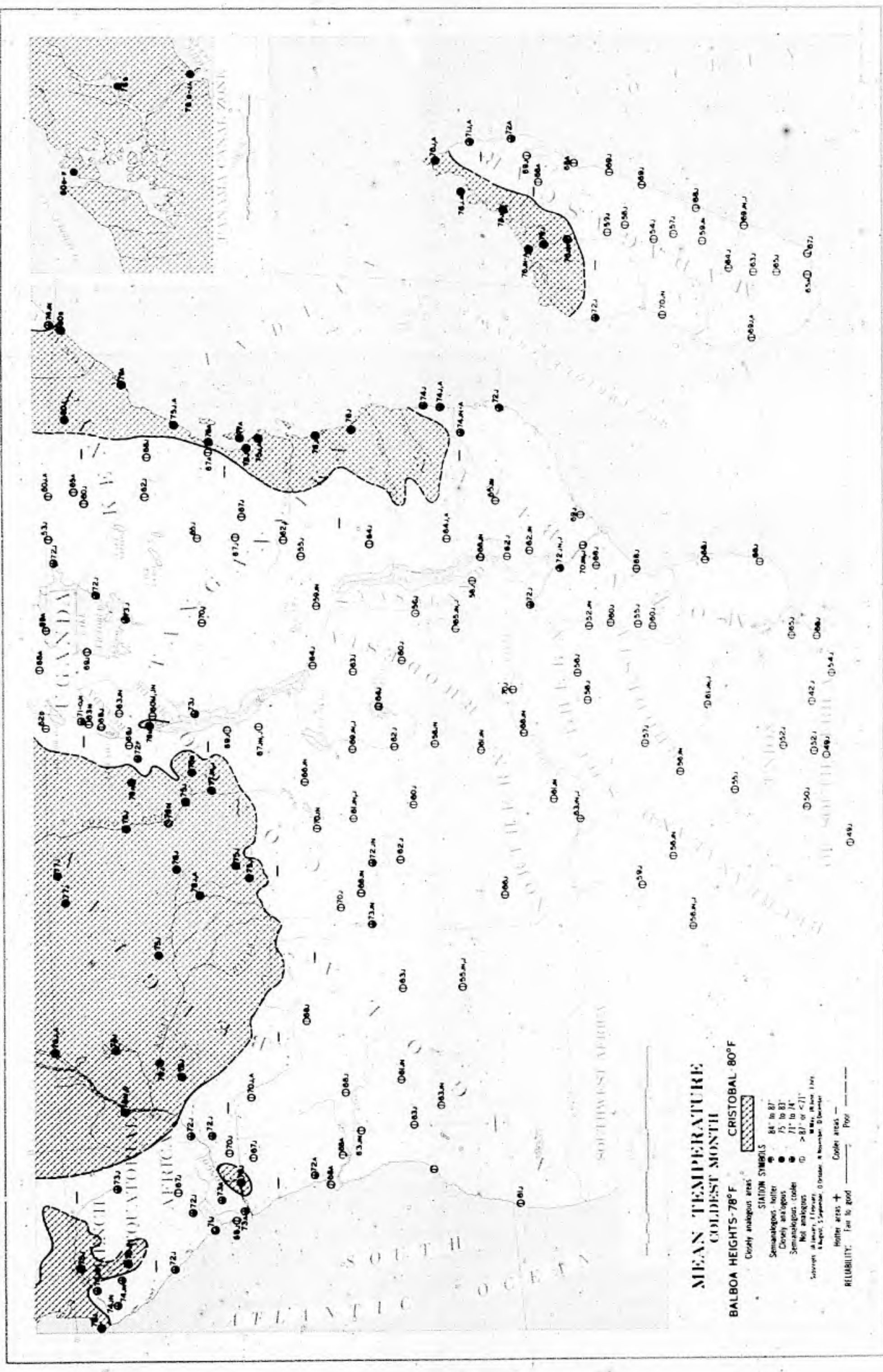


Figure 5

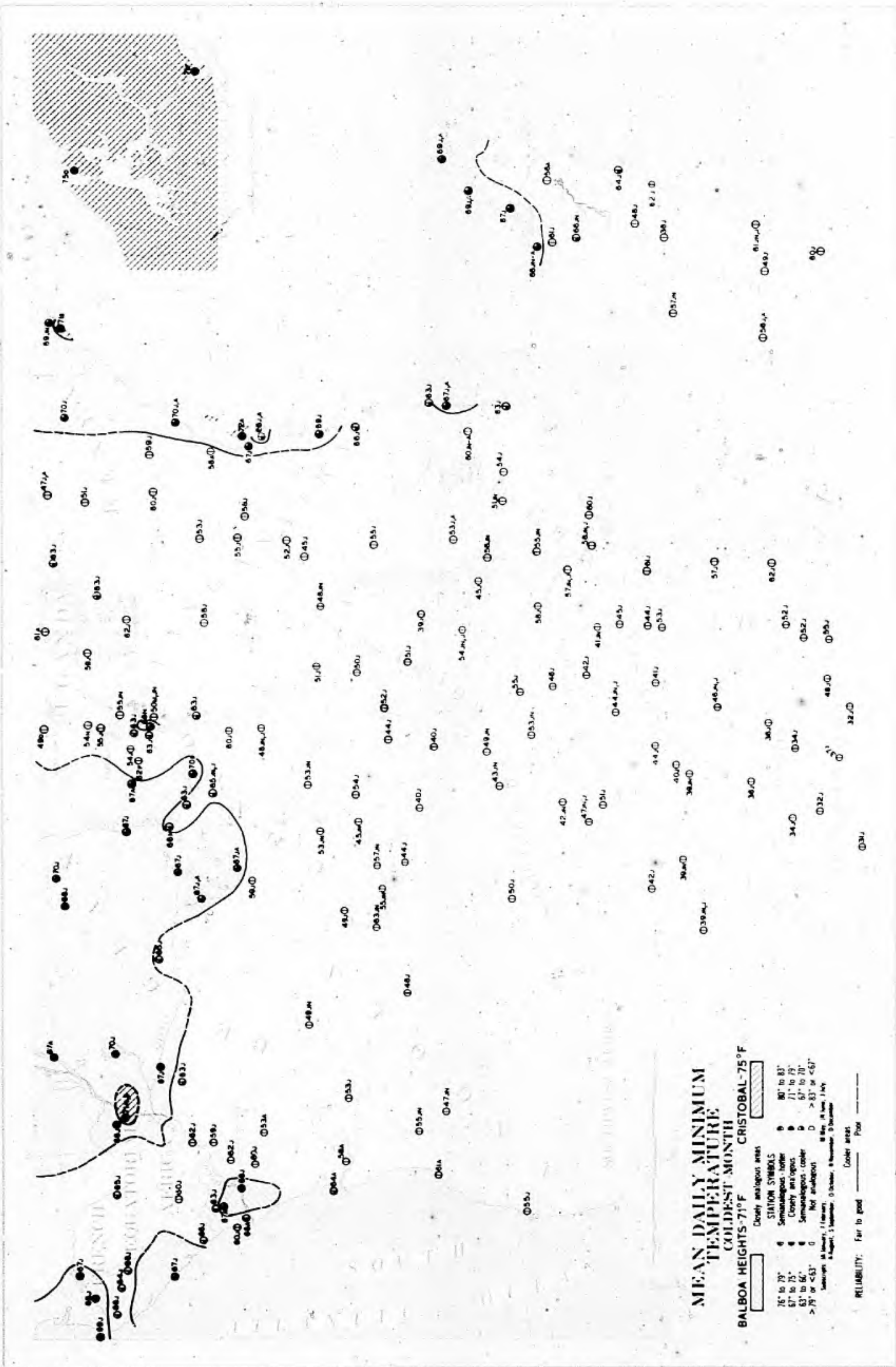
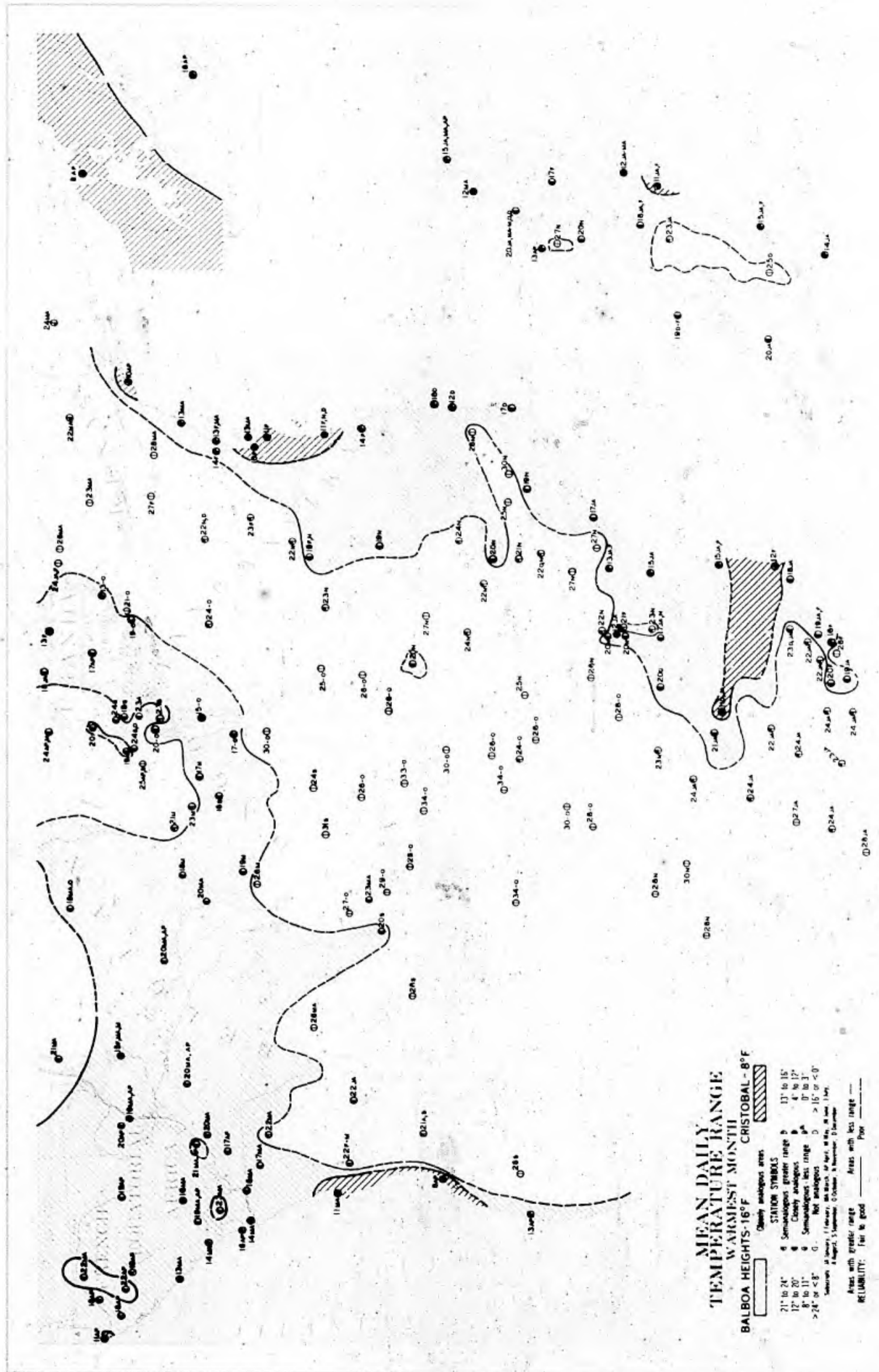


Figure 6



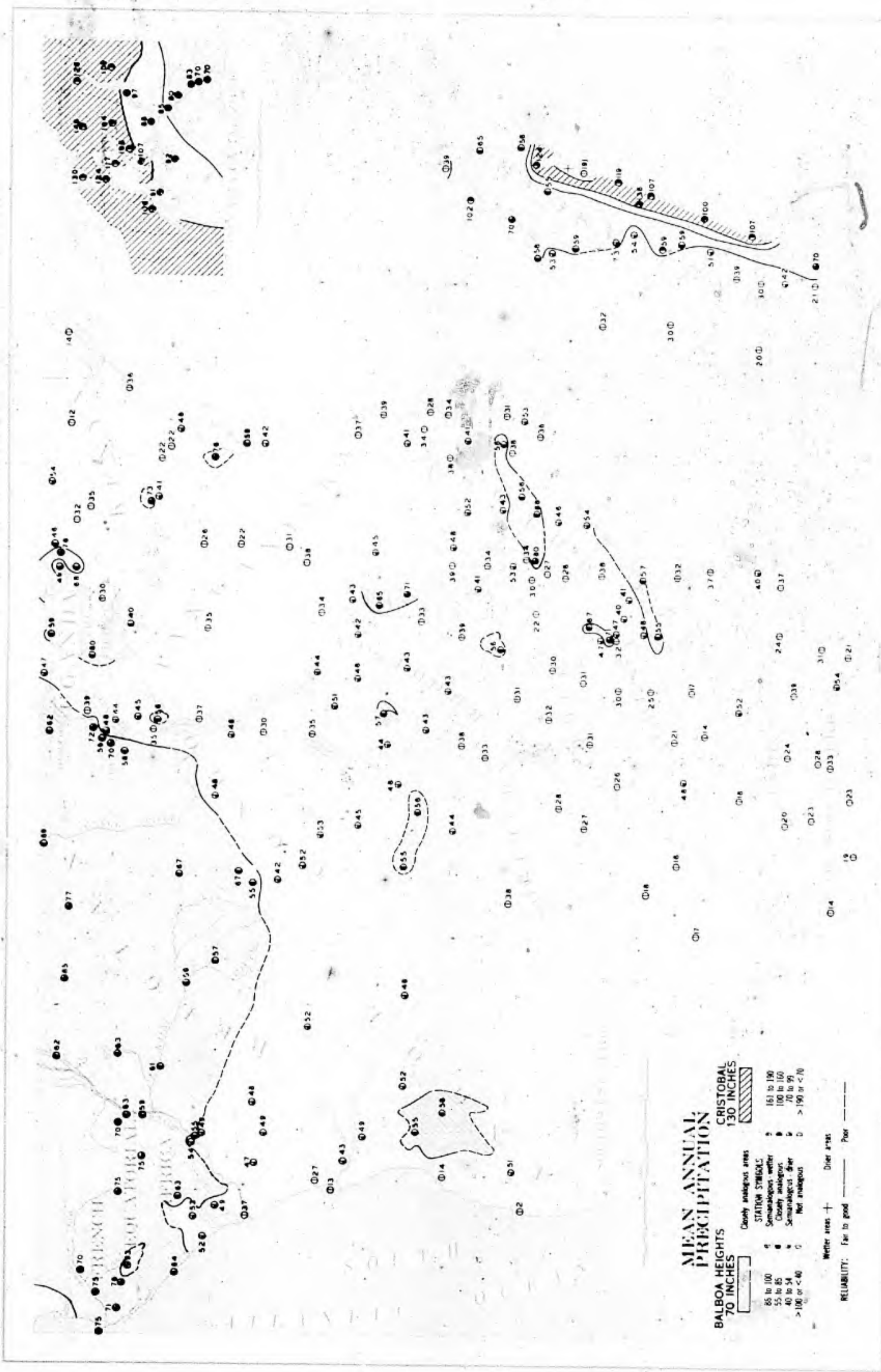
MEAN DAILY TEMPERATURE RANGE WARMEST MONTH
BALBOA HEIGHTS-16°F CRISTOBAL-8°F

Clearly analogous areas
 Areas with greater range
 Areas with less range
 Fair to good
 Poor

STATION SYMBOLS
 21° to 24° ◊ Semianalogous greater range
 17° to 20° ◊ Closely analogous
 8° to 11° ◊ Semianalogous less range
 >24° or <8° ◊ Not analogous

Stations at January, February, March, April, May, June, July, August, September, October, November, December

CLIMATIC VALUES OF PAVANA TUNNEL, CHINA AND NEARBY AREAS



MEAN ANNUAL PRECIPITATION

BALBOA HEIGHTS 70 INCHES

CRISTOBAL 130 INCHES

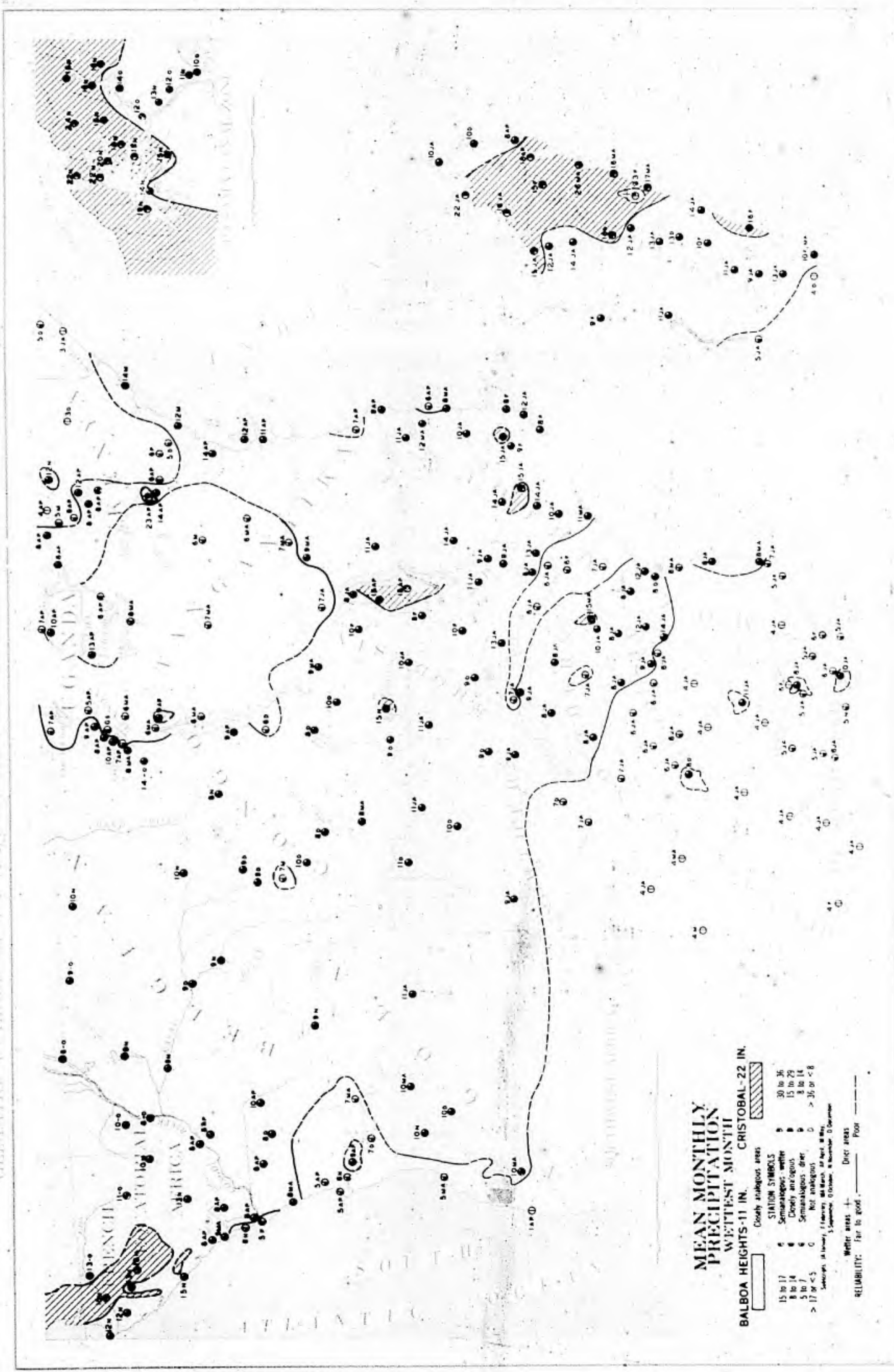
65 to 100
 55 to 85
 40 to 54
 >100 or <40

Fair to good
 Poor

Drier areas

Fair to good
 Poor

Figure 8



MEAN MONTHLY PRECIPITATION
WETTEST MONTH

BALBOA HEIGHTS-11 IN. **CRISTOBAL-22 IN.**

Closely analogous areas

STATION SYMBOLS

15 to 17	6	Semiarid; wetter	9	30 to 36
8 to 14	4	Closely analogous	8	15 to 29
5 to 7	3	Semiarid; drier	7	8 to 14
> 17 or < 5	5	Not analogous	5	> 36 or < 8

Subscript: 1, January; 2, February; 3, March; 4, April; 5, May; 6, June; 7, July; 8, August; 9, September; 10, October; 11, November; 12, December.

RELIABILITY: Wetter areas + Drier areas
 Fair to good. ——— Poor

Figure a

CLIMATIC ANALOGUES OF PANAMA CANAL ZONE SOUTH CENTRAL AFRICA AND MADAGASCAR

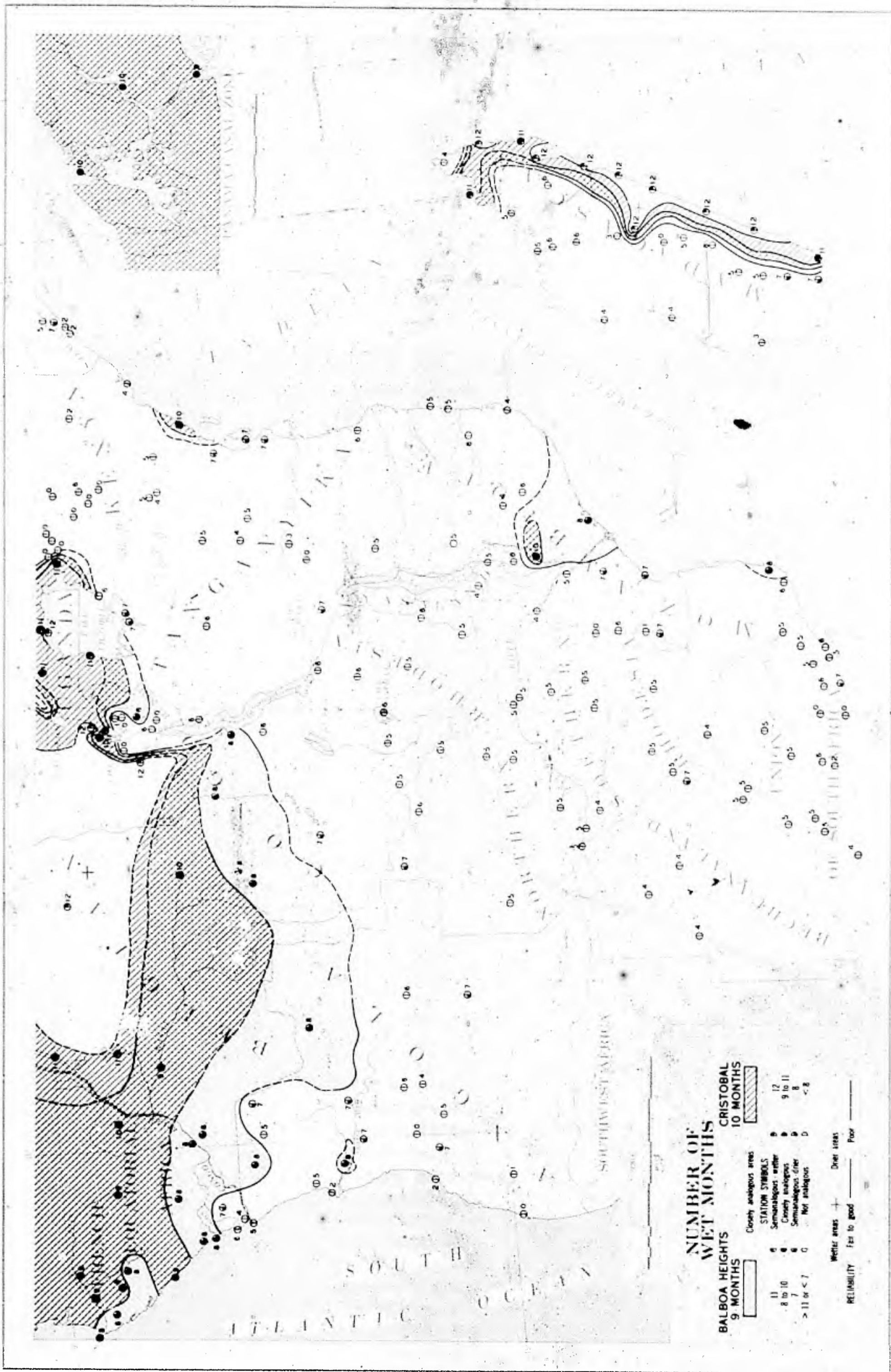


Figure 10

CLIMATIC ANALYSIS OF PANAMA CANAL ZONE SOUTH CENTRAL AFRICA 5.50 MADAGASCAR

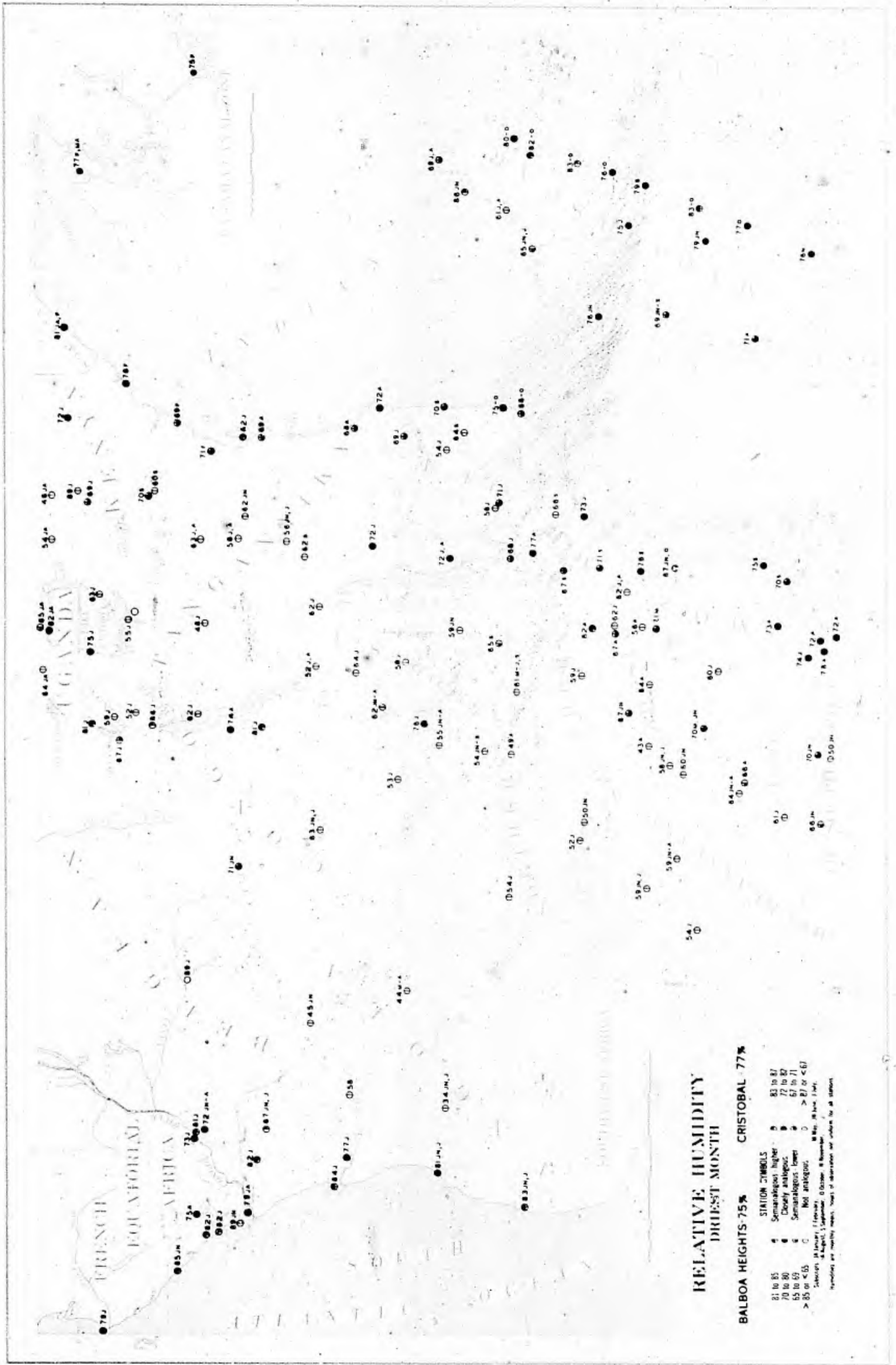


Figure 11

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**ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA**

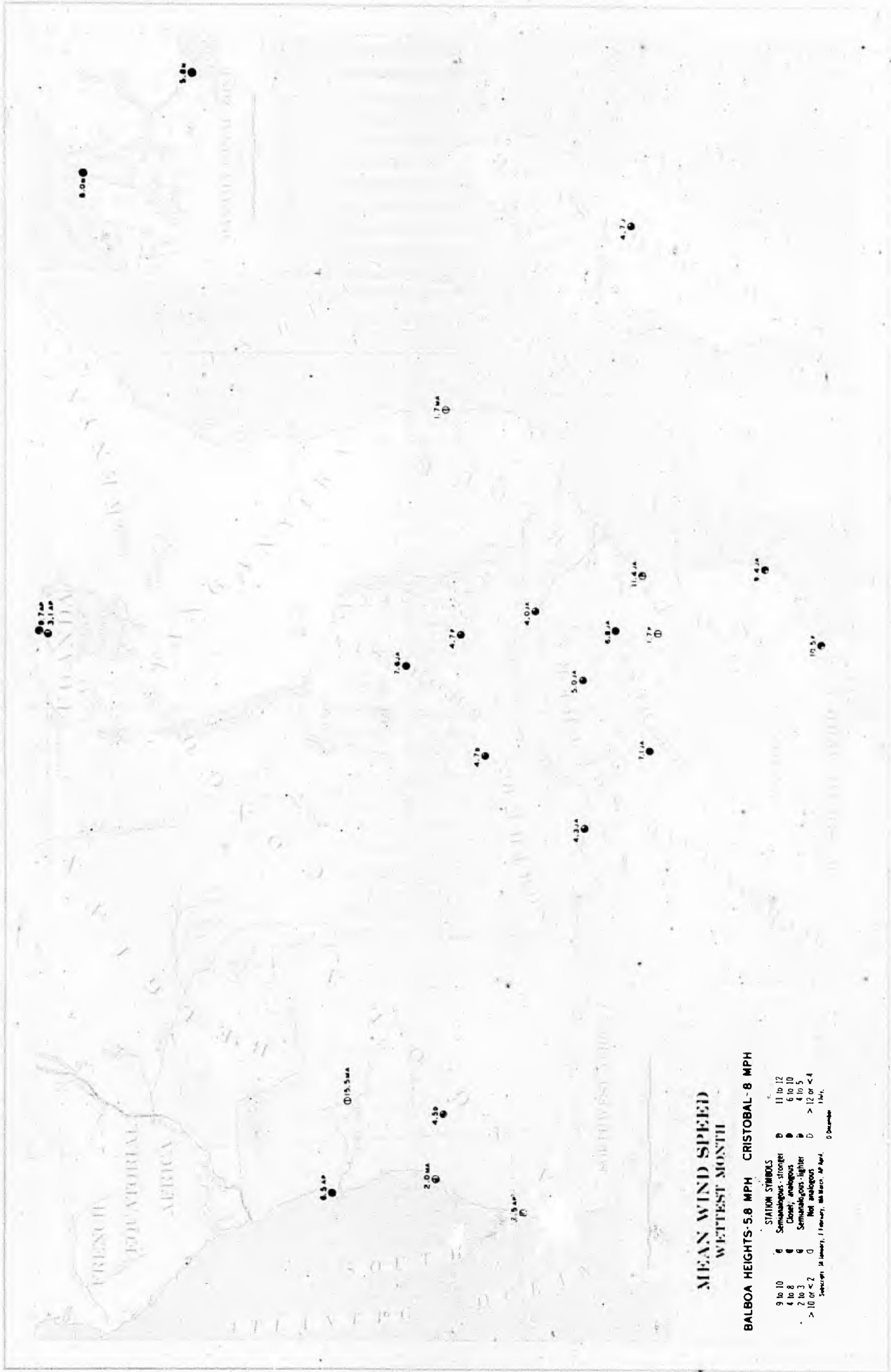
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CLIMATIC ANALYSIS OF PANAMA CANAL ZONE - 504 III CENTRAL AREA - 505 - 514 - 515 - 516 - 517 - 518 - 519 - 520 - 521 - 522 - 523 - 524 - 525 - 526 - 527 - 528 - 529 - 530 - 531 - 532 - 533 - 534 - 535 - 536 - 537 - 538 - 539 - 540 - 541 - 542 - 543 - 544 - 545 - 546 - 547 - 548 - 549 - 550 - 551 - 552 - 553 - 554 - 555 - 556 - 557 - 558 - 559 - 560 - 561 - 562 - 563 - 564 - 565 - 566 - 567 - 568 - 569 - 570 - 571 - 572 - 573 - 574 - 575 - 576 - 577 - 578 - 579 - 580 - 581 - 582 - 583 - 584 - 585 - 586 - 587 - 588 - 589 - 590 - 591 - 592 - 593 - 594 - 595 - 596 - 597 - 598 - 599 - 600 - 601 - 602 - 603 - 604 - 605 - 606 - 607 - 608 - 609 - 610 - 611 - 612 - 613 - 614 - 615 - 616 - 617 - 618 - 619 - 620 - 621 - 622 - 623 - 624 - 625 - 626 - 627 - 628 - 629 - 630 - 631 - 632 - 633 - 634 - 635 - 636 - 637 - 638 - 639 - 640 - 641 - 642 - 643 - 644 - 645 - 646 - 647 - 648 - 649 - 650 - 651 - 652 - 653 - 654 - 655 - 656 - 657 - 658 - 659 - 660 - 661 - 662 - 663 - 664 - 665 - 666 - 667 - 668 - 669 - 670 - 671 - 672 - 673 - 674 - 675 - 676 - 677 - 678 - 679 - 680 - 681 - 682 - 683 - 684 - 685 - 686 - 687 - 688 - 689 - 690 - 691 - 692 - 693 - 694 - 695 - 696 - 697 - 698 - 699 - 700 - 701 - 702 - 703 - 704 - 705 - 706 - 707 - 708 - 709 - 710 - 711 - 712 - 713 - 714 - 715 - 716 - 717 - 718 - 719 - 720 - 721 - 722 - 723 - 724 - 725 - 726 - 727 - 728 - 729 - 730 - 731 - 732 - 733 - 734 - 735 - 736 - 737 - 738 - 739 - 740 - 741 - 742 - 743 - 744 - 745 - 746 - 747 - 748 - 749 - 750 - 751 - 752 - 753 - 754 - 755 - 756 - 757 - 758 - 759 - 760 - 761 - 762 - 763 - 764 - 765 - 766 - 767 - 768 - 769 - 770 - 771 - 772 - 773 - 774 - 775 - 776 - 777 - 778 - 779 - 780 - 781 - 782 - 783 - 784 - 785 - 786 - 787 - 788 - 789 - 790 - 791 - 792 - 793 - 794 - 795 - 796 - 797 - 798 - 799 - 800 - 801 - 802 - 803 - 804 - 805 - 806 - 807 - 808 - 809 - 810 - 811 - 812 - 813 - 814 - 815 - 816 - 817 - 818 - 819 - 820 - 821 - 822 - 823 - 824 - 825 - 826 - 827 - 828 - 829 - 830 - 831 - 832 - 833 - 834 - 835 - 836 - 837 - 838 - 839 - 840 - 841 - 842 - 843 - 844 - 845 - 846 - 847 - 848 - 849 - 850 - 851 - 852 - 853 - 854 - 855 - 856 - 857 - 858 - 859 - 860 - 861 - 862 - 863 - 864 - 865 - 866 - 867 - 868 - 869 - 870 - 871 - 872 - 873 - 874 - 875 - 876 - 877 - 878 - 879 - 880 - 881 - 882 - 883 - 884 - 885 - 886 - 887 - 888 - 889 - 890 - 891 - 892 - 893 - 894 - 895 - 896 - 897 - 898 - 899 - 900 - 901 - 902 - 903 - 904 - 905 - 906 - 907 - 908 - 909 - 910 - 911 - 912 - 913 - 914 - 915 - 916 - 917 - 918 - 919 - 920 - 921 - 922 - 923 - 924 - 925 - 926 - 927 - 928 - 929 - 930 - 931 - 932 - 933 - 934 - 935 - 936 - 937 - 938 - 939 - 940 - 941 - 942 - 943 - 944 - 945 - 946 - 947 - 948 - 949 - 950 - 951 - 952 - 953 - 954 - 955 - 956 - 957 - 958 - 959 - 960 - 961 - 962 - 963 - 964 - 965 - 966 - 967 - 968 - 969 - 970 - 971 - 972 - 973 - 974 - 975 - 976 - 977 - 978 - 979 - 980 - 981 - 982 - 983 - 984 - 985 - 986 - 987 - 988 - 989 - 990 - 991 - 992 - 993 - 994 - 995 - 996 - 997 - 998 - 999 - 1000



**MEAN WIND SPEED
WETTEST MONTH**

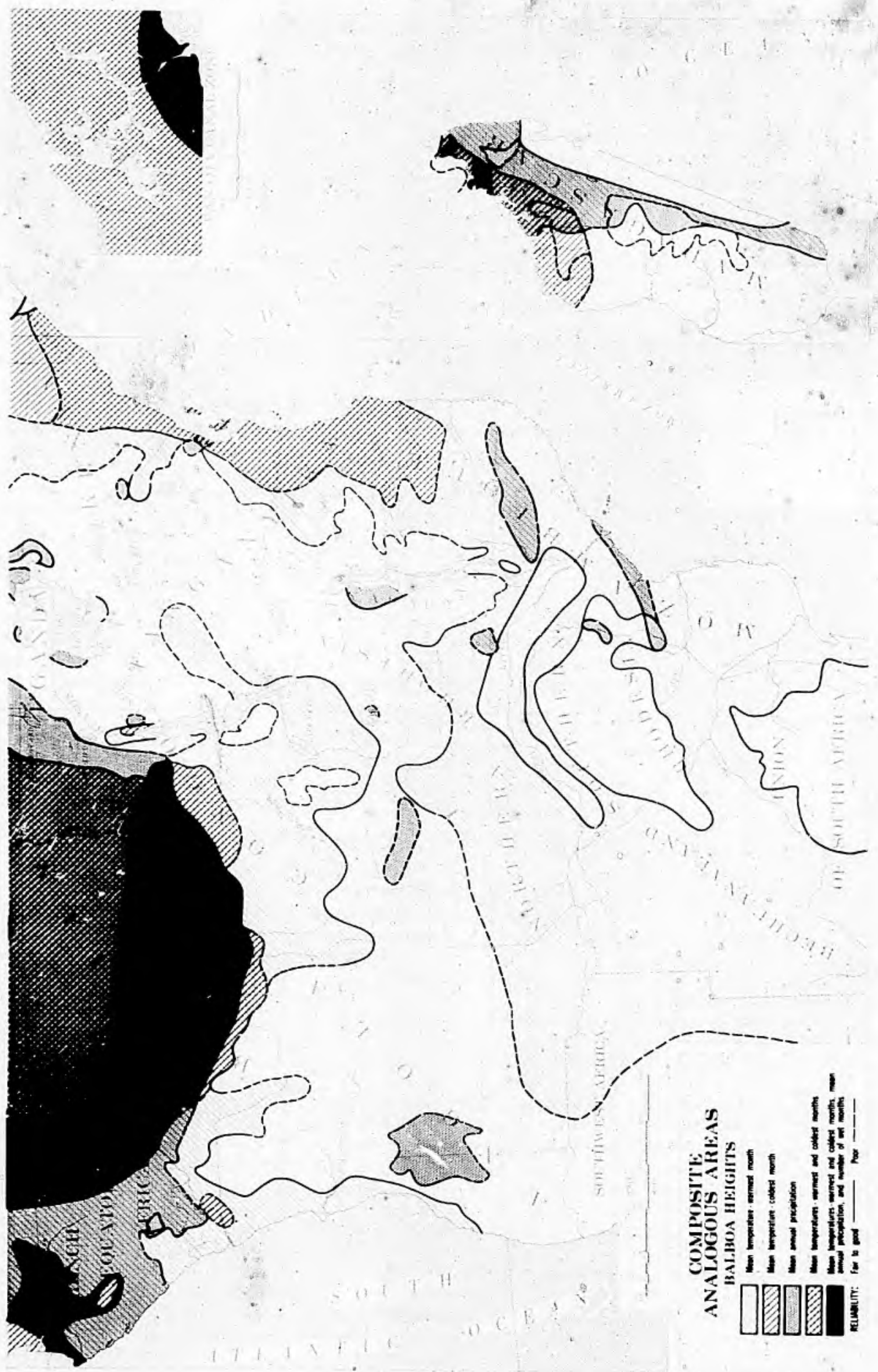
BALBOA HEIGHTS - 5.8 MPH CRISTOBAL - 8 MPH

STATION SYMBOLS

9 to 10	◐	Semianalogous - stronger	◑	11 to 12
4 to 8	◒	Closest, analogous	◓	6 to 10
2 to 3	◔	Semianalogous - lighter	◕	4 to 5
> 10 or < 2	◖	Not analogous	◗	> 12 or < 4

Stations in January, February, March, April, May, June, July, August, September, October, November, December

Figure 13



**COMPOSITE
ANALOGOUS AREAS
BALBOA HEIGHTS**

- Mean temperature warmest month
 - Mean temperature coldest month
 - Mean annual precipitation
 - Mean temperatures warmest and coldest months
 - Mean temperatures warmest and coldest months, mean annual precipitation, and number of wet months
- RELIABILITY: Fair to good ——— Poor ———

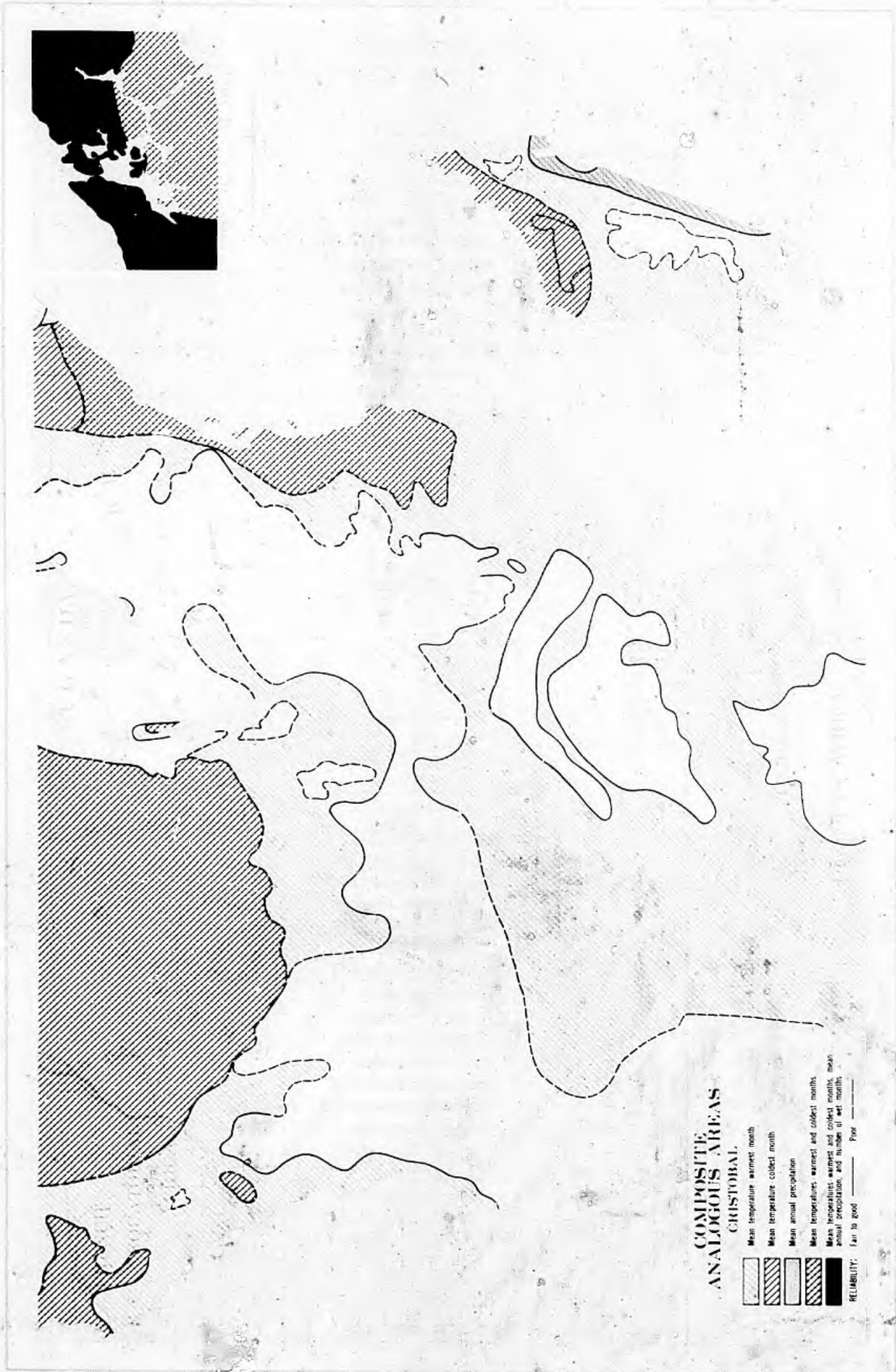


Figure 15

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