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WEATHER MAP TYPES AND ASSOCIATED CLOUD DISTRIBUTION OVER ALBERTA AND BRITISH COLUMBIA, 1975

by

ROLF CHRISTIAN HOPKINSON

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Weather Map Types and Associated Cloud Distribution Over Alberta and British Columbia, 1975", submitted by Rolf Christian Hopkinson in partial fulfilment of the requirements for the degree of Master of Science in Geography.

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Date 19 December 1979

DEDICATION

This thesis is dedicated to my parents, Geoffrey and Jane.

ABSTRACT

This is a pilot study which investigates the relationship between cloud distribution and certain weather map types over Alberta and British Columbia during 1975. Using surface map types developed by Kociuba, associated cloud patterns, interpreted from satellite imagery are documented and discussed. Also developed by Kociuba was a similar map catalogue of 500-mb circulation patterns. The 500-mb maps associated with each of the surface types examined in the study are employed in an attempt to explain the distribution of middle and high level cloud, not accountable for by the surface map types alone.

Finally, the study is discussed in terms of operational and design problems which were encountered and suggestions are tentatively made for use in future synoptic investigations of this nature.

ACKNOWLEDGMENTS

I wish to extend my sincere appreciation to my departmental supervisor, Dr. E. R. Reinelt for his unfailing support and for his suggestions, without which this thesis would never have become a reality. I am also indebted to Dr. N. R. Seifried and to Dr. W. M. Schultz for their willingness to serve on the examining committee.

I am very grateful to Mr. P. Kociuba and his associates at the Arctic Weather Centre in Edmonton for furnishing me with the necessary data regarding the surface and 500-mb map types for 1975. Furthermore, I would like to thank Mr. Kociuba for his ideas and encouraging words which provided the framework for this thesis.

Finally I wish to extend my appreciation to Ms. M. Murphy, who continually provided me with the inspiration to complete this work when my full time occupation created especially heavy demands.

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CHAPTER 1

INTRODUCTION

Perhaps the most elaborate description of synoptic climatology is that due to Barrett (1974), who made the following comments:

> Synoptic climatology ". . . seeks to provide a fresh basis for regional climatology not subject to such abstract statistical approaches. Synoptic climatology involves the study of general weather characteristics through their relationships with patterns of airflow or 'airflow-types' as they have become known (Barry and Chorley 1968). Such analyses depend more on categorization of pressure map patterns than upon analyses of the more traditional climatic statistics. Thus new problems of classification are encountered, but it has been argued that such approaches are worthwhile since synoptic climatological models 'allow climatological averages to be calculated on a realistic synoptic basis rather than for arbitrary time periods' (Barry 1963)."

A more concise definition is that made by Barry and Perry (1973):

> The field of synoptic climatology is concerned with obtaining insight into local or regional climates by examining the relationship of weather elements, individually or collectively to atmospheric circulation processes.

In a practical sense these circulation processes are deduced from surface and 500-mb synoptic charts which, by virtue of their small scale, include only the larger meteorological features. Such features would include (in the form of isobar patterns, or contour patterns) the major ridges and troughs, cyclones and anticyclones, along with active fronts. The small features, and those existing only for short periods, such as tornadoes, could clearly not be included. With this in mind, Stringer (1972) wrote the following regarding the merit of the synoptic chart:

> The synoptic picture of weather as implicit in the chart is, therefore, by no means complete. Nevertheless, studying a series of successive charts does enable one to build up a valuable mental model of meteorological conditions.

The synoptic climatologist may, therefore, be regarded as one whose discipline lies between traditional climatology, and synoptic meteorology.

One approach to synoptic climatological studies is that which was undertaken individually by three workers in the British Isles, namely Shaw (1962), Smithson (1969), and Matthews (1972). In essence, each of these workers sought to establish a connection between precipitation intensity and amount, and certain synoptic types. Shaw, for instance, examined percentages of total precipitation which were attributable to each of eight synoptic conditions, (see Figure 1.1) and employed a nine-year data base. For each observation, the synoptic type was determined from the surface weather map.

Within any one airmass type, however, considerable variation may exist in terms of temperature and

HOMOGENEOUS AIRMASS TYPES	Maritime Polar Continental Polar Arctic
FRONTAL TYPES	Warm Front Cold Front Occluded Front
OTHER TYPES	Thunderstorms Polar Lows

Figure 1.1. The eight synoptic conditions employed by Shaw (1962).

humidity, and the distinction between unlike airmass types is an arbitrary assignment. Furthermore, airmass types derive their physical characteristics from underlying surface conditions in their source regions. Hence, airmass modification attributable to changing surface conditions, with subsequent movement away from the source region, is a distinct possibility. It is seen, therefore, that the physical characteristics of an airmass are to a large extent dictated by the trajectory, i.e., by the thermal properties and the moisture of the underlying surface over which it may pass. The trajectory (or circulation pattern) of an airmass is in turn controlled at the surface by the pressure pattern, and aloft by the height contour patterns shown on constant pressure maps.

Kociuba (1974) summarized the above considerations thus:

> Since atmospheric patterns are continuous, the delimitation between classes is somewhat arbitrary and therefore rather unsatisfactory. Another problem arises with limiting the number of map types. The decisions of any two meteorologists may well differ, so that a unique classification cannot be obtained.

It would appear therefore that a statistical analysis of the pressure field might serve as a valuable basis for developing a classification of synoptic types, or conditions. Furthermore, such a method would exclude the problems arising from arbitrary divisions between one airmass type and another.

The classification of weather patterns into a series of groups or synoptic conditions is referred to as weather typing.

Using a classification system developed by Lund (1963), Kociuba (1974) was able to determine 33 frequently occurring surface pressure patterns in northwestern North America, using a twenty-six-year data base.

The primary tool in this investigation was the equation for determining the linear correlation coefficient, as developed and used by Lund (1963).

$$R_{xy} = \frac{\sum_{i=1}^{n} \left\{x_i - \bar{x}\right\} \left\{y_i - \bar{y}\right\}}{\left\{\sum_{i=1}^{n} \left[x_i - \bar{x}\right]^2 \sum_{i=1}^{n} \left[y_i - \bar{y}\right]\right\}^{\frac{1}{2}}} \qquad (1)$$

where R is the linear correlation coefficient,

n is the number of grid points to be analyzed,

x_i are the n values for a given day,

y_i are the n values corresponding to another day.

For each month during the period 1954-1971, Kociuba determined correlation coefficients of each map with all other maps in the series. Using equation (1) he was only able to process one month's data at any one time, because of restrictions imposed by computer core availability.

Figure 1.2 shows the 'data window' used by

Kociuba, containing 23 grid points, i.e., with $n = 23$. Correlation coefficients which exceeded 0.7, 0.8 and 0.9 were tabulated. It should be noted that $R_{xy} = 1$ indicates a perfect positive correlation between any two maps, and $R_{xy} = -1$ indicates a perfect negative, or inverse correlation. For example, the correlation coefficient of a low-pressure cell compared with that of a high-pressure cell with an identical isobaric pattern, but having a pressure gradient trending in the opposite direction, would give a correlation coefficient of -1.

The map which correlated with the greatest number of other maps with a correlation coefficient of 0.8 or higher, was selected as a map type, and along with the maps with which it correlated at this or at a higher value, was excluded from any further stages in the selection process.

Thus, for any month, the process was continued until the number of different types for that month reached the predetermined maximum of 30. It should be pointed out that any map which did not correlate with any other map in the month with a correlation coefficient of at least 0.8, was not assigned to a type.

Following this procedure, all monthly types were compared, and a similar sorting process was undertaken. Having completed the cataloguing for the 1954-1971 period, Kociuba assigned all maps for the 1946-1954 period to their respective types, again using equation (1).

In this manner the cataloguing of surface map types was completed; a similar procedure was carried out with 500-mb maps for 1963-1971.

Subsequent to the completion of his thesis, Kociuba's map-typing program was put into operational use at the Alberta Weather Centre in Edmonton on a full-time basis. For each of the four daily weather observations made at 0000, 0600, 1200 and 1800 UTC, the region within the grid shown in Figure 1.1, was assigned a specific map type.

Having thus developed a series of synoptic patterns, the climatologist may, both spatially and temporally, investigate the relationship that may exist between each of the types, and any number of meteorological variables. Such variables might include temperature, humidity, precipitation or the incidence of cloud cover, for example.

In the present study, an attempt has been made to determine any relationships that might exist between cloud type and distribution, and both the surface and 500-mb map types as defined by Kociuba (1974), for Alberta and British Columbia during 1975.

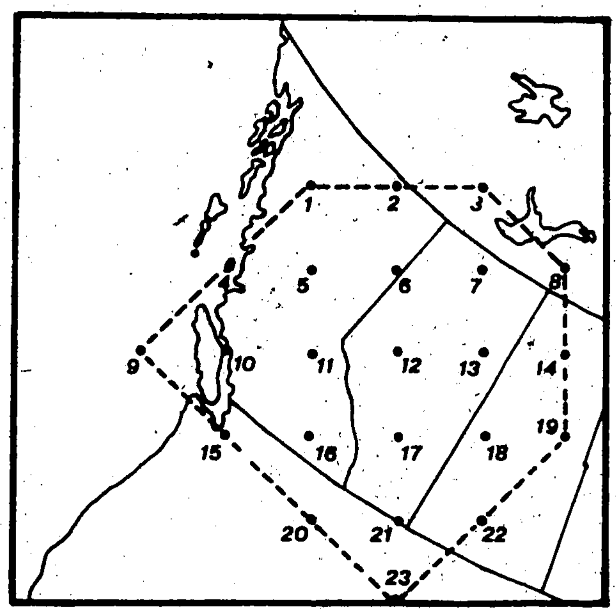

Figure 1.2. Data window used by Kociuba (1974).

CHAPTER 2

CLOUD COVER IN RELATION TO SYNOPTIC CONDITIONS

2.1 General

It has been recognized by Fritz (1964), and by Anderson, Ferguson and Oliver (1966), that certain atmospheric circulations appear to exhibit typical cloud patterns. The object of this study is to investigate the relationship between observed cloud patterns, determined from satellite imagery, and certain synoptic types shown to exist over Alberta and British Columbia during the year 1975.

Using Kociuba's map types, the ten most frequently occurring types for 1975 have been selected for examination in the present instance. These cumulatively represent 44.4% of all map types in the study region for that year. The uncorrelated maps were all incorporated into the remaining 65.6%.

In essence, the purpose of the present study is twofold. Firstly, an attempt has been made to determine whether any of the surface map types, or their associated 500-mb types, appear to exhibit typical or average cloud patterns or distributions within the study area. Secondly, the study might be regarded as a feasibility or pilot study into the usefulness of satellite imagery in synoptic climatological work.

Satellite imagery has in recent years become an invaluable tool in synoptic meteorology. Frequently the forecaster will employ satellite imagery to examine the cloud distribution associated with a particular feature known to exist from map analysis. Clearly the usefulness of such employment of imagery will increase in data-sparse regions such as the Arctic, for example. In terms of operational use, therefore, satellite photographs are used primarily to investigate individual synoptic events. To the best of the author's knowledge, however, no study employing satellite imagery has thus far been undertaken relevant to the synoptic climatology of this particular region.

2.2 The Nature of the Satellite Imagery in the Present Study

Satellite imagery was made available for interpretation by the Institute of Earth and Planetary Physics (hereinafter referred to as the I.E.P.P.), in conjunction with the Meteorology Division of the Department of Geography at the University of Alberta.

The receiving station operated by the I.E.P.P.

normally recorded between two to six passes per day for the year 1975. A pass may be considered to be that portion of the satellite's orbit which traverses an imaginary circle on the Earth's surface effectively described by the radius of reception of the ground-based antenna system which lies at its centre. It should be noted that, during the summer months, the northern hemisphere is illuminated for a greater duration in any 24-hour period than during the winter months. As a consequence, a greater number of passes will produce useful visible imagery during the summer, hence, the reason for the I.E.P.P. having recorded as many as six passes during the summer months, and as few as two per day during the winter.

The operational satellites used in 1975 by the I.E.P.P. were NOAA 3 and NOAA 4, owned and operated by the National Oceanic and Aeronautics Administration of the United States. Both satellites are now out of operational service, although they continue to orbit the Earth. The orbits of both satellites were similar in that each had an inclination to the polar axis of approximately 10°, and orbital periods of about 116 minutes. Typical operational altitudes of the NOAA satellites were of the order of 1500 km.

The sensing systems of the NOAA 3 and 4 crafts were also very similar. Both had the capability of providing vertical temperature profiles through the atmosphere, although VTPR data will not concern us here. Furthermore, both satellites carried two scanning radiometers, thus providing a parallel redundancy in the event of failure of one of the systems. The approximate rate of rotation of each radiometer was 1.25 seconds, during which time a scan was made from horizon to horizon, perpendicular to the satellite track, in both the visible and thermal infra-red portions of the electro-magnetic spectrum. Further information regarding technical aspects of the NOAA satellites under consideration is given in Appendix D.

For each pass within the range of I.E.P.P.'s receiving system, shown in Figure 2.1, both visible and infra-red signals are received in digital form. During operation, each scan line described by the radiometer consists of both sets of data which are transmitted from the satellite as VHF radio-waves. Each scan line is recorded by the I.E.P.P. laboratory on magnetic tape and, following the pass, a replay of the tape interfaced with both a computer and a cathode-ray tube (CRT), enables the digital information to be displayed as two separate images on 35mm film. It should be noted that one replay of the tape is required for the visible image and another for the infra-red, for any given pass.

For each map type under investigation, prints of both the visible and infra-red images were made on photographic paper, from the 35mm film. Care was taken to select imagery which corresponded as closely as possible to the time that the synoptic type was first determined to

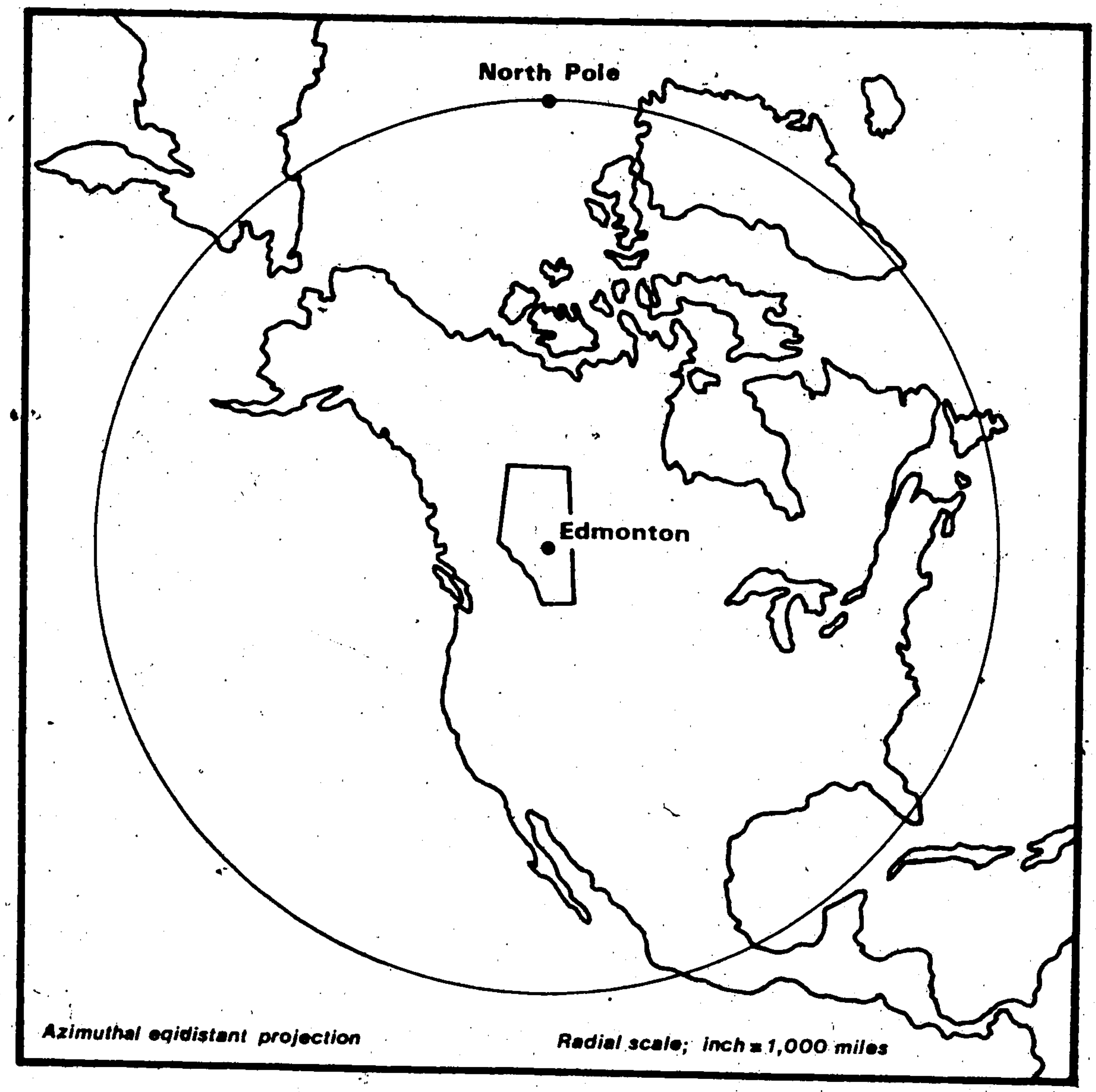

Figure 2.1. Map showing the effective radius of reception of I.E.P.P.'s satellite receiving station.

have existed. A further discussion of the synchronization of these times is given in Chapter 3.

One final point worthy of mention is that during 1975, a computer gridding program was developed by Reinelt et al. (1975). Most imagery recorded at the laboratory after July 1975 was, therefore, more readily interpreted as a result of the operational institution of this program.

2.3 Interpretation of Cloud from Satellite Imagery

A considerable amount of material has been published on cloud interpretation from satellite pictures. One of the first treatises on the subject was that written by Anderson, Ferguson and Oliver (1966). During the ensuing seven years, however, the advances made in interpretational techniques, and the growing sophistication of on-board sensing systems justified the publication by Anderson and Veltischev (1973), of a second and more comprehensive technical note on cloud interpretation from satellite imagery.

More specific studies regarding certain operational techniques have also been published in recent years, in association with the continual improvement of resolution on satellite imagery. For instance, Smith (1968) investigated a method for determining surface ridgelines from satellite pictures, based on observed cloud types which, on the basis of observational evidence, were found to be coincident with the ridge on most occasions. In a later paper, Whitney, Timchalk and Gray (1966) discussed the determination of jet stream positions from satellite imagery.

Alaka (1960), although not specifically concerned with remote sensing, provides considerable insight into the structure of clouds at various levels in mountainous regions. Particularly useful in the present instance was his discussion of lee-wave and rotor clouds which typically form along the leeward edges of mountain barriers; such clouds were frequently observed in the study area in the present work.

CHAPTER 3

METHODOLOGY AND TECHNIQUES EMPLOYED IN THE STUDY

3.1 Selection of the Study Area

Initially, the choice of the study area posed some problems. A broader view of the overall synoptic pattern might in many ways have been desirable, with the possible incorporation of Saskatchewan and Manitoba, and a large portion of the Northwest Territories into the study. The constraints imposed by Kociuba's data-window, however, would not permit such a broad overview, and so the need for reducing the size of the area became evident. Similarly, no one orbital pass could be relied upon to cover a sufficiently wide path to include all the provinces west of Ontario on a day-to-day basis.

A meso-scale study also had to be ruled out because of the scale of the imagery, coupled with the unsuitability of the resolution of the two-channel scanning radiometer system on the satellites.

Clearly, therefore, the study area was determined almost entirely by the area bounded by Kociuba's grid, the

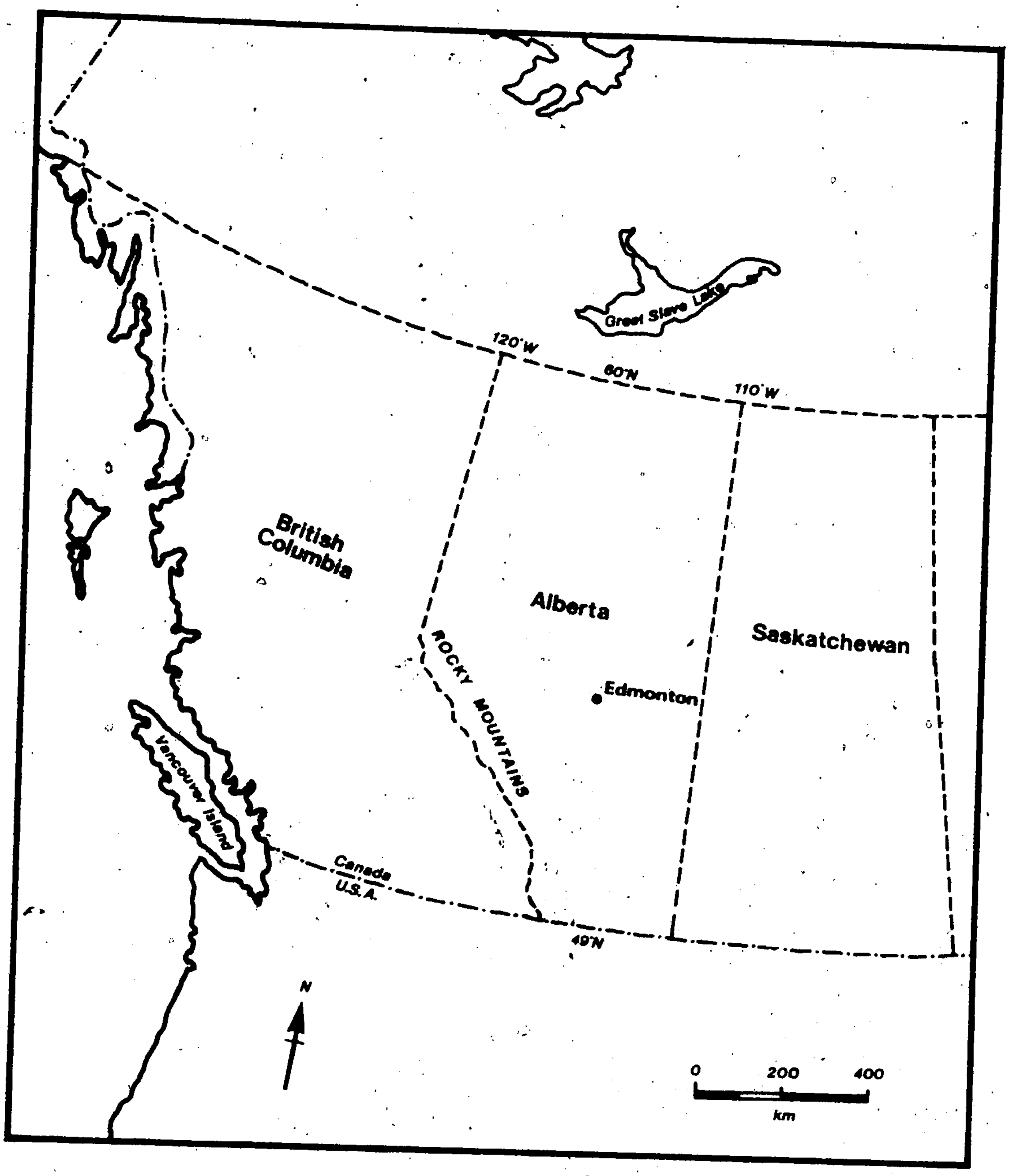

Figure 3.1. The Study Area

useful area scanned by the satellite on any pass from day-to-day, and by the resolution of the imaging systems on the satellite.

Alberta and British Columbia were finally decided to constitute the study area, although when it was considered relevant to the study, reference was made to major areas of cloud in contiguous areas. The Northwest Territories were necessarily excluded from the study, since, for much of the year (excluding the summer months) insufficient light was available north of 60°N to produce useful imagery in the visible portion of the spectrum.

3.2 Some Further Initial Considerations

During preliminary investigation, it was decided that an estimate of cloud cover (in tenths) should be made for each of the physiographic regions within the study area. These regions comprise the Coastal Mountain Ranges of British Columbia, the British Columbia Interior, the Rocky Mountains, the Rocky Mountain Foothills, and lastly, the Plains or Prairie regions to the east.

However, such estimation of cloud cover was excluded from the study, largely as a result of the findings of Young (1967). He conducted an experiment in which ten qualified weather observers were set the task of estimating the cloud cover in tenths on various satellite photographs, and 'torn paper' tests. Analyzed results of

Young's work indicated that the estimates of cloud cover were significantly different within the group, and he concluded that extreme care must be taken in making such estimates until such time as automated processing techniques are brought into general use.

During the planning stages, consideration was also given to the possibility of producing density-sliced facsimile copies of the images, employing the original digitized information directly from magnetic tape, a computer system, and a suitable output device such as a line printer or scanner. During 1975, however, tapes of digital information from satellite passes were only stored for a three-month period, and thereafter were erased and used again. It should be noted that density-slicing is in essence a process whereby a particular spectral band, or tone, may be selectively removed from, or enhanced on an image. This would have been of particular interest in the identification of various cloud layers, with particular reference to the infra-red photographs where each tone on the image corresponds to a unique temperature range. Reeves (1975) documented various techniques used in density-slicing. Less effective than the electronic method of density-slicing outlined above, is the photographic method. In this method, the image is illuminated with a variety of different coloured light, each of which will enhance a particular tone on the photograph. Largely because of time restrictions, density-slicing was not feasible by either of the above methods. An unsliced pair of photographs regarded as being most representative of each surface synoptic type has been included in Appendix A.

3.3 Data Extraction

The data were drawn from two primary sources. Information documenting the synoptic conditions existing over the region for each 12-hour period was supplied by the personnel at the Arctic Weather Centre of the Atmospheric Environment Service in Edmonton. Information regarding cloud types associated with these synoptic types was received directly from the weather satellites NOAA 3 and 4, and was made available through the I.E.P.P.

The optimum time of passage of the satellite over the reception area was 1700 hours, coordinated universal time (UTC). At this time, the satellite's track passed almost directly overhead of the Edmonton receiving station. Since Edmonton is located approximately at the geometric centre of the study region, all of the study area appeared on images scanned near 1700 UTC. Due to the period of the satellite, and also because of its sun-synchronous orbit, it could not be relied upon to pass directly overhead on a day-to-day basis. The visible image of any pass taken at 1700 or later, was at least, even during the mid-winter, helpful to some extent in interpreting cloud patterns. However, on earlier orbits insufficient light was available in winter to produce any useful imagery in the visible portion of the spectrum. On most occasions, therefore, either an earlier or a later pass than the ideal acquisition of signal at 1700, had to be taken. In extreme cases, this led to the omission of a small portion of either the eastern or the western parts of the study region from the imagery. This problem was to some extent alleviated after the gridding program was instituted on an operational basis. The gridding program involved a correction for the curvature of the Earth's surface. Hence, the edges of the scanlines which constituted zones of high distortion were 'stretched' perpendicularly to the satellite's track on the corrected imagery, and every such image essentially portrayed a planimetric surface.

It is clear, therefore, that because of the constraints imposed by the times of useful imagery being available, an isolated occurrence of any particular synoptic condition at 2400 UTC could not be analyzed.

When a condition to be analyzed occurred between 1200 and 2400 UTC on the following day (assuming that condition to have persisted throughout the intervening period) no problems arose, since the imagery time would fall between these two periods. In such situations, therefore, the imagery was assumed to have accurately portrayed cloud conditions coincident with the synoptic condition under scrutiny. At those times, when a condition was found to exist at 1200 UTC, but not at 2400 UTC on the following day, it was assumed that conditions between those times would not change very rapidly. Bearing this assumption in mind, it was further assumed that the imagery closest to 1700 UTC would still represent the main cloud features of the synoptic condition in question. All isolated conditions existing only at 2400 UTC were excluded from the study, but those existing at 1200 UTC were paired with the imagery scanned most closely to 1700 UTC for the same day.

For each of the ten synoptic types under consideration, the times of occurrence were analyzed and, bearing in mind the above restrictions, were paired with the appropriate satellite imagery. For each occurrence of each type, extensive notes were made regarding the nature of the cloud cover, employing both visible and infra-red images. The notes included extents of major cloud areas, and types observed, and also the apparent relationships of these clouds to various physical features of the underlying Earth's surface. A suitable clear-plastic grid overlay was used for locating various physical and political boundaries within the study region prior to the interpretation of the gridded imagery, later in 1975.

During instances in which one of the image pairs was unusable, its counterpart alone was used for the analysis. The only exception to this rule was made during the winter season when, for one reason or another, the infra-red image was of too poor a quality to analyze. During this period, the visible image alone was not suitable by itself to effect a useful analysis.

CHAPTER 4

RESULTS OF THE SURFACE ANALYSES

4.1 General

In order that the results might be readily compared, each of the synoptic conditions will be listed separately in the order in which the analyses were carried out. At the beginning of each individual condition, Kociuba's surface map type has also been displayed.

4.2 Synoptic Type 1

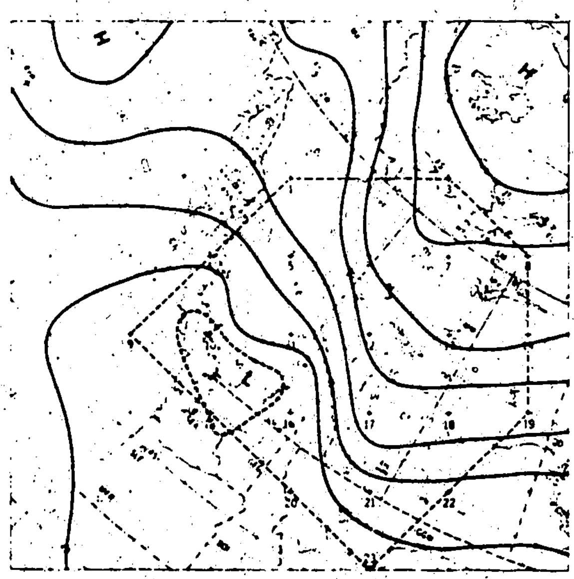

Figure 4.1. Surface Synoptic Type 1

During 1975, Kociuba's surface type 1 occurred on 24 separate days, which represented approximately 5% of all types during that year. As may be seen from the map type (Figure 4.2), this condition was primarily found during the winter, since the essential feature was a high-pressure cell centered in the Northwest Territories. The effect of this high at the surface would produce an easterly or northeasterly flow over much of Alberta, with the steepest pressure gradient being along the eastern slopes of the Rocky Mountains.

A light easterly flow prevails over the lower mainland of British Columbia, induced by a low-pressure system centered just off the coast at about 48°N.

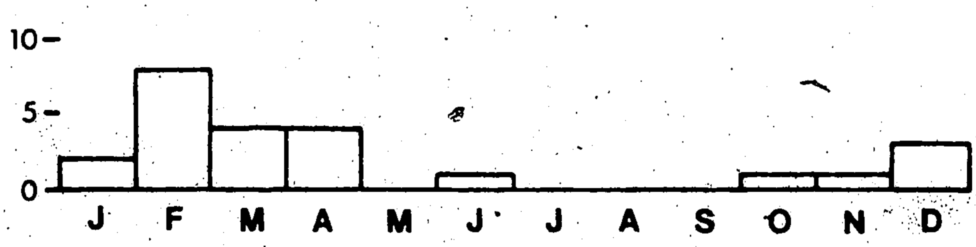

Figure 4.2. Number of days experiencing synoptic Type 1, 1975.

Analysis of the satellite imagery revealed that the British Columbia coast was generally devoid of any major areas of cloud under the influence of this weather type. Convective elements such as scattered cumulus (Cu) and sometimes even towering cumulus (TCu), or cumulonimbus (Cb) were frequently seen along the western slopes of the Coastal Ranges, and also in the regions of Vancouver Island and the adjoining coastal waters. Over the coastal waters along the entire B.C. coast, and extending 200 to 300 miles offshore, an open-celled Cu pattern was frequently observed, which presumably was indicative of a fairly strong contrast in temperature between the warm ocean surface and the relatively cool overlying airmass. It may be noted that any convective pattern such as this suggests that the ground or ocean surface is marginally warmer than the overlying air, but as this temperature differential increases, an open rather than a closed cellular pattern will result (Anderson and Veltischev, 1973).

To the north of Vancouver Island, no significant areas of cloud of major vertical development other than Cu or TCu were observed. To the south of the island, however, frontal activity was apparent, probably in association with the previously mentioned low, where considerable middle and high level cloud was noted. Associated with the onshore wind in Northern Washington, there was considerable convective activity on a number of occasions as evidenced by considerable Cu, stratocumulus (Sc), and TCu.

It is noteworthy that in the absence of higher cloud along the coastal waters, the open-celled cumulus pattern frequently assumed a vortical configuration which was normally centered slightly to the west of the Washington coast at latitude 48°N.

For the most part, the British Columbia interior was cloud-free, apart from the occasional times when the Cu elements were apparent, although these seldom amounted to anything more than widely scattered clusters.

The Rocky Mountains also appeared to be generally free of cloud, but certain factors made nephanalysis in the mountains a difficult task.

Because of high altitude, and hence relatively low temperatures, especially during the winter, cloud cover on the infra-red image was very hard to distinguish from cold ground surfaces. Only relatively dense and high layers of Ci or cirrostratus (Cs) were easily recognized.

Moreover, since on most occasions insufficient light was available to produce good imagery in the visible portion of the spectrum during the winter, interpretation necessarily rested mainly on the infra-red imagery. Similarly, any small areas of Cu or Ac in the mountains were difficult to distinguish from areas of snow or ice-fields.

Central and Southern Alberta were generally covered with a thick and continuous layer of As or Ac, which was frequently found to be overlain with patches of

Ci or Cs which became more dense with eastward extent. North-western and northern portions of Alberta remained relatively cloud-free, presumably as a result of their close proximity to the high-pressure system over the Northwest Territories.

In summary, therefore, the B.C. coast and frequently the interior, experienced sunny conditions under the influence of this synoptic type, excepting the extreme southwestern corner of British Columbia. Here, an As or Ac layer was found to persist, probably as a result of a surface onshore wind created by the low-pressure centre (see Figure 4.1).

Alberta generally saw overcast conditions associated with what appeared to be a far more extensive area of cloud over Saskatchewan. The only exception to this observation was found in Northwestern Alberta where skies were for the most part cloud-free.

4.3 Synoptic Type 2

This synoptic type accounted for 9.4% of all observations during 1975, and was present over the study region on a total of 52 days. Bearing in mind that the synoptic type was recorded twice during each 24-hour period, there were 68 occurrences of this condition in all. Only 42 sets of photographs were analyzed, however, since 10 sets had to be excluded on the basis of poor image quality.

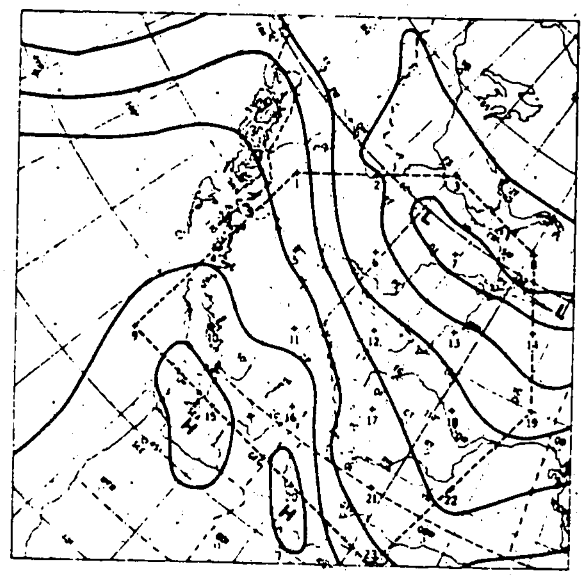

Figure 4.3. Surface Synoptic Type 2

The principal features characteristic of this condition may be seen in Figure 4.3. The centre of a high pressure system is established over Northwestern Washington, immediately to the south of Vancouver Island. To the northeast of the high, and centered along the 60^{o}N parallel between 100 and 120^{o}W, lies a fairly deep low-pressure area. The net effect of these two systems is to induce a west-northwesterly surface flow throughout the entire study area.

It will be noted from Figure 4.4 that the frequency of occurrence of this synoptic type was distributed fairly evenly throughout the year, exhibiting slight minima during the late winter and spring, and also during September.

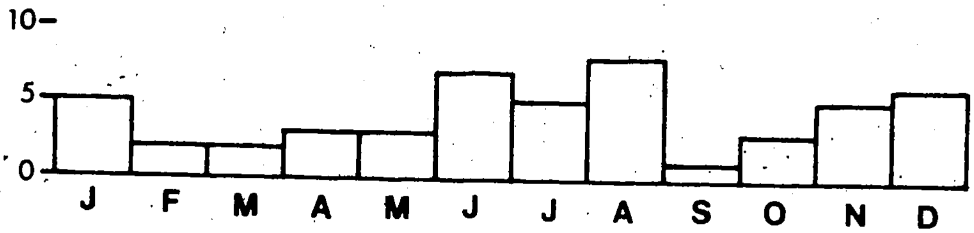

Figure 4.4. Number of days experiencing Synoptic Type 2, 1975.

Once again, whereas no single average cloud pattern could be identified as being associated with this synoptic type, certain recurrent features were evident.

In 20 instances, the west coast of British Columbia was almost entirely covered by a broken to overcast condition of either middle or high cloud; in 22 cases, similar cloud cover prevailed also over the interior of the province. Seldom, therefore, was British Columbia devoid of any large areas of cloud. At times, when conditions were otherwise cloud-free, lines of Cu were evident, paralleling the western (windward) side of the Coastal Ranges. This cloud was presumably the result of forced ascent, and resultant adiabatic cooling to the dew-point temperature under the influence of the westerly onshore flow.

By contrast, the Rockies both in British Columbia and Alberta, remained largely cloud-free, with the exception of six occasions, during which a broken or overcast condition was observed.

Generally, Alberta remained free of any extensive overcast areas, except in eastern and northeastern regions, which frequently experienced a thin Cs cover, presumably associated with the centre of the low-pressure area shown in Figure 4.3.

On five occasions, a miniature vortical pattern was apparent over Central Alberta, which comprised Ac or Ci cloud. It is believed that this phenomenon was a manifestation of secondary cyclonic development behind a front which lay to the east of the province. The existence of a front in this area is supported by the frequent presence of cirrus in Eastern Alberta, as mentioned above.

During the winter months, it appeared in several instances that the southeastern portion of Alberta was covered with a cumuliform cloud. The persistence of this pattern, and its predictably regular shape, suggested, instead, a snow cover rather than a cloud layer. It is thought that, in forested areas of Alberta, the tendency would be for snow to be shed from winter foliage, or the bare branches of deciduous trees. The southeastern portion of the province, however, is devoid of forest, and hence snow cover on the exposed ground surface might be expected to be readily identifiable.

In the months of June to November inclusive, the presence of Cb cloud in areas other than the foothills was noted in 10 instances. Also, during these months, convective activity inferred from the existence of lines of Cu, or Cb, was observed in the foothills on 12 occasions.

Once again, lee-wave Ci along the eastern edge of the Rockies was observed. There were 10 such occurrences noted throughout the year with a slight maximum during the months of June, July, and August. Furthermore, it was noted that such lee-wave cloud was normally confined to the extreme southern portions of the province.

Evidence of the existence of a stable westerly flow over the Rocky Mountains was also found when Southern Alberta was generally overcast. At these times, a cloud-free corridor was sometimes found to exist between the main cloud area and the mountains. This was presumably indicative of adiabatic warming, and hence dissipation of cloud in regions of rapidly descending air along the leeward slopes. The cloud sheet to the east of the clearing is a phenomenon usually referred to in Alberta as the 'Chinook Arch'.

4.4 Synoptic Type 3

During 1975, the presence of this synoptic type was reported on 26 days over the study area, of which only 18 days were analyzed either because of imagery being unavailable, or image quality being too poor.

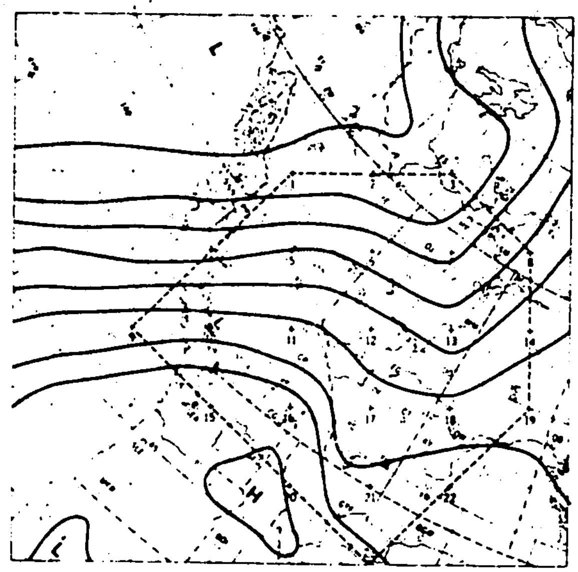

Figure 4.5. Surface Synoptic Type 3

This particular condition was found to occur almost exclusively during the winter months. During the months April to September inclusive, only one occurrence was reported. A seasonal distribution of this condition is shown in Figure 4.6.

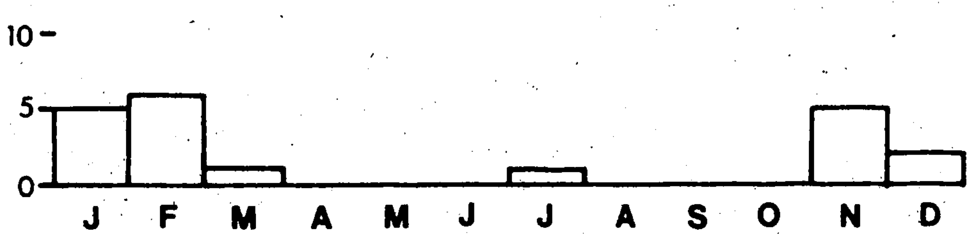

Figure 4.6. Number of days experiencing Synoptic Type 3, 1975.

The primary features of Type 3 (Figure 4.5) are a deep low-pressure area situated in the northeastern portion of the Gulf of Alaska, and a region of high-pressure centred in Idaho. The combined effect of these two systems is to produce a strong southwesterly surface flow over the entire study region, with the possible exception of Southern Alberta where the winds would blow from the west.

The low-pressure area, clearly visible as a large cyclonic vortex on most of the imagery, was responsible for producing broken to overcast conditions over the study area on several occasions.

The Coastal Ranges of British Columbia were found to be covered with broken to overcast high or middle cloud on 14 of the 18 days analyzed. On three of these days, however, the overcast was restricted to the coastline to the south of 55^{o}N. Also of interest in this portion of the study area, and noted in two instances, was the incidence of lee-wave Ci along the eastern edges of the Coastal Ranges.

In Central British Columbia, only in one instance did extensive cloud exist at the lower levels, unobscured by any higher layers. This condition occurred in July, a time when convective activity might be expected to be at its peak; at this time nearly all of the British Columbia interior was covered with a broken layer of open-celled Cu. On 12 of the remaining 17 days, however, the interior was covered with either broken or overcast middle or high cirriform cloud. Typically, during these times, broken fragments of Ac or As were overlain by north-to-south oriented bands of Ci.

The Rocky Mountains were generally found to be cloud-free; in only seven instances was any distinct cloud observed along their crest. This cloud was usually wispy Ci, associated with the more densely covered areas of British Columbia or Alberta.

The Plains of Alberta were also found to be frequently covered by fairly dense cloud, as were the foothills and northern regions. On six of the 18 days, Alberta was found to have been mostly overcast throughout, with the exception of the Rockies. Cloud was typically found to have been Cs in these instances. Middle cloud was also noted on several occasions, though only twice was it found to cover extensive areas as a broken or overcast condition.

Only in two instances was Cb observed in Alberta, a fact readily explained in that this was primarily a winter synoptic type.

Finally, lee-slope effects such as lee-wave Ci, or distinct clearing of otherwise extensive cloud along the eastern slopes of the Rockies, were found to occur on 10 occasions. The frequent occurrence of lee-wave phenomena was likely indicative of a deep, stable flow of air over the Rocky Mountains. The frequent incursion of cloud from the Pacific into both British Columbia and Alberta does suggest an approximately westerly flow extending upwards to at least the 500-mb level.

4.5 Synoptic Type 4

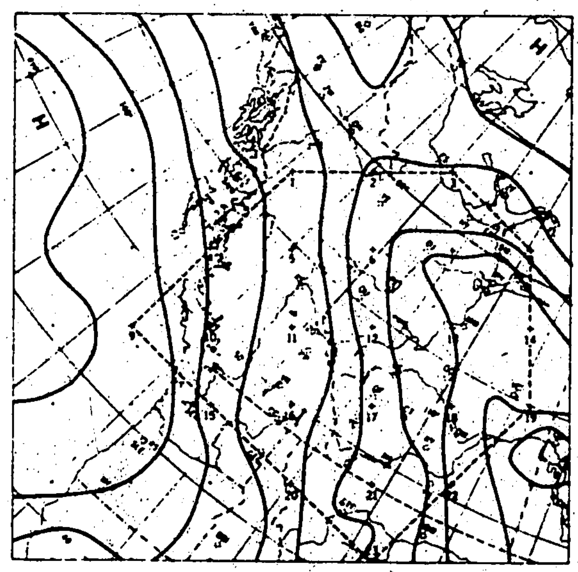

Figure 4.7. Surface Synoptic Type 4

The most prominent features of this synoptic type are a deep area of low-pressure centred over east Central Saskatchewan, and a broad high-pressure zone to the west with its centre at approximately 55°N, 140°W. The isobaric configuration was such that a northwesterly surface flow was produced over much of Alberta and British Columbia. It will be noticed from Figure 4.8 that this was primarily a summer condition, showing a distinct maximum frequency in June.

During 1975, Synoptic Type 4 was found to occur on 52 days. Only 30 sets of photographs were analyzed, since this type appeared at 0000 UTC in a number of instances, and no imagery was available of the study area at this time. Three sets of imagery were rejected from analysis because of poor image quality.

It was noted that once this synoptic type had become established over the region, it tended to persist for 12 hours or more on 16 occasions. Cloud patterns associated with this type were fairly diverse, ranging from almost total cover in some instances to virtually cloud-free conditions in others. Some notable recurrent events were, however, appar~~ent.~~

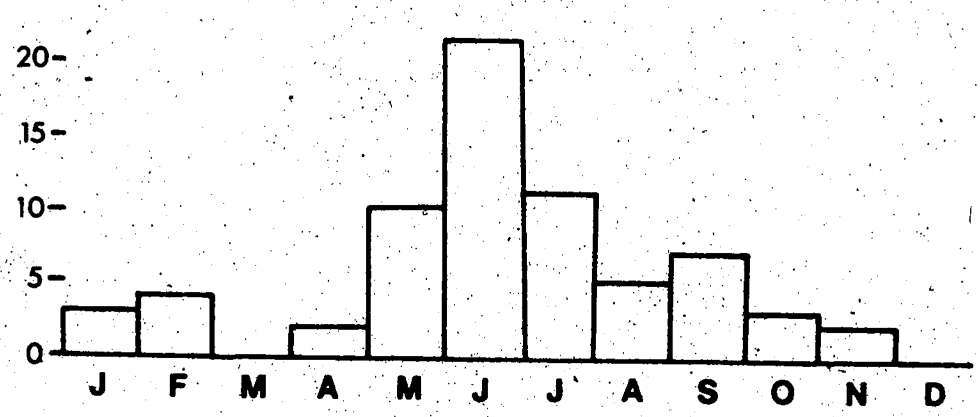

Figure 4.8. Number of days experiencing Synoptic Type 4, 1975.

Only in four instances was any low cloud noted over the Coastal Ranges in the absence of any higher layers of cloud. The Coastal Ranges experienced a scattered condition of middle or high cloud on eight occasions, and broken to overcast conditions of middle or high cloud were noted 14 times during the year. Generally, during the first five months of the year, the Coastal Ranges remained cloud-free. A similar situation was found to exist over the interior of British Columbia, in that in the absence of any higher cloud, low cloud was only witnessed in three instances.

On 20 of the 30 days analyzed, the interior of British Columbia was, at least in part, found to be covered with a broken or overcast layer of middle or high cloud. It was observed that on six of these days, the cloud was confined to the more mountainous areas in the extreme southeastern portion of British Columbia; on these occasions, an apparently dense cover of cirrostratus prevailed in this area. Scattered middle or high cloud was noted over the British Columbia interior in only four instances.

The high to middle broken or overcast conditions were also found to prevail over the Rockies on 16 occasions, all between April and October. Five of these occurrences were restricted to the Rockies south of 55°N.

In eight instances, the effects of lee-waves were noted along the eastern edges of the Rockies. These effects were primarily manifested by distinct local clearing of otherwise extensive areas of higher cloud, along the immediate eastern flank of the mountains.

Convective cloud was only observed seven times along the foothills of the Rockies in the form of towering cumulus (TCu) or Cb, all between the months of April and August, inclusive. Excluding the foothills, Cb was present in Alberta on 13 occasions, and no particular area appeared to have been preferred.

Overcast or broken middle cloud was observed in Alberta on 12 occasions, and in 18 instances, high broken or overcast conditions were reported. It should be borne in mind that only on eight of these occasions did an overcast or broken condition cover the entire province, and hence it was possible for a broken condition existing in Northern Alberta to occur simultaneously with an overcast condition in the southern portion of the province.

4.6 Synoptic Type 5

It is unfortunate that of the 17 days on which this synoptic condition occurred, only eight days could be analyzed in detail in this study. Thus, since the sample analyzed was so small, any conclusions based on the available data would be suspect, and so in the discussion of this type, no attempt has been made to describe an average cloud-pattern associated with it.

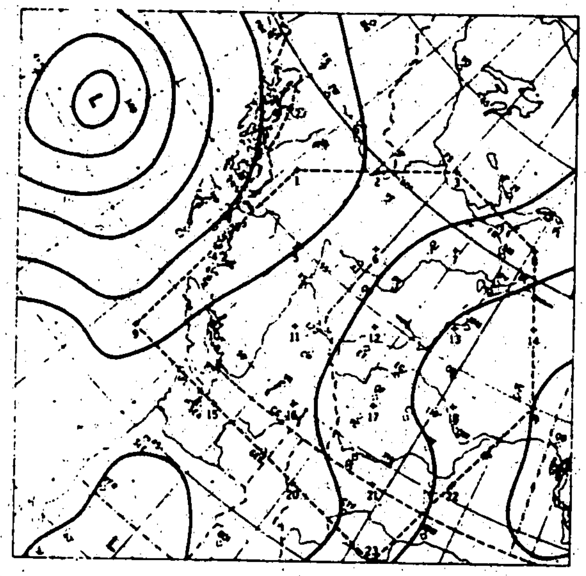

Figure 4.9. Surface Synoptic Type 5

A gentle southerly flow occurred at the surface over most of the study area, extending as far west as the border between Alberta and British Columbia. A fairly deep low centred west of the Queen Charlotte Islands produced a stronger southerly flow over the coastal waters of British Columbia.

Reference to Figure 4.10 indicates that there does not appear to be any distinct seasonal distribution of this type, although two maxima are evident in April and August. In January, June, July and September, there were no occurrences of this synoptic type.

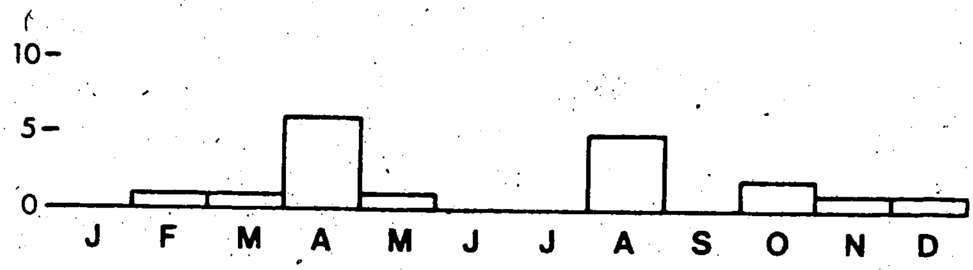

Figure 4.10. Number of days experiencing Synoptic Type 5, 1975.

In seven of the eight occurrences, the Coastal Ranges of British Columbia were found to be covered with broken to overcast conditions of middle or high cloud. Of the three cloudy days in August and October, two revealed the existence of cloud only in the extreme southern portions of the Coastal Ranges.

Similarly in the interior of British Columbia, of the three days experiencing cloud in August and October, all three showed that only the south was covered by a broken or overcast condition of cirri-form cloud, while to the north, generally clear conditions prevailed. Of the remaining five days during which such cloud was observed over the interior, in the single occurrence in May the cloud was confined to the western portion of the interior.

Again, the Rockies posed something of a problem in that middle cloud, especially when scattered, being difficult to distinguish from areas of snow and icefields. Only on two occasions are cloud positively identified over the Rocky Mountains. It was also recognized that Synoptic Type 5 was not particularly conducive to the formation of lee-wave cloud; only in three instances was lee-wave Ci noted.

In no instance was Alberta found to have any extensive areas of cloud, except on one occasion when Southern Alberta was covered by Cs. Patchy, scattered middle cloud was observed on three occasions, and apart from some instances in which scattered Cu was evident, the province was cloud-free with this synoptic type.

4.7 Synoptic Type 6

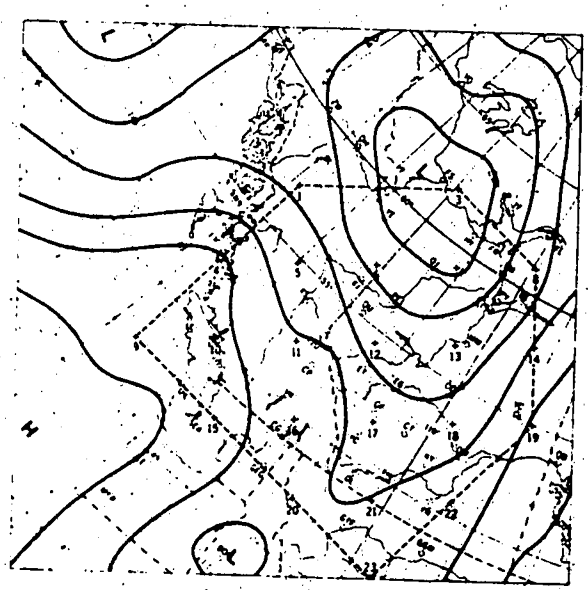

Figure 4.11. Surface Synoptic Type 6

Synoptic Type 6, although ranked ninth in Kociuba's classification, was found to be the sixth most frequently occurring during 1975; hence, a departure has been made here from his numbering system.

Only eight days were analyzed of the 21 on which this condition was present. In 11 instances this type occurred during the night only, when imagery was not available for interpretation. This type was observed primarily between the months of April to September, inclusive, and only in three instances did it appear in any other months.

Primary features of the surface flow are evident from the isobaric configuration characterizing the type, Figure 4.11. A general westerly to northwesterly flow was established over all of British Columbia and Western Alberta where, along a trough line, the flow thence backed, and a south-southwesterly flow prevailed over the remainder of the province.

As a result of the onshore advection of moist air at the surface, British Columbia was generally found to be covered with extensive areas of cloud, the Coastal Ranges having high or mid-level, broken to overcast conditions in five instances. In only one case were the Coastal Ranges covered with broken alto-cumulus elements in the absence of any higher cloud layer.

Similarly, in Central British Columbia, middle or high cloud was observed to have constituted broken or overcast conditions in five instances and, on two other

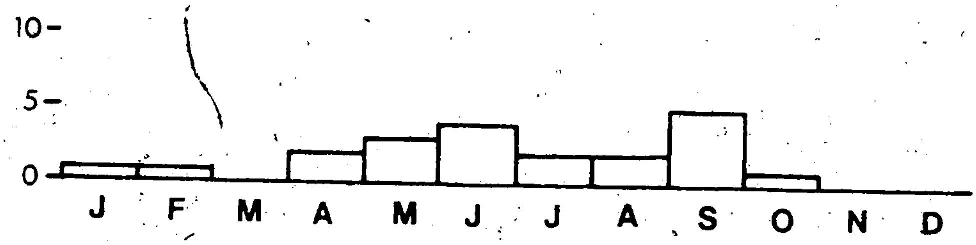

Figure 4.12. Number of days experiencing Synoptic Type 6, 1975.

occasions, areas of broken or overcast cloud of this type covered parts of the interior. Scattered elements were present once, and, also on one occasion, broken Cu was observed to cover much of the interior.

Only in two instances was broken cloud observed over the Rockies; lee-waves along their eastern slope were also noted twice. No distinct recurrent cloud patterns were observed in the rest of Alberta, although broken high cloud was noted four times, and broken middle cloud on two occasions, but only in one instance did cloud cover a large portion of the province. Cb was only present three times, once in the foothills as a few isolated cells, once in Central Alberta, and once in the north, each time in small isolated cells.

In summary, overcast conditions were prevalent throughout much of coastal and central British Columbia on 50% of the days analyzed. The Rocky Mountains and most of Alberta were largely devoid of any extensive cloud cover, although localized areas of broken or overcast cloud were observed on six occasions. Finally, Type 6, although occurring primarily during the summer months, did not appear to have been conducive to widespread convective activity.

4.8 Synoptic Type 7

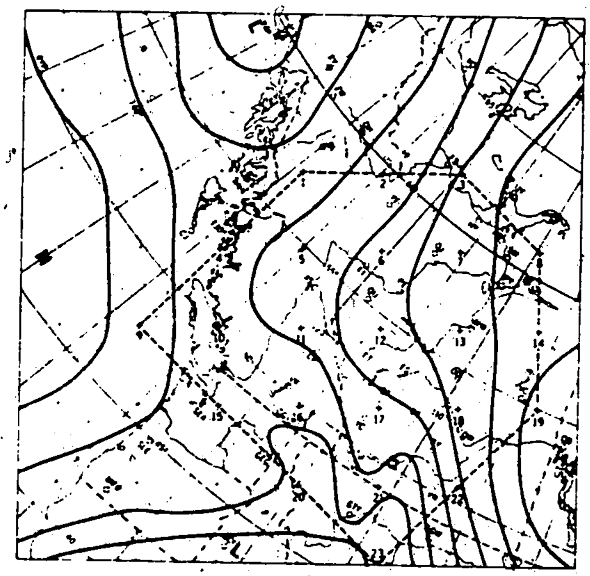

Figure 4.13. Surface Synoptic Type 7

The Coastal Ranges of British Columbia were found to be overcast only once. On this single occasion a solid overcast of middle cloud was present, overlain in some areas by patchy Ci. Only in two other instances was any significant cloud present, namely scattered Ac. In the interior of British Columbia, middle to high level cloud was observed on four occasions. Scattered Ac was observed twice, and broken Ac with some patchy Ci was also noted twice. In only one of these cases did broken cloud cover the interior extensively, the other occurrence being restricted to southeastern British Columbia.

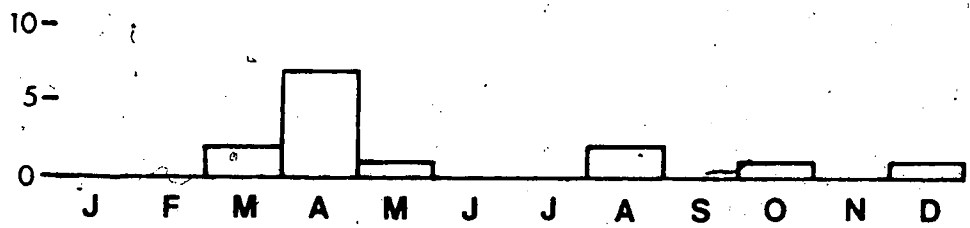

Figure 4.14. Number of days experiencing Synoptic Type 7, 1975.

No significant areas of cloud were found to persist over the Rockies. There was one occurrence of broken Ci, but this was restricted to the mountains to the south of 55°N. On one other occasion, scattered Ac was present over much of the mountains.

To the north of 56°N, Alberta remained almost entirely cloud-free, but the south, and especially the southeast of the province, frequently experienced overcast conditions. On four occasions, southeastern Alberta exclusively was covered by broken to overcast high or middle cloud. The entire southern portion of the province was also covered with broken Ac in one instance. Central Alberta was covered by broken middle cloud on one occasion, at which time the remainder of the province was almost entirely cloud-free. In two instances only was cloud found to have covered nearly the entire province, when Ac again appeared to have been the prominent type. Similarly, Alberta to the south of 56°N had broken Cu on one day during which little other cloud was observable over the province.

In no instances were either lee-waves or Cb cells observed in Alberta.

Further to the discussion of middle and high cloud in Southern Alberta, it may be said that the cloud in that area was observed to terminate abruptly along the western flank of the Rockies. Noting that an easterly surface flow prevailed in Southern Alberta with this synoptic type, it seems reasonable to suppose that the cloud in this area is due to upslope. In central and northern regions, which are further removed from the mountains, and under a more southerly or southeasterly flow, no upslope cloud would be expected to occur.

4.9 Synoptic Type 8

In 1975, this synoptic type was experienced on 17 days; of those, 10 were excluded from analysis since they occurred during the night-time only. This type is characterized by a deep low-pressure area centred just off the coast of British Columbia. A ridge over Saskatchewan and Northern Alberta, and a ridge in Washington, combine to produce a strong southwesterly flow in Southern British

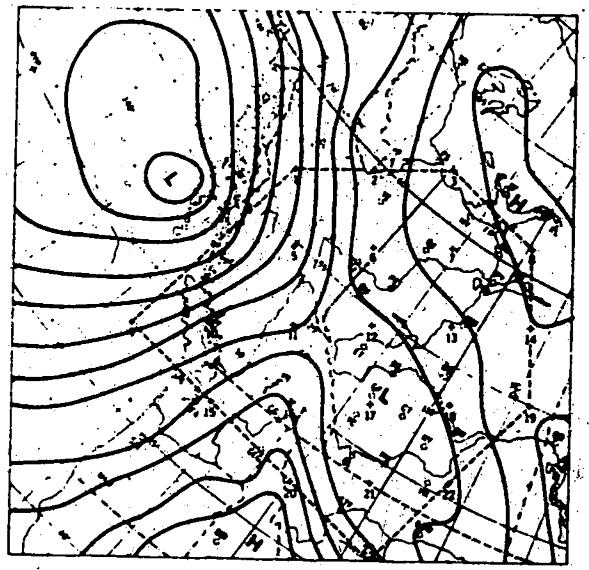

Figure 4.15. Surface Synoptic Type 8

Columbia, which on reaching the Rocky Mountains, slackens and splits, one portion proceeding northwest, the other southeast. With the exception of southeastern Alberta, most of the province experiences a weak easterly flow. (See Figure 4.15.) It should be pointed out here that, once again, a digression has been made from Kociuba's numbering, he having designated this as Type 11.

On two occasions, low cloud was noted in the Coastal Ranges of British Columbia: once generally throughout the mountains, and once as a distinct line of TCu along the windward slope, presumably as a result of forced ascent, and subsequent adiabatic cooling of the air. Middle cloud was also noted on two occasions. On one of these the cloudiness consisted of a fairly general broken layer of Ac, and scattered Ci which lay along the coastline; and on the other occasion, Ac was confined to southwestern British Columbia, in particular to the region of the lower mainland.

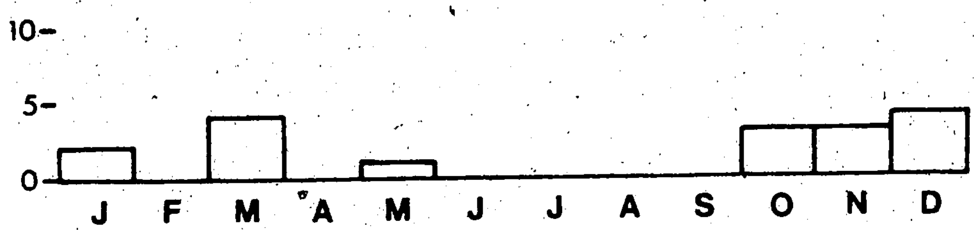

Figure 4.16. Number of days experiencing Synoptic Type 8, 1975.

In only one instance was the interior of British Columbia covered with open-celled Cu in the absence of any higher cloud. Broken or overcast conditions of middle or cirri-form cloud occurred seven times, but only on three occasions did this cloud extend over all of the interior. On two days the northern interior alone was covered, and in the other two cases only the southern portions had this type of cloud.

The Rocky Mountains experienced overcast conditions in only three instances. Broken Ac was noted on one occasion, as was some scattered Ac in another. In all cases, the overcast condition was caused by Cs. Lee-wave cloud was noted once, and in two instances when Southern Alberta was overcast the cloud terminated abruptly a few miles to the east of the mountains. Possibly this effect is indicative of lee-clearing, produced by subsidence in the westerly flow.

Only in one instance was Alberta completely overcast at a time when considerable cloud also covered much of British Columbia; the cloud shield passed apparently with little disturbance over the Rockies and, on reaching the leeward side in Alberta, assumed the form of banded As and Ci, the bands paralleling the mountains. At this time, a cloud-free area existed in Central Alberta, but in the northeast, scattered Ci was evident. In four other instances Southwestern Alberta was covered with broken to overcast As or Ac, while in one case much of the south of the province was covered with what appeared to be St or As. In this last instance, a well-defined cloud-free lane existed between the edge of this cloud, and further areas of cloud over the Rockies themselves.

4.10 Synoptic Type 9

Type 9 occurred only on 10 days during 1975; all cases were confined to the winter months between October and February. The most prominent feature of the pressure pattern defining this map type was a very deep low in the Gulf of Alaska, which effectively was responsible for producing a southwesterly to southerly flow over the entire study area. (See Figure 4.17.) Hence, advection of relatively warm, moist air into the study region was the

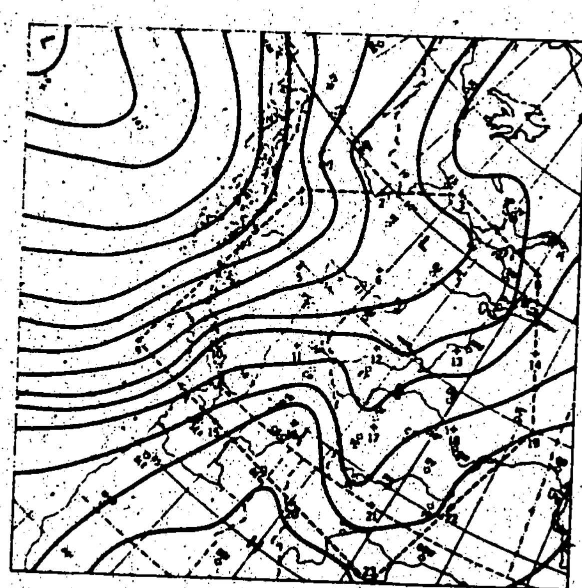

Figure 4.17. Surface Synoptic Type 9

primary effect.

Since there were so few Type 9 occurrences, little can be said about the average cloud pattern associated with it. No extensive areas of cloud were found to persist with regularity over the area, although fragmented patches of Ci and Ac were noted, either in British Columbia or Alberta, on four of the five days analyzed. Again, as with Synoptic Type 8, distinct lee-clearing occurred on three occasions in the neighbourhood of the eastern slopes of the Rockies. Isolated areas of Cu and Sc were noted both in British Columbia and Alberta; in two instances, what appeared to be lee-wave Ci in the Rockies was observed. No other items of interest were seen.

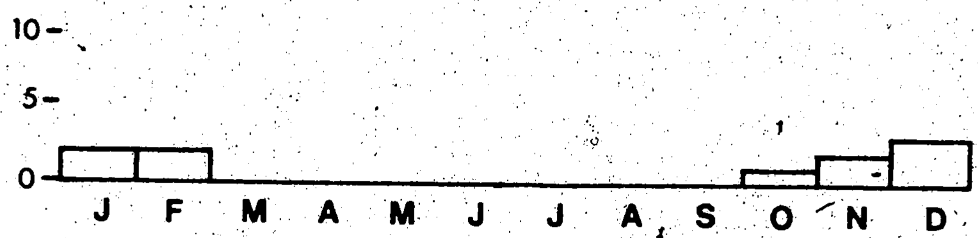

Figure 4.18. Number of days experiencing Synoptic Type 9, 1975.

It would appear as though the southwesterly flow was a stable one, as evidenced by the lee-clearing and general lack of any extensive areas of cloud in either of the provinces; care must be taken, however, in making any summary conclusions of this type, in view of the fact that it occurred so seldom during 1975.

4.11 Synoptic Type 10

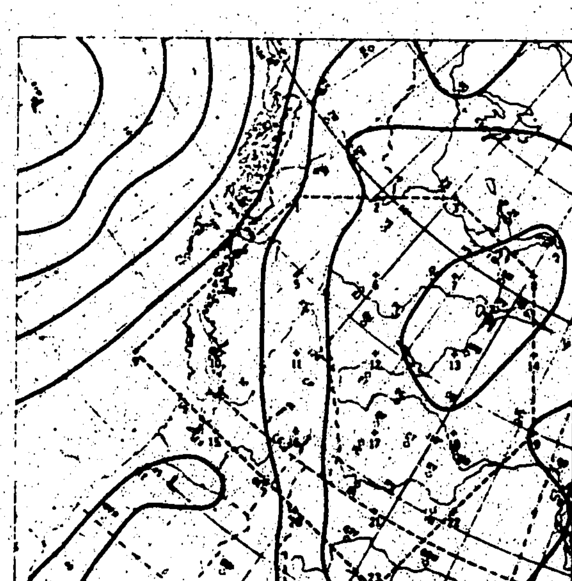

Figure 4.19. Surface Synoptic Type 10

The tenth and final surface synoptic type analyzed was ranked as 27th in Kociuba's frequency hierarchy. This type was found to have occurred on 20 days during 1975; of those, 11 were analyzed in detail.

The pressure pattern features a broad ridge over Alberta and British Columbia, and a large low-pressure system centred in the Gulf of Alaska. (See Figure 4.19.) A second, and apparently minor surface trough oriented approximately north-south, lies over Washington and Oregon. The 1975 frequency distribution of this type is shown in Figure 4.20; a slight maximum occurs during March, but no distinct seasonal pattern is discernable.

The Coastal Ranges of British Columbia were observed to have been covered with Ci and Ac in 10 instances. In all cases, cloud was only observed to the south of 56°N, but its persistence was remarkable. At times, this cloud was quite thin and patchy, but nevertheless it constituted a recurrent feature of this type. Only on four occasions did this cloud penetrate into the interior of British Columbia, and when it did so, also was confined to the south of 56°N.

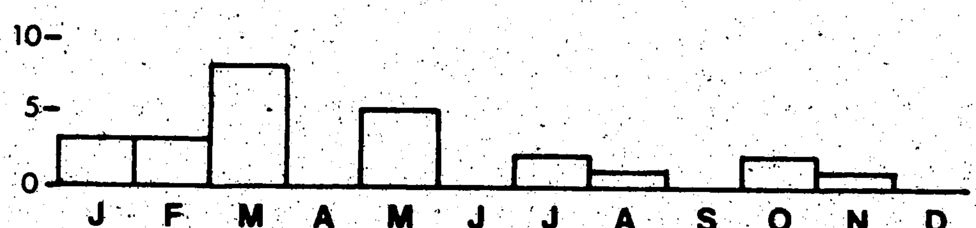

Figure 4.20. Number of days experiencing Synoptic Type 10, 1975.

Other areas of cloud, not apparently associated with the main deck of cloud to the west were noted, but generally were just small patches of thin Ac. The exception to this was a fairly large cluster of Cb cells centred at 55°N, 122°W on July 9th.

The Rockies were only obscured by cloud on one occasion, when fragmented Ci covered them fairly extensively. Other than in this single instance, they appeared entirely cloud-free. The remainder of Alberta was only observed to have been extensively covered on one occasion, when Ac lay over much of eastern, central and northern portions of the province. Patchy Ac and Ci were observed over the foothills on three occasions, and southern Alberta experienced a broken cover of Ac overlain with wisps of Ci four times. This cloud marked the northernmost extent of an apparently larger system to the south of the province.

CHAPTER 5

THE 500-mb ANALYSIS

5.1 General

Since an entire reanalysis of the 1975 satellite imagery in terms of Kociuba's 500-mb map types would have proven excessively time consuming, a shorter method was sought in order to determine any relationships between cloud types and the contour patterns of the 500-mb surface. Furthermore, it was deemed valuable to assess descriptively any relationships between surface map types and the 500-mb map types associated with them. The most expedient approach was finally considered to have been that outlined below.

For each surface map type analyzed in the first part of the study, the 500-mb types associated with them were noted, and the tabulated results appear on the following pages. A histogram plotting surface types against the number of 500-mb types associated with them is given in Appendix C, and it is from this graph that some primary conclusions regarding the 500-mb surface were drawn. Consideration was given chiefly to the actual number of 500-mb types associated with each surface type. The fewer the 500-mb types associated with any surface pattern, the more positive the association was assumed to have been between the two; conversely the surface types which were associated with many 500-mb types were indicative of a poor association. Further to these considerations, an index of this association was derived, which took into account not only, the number of 500-mb types associated with each synoptic condition, but also the frequency of occurrence of the surface condition during the study period.

Simply, the index took the following form:

$$I_A = S/F \qquad (2)$$

where I_A is the index of association,

S represents the number of occurrences of any surface synoptic type,

F is the number of 500-mb map types associated with the corresponding S value for 1975.

It should be noted that in this portion of the study, the total numbers of occurrence (totalled using 12-hourly rather than 24-hourly increments) were used to derive data regarding surface and 500-mb occurrences. In essence the association index is nothing more than a simple ratio which expresses the ratio of 500-mb types to any given surface condition. Nevertheless, since large differences occurred in the relative numbers of surface map types falling within each group, it is felt that the derived I_A values will compensate for these differences, and hence will allow comparisons between groups. The higher the I_A value, the stronger the observed association will be. For example, in the limiting case where a surface condition were to be associated with only one 500-mb map type, the association would be very strong, and any increase in the S-value would only serve to increase the association index. Also I_A can never attain a value of zero, or any negative value.

The most frequently occurring 500-mb map type was analyzed in more detail, for each of the 10 surface types, and typical cloud conditions found to coexist between the surface pattern and the 500-mb type were discussed. The tabulated results of the 500-mb level are given in Appendix C, and the 500-mb maps themselves appear in Appendix B.

5.2 Results of the 500 mb Analysis

In the presentation of the results, each surface type has been discussed separately, and in descending order of I_A value.

5.2.1 Surface Type 2: I_A = 5.8

The most frequently associated 500-mb map was map Type 1, which represented an almost zonal flow over the study region. This map accounted for 42.7% of all surface Type 2 occurrences during 1975. The surface low, approximately paralleling 60°N latitude, is reflected by a similar although less pronounced trough at 500 mb. (See Appendix B.) The upper trough paralleling the coast of British Columbia is expressed, however, as a surface ridge.

The summary of cloud conditions for surface Type 2 accords well with conditions which might be considered typical of 500-mb Type 1, in that, on the basis of the summary, a deep stable westerly flow was postulated to exist over the Rocky Mountains. Since both surface and 500-mb flows exhibited similar patterns, cloud features found to have been recurrent might have been accounted for by flows at either of those levels. The existence of lines of Cb cells on a number of occasions in the Alberta Foothills also correlates well with the zonal 500-mb flow. It is assumed that in the event of convective activity along the eastern flanks of the Rockies, enhancement of such activity might occur with simultaneous cooling and moist air advection at the 500 mb level resulting from such a westerly flow.

The second most frequently occurring 500-mb type was map Type 2, which also has a strong zonal characteristic. It differed, however, from Type 1 in that a weak ridge rather than a trough lay over British Columbia. It is felt though, that subtleties of this order of magnitude would not produce any major variations in cloud pattern over the study area, and hence 500-mb maps 1 and 2 were considered to have exercised generally similar effects in this regard.

It is interesting also to note that even the third most frequent 500-mb surface (map Type 11), which occurred six times during 1975, also represented a predominantly zonal flow over the entire southern portion of the study area.

5.2.2 Surface Type 3: $I_A = 3.3$

Some distinct similarities existed between surface Type 3 and surface Type 2 with regard to their associated 500-mb patterns. Again, as with Type 2, 500-mb maps 1 and 2 were the most frequently associated with the surface type, accounting cumulatively for 48.4% of all occurrences. The third most frequently associated 500-mb type was Type 8 which accounted for 22.6%. A departure from the zonal pattern is found here, in that a distinct ridge lies over Alberta, to the west of which a long-wave trough is entrenched in the Gulf of Alaska.

From the cloud analysis of the surface type, it is apparent that the number of instances of overcast conditions over the study area decreased from 14, along the Coastal Ranges, to six over eastern sections of Alberta. This evidence does not conflict with what we might have expected from the 500-mb flow. In the presence of 500-mb map 8, cloud would be expected to exist along the coast as a result of close proximity to the long-wave trough in the Gulf. Similarly, if the zonal flows were in existence, any cloud associated with short-wave disturbances in the regional flow, might reasonably be expected to dissipate with eastward progression as a result of lee subsidence caused both by the Coastal Ranges and the Rockies. It must be noted that the mechanisms which produced this lessening of cloud amount with eastward progress across the region could not have been deduced from the surface map alone. There appeared, therefore, to have been a better association between cloud distribution and the upper flow in this instance.

5.2.3. <u>Surface Type 6</u>: $I_A = 3.3$

Again it was observed that 500-mb Types 1 and 2 were the most frequently occurring, cumulatively accounting for 50% of all types associated with the surface condition. During the initial part of the study, only eight days were analyzed, and no recurrent cloud features were found to exist as a result. A general trend, and one which should be treated cautiously, was that as with surface Type 3, cloud amounts seemed to decrease with progression away from the coast. The zonal flow aloft might, therefore, have been postulated from the surface analysis. The existence of a surface low over Alberta, however, apparently produced little or no cloud, and the 500-mb level alone seemed to have dominated the cloud distribution. Any inferences that might be drawn from the data are tenuous, since the sample is essentially small, and no further discussion regarding this synoptic type seems warranted at this stage.

5.2.4. Surface Type 4: $I_A = 3.2$

Of all the types treated in this section, Type 4 was the most difficult to interpret since it was associated with 18 distinct 500-mb types together with some uncorrelated types. Reference to Appendices B and C indicates the diversity of these 500-mb types. Again, however, the zonal flows were the most common and possibly accounted for the relatively high incidence of lee-wave activity noted along the eastern slopes of the Rockies. Nothing can be suggested which might explain the diversity of these 500-mb types with the exception that this surface type ranked together with surface Type 2 as the most frequently occurring, and one might reasonably expect the numbers of 500-mb types to increase with increasing frequency of surface occurrence. It may be noted that although the number of 500-mb types was high, the I_A value was relatively low because of the high frequency of occurrence - 'S' in equation ~~(2)~~.

5.2.5 Surface Type 1: $I_A = 3$

Figure 4.2 indicates that Surface Type 1 exhibited a predominance during the winter months, and is typified by a net easterly flow over the study area. The 500-mb Types 1 and 3 were found to have been the most frequent, and together accounted for approximately 48.5% of all occurrences. In contrast to 500-mb map Type 1, Type 3 effectively produced a generally southwesterly flow over most of Alberta and southeastern British Columbia, and a circular cyclonic pattern over the remainder of the latter. Both 500-mb types then, produced net onshore flows which served to oppose the surface flow.

Only one recurrent feature of any significance was noted from the surface analysis, namely the frequent existence of Ac or As over Central and Southern Alberta in the absence of any higher cloud in the vicinity. By way of explanation, the surface flow represents an upslope condition in which forced ascent of the air at the surface, produced by the foothills, results in adiabatic cooling of the air, and the subsequent production of cloud. The absence of any high cloud is presumably a result of the fact that the flow aloft is a stable westerly, and any tendency for cloud to form in this flow is suppressed as it undergoes adiabatic warming to the lee of the Rockies. Generally it was noted that British Columbia and Northern Alberta were devoid of any extensive areas of cloud under these synoptic conditions.

The cloud distribution under discussion was noted on seven days during which surface Type 1 was in existence. Of these, three were associated with 500-mb map 1, one with map 4, one with map 28, and the remaining two occurrences were associated with uncorrelated 500-mb types. From subjective determination, there appears to be little similarity between the 500 mb types; map Type 28 for instance exhibits a highly azonal flow compared with map Type 1. Similarly, the uncorrelated types were determined by Kociuba to have been most similar to Type 24, again a type with no recognizable zonal component. At a cursory glance, therefore, it seems that the upslope condition is relatively independent of the 500-mb flow. Admittedly, almost 50% of the occasions under consideration were associated with 500-mb map Type 1 - the zonal flow - but the sample being examined is unfortunately too small to justify making any generalizations regarding the significance of this relationship.

5.2.6 <u>Surface Type 10</u>: $I_A = 2.3$

Since only 11 days of the 20 on which this type occurred were analyzed in detail, it is impossible to draw any meaningful conclusions from such a small sample. Some noteworthy features were however noted, and bearing in mind the sample size, appeared to have a marked recurrence. The Rockies were only found to have been obscured by cloud on one occasion, and at that time, were covered with patchy Ci only. Similarly, Alberta experienced extensive cloud cover only once when Ac was found to prevail. These phenomena are explained to some degree by the existence of the surface ridge over the province, and the associated 500-mb surfaces were generally characterized by a ridge over the Prairie Provinces which was found to have existed on 13 of the 25 times in which the surface type prevailed. The 500-mb ridge was accounted for by four distinct map types, but the subtleties that distinguished them from one another were so slight that little difference would likely have occurred in terms of cloud patterns produced by them. The dominant feature of the 500-mb type 28 for instance, is a very sharply defined ridge, the axis of which coincides with the longitudinal axis of the Rocky Mountains; map 18 indicates a similar situation with the exception that the trough to the west is closer to the British Columbia coast than is the former. Further comparisons may be made from the attached maps (Appendix B) but in essence 500-mb maps 3, 8, 18 and 28 were regarded as being similar types. A remarkable association hence existed between surface Type 10 and its coincident 500-mb types.

5.2.7 <u>Surface Type 9</u>: $I_A = 2.2$

Because so few occurrences of this type were found during 1975, the sample was too small even for any general trends to appear. Of the days on which this type did exist, no extensive areas of cloud were noted over the study region. At the 500-mb level, flows that were almost zonal persisted for seven of the 11 occurrences, and the third most common type, map 8, constituted a ridge over the study area. None of these types might normally be expected to produce any significant cloud.

5.2.8 Surface Type 8: $I_A = 2.0$

On 11 of the 17 days during which this surface type occurred, flows that were very close to being zonal prevailed. Five distinct flows corresponded with the remaining five days, and are shown in Appendix B. Most are represented by ridge forms or in the singular case of Type 15, a cutoff low centred to the northeast of Edmonton. The surface low is a complex one, and with the exception of British Columbia, it is hard to relate cloud conditions to the flow patterns. As might be expected from the surface configuration, moist air advection from the southwest is evidenced by generally cloudy conditions, particularly in southwestern British Columbia. The general westerly flow at the higher levels can only serve to enhance this process.

Cloud in Alberta showed no apparent recurrent patterns (which may perhaps be explained by the weak and poorly defined surface flows) with the exception of the southwest where middle cloud was noted on several occasions. It is assumed that this was a lee-wave effect resulting in part from a zonal flow at 500 mb and a disorganized surface flow which possibly represented a weak frontal zone.

5.2.9 <u>Surface Type 7</u>: $I_A = 1.7$

Again, from the summary regarding cloud relating to this surface condition, the primary features noted were those indicating upslope conditions in the southern portion of Alberta. From Figure 4.13, the low-pressure system centred to the south of the province induced an east-south-easterly flow over the mountains, and under the influence of this flow, middle and high cloud was found to have over-lain southern portions of the province on four of the eight days analyzed. It was noticed also that this cloud layer appeared to terminate abruptly along the eastern slopes of the Rockies as a well-defined line. From the table of associated 500-mb types it will be noticed that, with all maps, a fairly strong flow perpendicular to the Rockies was prevalent and, furthermore, this flow was directly opposed to the surface winds. It would seem evident, therefore, that the 500-mb flow was a stable one, and that descent on the leeside of the mountains with resultant adiabatic warming and drying had the effect of dissipating cloud which might have been attributable to the surface upslope effect. This idea is reinforced by the fact that with the exception of one instance, Northern Alberta remained primarily cloud-free under the influence of the 500-mb ridge.

Little can be said regarding British Columbia, since no recurrent features were found of any significance. It was noted, however, that only once were the Coastal Ranges obscured by any extensive areas of cloud and, apparently, fair conditions prevailed for the most part, in association with the surface high-pressure system in the Pacific.

5.2.10 Surface Type 5: $I_A = 1.6$

The final surface type under analysis, and that having the lowest I_A value, was associated with 11 distinct 500-mb map types. Furthermore, surface Type 5 only occurred on 17 days during 1975. The 500-mb maps exhibited a marked diversity and, with the exception of map type 1, the zonal flow, little repetition was noted among these types. Only eight days were analyzed, but on seven, the Coastal Ranges of British Columbia were found to have been obscured by middle and high cloud. Because of the diversity of the 500-mb types, the cloud seems to have recurred as a result of the surface low pressure area which produced an onshore flow, rather than as a result of the flow aloft. Once again, a general decrease in cloud amounts was noted with eastward progression through the study area, and it is assumed that this effect was the result of two factors. Firstly, any air advected from the west at the 500-mb level would have tended to dry out with its passage over the topographic barriers posed by the Coastal Ranges and the

Rockies, and secondly, if the surface flow were the controlling influence of cloud, then amounts would be expected to decrease with proximity to the high pressure area over Alberta. It is impossible unfortunately, because of time constraints, to examine cross sections through the atmosphere other than those at the surface and 500-mb levels. It is evident, therefore, that middle cloud, that is, cloud in the vicinity of 700-mb, cannot be accounted for accurately from analysis of the flow-patterns at either of these levels.

In the present instance, since cloud over much of the study region (excluding the coast) was middle cloud, and as the 500-mb types were diverse, then it would seem in this case as though the surface pattern had a more dominant influence over the distribution of middle cloud than did the 500-mb flow patterns.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 General

A presentation is given first of the nature of certain problems encountered in the study, divided broadly into operational problems and design problems. Following this, a general summary of the findings is put forth, and some suggestions for future studies in the field are provided.

6.2 Operational Problems

The operational problems were considered to have been those that directly or indirectly stemmed from physical constraints imposed by equipment used in the study. Primarily these were twofold, and although distinct from one another, both had the effect of creating more room for error in the subjective analysis of cloud types.

Firstly, without sensitometric techniques and a well established process of quality control, the possibility of significant variations in the gamma slopes of the enlarged prints were distinct. Density variations will occur with varying chemical conditions in the darkroom, and also will result from variations in the densities of the original 35-mm negatives. The introduction of the gridding program was invaluable in standardizing the final print quality, in that each negative bore a step-wedge or grey scale, but prior to this, print density was entirely an arbitrary decision. Stemming from these facts, therefore, what might have been the same cloud type on two separate prints, could have been expressed in terms of two different densities. Thus, errors could easily have arisen while attempting to distinguish cloud types in terms of their brightness. It is believed, however, that these errors were minimized by employing relative rather than absolute brightness as a guide. For example, if cumulus were identified by its texture, a specific grey shade could automatically have been attached to all cloud at this level. Hence, on the infra-red imagery brighter returns would obviously indicate lower temperatures, and presumably higher altitude cloud than the cumulus.

Secondly, and especially during the early part of the year, poor quality of the 35mm film resulted from a faulty advance mechanism during the scanning of the imagery in the laboratory. Also, the output level of the oscilloscope tended to fluctuate occasionally, causing variations in the brightness on certain image frames. These two factors combined to produce imagery which sometimes was of marginal quality from an interpretational standpoint.

Finally, and again relating to the gridding program discussed earlier, it should be mentioned that prior to the establishment of this program, accurate placement of the overlay on the imagery was frequently impossible. When physical features of the earth's surface were obscured by extensive cloud areas, the task of aligning the grid became particularly difficult. Also, prior to the gridding program, a correction for the curvature of the earth's surface was not made, and distortion was inherent in all the imagery because of this. Hence the overlay had to be continually adjusted to reduce the effects of this distortion when interpreting cloud in different parts of the study area.

6.3 Design Problems

It was assumed during the analysis, whenever a particular map type was found to occur, that general regimes of moisture and temperature would be very similar to those associated with all other occurrences of that map. This is clearly a fallacy in light of the fact that several of the synoptic types exhibited no pronounced seasonal preference. Related to this, also, it is pointed out that none of Kōciuba's types included frontal information.

Since fronts are frequently essential to the understanding of cloud distribution, the omission of such consideration would have been unforgivable had more time been available. It is important to realize that, in the undertaking of further studies such as this, airmass types and frontal zones must be given consideration.

From the results, it is suggested that had consideration been given to frontal systems, the cloud distributions that otherwise appeared to have had no logical explanation might have been more readily explained.

6.4 Summary

An attempt was made to relate cloud conditions over Alberta and British Columbia during 1975 to ten distinct surface pressure patterns. Because of time constraints, an entire reanalysis of these cloud patterns in association with the 500 mb types coincident with them was not possible. Instead, however, the 500-mb maps associated with each surface map were described and an attempt was made to explain certain cloud characteristics in terms of the 500-mb map types associated with each surface type. Also as a result of the somewhat prohibitive time required to perform the individual analyses of the photographs, the data period was necessarily limited. Consequently, the samples were in some cases too small for any average cloud conditions to have revealed themselves. Broadly speaking, cloud patterns appeared to have been associated more closely with the 500-mb map types than they did with the surface patterns, but in many cases both surface and 500-mb maps were required in order to explain cloud at various levels. The effect of the orography of the study area cannot be overstressed. The Rockies and, to a lesser degree, the Coastal Range Mountains exercised a large influence on cloud patterns which, in several instances, apparently "conflicted" with the surface map type. For example, lee-wave clouds were noted frequently with the influence of a general westerly or southwesterly flow at the 500-mb level, usually regardless of the surface pressure pattern. Similarly the orographic effects of the Coastal Range Mountains in producing convective activity along their windward slopes appeared to have little relationship to the flow aloft.

In conclusion, therefore, by studying the nature of the atmosphere, we are considering a dynamic three-dimensional medium, the processes within which involve diverse variables. The prime objective should then be to simplify the study to an optimum extent, such that one should eschew irrelevant information and exclude data which are not within the realm of predetermined constraints. It is felt, however, that in the present study an over-simplification has been made, to some extent out of necessity, in an attempt to reduce the overall time spent extracting data and analyzing imagery. These facts in themselves dictated that the period of data collection should be short. It is suggested that future studies of this type might prove valuable provided that a sufficiently long data collection period is chosen; a period of at least five years is tentatively recommended. This would clearly involve an automated means of processing the data, such as the digitizing of individual scan-lines at the time of reception of the satellite imagery. Such information might be stored on a disk for later computer processing at a convenient time. It is also felt that such methods might be employed to actually analyze the data, and hence reduce the subjective errors associated with manual analysis of each piece of imagery.

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APPENDIX A

REPRESENTATIVE PHOTOGRAPHS OF EACH SURFACE MAP TYPE

NOTE: Where possible, both infra-red and visible images have been included.

Figure A-1. Surface Type 1, I.R. Image

Figure A-2. Surface Type 1, Visible Image

Figure A-3. Surface Type 2, I.R. Image

Figure A-4. Surface Type 2, Visible Image

Figure A-5. Surface Type 3, I.R. Image

Figure A-6. Surface Type 3, Visible Image

Figure A-8.

Figure A-9. Surface Type 5, I.R. Image

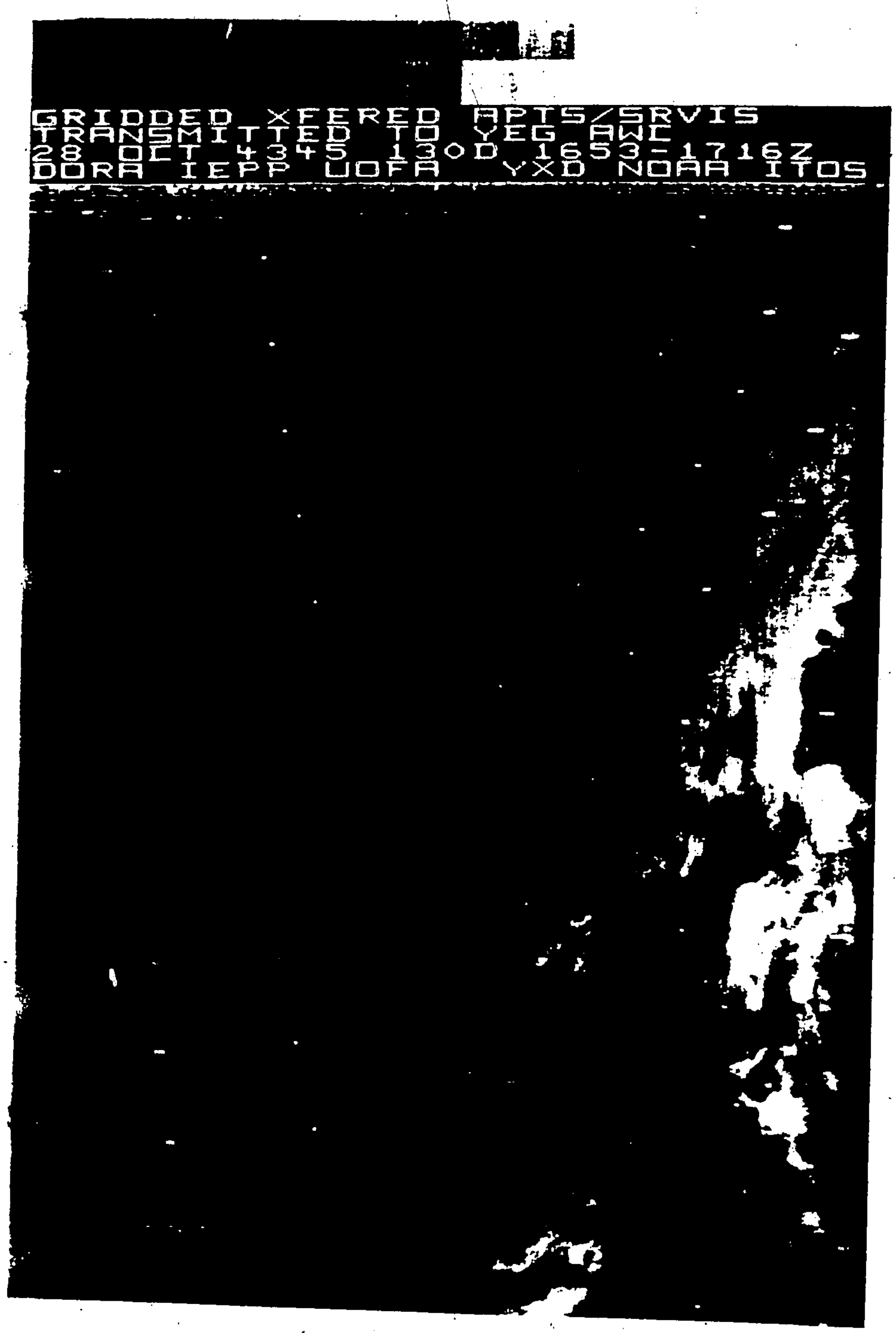


Figure A-10. Surface Type 5, Visible Image

Figure A-11. Surface Type 6, I.R. Image

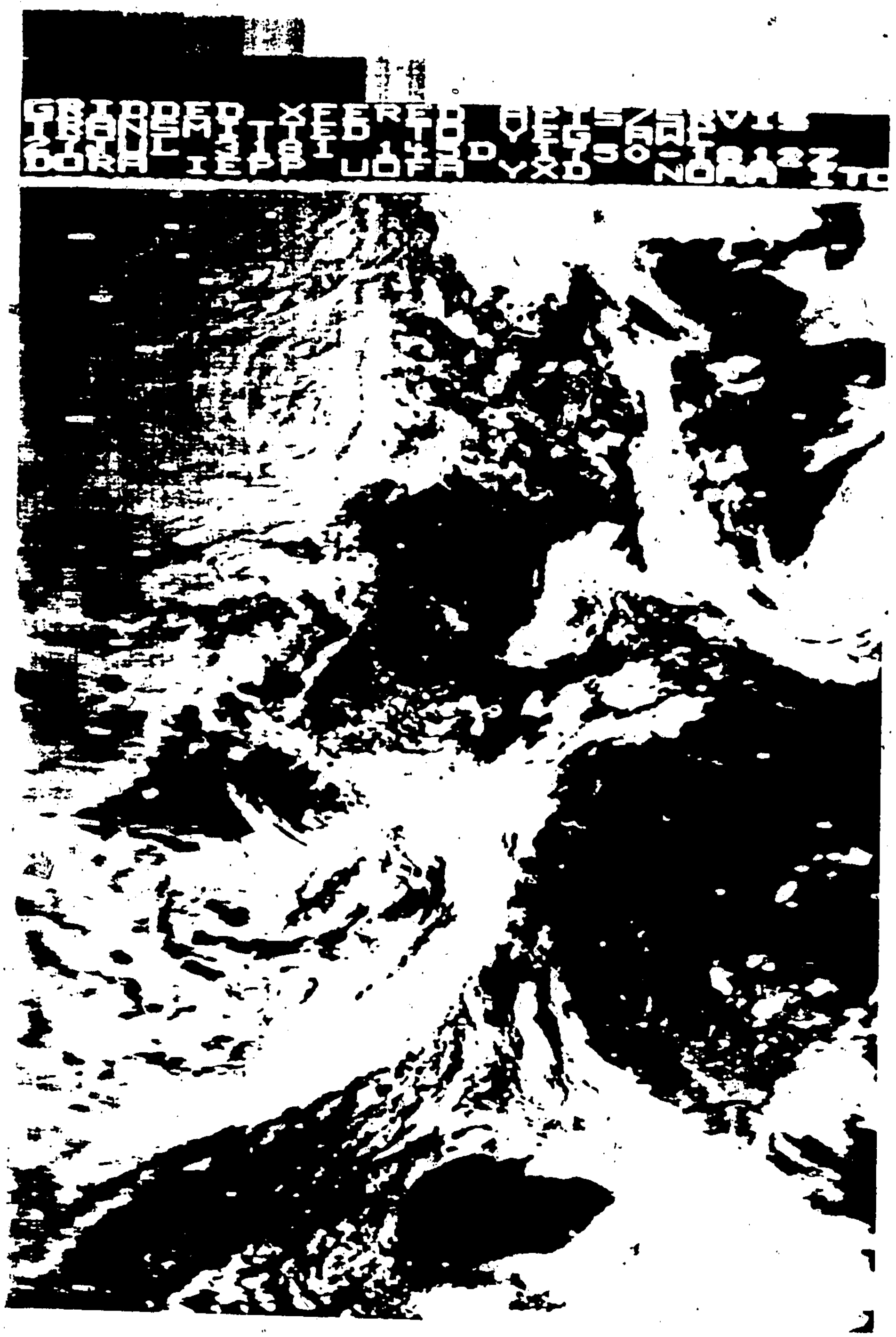


Figure A-12. Surface Type 6, Visible Image

Figure A-13. Surface Type 7, I.R. Image

Figure A-14. Surface Type 7, Visible Image

Figure A-15. Surface Type 8, I.R. Image

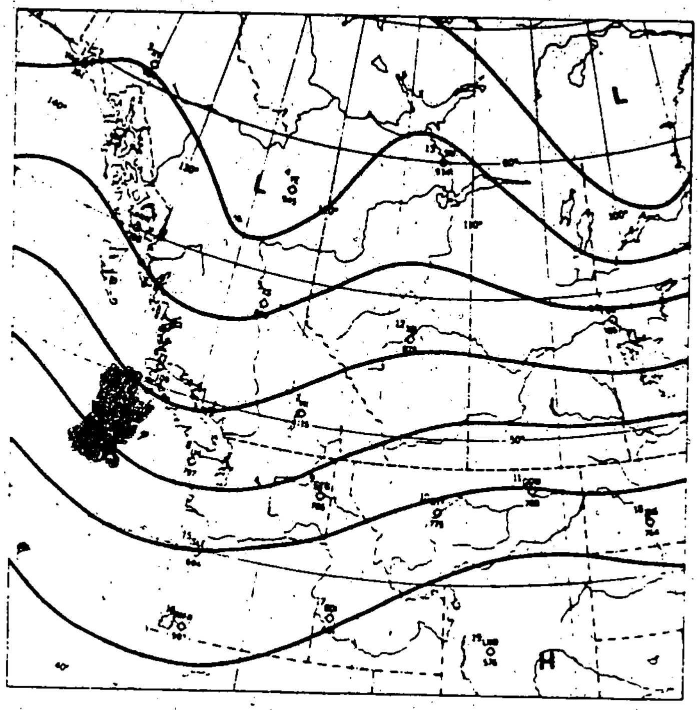
Figure A-16. Surface Type 9, I.R. Image

Figure A-17. Surface Type 9, Visible Image

Figure A-18. Surface Type 10, I.R. Image

APPENDIX B

500 mb MAP TYPES USED IN THE STUDY



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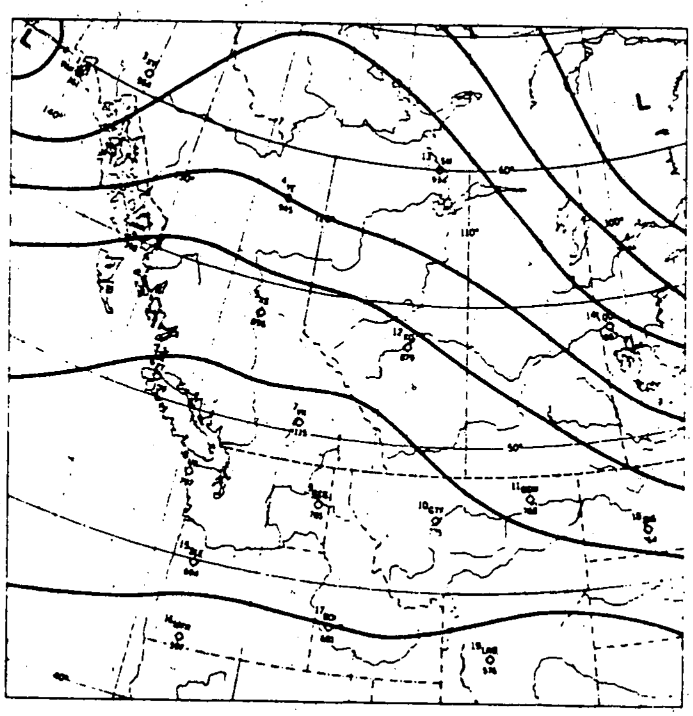

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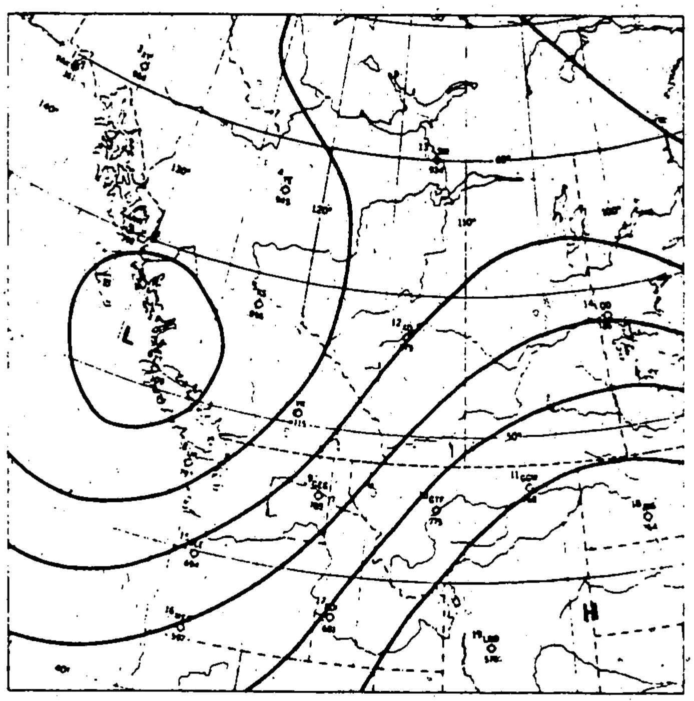

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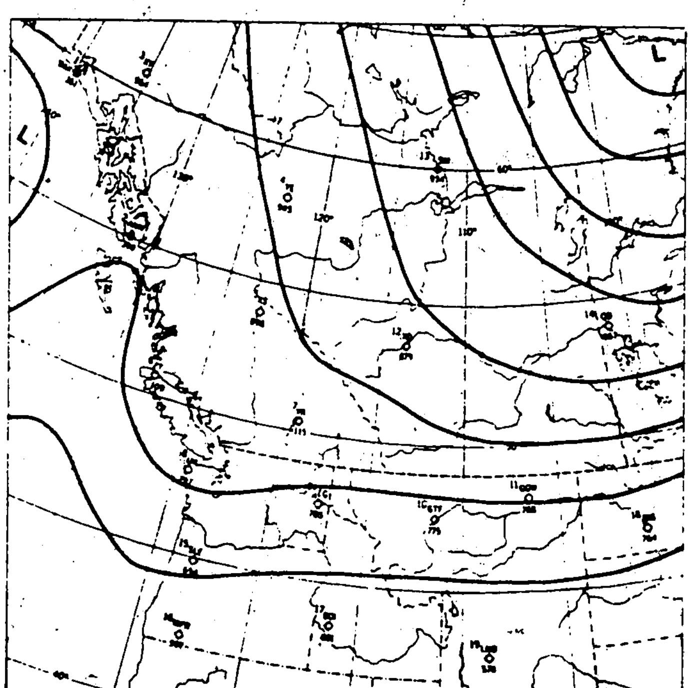

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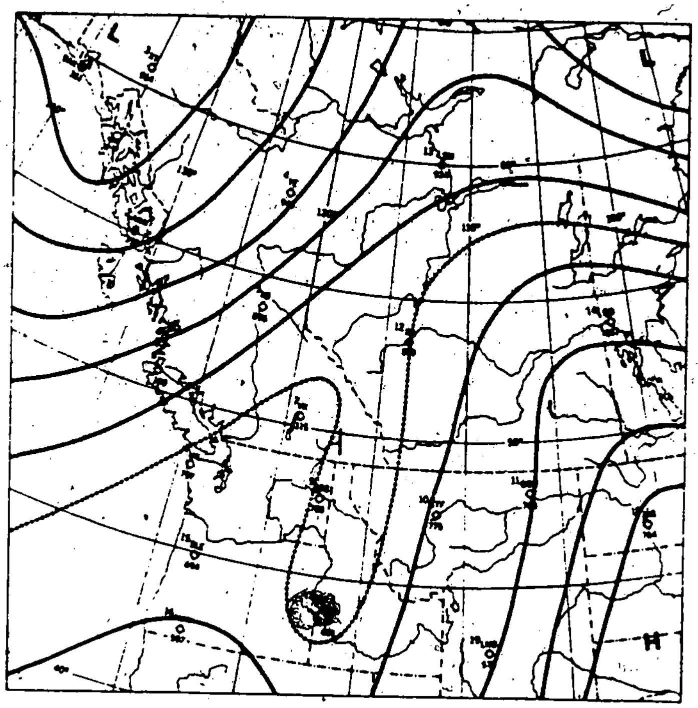

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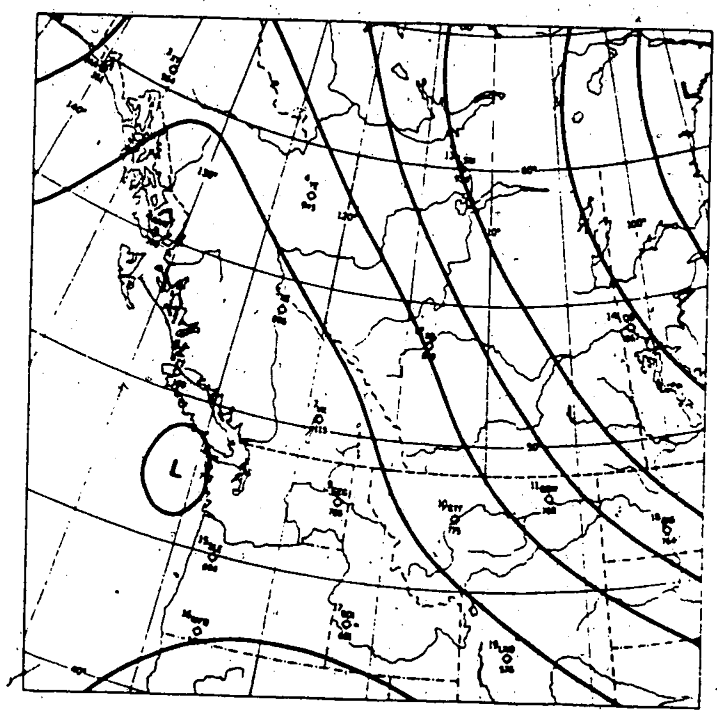

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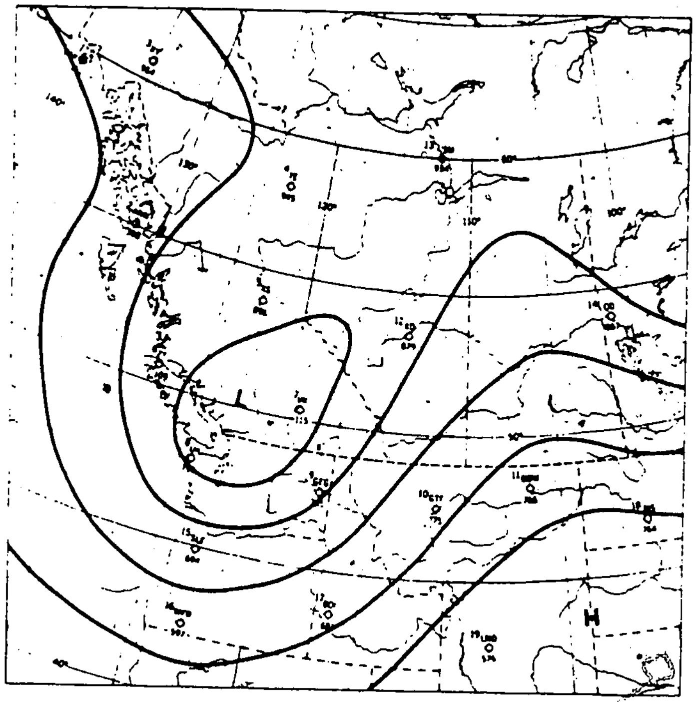

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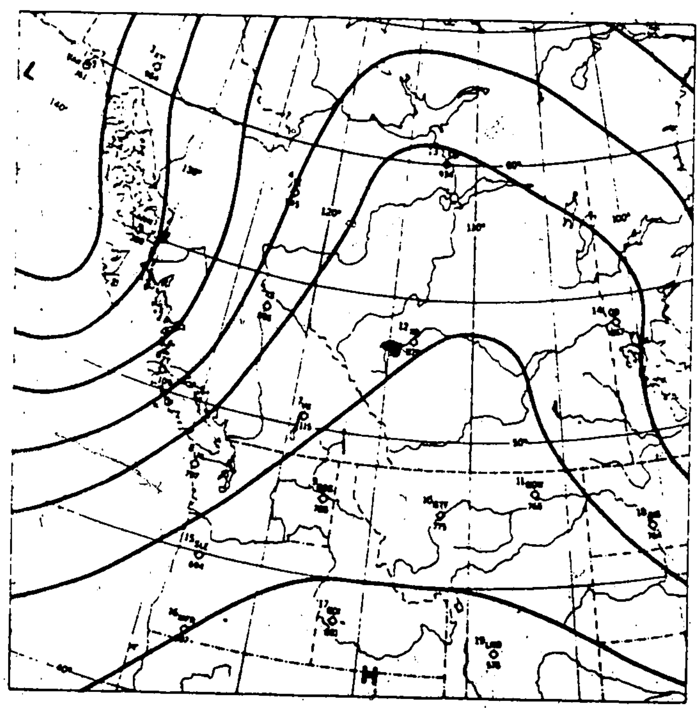

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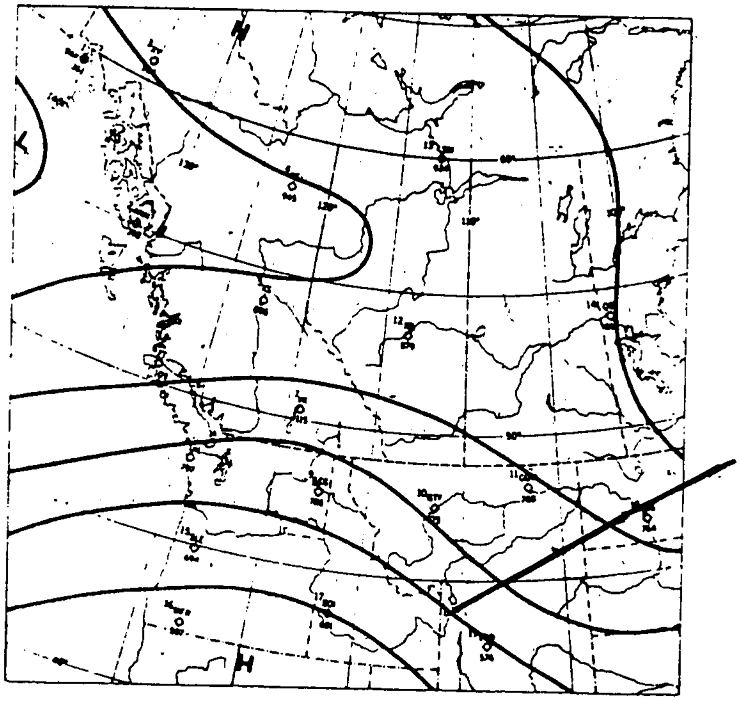

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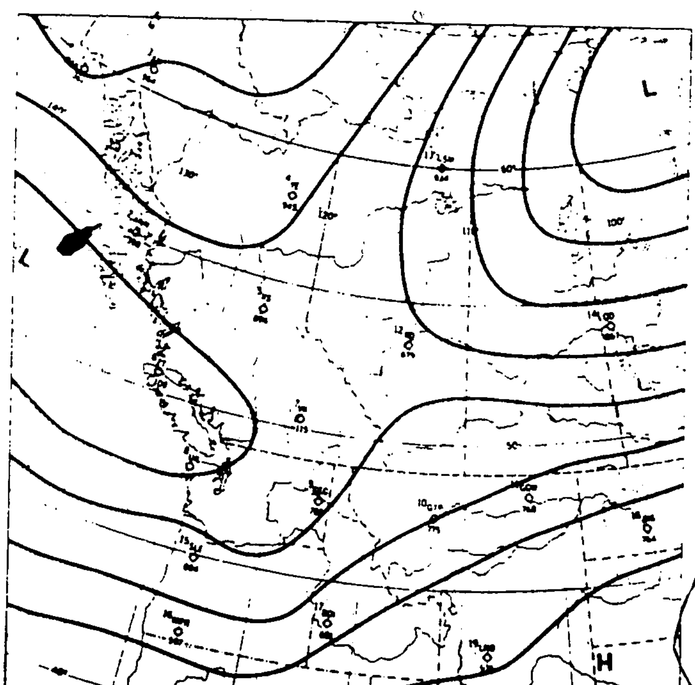

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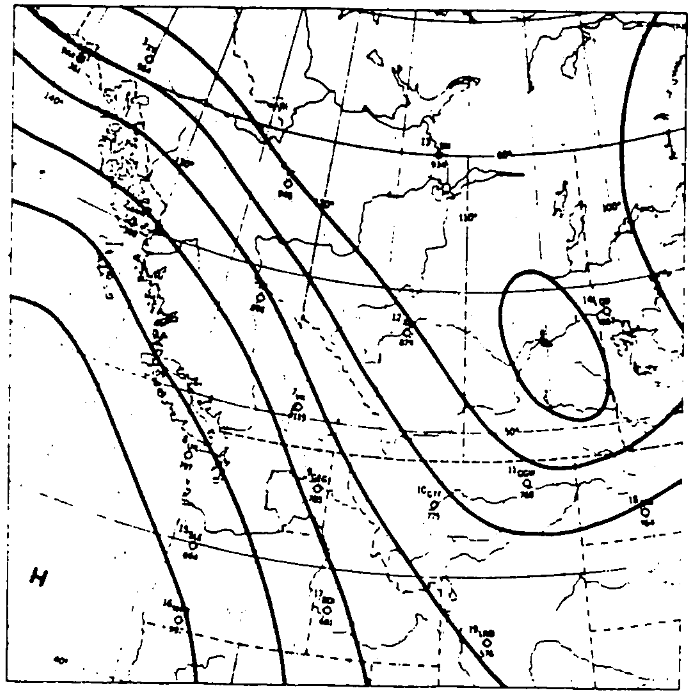

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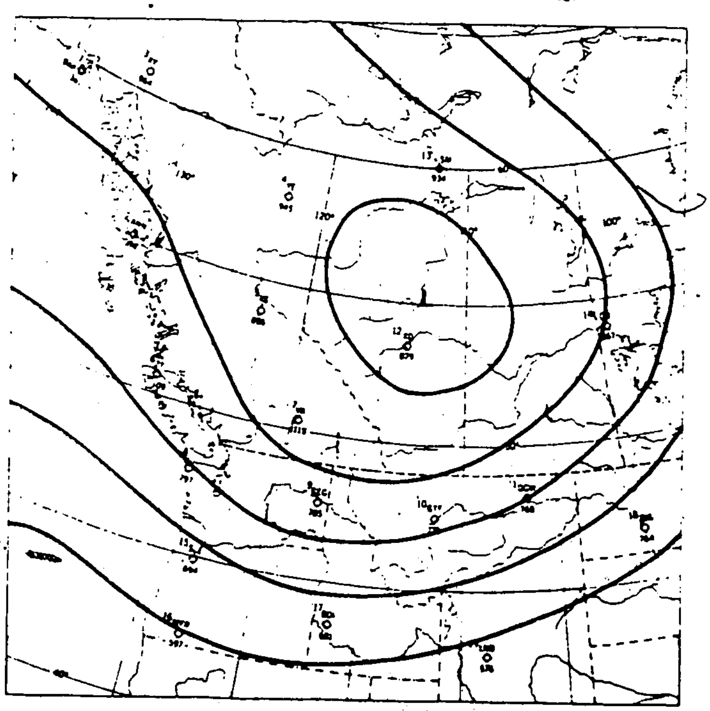

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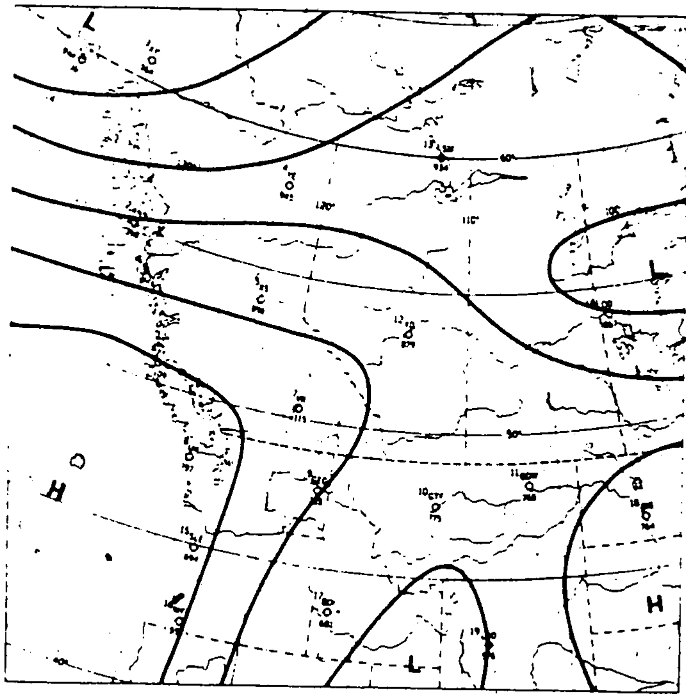

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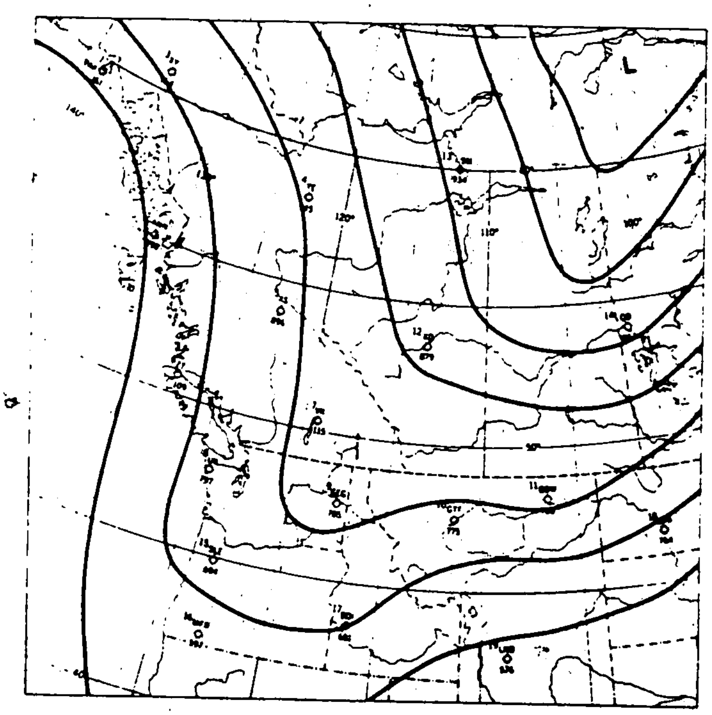

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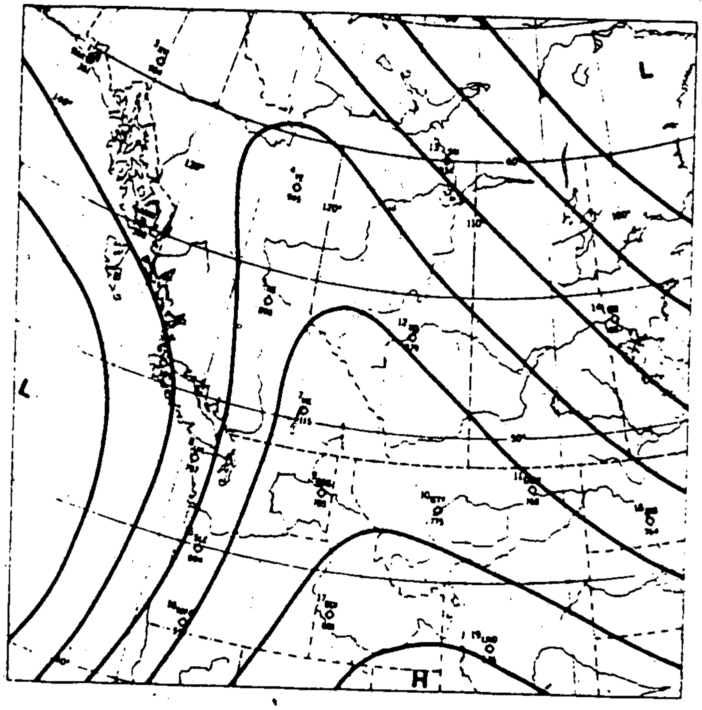

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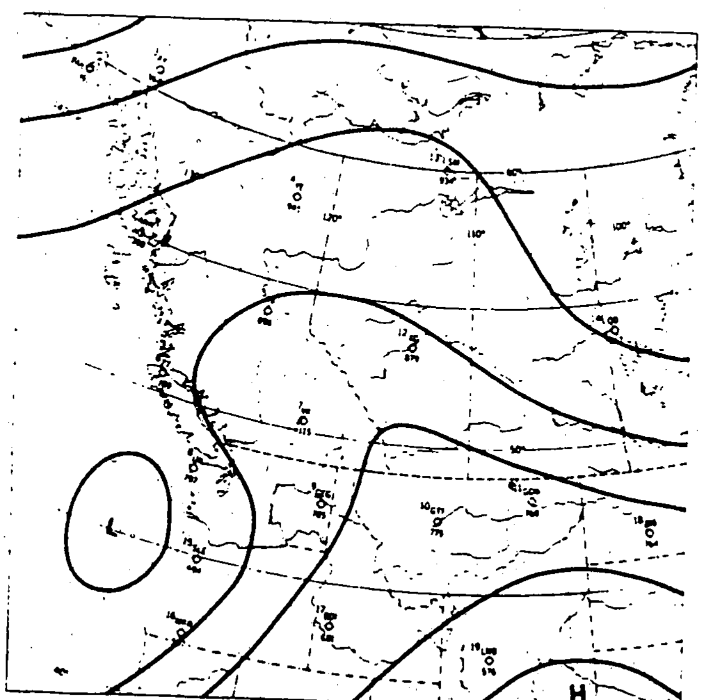

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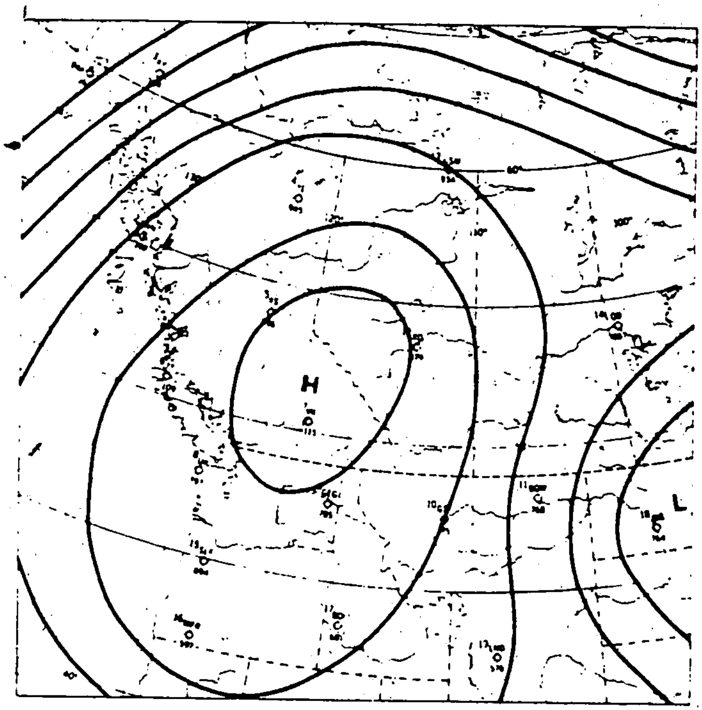

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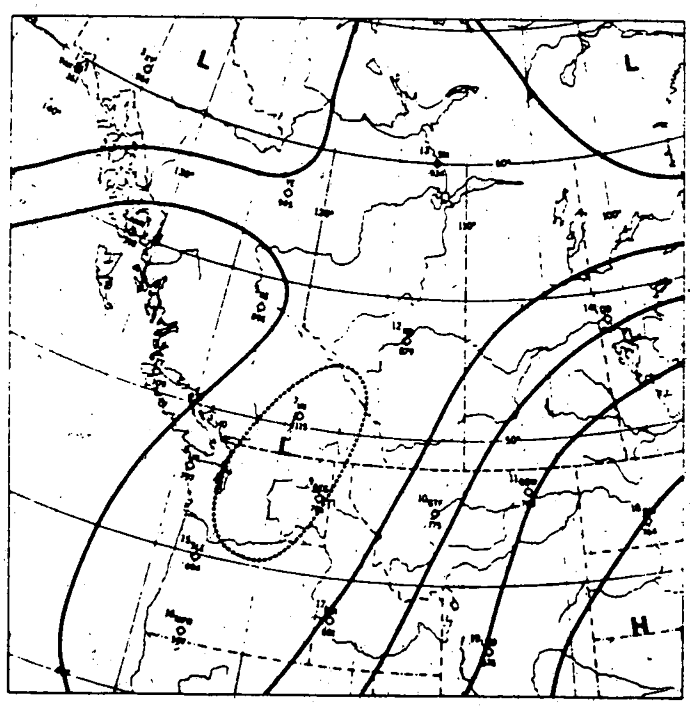

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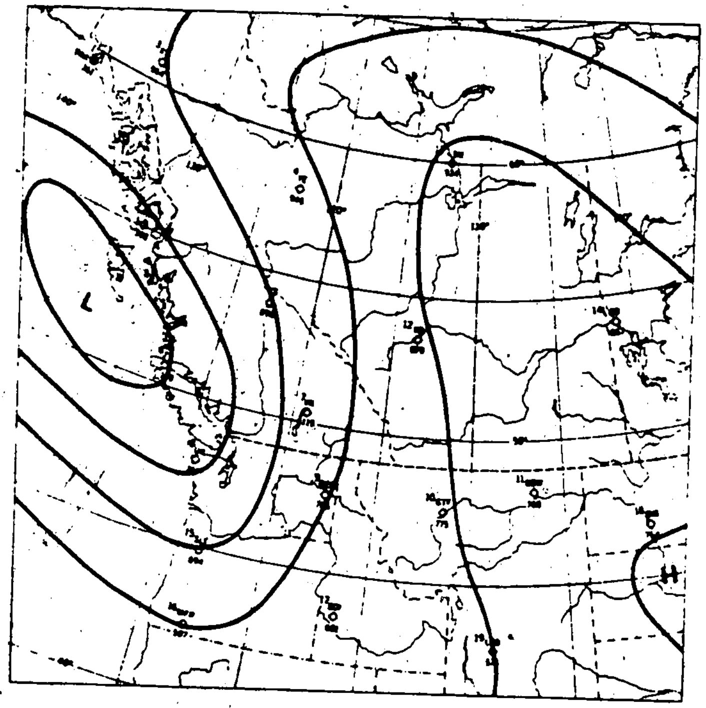

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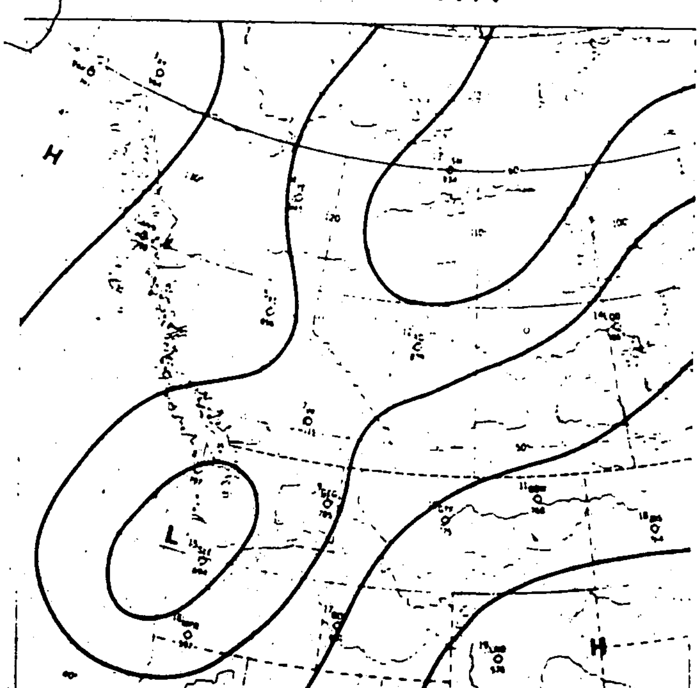

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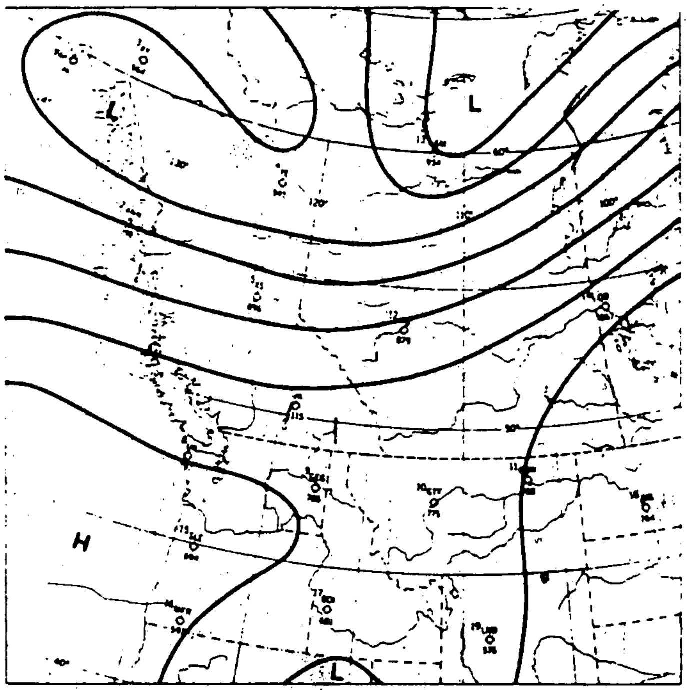

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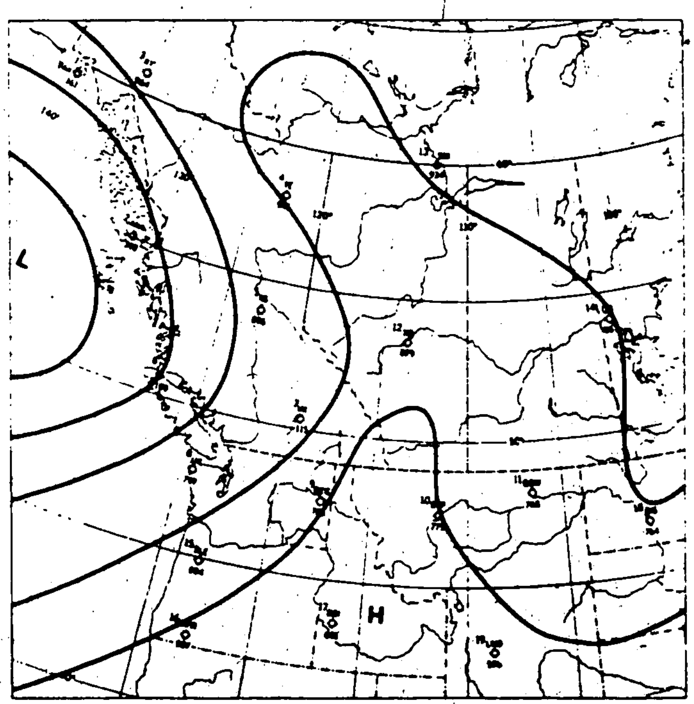

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* MAP TYPE 26 *
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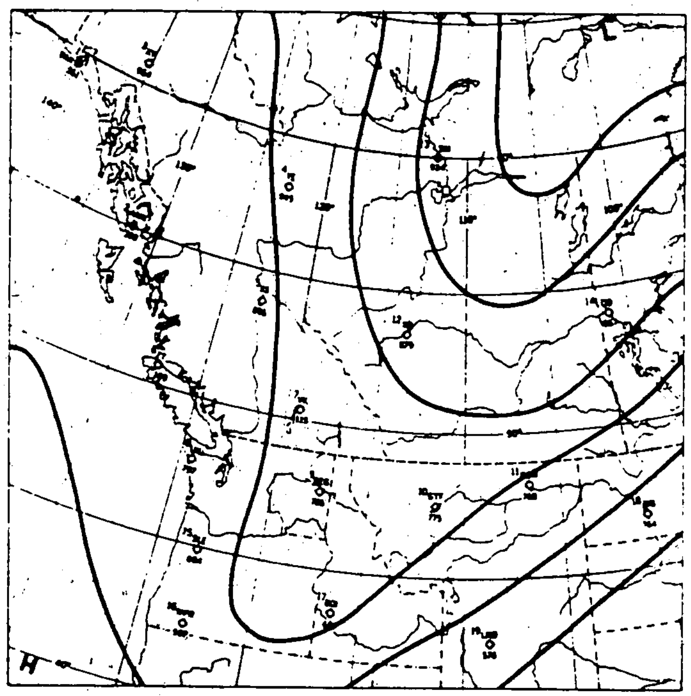
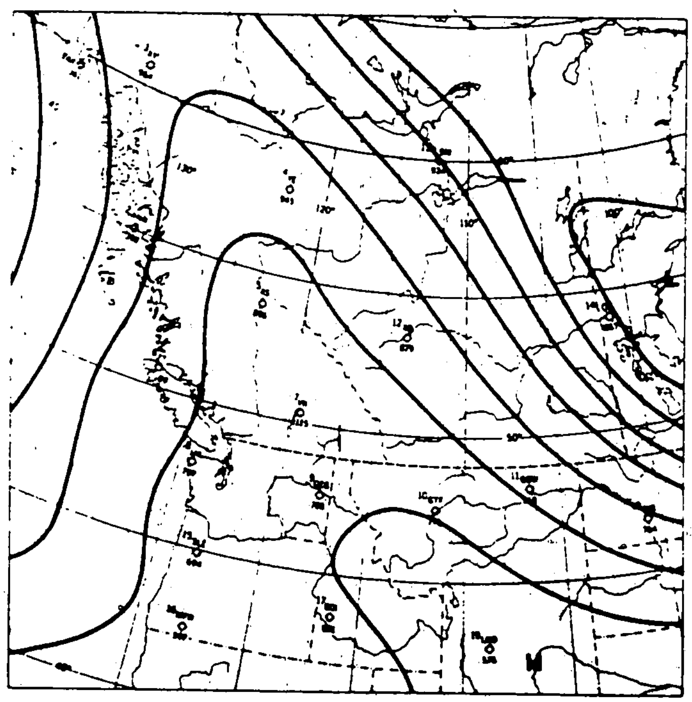
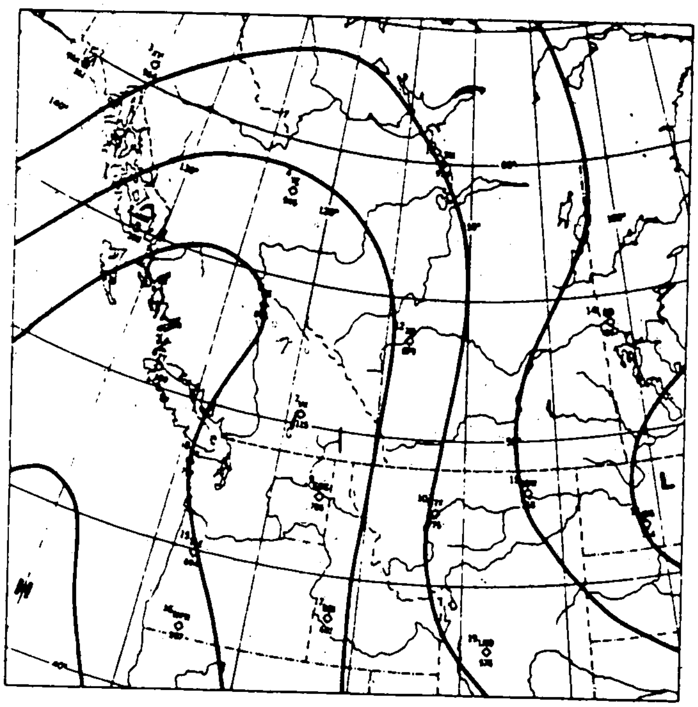


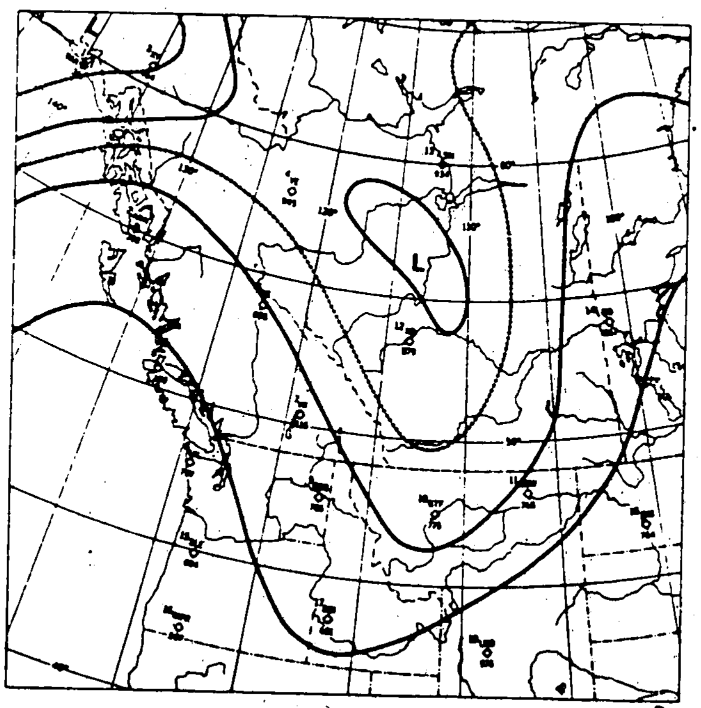
****
*   500 MB.   *
* MAP TYPE 27 *
****



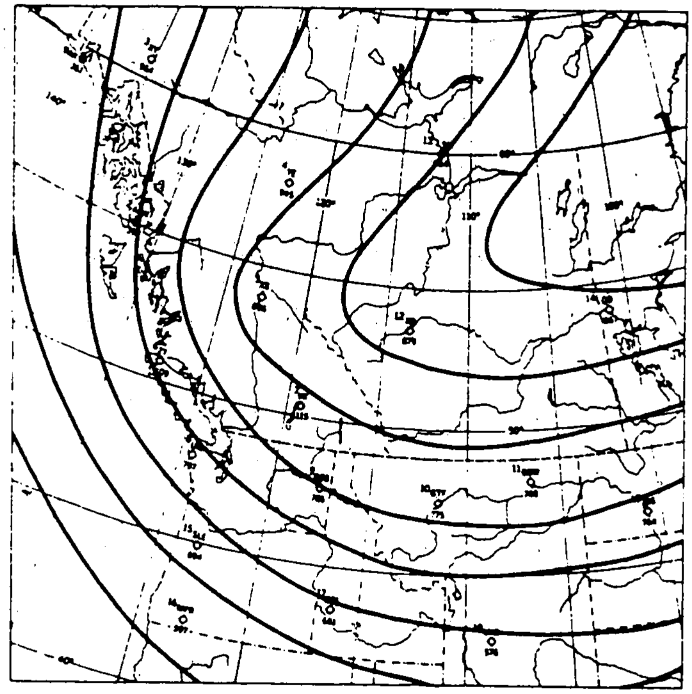
****
*   500 MB.   *
* MAP TYPE 28 *
****



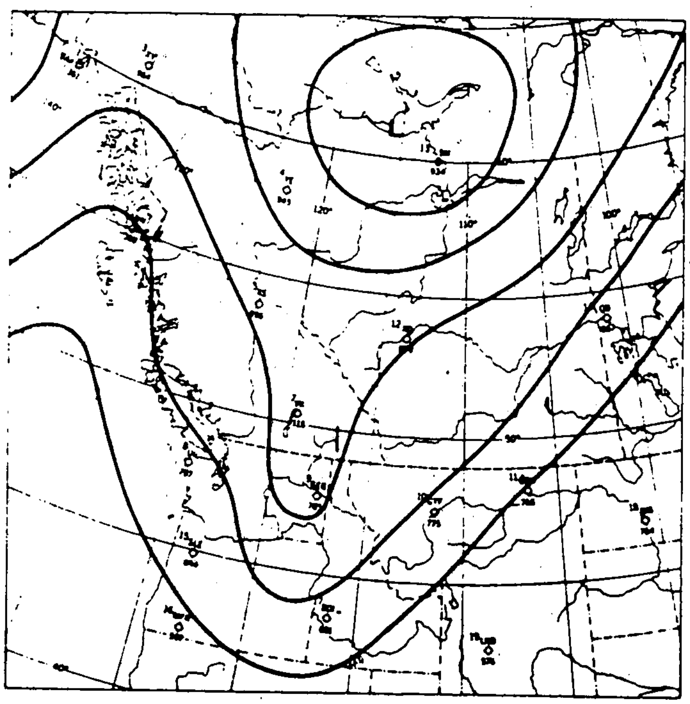
****
* 500 MB. *
* MAP TYPE 29 *
****



****
* 500 MB. *
* MAP TYPE 30 *
****



****
* 500 MB. *
* MAP TYPE 32 *
****



****
* 500 MB. *
* MAP TYPE 33 *
****

APPENDIX C

TABULATED RESULTS OF THE

500 mb ANALYSES

Table C-1. Surface Type 1 with Associated 500 mb Types.

500 mb Map Type	Total # Occurrences	Percentage of Total
1	12	36.36
2	2	6.06
3	4	12.12
4	2	6.06
6	1	3.03
7	1	3.03
14	1	3.03
28	1	3.03
U	8	24.24
TOTAL	32	

$I_A = 3$. Note: Calculation excludes uncorrelated data.
S = 24, F = 8

Table C-2. Surface Type 2 with Associated 500 mb Types.

500 mb Map Type	Total # Occurrences	Percentage of Total
1	29	42.65
2	10	14.71
3	3	4.41
4	1	1.47
8	2	2.94
11	6	8.82
16	5	7.35
24	2	2.94
25	2	2.94
27	2	2.94
U	1	1.47
15	1	1.47
Missing	4	5.88
TOTAL	68	

I_A = 5.8. Note: Calculation excludes missing data and uncorrelated 500 mb types. S = 64, F = 11

Table C-3. Surface Type 3 with Associated 500 mb Types.

500 mb Map Type	Total # Occurrences	Percentage of Total
1	8	25.81
2	7	22.58
3	1	3.23
8	7	22.58
14	1	3.23
16	1	3.23
20	1	3.23
30	1	3.23
M	4	12.90
TOTAL	31	

I_A = 3.4. Note: Calculation excludes missing data.
S = 27, F = 8

Table C-4. Surface Type 4 with Associated 500 mb Types.

500 mb Map Type	Total # Occurrences	Percentage of Total
1	13	19.12
2	6	8.82
3	3	4.41
4	2	2.94
5	1	1.47
6	1	1.47
8	2	2.94
11	9	13.24
12	1	1.47
14	6	8.82
15	3	4.41
17	1	1.47
20	1	1.47
22	1	1.47
26	1	1.47
30	2	2.94
32	2	2.94
33	2	2.94
U	10	14.71
M	1	1.47
TOTAL	68	

$I_A = 3.2$. Note: Calculation excludes uncorrelated values and missing data. S = 57, F = 18

Table C-5. Surface Type 5 with Associated 500 mb Types.

500 mb Map Type	Total # Occurrences	Percentage of Total
1	5	25.00
2	1	5.00
3	1	5.00
8	1	5.00
11	1	5.00
14	1	5.00
16	1	5.00
18	2	10.00
19	2	10.00
21	2	10.00
29	1	5.00
U	2	10.00
TOTAL	20	

I_A = 1.6. Note: Uncorrelated types were excluded from the calculation. S = 18, F = 11

Table C-6. Surface Type 6 with Associated 500 mb Types.

500 mb Map Type	Total # Occurrences	Percentage of Total
1	9	32.14
2	5	17.86
5	3	10.71
8	2	7.14
11	2	7.14
16	1	3.57
25	1	3.57
U	4	14.29
M	1	3.57
TOTAL	28	

I_A = 3.3. Note: Uncorrelated values and missing data were excluded from the calculation.
S = 23, F = 7

Figure C-7. Surface Type 7 with Associated 500 mb Types.

500 mb Map Type	Total # Occurrences	Percentage of Total
1	1	5.26
3	2	10.53
5	1	5.26
8	1	5.26
12	1	5.26
19	4	21.05
U	7	36.84
M	2	10,53
TOTAL	19	

I_A = 1.7. Note: Uncorrelated values and missing data were excluded from the calculation.

S = 10, F = 6

Table C-8. Surface Type 8 with Associated 500 mb Types.

500 mb Map Type	Total # Occurrences	Percentage of Total
1	7	41.18
2	2	11.76
8	1	5.88
11	2	11.76
15	1	5.88
18	1	5.88
19	1	5.88
26	1	5.88
M	1	5.88
TOTAL	17	

I_A = 2. Note: Missing data were excluded from the calculation. S = 16, F = 8

Table C-9. Surface Type 9 with Associated 500 mb Types.

500 mb Map Type	Total # Occurrences	Percentage of Total
1	2	18.18
2	5	45.45
8	2	18.18
11	1	9.09
14	1	9.09
TOTAL	11	

$I_A = 2.2$.

Table C-10. Surface Type 10 with Associated 500 mb Types.

500 mb Map Type	Total # Occurrences	Percentage of Total
1	2	8.0
2	1	4.0
3	2	8.0
8	2	8.0
11	1	4.0
12	1	4.0
18	4	16.0
28	5	20.0
M	4	16.0
U	3	12.0
TOTAL	25	

$I_A = 2.3$. Note: Missing and uncorrelated values were excluded from the calculation. S = 18, F = 8

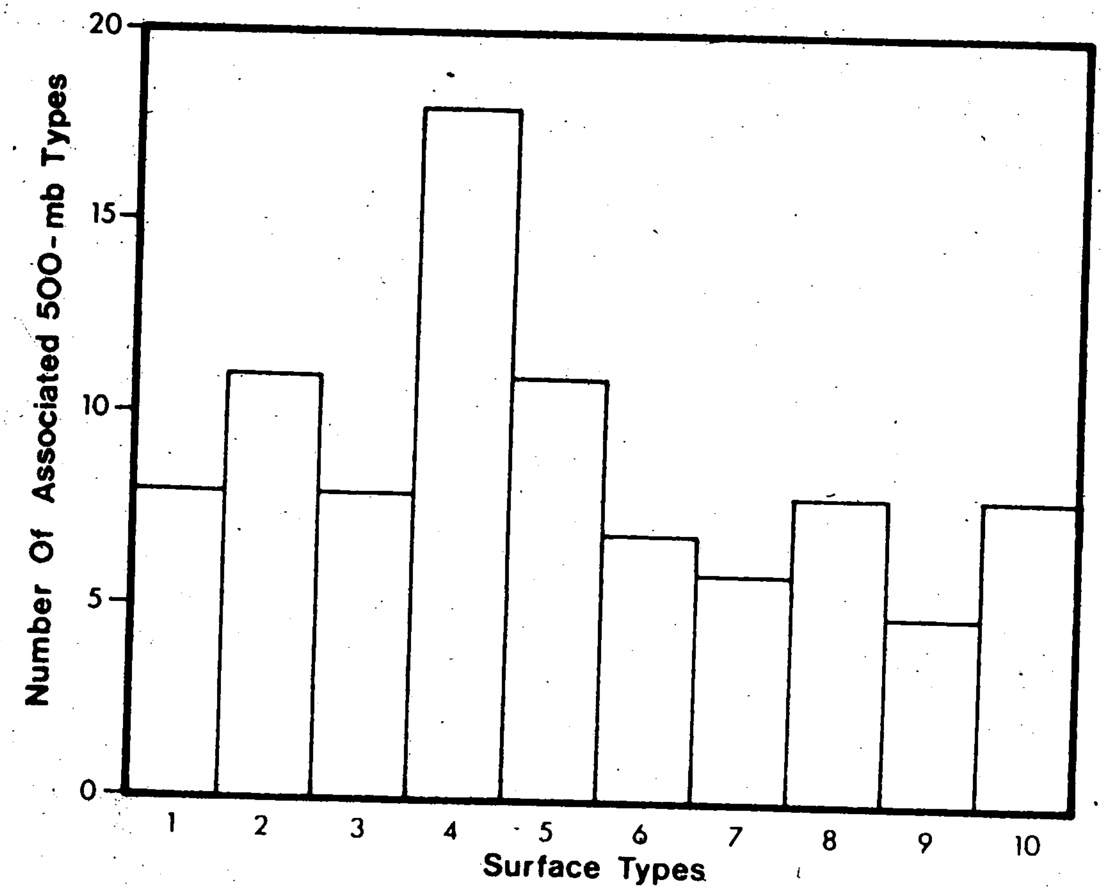


Table C-11. Histogram Plotting Each Surface Map Type with Associated 500 mb Types.

APPENDIX D

NOMINAL ORBITAL PARAMETERS OF ITOS D-G SPACECRAFT

Parameters	Values
Altitude (above earth surface)	790 n. mi. (1464 km)
Apogee and Perigee	790 25 n. mi. (1464 46 km)
Inclination	101.7°
Nodal Period	115.14 min.
Spacecraft Sun Angle	Varies with month of launch. Should be kept between 30° and 60° during the active lifetime of the spacecraft.
Precession of Nodes	0.9857° per day for complete sun synchronism.
Equator crossing time (northbound)	1500 or 2100 local solar time

(from Schwalb, 1972, p. 3)