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Final Report

METEOROLOGICAL INTERPRETATION OF SATELLITE CLOUD PHOTOGRAPHS

Prepared for:

METEOROLOGICAL SATELLITE LABORATORY
U. S. WEATHER BUREAU
WASHINGTON, D. C.

CONTRACT Cwb 10481

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STANFORD RESEARCH INSTITUTE
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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

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ABSTRACT

The meteorological interpretation of satellite cloud photographs was investigated through a series of TIROS III orbits over the North Atlantic between the 7th and 16th of September 1961. During this period, the photographs exhibited poor resolution and meteorological interpretations were based primarily on cloud cover patterns alone. It is concluded that, in general, the cloud cover enabled recognition of major frontal bands, post-frontal areas, large scale vortices and well developed ridges or high cells. The jet stream location may be inferred to some degree from the distribution of synoptic entities as expressed in the over-all cloud cover pattern.

The vertical motion and changes in cloud cover were studied for two stations (Ocean Station Vessels C and D) using the adiabatic method. Time sections of these parameters indicated that there was good correspondence between upward motion and a small difference between temperature and dew point difference, except near frontal boundaries. Upward motion is observed in a pre-frontal area, downward motion through a deep layer within frontal boundaries and upward motion in the post-frontal area. Changes in vertical motions were expressed in the cloud cover by changes in coverage and/or type, as well as in precipitation amounts and/or type.

It was shown that the direction of the large-scale vertical motion is dependent primarily on the backing or veering of wind with height.

The interrelationship of pressure patterns, cloud patterns, jet streams and types of temperature soundings are generalized into three regimes and presented in schematic form.

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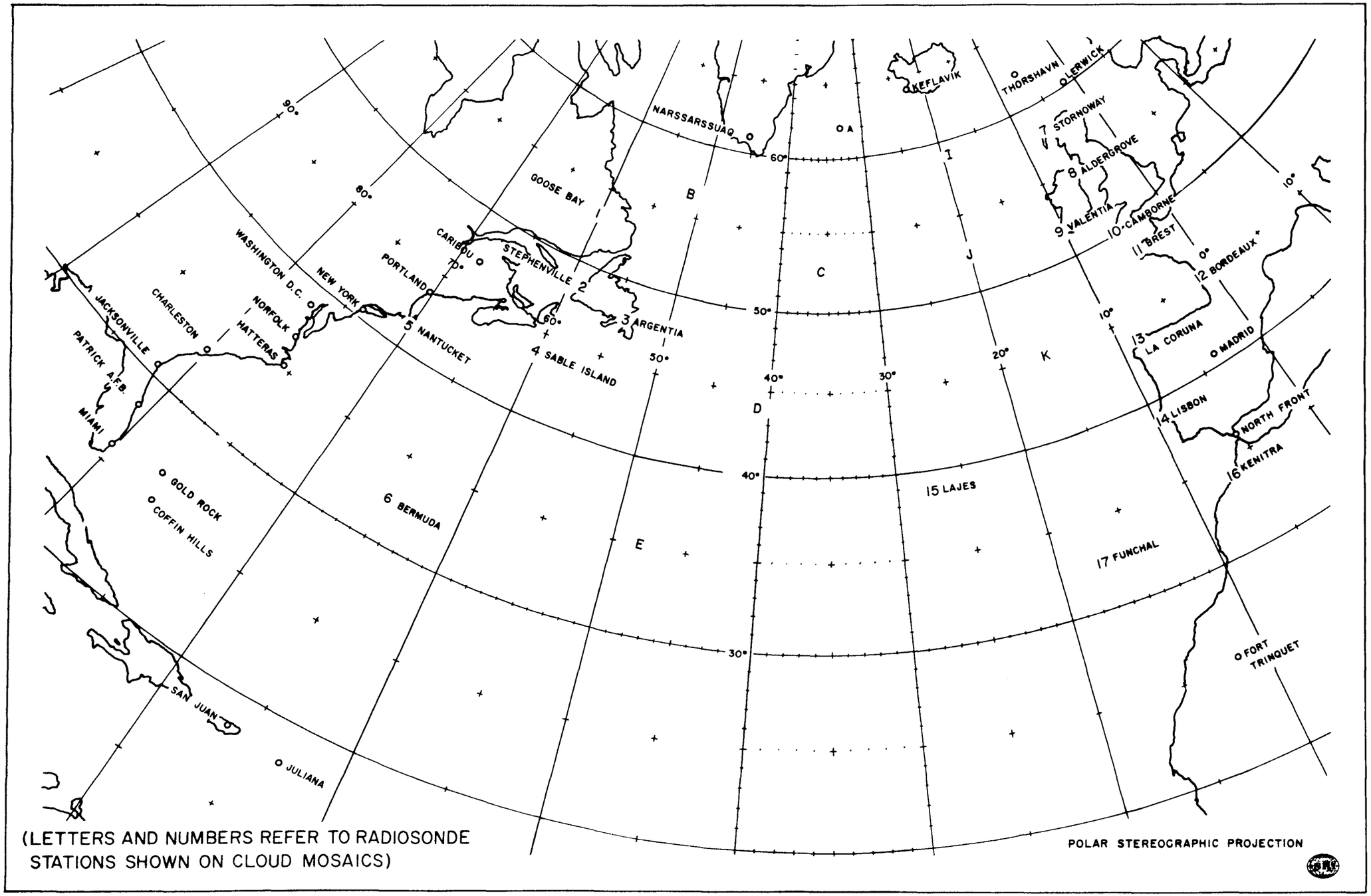

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METEOROLOGICAL INTERPRETATION OF CLOUD PHOTOGRAPHS

I INTRODUCTION

A. General

This investigation, done in persuance of Contract Cwb 10481, is confined to the interpretation of TIROS III Satellite photographs taken during a ten-day period from the 7th through the 16th of September 1961 in the Atlantic. In a real sense, however, it represents a continuation of the research study* begun in the Pacific under Contract Cwb 10238, since both studies are directed toward revealing those features in satellite photographs that will be of operational use in the forecast office. The emphasis here is on the analytical implications of the cloud photographs.

Experience with satellite cloud data has indicated that the cloud patterns are varied and complex. However, if these patterns are to be used as a diagnostic tool to supplement the conventional meteorological analysis, apart from their use as a forecasting tool, then some rationale must be found for interpreting the "meaning" of these cloud patterns.

Cloud pattern models were introduced by Bergeron in 1951, and by Boucher and Newcomb in 1962, among others, and a study is currently under way, under the auspices of the U.S. Weather Bureau, to classify and categorize the cloud vortex patterns seen in the TIROS photographs. Most of these approaches dealt with the development and characteristics of a single meteorological element--namely, the occluding wave cyclone.

The importance of this synoptic element as a weather-producing factor makes attention to it both sensible and necessary. However, now that satellites are capable of providing photographs of cloud patterns on a planetary scale it seems reasonable to extend the modeling to include circulations and patterns other than just that of the occluding wave system.

It will be shown that the gross cloud patterns in these other systems may be subject to generalizations, much as the cloud patterns accompanying a developing wave system have been.

Developing pattern association on this scale may be of assistance in establishing the location of the maximum isotach centers along the jet stream, the slope of the upper air circulation with respect to the surface circulation, and locations of the tropopause regimes. The distribution of these needs to be known on more than just a localized basis.

The Atlantic Ocean area was selected because this region has an abundance of maritime weather reports and more official weather station vessels than the Pacific, so that comparison of surface reports and cloud cover can be made over a more extensive area, and also a comparison of cloud systems in the two oceanic regions might reveal significant regional differences.

The period 7 September through 16 September 1961 was chosen because certain features of the meteorological events during this sequence to some degree resembled those in the Pacific during the study under Contract Cwb 10238. This synoptic series is characterized by a large-scale low pressure system located in the central North Atlantic during the first half of the ten-day period. Although this low system stagnates, the associated frontal system continues its eastward progression, moving out of the cyclonic circulation. In the second half of the period, Hurricanes Betsy and Debbie move in turn into the westerly circulation as extra-tropical cyclones,

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*References are listed at the end of the report.

resulting in a highly developed meridional circulation on the 15th and 16th of September.

Although pictures from numerous satellite orbits over the North Atlantic were available during the ten-day period, only those that covered this area within three hours of the 1200 GMT synoptic reporting time were utilized in order to reduce the extrapolating of meteorological parameters when comparing cloud data. Unfortunately, however, cloud photographs taken during this period show poor resolution, and the quality of the cloud photographs are such that meteorological interpretations, of necessity, have to be based on the appearance of the gross cloud coverage rather than on character and detail of small cloud elements.

This did not hamper the study, since investigation of cloud patterns is the major objective of the report. For interpretations of other than broad-scale patterns, pictures of such poor quality could be of only limited use.

Despite the poor resolution of the satellite photographs, it is hoped that the resulting interpretations will be pertinent and useful for the meteorologist in the field, particularly those who must make analyses and forecasts for areas of sparse data.

Section II of the report presents a description of the large-scale cloud distributions and their patterned association with the major circulation systems, including the jet stream. Section III discusses the association of atmospheric vertical motions with certain changes in the cloud field, as demonstrated in time sections at two ocean station vessels (OSV C 52.5°N, 35.5°W and OSV D 44.0°N, 41.0°W).

B. Data

The satellite cloud data utilized in this investigation were cleaned from 20 orbits of TIROS III which transited the Atlantic during the daylight hours from 7 to 17 September 1961, within 3 hours of 2100 GMT. The individual orbit paths are shown in Fig. 1; picture times and frame numbers utilized are listed in Table I.

Table I

DATA ON SATELLITE PHOTOGRAPHS

Film	Orbit Readout	Date	Pictures Start (GMT)	Frame Numbers Used
820T	819	7 September 1961	120237	2-18
821T	820	7 September 1961	135100	10-28
835T	834	8 September 1961	131704	14-28
836T	835	8 September 1961	145855	12-30
850T	849	9 September 1961	142430	11-31
864T	863	10 September 1961	134653	8-30
877T	876	11 September 1961	113323	19-29
878D*	877T	11 September 1961	131100	7-29
879T	878	11 September 1961	145614	5-27
892T	891	12 September 1961	123632	10-30
893T	892	12 September 1961	141846	6-28
906T	905	13 September 1961	120300	12-28
907T	906	13 September 1961	134410	7-27
921T	920	14 September 1961	131206	18-24
922T	921	14 September 1961	145500	12-32
935T	934	15 September 1961	123030	3-29
936T	935	15 September 1961	141908	12-30
948T	947	16 September 1961	101554	19-25
949T	948	16 September 1961	115828	12-26
950T	949	16 September 1961	134336	10-30

*Orbit 878T is mislabeled 878D on film.

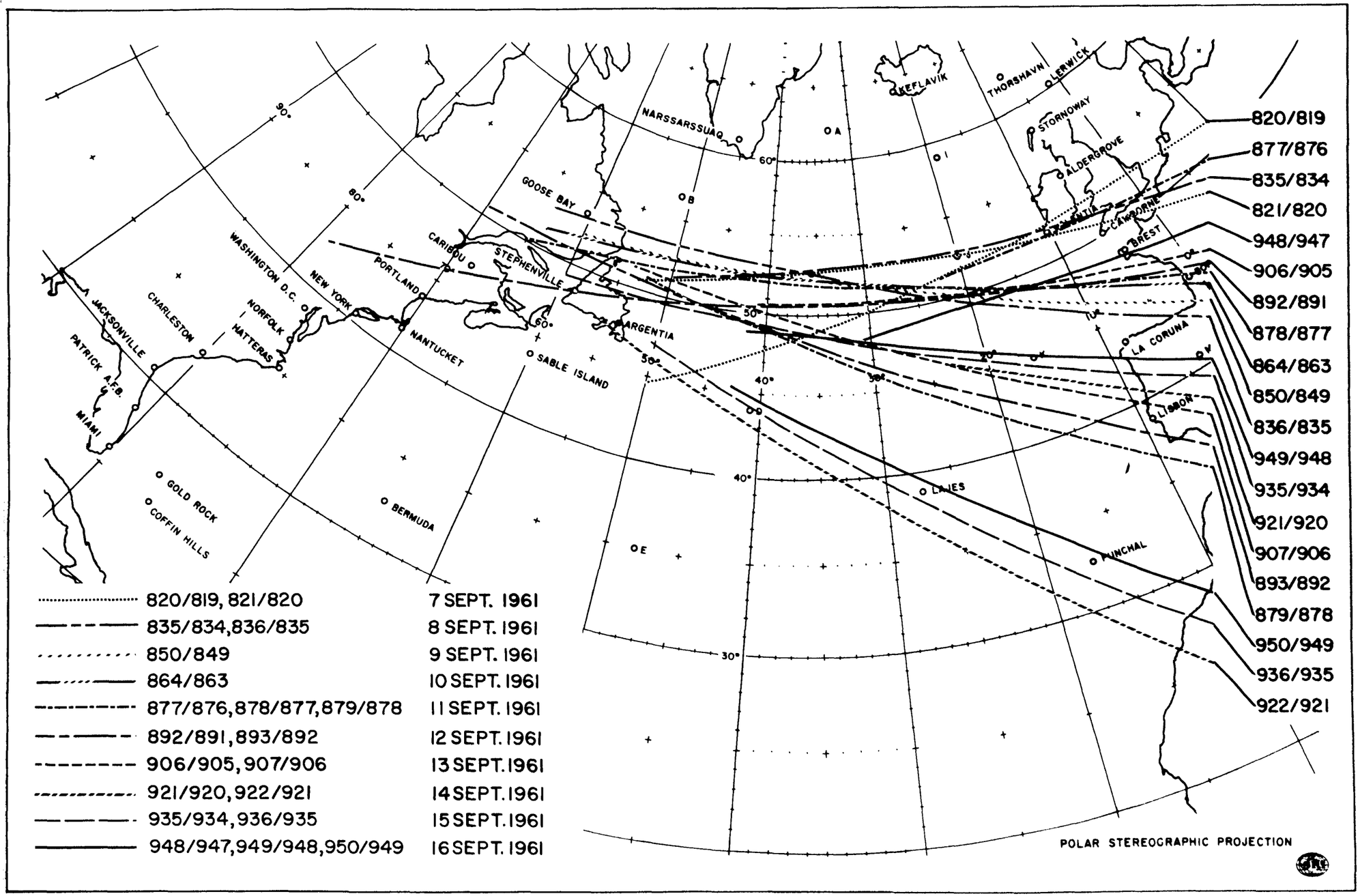

FIG. 1 PATHS OF ORBITS UTILIZED

Mosaics were constructed from the photographs by matching cloud elements on successive frames in a manner that provided a reasonable spatial relationship when compared with synoptic features. Detailed analysis of cloud elements near the limits of each photograph can only be made from the individual photographs, since the geographical relation of individual cloud elements on an individual picture may become distorted in the mosaic because of mechanical problems inherent in the mosaic construction.

After these mosaics were constructed, the surface and jet stream analyses were superposed to aid in the meteorological interpretation. To facilitate the comparison of the cloud patterning with synoptic data, rectifications of the mosaics for each orbit were made on a polar stereographic projection of the proper scale. Photograph gridding and rectifications were done in accordance with data and procedures set forth by Fujita in 1961 and 1963, by Goldshlak in 1962, and by the U.S. Weather Bureau in 1962. Rectification eliminates the distortions on the mosaics arising from the various perspective views involved. Accurate positioning of rectified cloud patterns was accomplished by reference to landmarks in 19 of the orbits. In one orbit it was necessary to use clouds from an adjoining orbit to position the cloud patterns. Location errors are considered to be within the tolerances mentioned by Fujita, 1961, 1963 (i.e., within 21 miles at the principal point).

The basic synoptic and analysis data were obtained from the U.S. Weather Bureau Northern Hemisphere charts for the surface, 700-, 500-, and 300-mb levels, and the U.S. Weather Bureau Daily Series of Northern Hemisphere Data Tabulations. The analysis of the 300-mb chart in the eastern Atlantic and the European area is that of the authors, since the Weather Bureau analysis did not extend beyond the central Atlantic. An overlay of cloud reports was prepared to supplement the data contained on the surface charts within the viewed area. These reports were extracted from the U.S. Weather Bureau Historical Weather Series. In addition, radiosonde and upper wind data for those stations within the viewed area were plotted for consideration.

II SYNOPTIC CLOUD PATTERN EXAMPLES

This section presents a description of the synoptic cloud pattern examples between 7 and 16 September 1961.

During the first half of this ten-day period, the pressure regime in the North Atlantic was characterized by a slow moving large-scale low-pressure cell and occluding frontal system. Although this cyclonic system stagnated, the frontal system continued to move eastward. Rather strong winds were present at the 300-mb level, north of the 40th parallel. Deep lows at the surface were accompanied by pronounced troughing and closed circulations aloft.

In the second half of the period, the pressure regime was characterized by the entrainment of two hurricanes into the westerlies and culminated in a well-developed meridional circulation toward the end of the period. At the 300-mb level, this change to a meridional flow was reflected in a readjustment of the wave length which resulted in the development of a long wave trough in the eastern Atlantic.

The Polar front jet stream complex was observed throughout most of the north Atlantic during these ten days. On all days, the jet stream complex was analyzed as two individual jet streams, though both were not necessarily equally intense or extensive on any one day.

Photographs from the wide-angle camera of TIROS III gave a good day-to-day coverage of the gross cloud patterns. The orbital paths were such that most of the photographed area was located north of the 40th parallel during the first 7 days. As a consequence, the cloud patterns televised were those primarily associated with the deep cyclonic circulations in the North Atlantic. On the last 3 days, the orbit paths shifted to more southerly latitudes and the satellite was able to televise the cloud patterns that occurred during the pronounced meridional flow.

During the period studied, the picture resolution was insufficient to distinguish cloud character, and meteorological interpretations of the cloud patterns were made in terms of coverage only.

In all the synoptic examples, the joint use of the cloud pictures and the analyzed weather maps resulted in identification of the local cloud pattern associated with a particular synoptic scale weather element. In some cases, the cloud-cover patterns alone were sufficient to identify their association with certain synoptic elements particularly as major frontal cloud bands, post-frontal areas, large-scale vortices and high-pressure cells or ridges. The contrast between the relatively unbroken and extensive cloud fields associated with the fronts or pressure centers and the broken and mottled appearance of the post-frontal areas was always fairly distinct, even though small-scale cloud features were obscured.

A discussion of each individual day in the ten-day period follows. Illustrational material for each example consists of (1) analysis of the 1200 GMT surface chart, (2) analysis of the 1200 GMT 300-mb chart, (3) mosaics of cloud photographs for the individual orbits utilized and radiosonde plots of stations within the viewed area, (4) an overlay of cloud reports within the viewed area (5) a rectification of the mosaics to a polar stereographic projection. The surface analysis and jet stream axis at the 300-mb level are added to the rectification to facilitate an interpretation of the cloud distribution.

NOTE: Reference to both the actual cloud mosaic and the rectification should be made whenever cloud features are discussed in the descriptions of the synoptic examples. (Locations at the stations mentioned in the text are shown on the Frontispiece.)

A. 7 September 1961

The analysis of the 1200 GMT surface chart (shown in Fig. 2) indicates a migratory high pressure cell in eastern Canada and a deep low-pressure cell south of Greenland, accompanied by a well-occluded frontal system. The cold front portion of this frontal system extends

southward and westward along the 40th parallel to the east coast of the United States. Hurricane Betsy is located east of Bermuda. A subtropical anticyclone of moderate strength is located through the central and eastern Atlantic, south of the 40th parallel. A pronounced ridge extends northward from this high cell on a line just west of the British Isles. A frontless cyclone is located over the European coast.

The analysis of the 1200 GMT 300-mb chart is shown in Fig. 3. Minor ridging is indicated over eastern Canada. The center of the well-developed cyclone south of Greenland is almost directly above the location of the surface low pressure center. There is a cut-off anticyclonic circulation over Iceland, with westerly flow in the area breaking through south of the 55th parallel. Cyclonic circulation is present over Europe, and a small closed cyclone is indicated near Lisbon. Anticyclonic circulations are present to the east and west of Hurricane Betsy.

The analysis indicates two jet streams which flow around the cyclonic circulation south of Greenland. A maximum isotach area is located to the south of this cyclonic circulation. Jet stream conditions are re-established south of the cyclonic circulation over the European coast.

Mosaics (Fig. 4) and rectification (Fig. 5b) of cloud coverage over the North Atlantic were constructed from Orbits 820/819 and 821/820, which passed over the area at 1203 GMT and 1351 GMT, respectively.

One of the major cloud features apparent in the western Atlantic is the cloud vortex associated with Hurricane Betsy. Although a cloud free slot is evident on its eastern periphery, the high nadir angle and poor quality of the photograph precludes detailed analysis of the cloud distribution about this hurricane. Surface cloud observations, shown on the overlay (Fig. 5a), indicate that the cloud field east and north of the storm consists of small amounts of swelling cumulus, coupled with moderate amounts of middle and/or high clouds.

Radiosonde data in this area are available from Bermuda and Ocean Station Vessel E. The sounding at Bermuda, which lies to the west of Hurricane Betsy, shows a tendency towards stability between the 600- and 400-mb levels. The air is quite moist up to the 600-mb level but somewhat drier above this, indicating the effect of subsidence above the 600-mb level. The tropopause is quite high (150 mbs), typical of tropical maritime air. Clouds at the station are reported as low cumulus, altocumulus, and cirrus. Surface reports on the western periphery of the storm indicate the area to be partly cloudy, but in the cloud pictures this partial coverage is not seen, due either to poor resolution or to the large nadir angle involved.

Ocean Station Vessel E lies south of the cold front and east of Hurricane Betsy, and its sounding is representative of air in the western periphery of the subtropical anticyclone. The greatest degree of saturation occurs in the level below 850 mbs. Pronounced dryness is apparent in the layer between the 700- and 600-mb levels with a return to more humid conditions above the 500-mb level. The zone between 850 and 600 mbs is somewhat more stable than the rest of the sounding below the tropopause. Surface reports indicate scattered swelling cumulus and cirrus.

In the northerly latitudes the field of view extends through the Maritime Provinces and the extreme eastern portion of Canada. By and large this area appears to be cloud covered but again, the high nadir angles involved make this determination inconclusive. Offshore, however, there is a definite zone of clear area that extends from Goose Bay, Labrador, to Sable Island, and eastward to the central Atlantic. The few reports that are available in this area indicate the cloud types to be of the low cumuliform variety. A major clear area is located at the point of strong isobaric divergence on the southeast side of the migratory anticyclone to the west.

Radiosonde data in this area include data from Goose Bay, Stephenville, Argentia, and Sable Island and portrays conditions along the eastern periphery of the migratory high cell. These data reveal an

inversion below the 700-mb level, primarily due to subsidence and dew point temperatures that fell off quite rapidly up to the 850-mb level. These indications correlate with surface reports of stratocumulus or cumulus of limited development. Increased moisture is observed in the higher levels and two of the stations indicate the presence of high clouds. Goose Bay, Stephenville and Argentia lie close to the jet stream and exhibit high wind speeds above the 500-mb level.

The most outstanding cloud pattern feature in the western Atlantic is the semicirculat cloud free zone in the post-frontal region of the surface frontal system. This clearing separates the vase inspiraling cloud field on the west side of the cold front from the cloud field accompanying the surface cold front itself. The fact that the spiral cloud system in the post-frontal area lies close to the frontal cloud band might be an indication of the degree of the development of the low-pressure system.

This clear zone extends through the analyzed position of minimum pressure. However, the surface data such that the low-pressure center could be analyzed some 4 degrees to the south, in which case the clear zone would skirt the northern periphery of the surface low-pressure center. Whether or not the center of the barometric low and the center of the cloud vortex actually coincide is problematical because the center of the cloud vortex could not be located with certainty; whether such centers are coincident must be left for more extensive studies of cloud vortices.

The actual frontal position lies slightly east and south of the semicircular clear zone. Cloud masses lie along the entire extent of the frontal system, but the poor picture quality makes identification of cloud character quite uncertain. These frontal clouds are undoubtedly multi-layered, with thick altostratus predominating.

Surface reports in the post frontal area indicate that much of the cloudiness in the spiral vortex consists of low clouds. Where there are breaks in the low clouds, some stations report both middle and high clouds.

Radiosonde data in the area are available from Ocean Station Vessels B, C, and D. Ship B is located in the northwestern sector of the deep low pressure system, in an area of extensive cloudiness. The sounding shows marked stability from approximately the 950-mb to the 700-mb level. Dew-point temperatures indicate high relative humidity through this layer with lower humidity above. Surface reports show an overcast made up of cumulus fractus of bad weather and altostratus. This station is located north of the jet stream complex; the upper wind speeds are moderate.

Ship C, on the other hand, lies to the east of the barometric low pressure center in the semicircular ring of partial clearing behind the surface frontal position. Its upper air observation is similar to that of Ship B, although Ship C is located under very strong upper level winds. There is a stable layer between 850 and 680 mbs which may be a manifestation of the occluded front over the station. Saturated conditions extend to about the 550-mb level. The surface reports show overcast stratus with drizzle.

Ship D lies in the southern sector of the low pressure area, just south of the jet stream complex and north of the surface front. There is an inversion near 750 mbs. Below this level the air is quite humid with a fairly deep zone of drier air above. The surface observation shows cumulus topped by stratocumulus. Moderate wind speeds are evident through a very deep layer, reaching 50 knots at the 700-mb level.

In the eastern Atlantic the cloud patterns show a large clear field just east of the surface point of occlusion and an over-all semi-broken and striated cloud coverage through the area of the ridge at the surface. On this day the maximum amount of clearing does not coincide with the surface ridge line but rather lies to the west of it. The surface reports through the ridge indicate that the cloud mass north and east of the warm front (north of the clear area) is composed of substantial amounts of middle and/or high clouds (in addition to the low cloud types).

Ocean Station Vessels I, J, and K lie in the ridge line that preceeds the occluded system in the central Atlantic and on the high pressure side of the jet stream regime. Allowing for latitude changes within the same mass the three radiosonde soundings are similar in terms of temperature, although the dew point lapse rates are different.

At Ship I the satellite shows the cloud field to be overcast and extensive in coverage whereas Ships J and K lie in a more broken cloud field. The moisture lapse rate at Ship I shows marked dryness at the 900-mb level with humid conditions beginning at the 850-mb level and extending to at least the 400-mb level. The surface report indicates nearly overcast conditions of cumulus and altocumulus.

At Ship J the sounding shows alternating moist and dry layers up to the 500-mb level. The surface report shows scattered cloud cover consisting of stratocumulus, altocumulus, and cirrus.

Ocean Station Vessel K indicated rather humid conditions only below the 700-mb level. Its surface report indicates broken cloud cover of cumulus-topped-by-stratocumulus.

Over England and Europe the cloud cover is rather broken, with some indication that the lanes of clouds parallel the cyclonic circulation present in that area. Surface reports indicate a mixture of cumuliform and stratiform low cloud activity over England. Both middle and high clouds are reported in the regions of the cloud breaks.

Along the British Isles and France there are soundings from Stornoway, Aldergrove, Valentia, Camborne, and Brest that are contained within the satellite viewing area. All these stations show an unstable lapse rate and high humidity in the lower layers, a stable layer near the 800-mb level, pronounced dryness in the middle troposphere, and a return to more moist conditions above the 500-mb level. All of these stations report both low clouds and middle and/or high clouds, with the exception of Stornoway and Aldergrove, which report low clouds only.

On this day a double jet stream regime is observed in the western Atlantic. In its path about the cyclonic circulation the jet stream parallels, but lies somewhat north of, the semicircle of clearing. The northern (or Maritime Arctic) jet stream seems to stay just within the dense portion of the spiral cloud system; the southern (or Polar) jet stream is close to, or even partially in, the cloud field.

On the east side of the cyclonic circulation the Maritime Arctic jet stream flows northward, cutting across the dense pre-frontal cloud shield near the end of the occlusion. The Polar jet stream continues eastward to the point of occlusion and terminates just beyond, near the top of the clear region east of the warm front. The maximum isotach area remains to the west of the front, and bounds the southern half of the upper trough.

Through the region east of the front, the high pressure ridging is sufficient to weaken the jet stream, at least at the 300-mb levels. Over England, where the orientation of the cloud lanes reflect the cyclonic circulation, the jet stream complex has become reorganized. Here, the major breaks in the clouds are oriented parallel to the orientation of the jet stream complex.

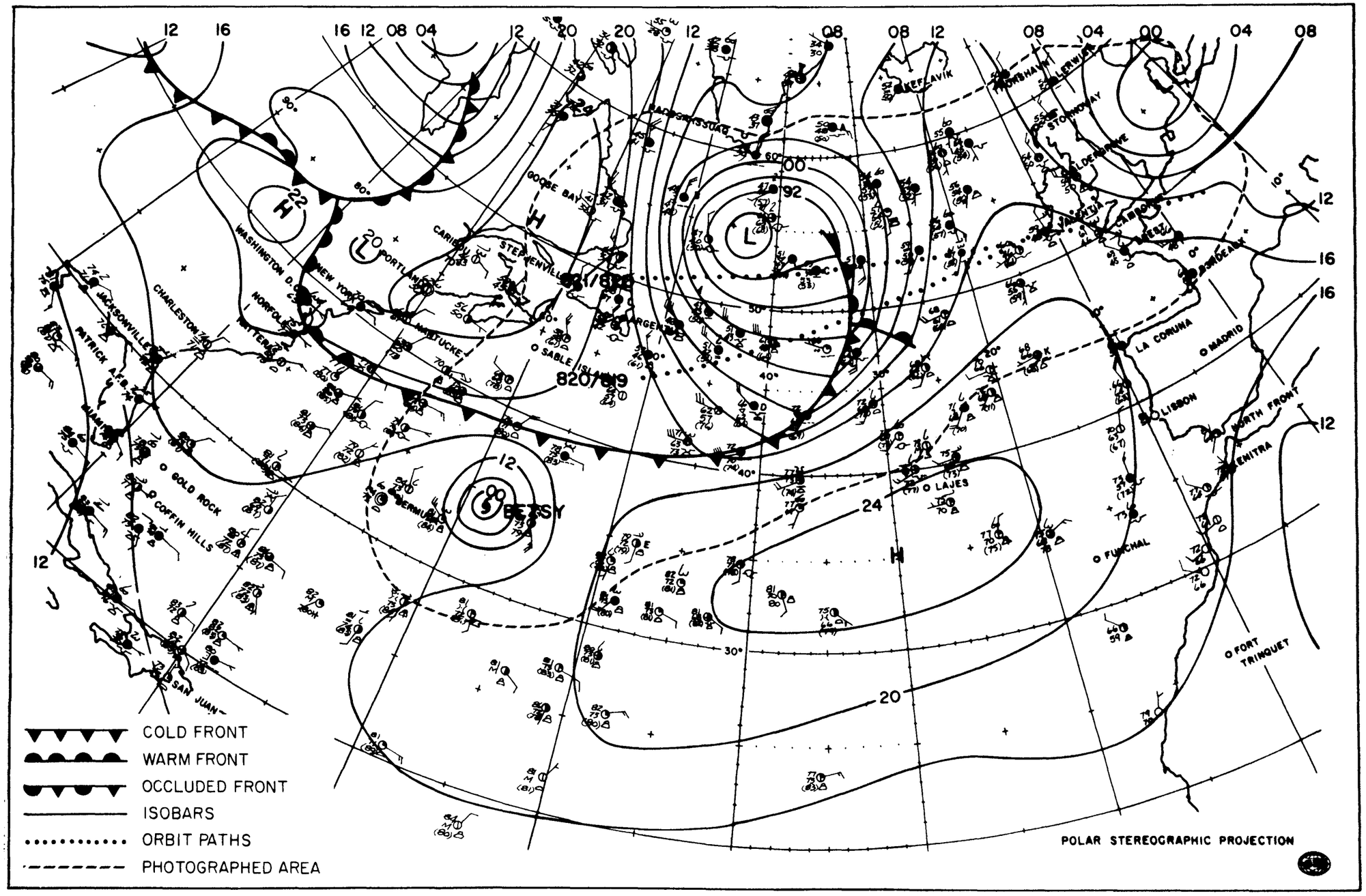

FIG.2 SURFACE MAP, 1200GMT, 7 SEPTEMBER 1961.

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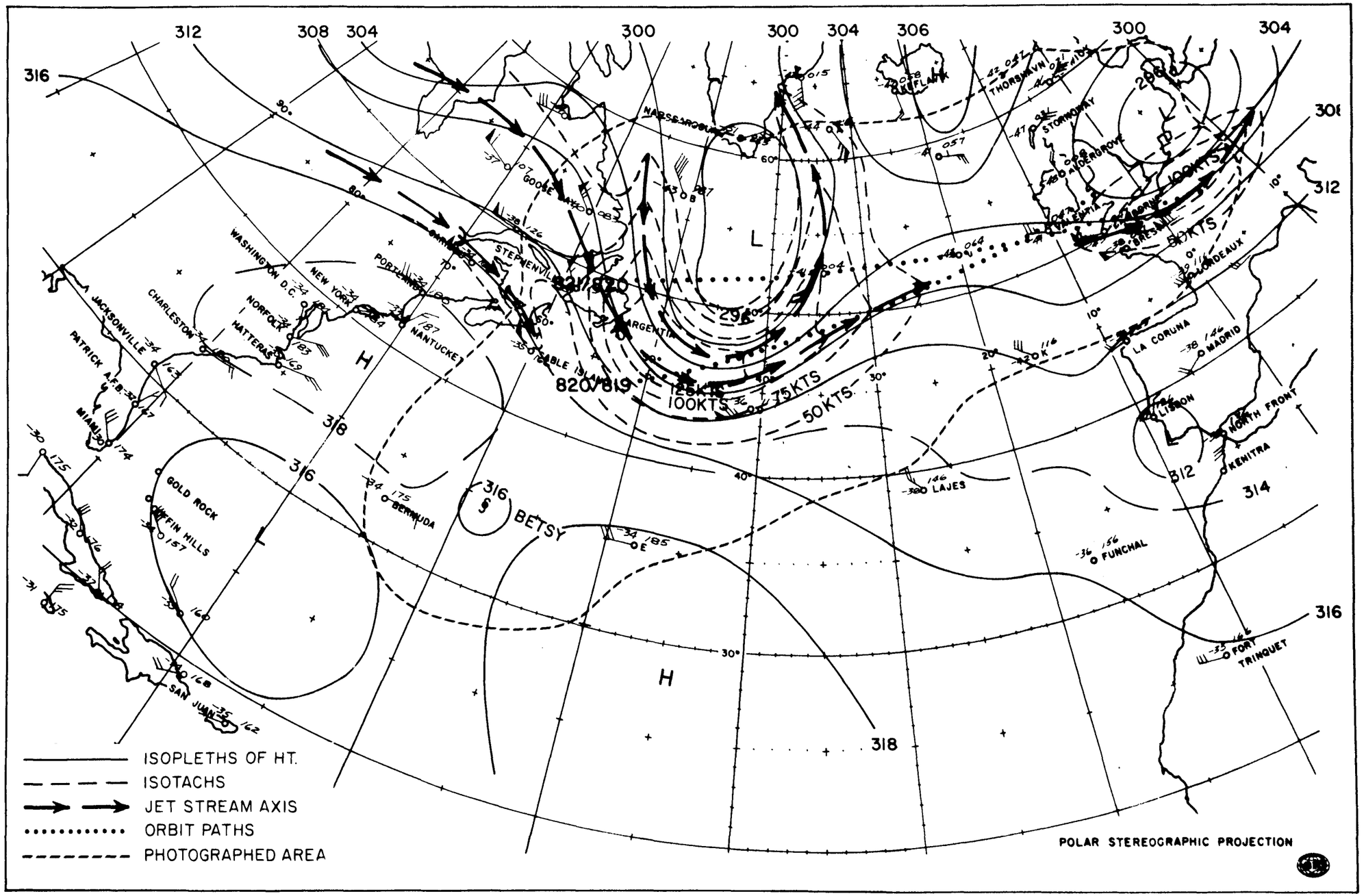

FIG. 3 300-mb MAP, 1200GMT, 7 SEPTEMBER 1961

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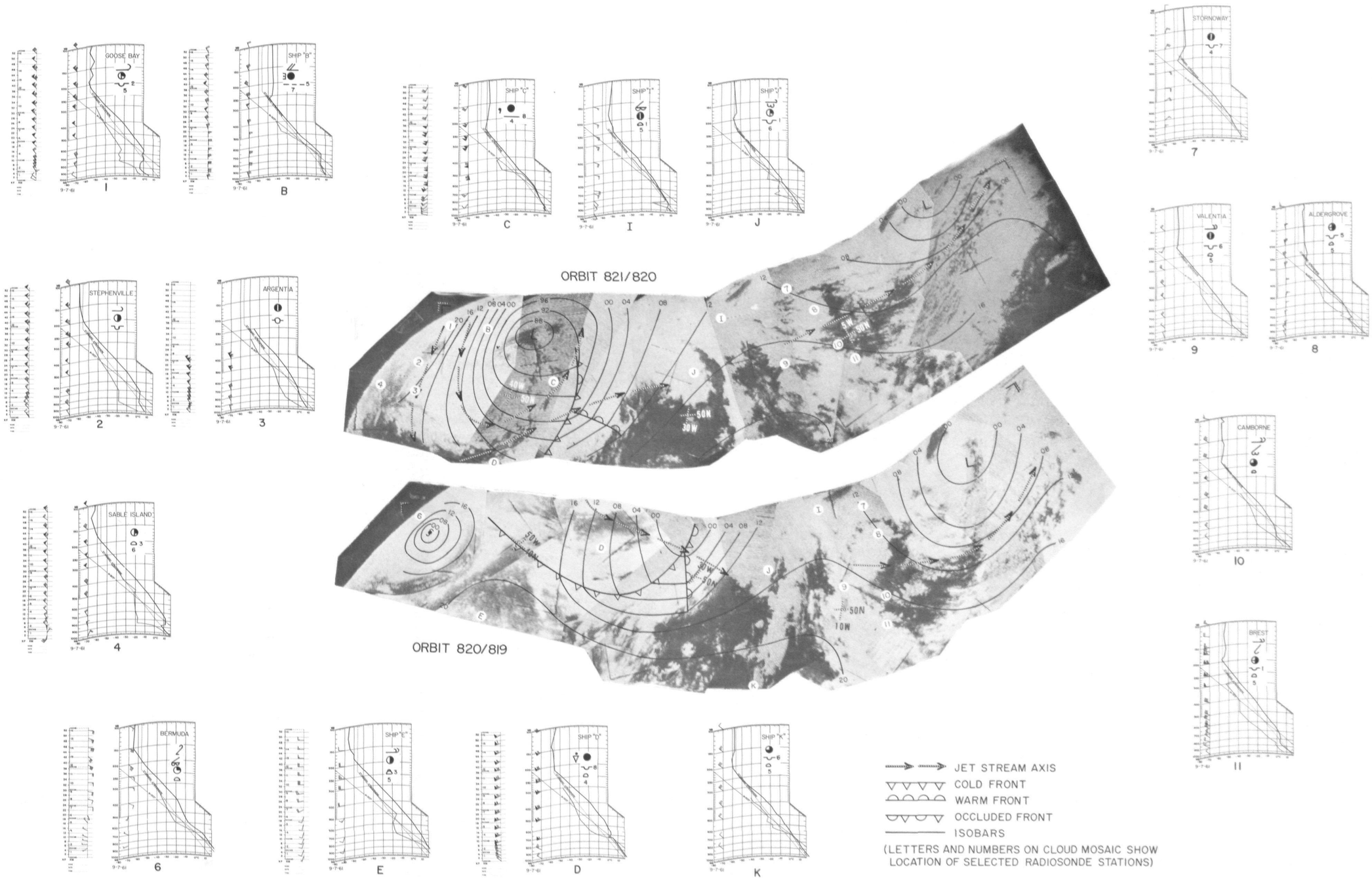

FIG. 4 CLOUD MOSAICS AND RADIOSONDE DATA FOR 1200GMT, 7 SEPTEMBER 1961

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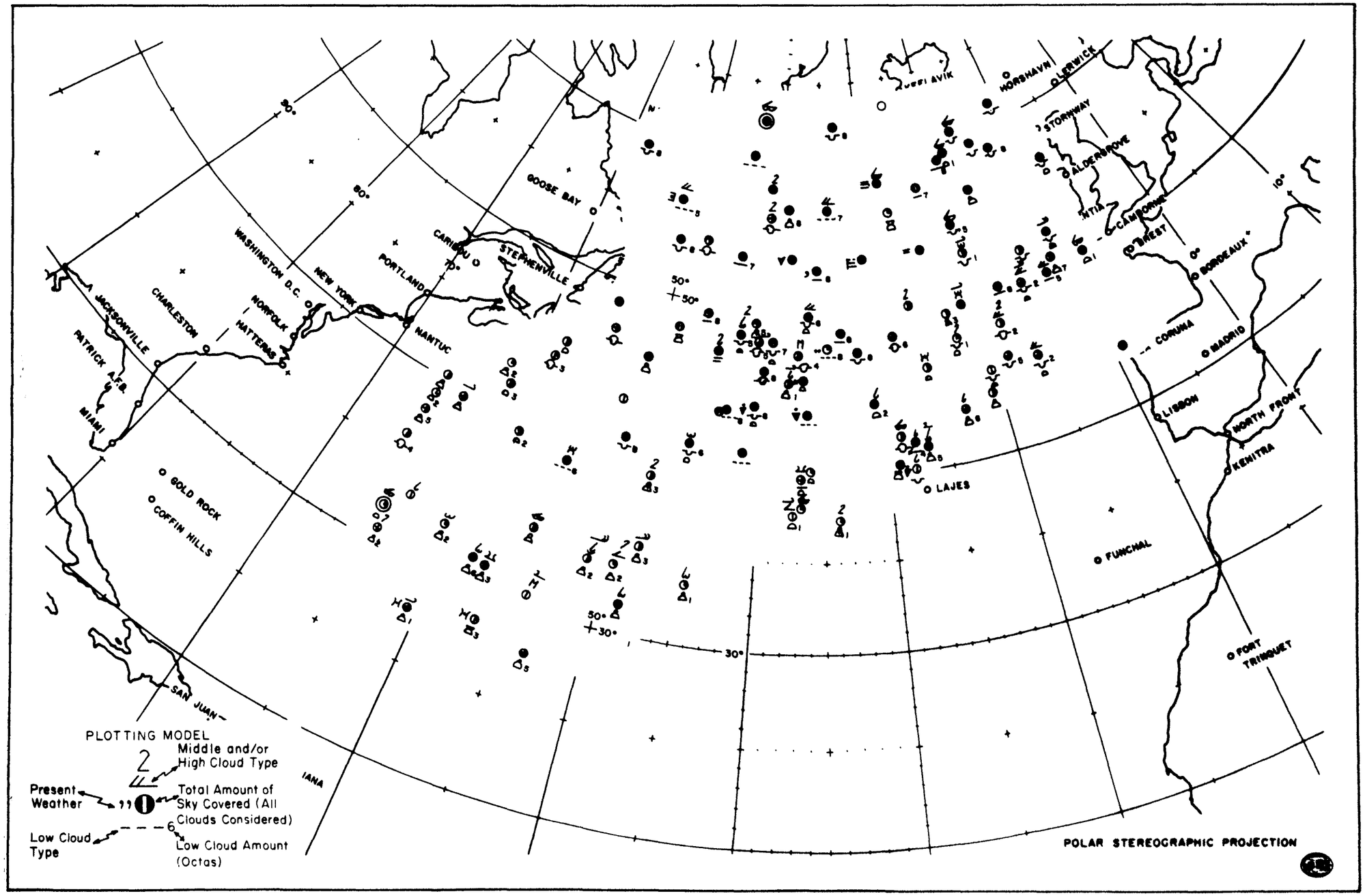

FIG. 5(a) CLOUD REPORTS FOR 1200GMT, 7 SEPTEMBER 1961

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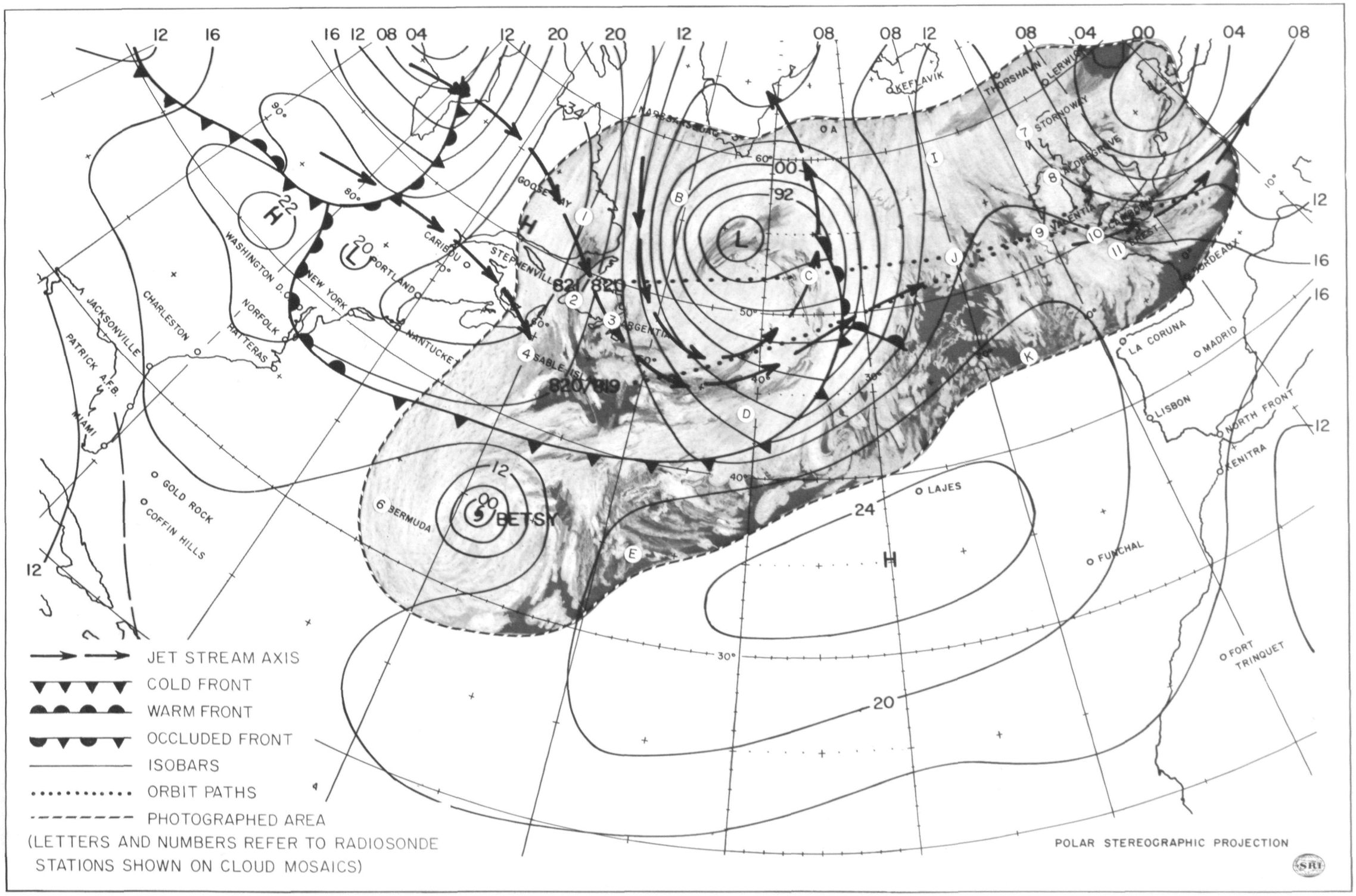

FIG. 5 (b) RECTIFICATION OF CLOUD PHOTOGRAPHS FOR 1200 GMT, 7 SEPTEMBER 1961

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B. 8 September 1961

The 1200 GMT surface analysis is shown in Fig. 6. In eastern Canada, the occlusion, in the last 24 hours, has progressed eastward to Goose Bay and Caribou, and is now embedded in a field of rather high pressure. The migratory anticyclone, seen on the 7th, has merged with the high pressure cell in eastern Canada. In the Atlantic, the low-pressure cell has deepened markedly, with the low pressure center itself moving southeastward and developing a northwest-southwest orientation. The frontal system associated with it has also progressed eastward and has begun to outrun the low pressure field. With the deepening of the low pressure system there has been a building of the high-pressure cell in the eastern Atlantic. In the more southerly latitudes, Hurricane Betsy has moved northwestward and joined with the surface front. The subtropical anticyclone remains strong and in about the same location as on the previous day.

The 1200 GMT analysis of the 300-mb level is shown in Fig. 7. With the collapse of the surface high cell over the Maritime Provinces, the flow at the 300-mb level also changes from meridional flow to zonal flow. Concomitantly, there is a corresponding intensification of the closed cyclonic circulation at the 300-mb level in the Atlantic with the deepening of the low at the surface. Within the limits of analytical accuracy, the axis of the low can be considered vertical.

Ridging is apparent just west of the British Isles with a cut-off anticyclonic circulation in the extreme northern latitudes of the map. The ridging aloft is displaced westward of that at the surface. Cyclonic circulation is observed over Europe.

The jet stream complex across the Atlantic is analyzed as two jet streams, whose interrelations are much the same as on the previous day. In the central Atlantic where the cyclonic circulation is oriented NW-SE, the principal isotach maximum is located at the southern limit of the cyclonic circulation. In the eastern Atlantic the jet stream exhibits considerable amplitude as it passes over the ridge. The northern jet stream (Maritime Arctic) curves around the cyclonic circulation while the southern Polar jet stream is interrupted over the ridge in the central Atlantic. This pattern of the jet stream complex was also noted in the weather situation of 18-29 May 1960 in the Pacific, studied under the previous contract.

Mosaics (Fig. 8) and rectification (Fig. 9) of cloud distribution over the Atlantic were constructed from Orbits 835/834 and 836/835 whose viewing times began at 1317 GMT and 1459 GMT, respectively. Their orbital paths are shown on Figs. 6 and 7. The area under surveillance includes the entire Atlantic north of the 40th parallel. Essentially both orbits view the same area, except for the area in eastern Canada which was viewed only on Orbit 836/835.

The synoptic situation in eastern Canada is one of rising surface pressures, accompanied by a weakening of the frontal system as it passes through a divergent wind field on the northern periphery of the high cell. This development undoubtedly accounts for the broken and disorganized cloud fields in the region south of the 50th parallel. Unfortunately, this area was only partially viewed on the previous day so that the nature of changes in the cloud field in the intervening period are not known.

The cloud cover north of Goose Bay is mostly overcast, being associated with the northern portion of the occlusion. South of Goose Bay, clouds are practically nonexistent along the position of the weak surface front.

Radiosonde data in the area are available from Goose Bay, Stephenville and Argentia. The Goose Bay sounding exhibits a small inversion at the 600-mb level with a high degree of humidity up to this level and drying above. Upper winds over the station are of only moderate strength. Stephenville, on the other hand, shows no inversion layer until the 250-mb level. The temperature is rather close to the dew point at the 700-mb level with the spread increasing above. Winds aloft over the station are rather strong. At Argentia, the temperature lapse rate is quite similar to that at Stephenville, but the spread between temperature and dew point becomes large almost

immediately above the surface and remains so to the 400-mb level where the dew point data terminate. Cloud coverage over these stations consists of stratocumulus, with altocumulus at Goose Bay and Argentia. The latter station also reports cirrus. These upper clouds may be present over the entire area.

The most striking feature in the cloud coverage across the Atlantic is the huge cloud vortex and associated frontal cloud band in the western and central Atlantic region. On this day the analyzed position of the surface low-pressure center seems to coincide better with the cloud vortex center than it did on the previous day. The post-frontal cloud regime is much more desiccated in the south and southeast sectors of the circulation than it was in the previous 24 hours. Where the clouds form into streets, the lanes appear to follow the streamlines of the surface wind rather than the isobaric curvature. Perhaps, in terms of photographic interpretation, cloud distributions of this nature should be ta'·en to mean considerable inflow into a low pressure center where the central pressure is quite low and cross-isobar flow is pronounced. The eroded cloud field behind the front is occurring in an area where the isobars diverge markedly.

Radiosonde data in this area are available from Ocean Station Vessels B, C, and D. Ship B is located in the northwest sector of the cyclonic circulation some distance from the jet stream complex. The winds aloft do not exceed 45 knots. The lowest layers of the sounding are characterized by a pronounced subsidence inversion whose base is located at about 870 mbs. The spread between temperature and dew point increased markedly through this layer. Clouds at this station are reported as stratocumulus.

Ocean Station Vessel C is located very close to the position of the low pressure center in the central Atlantic. The air is rather cold and unstable in the lower levels with the tropopause located at about 400 mbs. The spread between temperature and dew point is fairly small up to the 400-mb level, increasing somewhat above this point. Cloud cover over the station is reported as scattered swelling cumulus, middle and high clouds. Aloft, the winds do not exceed 30 knots.

Ocean Station Vessel D, to the south, displays a sounding which shows a pronounced inversion at the 800-mb level, due either to the extension of a front over this station or pronounced subsidence. The temperature/dew-point spread increases rapidly with altitude through this zone, which agrees with the surface report of stratocumulus with limited development. This station lies immediately to the south of the jet stream centrum as analyzed; wind velocities reach 110 knots between the 250- and 200-mb levels.

The position of the occluded front, as analyzed, lies in a cloudless region in the middle of the picture rather than in the dense cloud field itself. This discrepancy is most likely due to the time differential between the analysis on the cloud picture. Readjusting for this time difference would permit a repositioning of the front somewhat further to the east. When that is done, the analysis of the front will agree with the position of a dense cloud field. It is interesting to note that the point of occlusion (about 50°N) is analyzed at about the same latitude as the northern edge of the clear zone lying to the east of the warm front.

The pre-frontal cloud shield over the eastern Atlantic is reported as an overcast of stratocumulus or stratus, with some ships reporting the presence of higher clouds as well.

Radiosonde data in the area are available from Ocean Station Vessels I, J, and K which lie along the eastern periphery of the cyclonic circulation immediately along or just ahead of the frontal system. The temperature traces indicate that all three stations are in the same air mass and lie on the warm side of the jet stream complex. Although a frontal system has been analyzed on the surface map, there are no strong inversions indicating the front aloft at Ship I, Ship J, or Ship K. At Ship I the spread between temperature and dew point varies considerably with altitude, being most humid in the layer between 700 and 530 mbs. At Ship J the spread between temperature and dew point is rather small up to the 300-mb level. At Station K conditions are about the same. Surface reports show an overcast coverage

at Ships I and J consisting of low stratus, but higher clouds are probably present. At Ship K, the surface report indicates swelling cumulus, with the sky partially covered.

The cloud distribution through the ridge over England and France shows substantial clear areas only in the southwest, although numerous small breaks are found throughout most of the cloud field. These breaks in general are oriented NNW-SSE and more closely parallel the upper air than the surface flow. The ridge at the 300-mb level is centered over the frontal cloud in this particular instance. The upper level ridge is located far to the west of the ridge line at the surface.

Radiosonde data in the northern part of the ridge are available from Stornoway, Aldergrove, Valentia, Camborne, Brest, and Bordeaux. All of these stations show stability in the layer around the 800-mb level. All of the stations, with the possible exception of Brest, indicate a fair degree of moisture in the levels below these stable layers. Surface reports indicates substantial amounts of cloudiness at all of these cities, with Brest showing the least amount of coverage. The report at Brest also shows middle and high cloudiness, in addition to swelling cumulus, although the temperature/dew-point distribution at Brest in the high levels does not indicate a high degree of saturation.

Radiosonde data in the southern part of the ridge are available from La Coruna. Although this station appears to lie in a cloud-free area on the photographs, it actually reports a few tenths of cumulus and cirrus. The sounding is moist only in the lowest layers. The narrow elongated cloud line east of La Coruna may be a sea-breeze front along the north coast of Spain.

A comparison of the jet stream complex with the over-all cloudiness shows that, east of the Maritime Provinces, the northern (Maritime Arctic) jet stream more or less parallels a series of small breaks in the cloud field. Around the southern extent of the cyclonic circulation this jet stream path parallels the lanes of clouds (see south of OSV C). On the eastern periphery of the cyclonic circulation the cloud lanes lie at an angle to the jet stream and not parallel to it. In this area the cloud lanes seem to parallel the surface winds.

East of the Maritime Provinces, the southern jet stream flows over a field of broken cloud cover. At the base of the trough it passes over a dense cloud field (just east of OSV D) and thence into the partially clear area west of the surface front. Here, its path parallels the orientation of the cloud lanes.

The southern jet stream terminates just north and west of the point of occlusion at the surface. Its passage over the occlusion is prevented by the intense upper air ridge just east of the front.

Although the Polar jet stream is weakened over the ridge, it strengthens again on the east side of the region of partial clearing. The orientation of the cloud lanes in this area closely parallels the jet stream.

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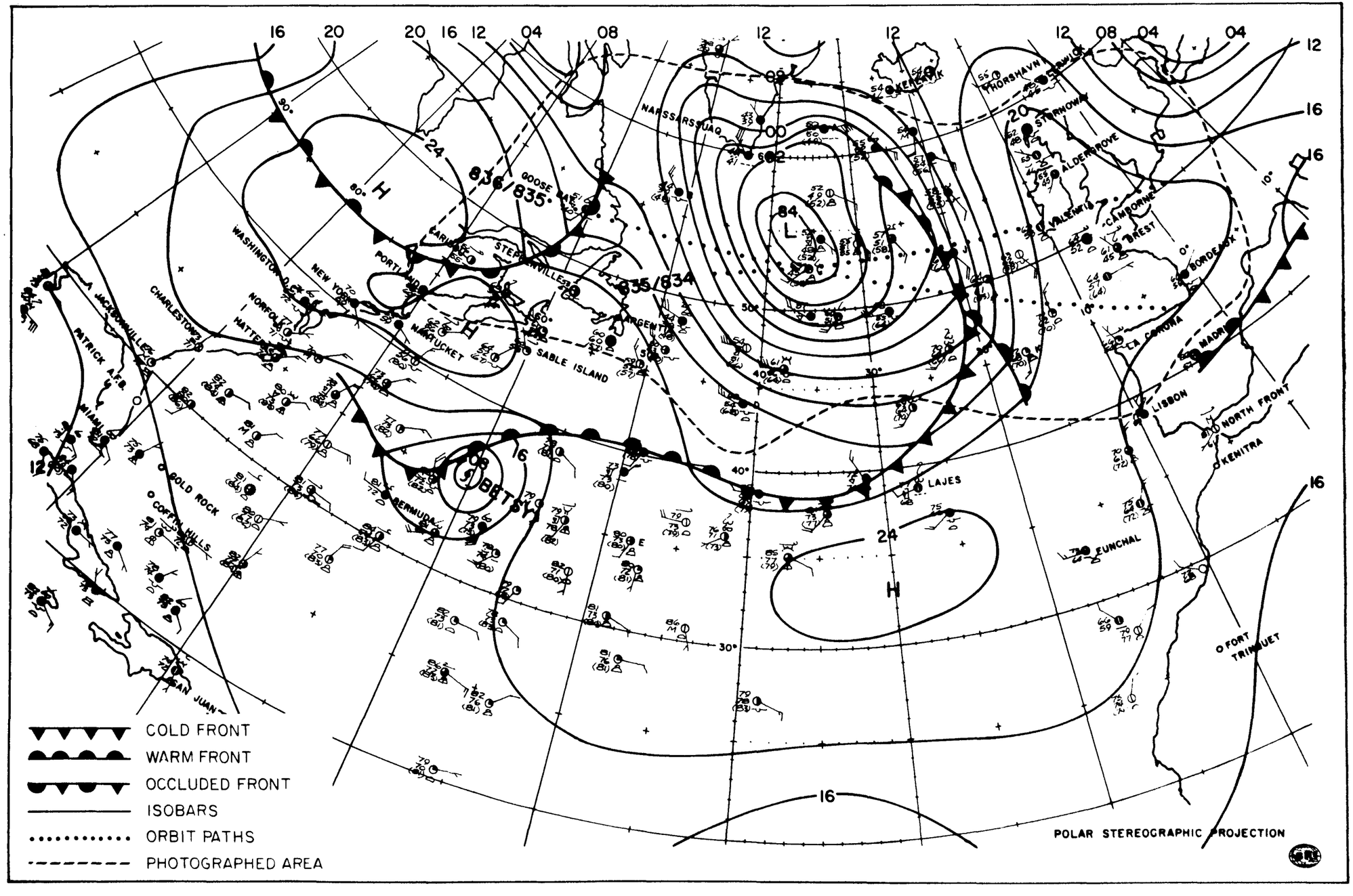

FIG. 6 SURFACE MAP, 1200GMT, 8 SEPTEMBER 1961

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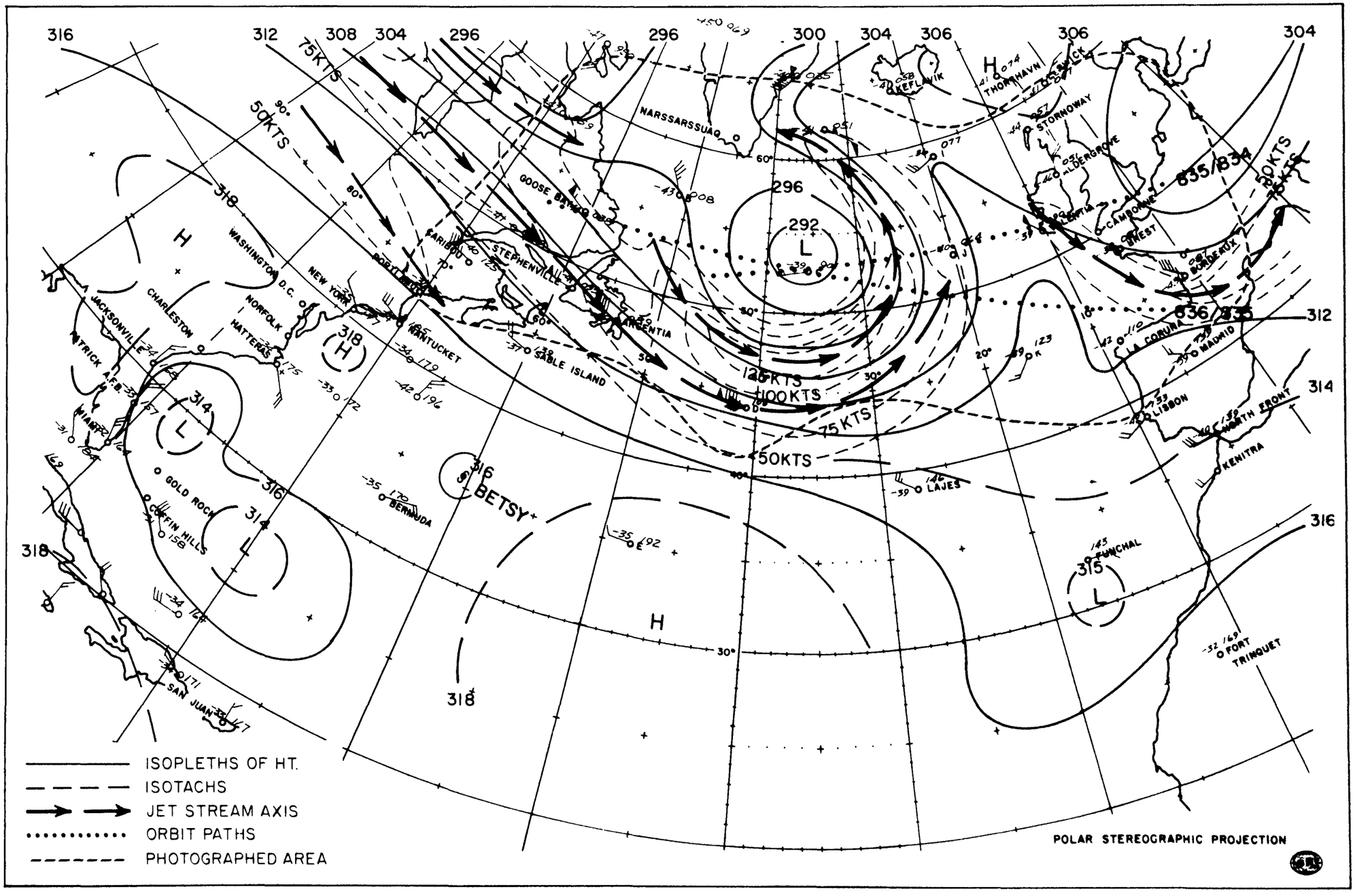

FIG. 7 300-mb MAP, 1200GMT, 8 SEPTEMBER 1961

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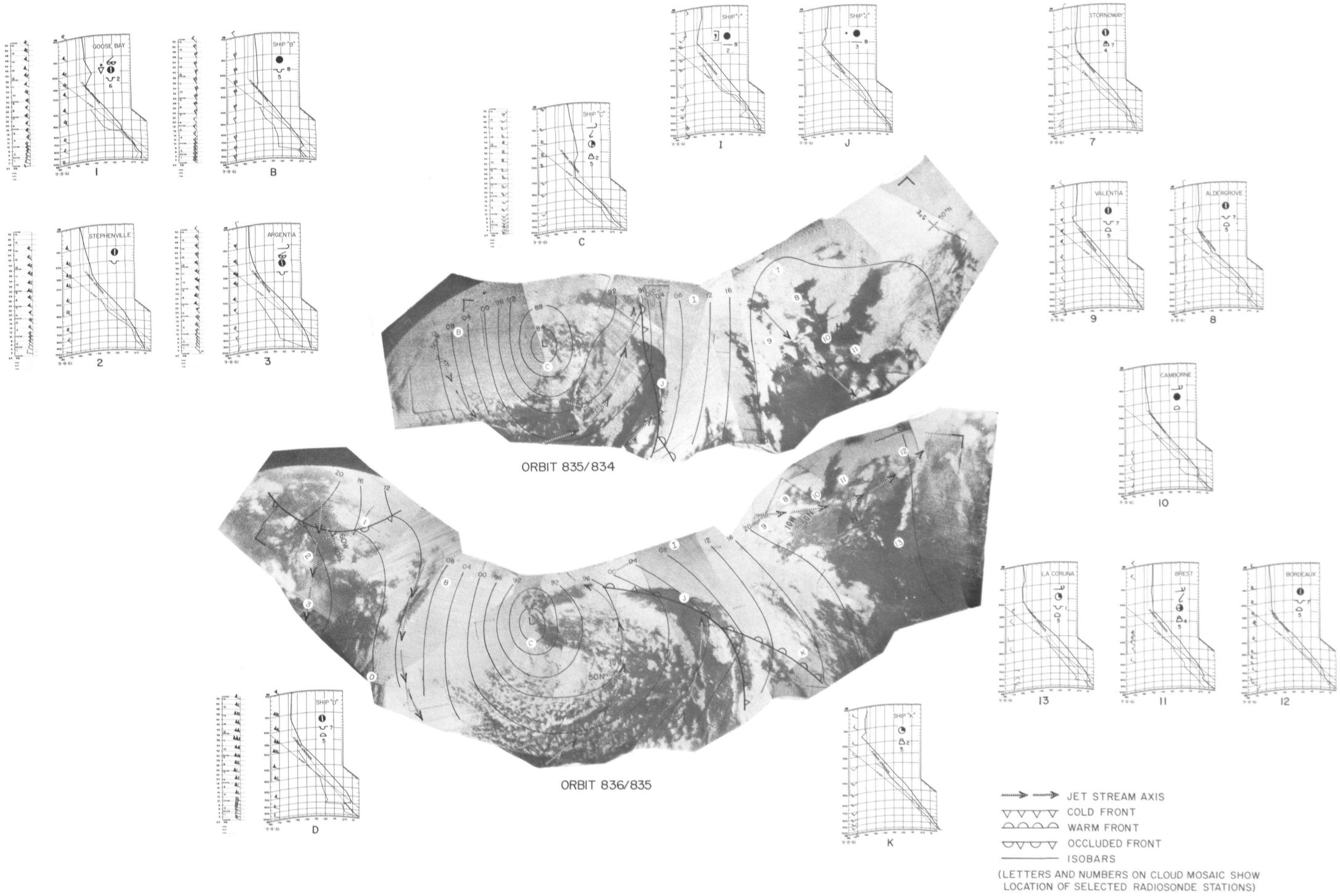

FIG. 8 CLOUD MOSAICS AND RADIOSONDE DATA FOR 1200GMT, 8 SEPTEMBER 1961

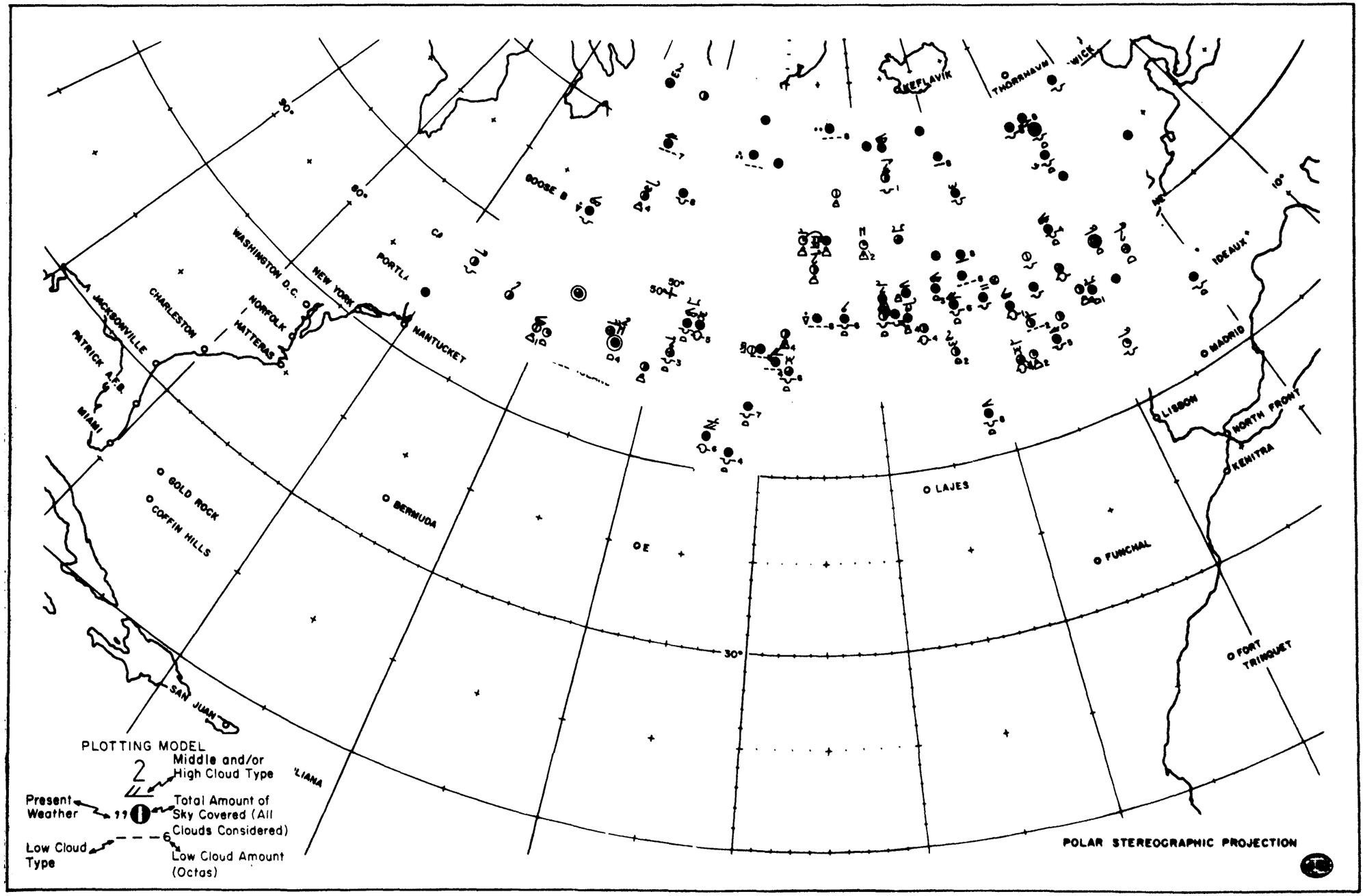

FIG.9(a) CLOUD REPORTS FOR 1200GMT, 8 SEPTEMBER 1961

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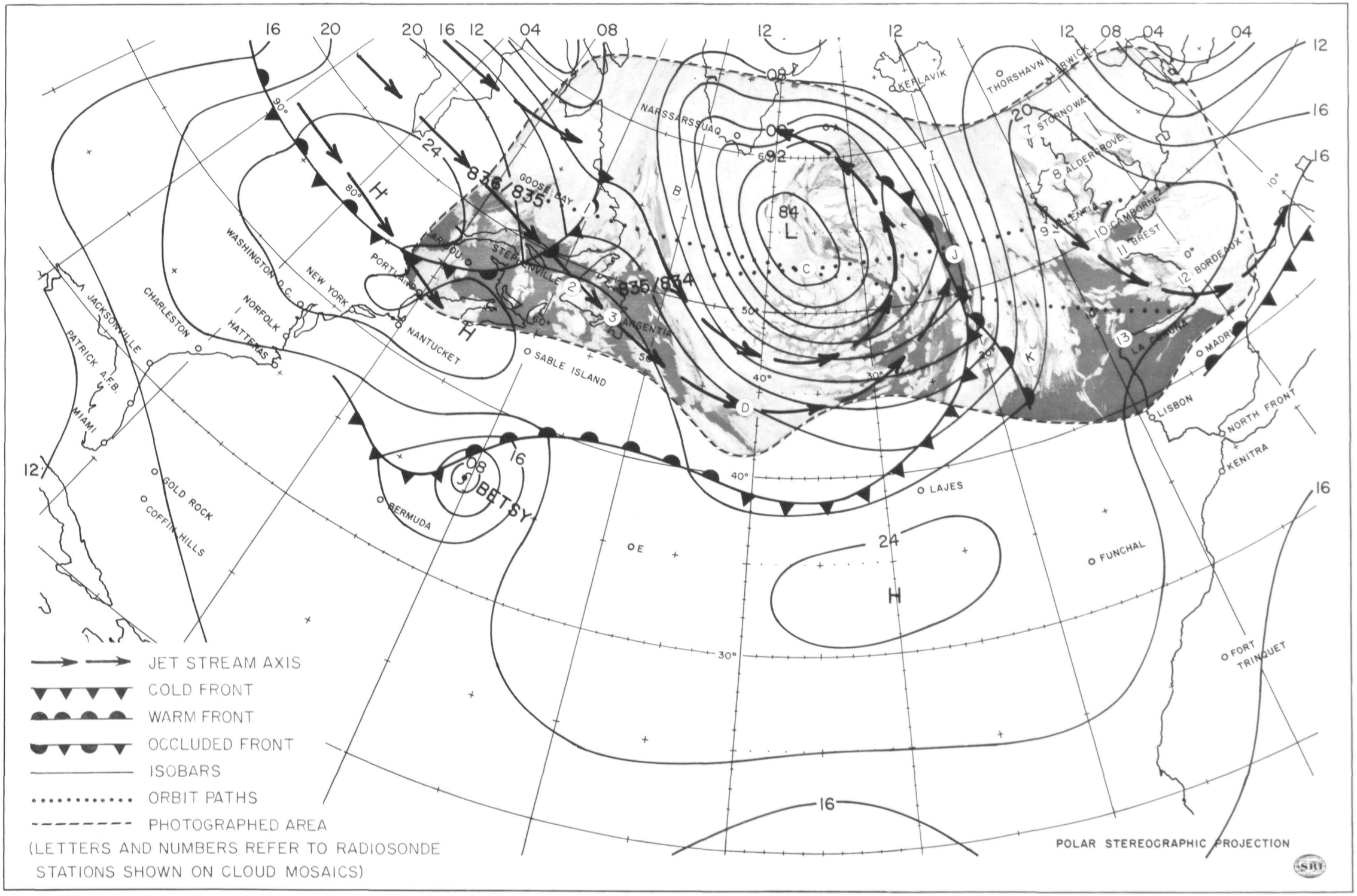

FIG. 9(b) RECTIFICATION OF CLOUD PHOTOGRAPHS FOR 1200 GMT, 8 SEPTEMBER 1961

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C. 9 September 1961

The analysis of the 1200 GMT surface chart is shown in Fig. 10. Over eastern Canada the ridge in this area has weakened between the 8th and 9th, and there is some evidence that a frontal field is developing between Stephenville and Goose Bay. In the past 24 hours the deep cyclone in the central Atlantic has moved only slightly northeastward. The occluded front, however, has continued its rapid eastward progression, moving to the vicinity of the British Isles. In the post-frontal area the isobaric pattern indicates a weak trough located to the south of the low pressure center. The ridge to the east of the occluded front still remains pronounced as it progresses eastward. In fact, a slight increase in the central pressure is indicated. Hurricane Betsy has recurved to the northeast during the past 24 hours.

The analysis of the 1200 GMT 300-mb level is shown in Fig. 11. A comparison with the upper air chart of September 8th shows a continued eastward progression of the cyclonic circulation in the eastern Atlantic. The center of this circulation has moved northeastward in correspondence with the movement of the low pressure cell at the surface and remains almost vertically over the surface low pressure center. In the western Atlantic an elongated cyclone, barely seen over eastern Canada on the previous day, has thrust eastward to a point near Ocean Station Vessel B. Westerly flow is well established in the middle latitudes from eastern Canada to the eastern Atlantic, with easterly flow across the higher latitudes of the Atlantic area.

Over Europe the upper circulation shows pronounced streamline divergence and weakening of the speed field. A ridge is present over Europe, and a weak trough has developed off the coast of Africa. Except for the reflection of Hurricane Betsy, the middle latitudes are dominated by an anticyclonic circulation.

The jet stream complex, as analyzed, consists of two streams. The most northern jet stream contains strong winds and extends in continuous manner around the upper cyclonic circulation. The southern jet stream is discontinuous and contains somewhat weaker wind speeds. A maximum isotach cell is located near Goose Bay in association with the closed circulation to the north. Another isotach area is found just south of the well-developed low cell in the central Atlantic. Strong winds also have developed in the eastern flow to the north of this low.

A mosaic (Fig. 12) and rectification (Fig. 13) of the cloud distribution was constructed from Orbit 850/849, whose viewing time across the Atlantic began at 1425 GMT. By virtue of the satellite orbital path, the area of view includes the entire Atlantic north of the 43rd parallel.

Extensive cloudiness exists over eastern Canada south of Goose Bay. This band of cloudiness extends eastward to about 45°W longitude, where it joins the cloud field of the spiral vortex.

Radiosonde data for this area are available from Goose Bay, Argentia, and Stephenville. Goose Bay lies in an air mass different from that of the other two stations, suggesting the existence of a frontal surface between them. This front could account for the existence of the dense cloud band in this area. The dew-point lapse rate at Goose Bay shows great variation with altitude, coming close to saturation only for brief height intervals. This station lies on the northern edge of the dense cloud field and only scattered altocumulus clouds are reported.

The soundings at Stephenville and Argentia are similar to each other. There is no great tendency towards saturation except in the very lowest layers. These stations report broken to overcast cloud coverage with the cloud type not specified.

Probably the most outstanding cloud feature on the mosaic is the extensive cloud system about the analyzed cyclonic pressure system in the middle Atlantic and the widening of the characteristic post-frontal "clear slot" seen from Ocean Station Vessels I to K. Cloud types within the vortex itself consist of stratus and stratocumulus (around Ocean Station Vessels B and C). Clouds in the immediate

post-frontal area (see west of OSV K) are more cumuliform in appearance. The apparent center of the cloud vortex lies fairly close to the analyzed surface center of the low pressure system. A comparison with the rectification of the previous 24 hours shows that the clear area to the southeast of the low is more extensive than that of the previous day and extends northward to the northeast sector of the low.

Ships B and C lie in the western portion of the cyclonic vortex. Their radiosonde data, in terms of the temperature distribution, are rather similar for the most part. The tropopause at both stations lies near the 250-mb level. Ship B displays a stable layer near the 600-mb level. The dew-point spread increases rapidly through this stable layer, with the sounding having shown quite humid conditions up to this point. An overcast of cumulus-topped-by-stratocumulus is reported. Ship C, being near the center of the cyclone, does not show lapse-rate stability in the troposphere. The temperature and dew point show that high humidity occurs below the 800-mb level and above the 500-mb level. Here, an overcast of swelling cumulus is reported.

Ocean Station Vessels I, J, and K lie in the zone of partial clearing associated with the post-frontal circulation. The radiosonde data at these stations indicate that Ships J and I are in fairly cold air, on the north side of the jet stream complex. The distribution of moisture at these stations is rather similar, exhibiting a progressive increase in temperature/dew-point spread with altitude. Ship I reports a near overcast of stratocumulus while Ship J reports a small amount of fair weather cumulus. The sounding at Ship K, however, indicates cold air near the surface with a stable layer near the 700-mb level, perhaps reflecting the presence of a front over the station. The difference between temperature and dew point shows that high humidity occurs below the front, drying through this front and moisture aloft. Ship K lies to the south of the jet stream complex and is reporting small amounts of swelling cumulus, coupled with moderate amounts of middle and high clouds.

On this date the surface front lies far in advance of the parent low. The pre-frontal cloud structure (near 50°N and 10°W) is clearly evident, and is somewhat narrower than on the previous days. Fortunately, radiosonde data in the frontal cloud area are available from Valentia. Near-saturated conditions are reported below the 600-mb level which correlates with a reported low overcast of stratus. The presence of moisture at high levels as well indicates that middle and/or upper clouds also may exist. Observations along the British Isles indicate precipitation north of the point of occlusion.

By this day the cloudiness within the ridge to the east has become more sparse within the past 24 hours. In general the distribution is rather chaotic, with some of the distribution in the cloud population being associated with land features. An area of partial clearing extends to quite high latitudes. Major clearing is centered south of the surface anticyclone. The northern periphery of this major clearing is located at about the same latitude (52°N) at the point of occlusion.

Radiosonde data in the ridge are available from Aldergrove, Camborne, Brest, Bordeaux, and La Coruna. Allowing for latitudinal differences, the soundings of the temperature lapse rates are almost identical. The moisture distribution varies, however, at the various stations. Stornoway and Aldergrove, which lie just in advance of the pre-frontal cloud shield, show near saturation condition in the levels above 500 mbs. Camborne and Brest show a fair amount of moisture throughout the sounding above 700 mbs. Bordeaux and La Coruna, which lie near the center of the high pressure cell, show dry air throughout except in the very lowest layers. All stations report the tropopause near the 200-mb level.

In the western Atlantic the jet stream complex enters the viewed area on a northwest-southeast orientation with the northern jet stream passing almost directly over Goose Bay. A maximum isotach area lying over Goose Bay is associated with the intrusion of a short-wave trough into this region. Based on the cloud report at Goose Bay, this isotach area is accompanied by a shield of altocumulus on the warm side of the

jet stream. The southern jet stream in this complex extends for a distance along the periphery of the dense cloud field considered to be part of a developing frontal discontinuity. Extensive low cloud cover does not permit observation of any upper cloud but stations further south report middle and high clouds and these probably extend to the jet stream location as well.

In the central Atlantic the jet stream complex extends around the base of the cyclonic circulation. The northern jet stream skirts the southern portion of one of the spiraling cloud arms. There seems to be a line of breaks in the cloud field just under the maximum isotach field at the base of the trough that parallels the orientation of this jet stream. The southern jet stream in this region overrides a cloud field to the south of the spiral arm. There are no apparent breaks in the cloud field that correlate with the orientation of this jet stream.

In the eastern Atlantic the northern jet stream, in the process of its recurvature around the northern side of the cyclone, crosses the apex of the clear area. There is a suggestion that a thin detached band of clouds, just behind the frontal cloud system, parallels the jet stream orientation. The surface reports indicate that some of these clouds are of the cirrus type.

The southern jet stream terminates in the area of partial clearing behind the cold front. At this point the cloud lanes are oriented almost perpendicular to the jet stream itself. Surface reports indicate these clouds to be primarily low cloud types.

Unfortunately, the picture quality does not permit distinction of cloud layers. There may be streaks of middle and high clouds that trace the course of the jet stream complex quite well. That they do not appear on these low-resolution photographs certainly does not preclude their existence.

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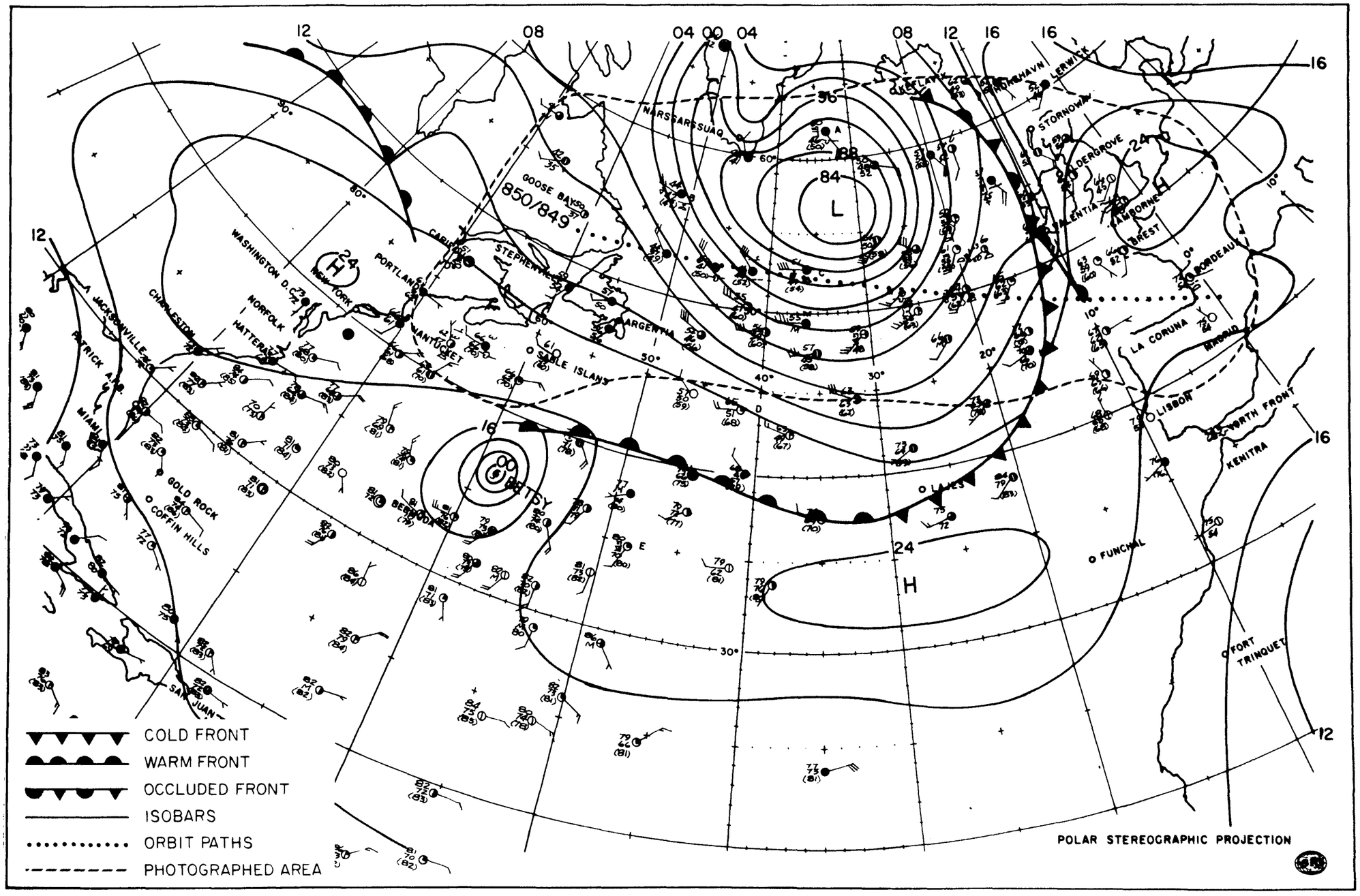

FIG. 10 SURFACE MAP, 1200GMT, 9 SEPTEMBER 1961

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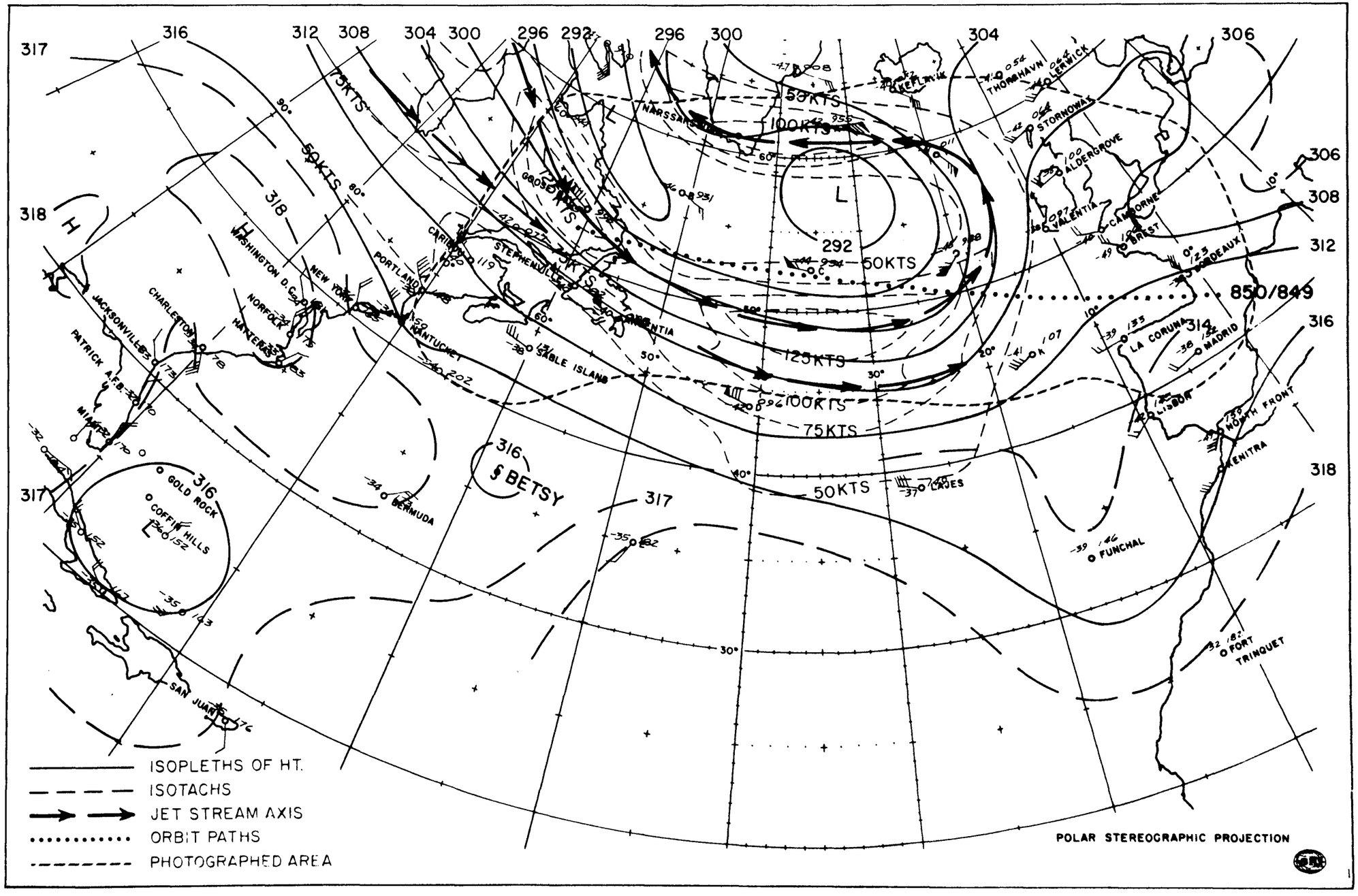

FIG. 11 300-mb MAP, 1200GMT, 9 SEPTEMBER 1961

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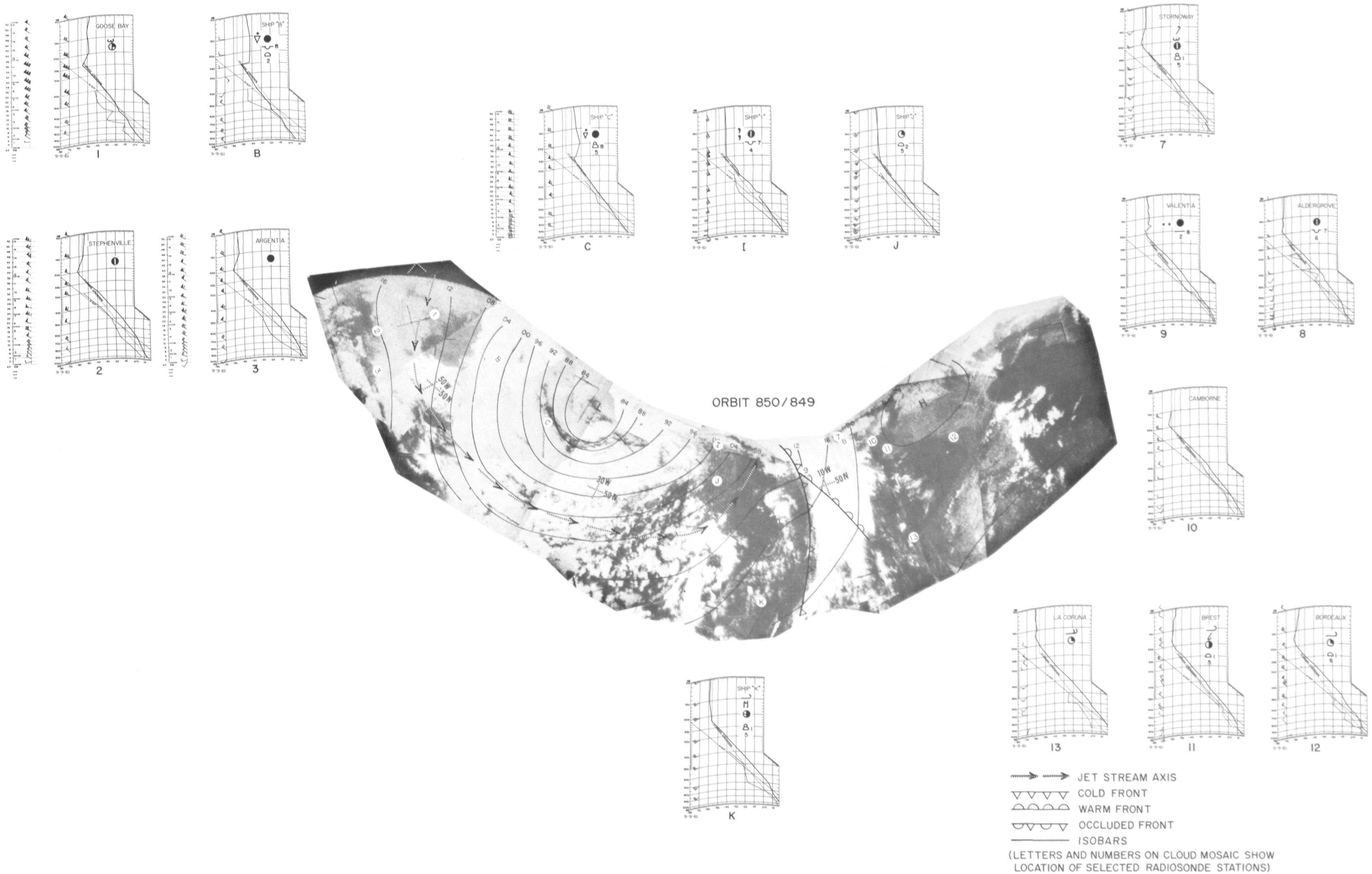

FIG. 12 CLOUD MOSAICS AND RADIOSONDE DATA FOR 1200GMT, 9 SEPTEMBER 1961

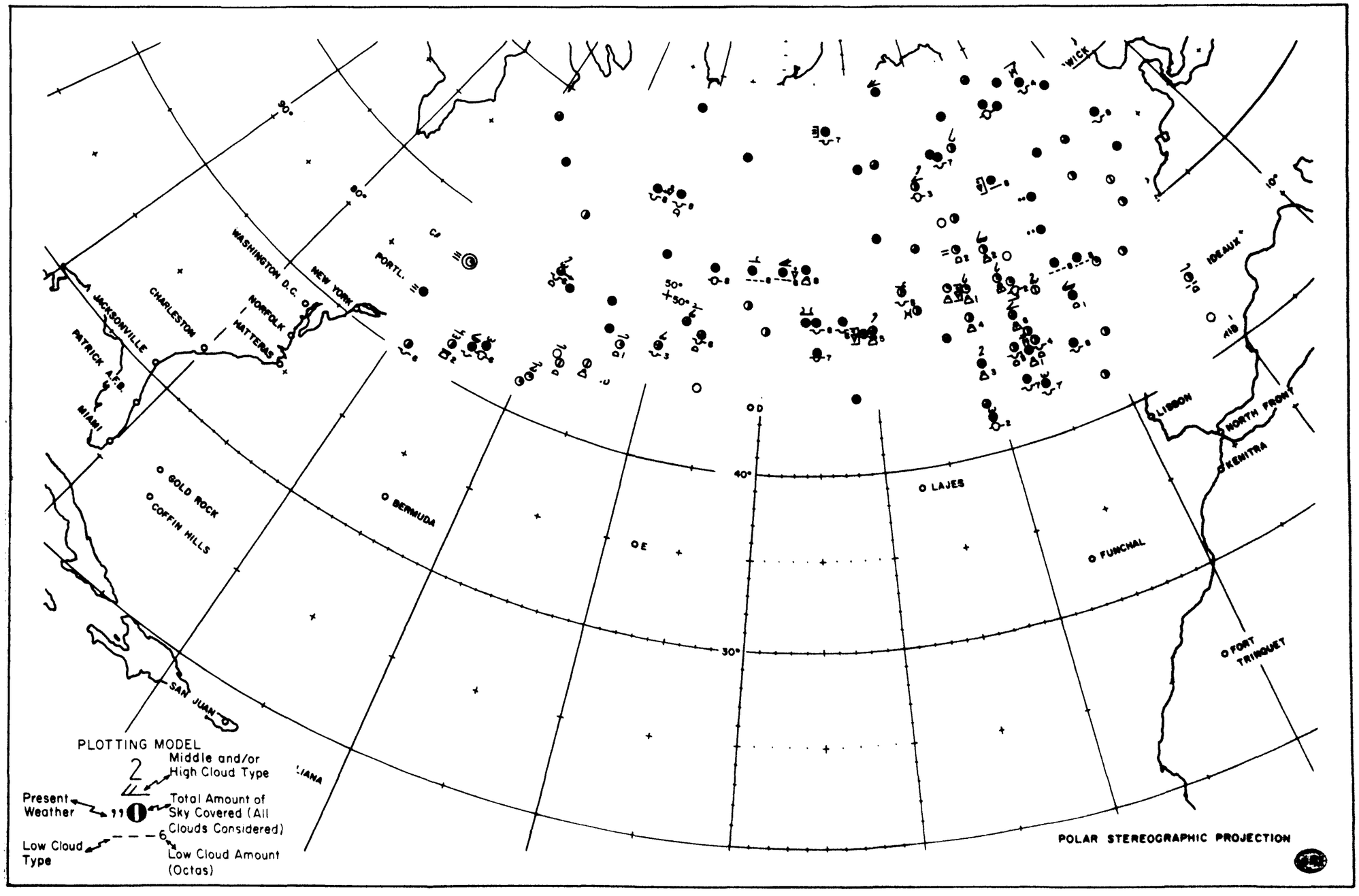

FIG. 13(a) CLOUD REPORTS FOR 1200GMT, 9 SEPTEMBER 1961

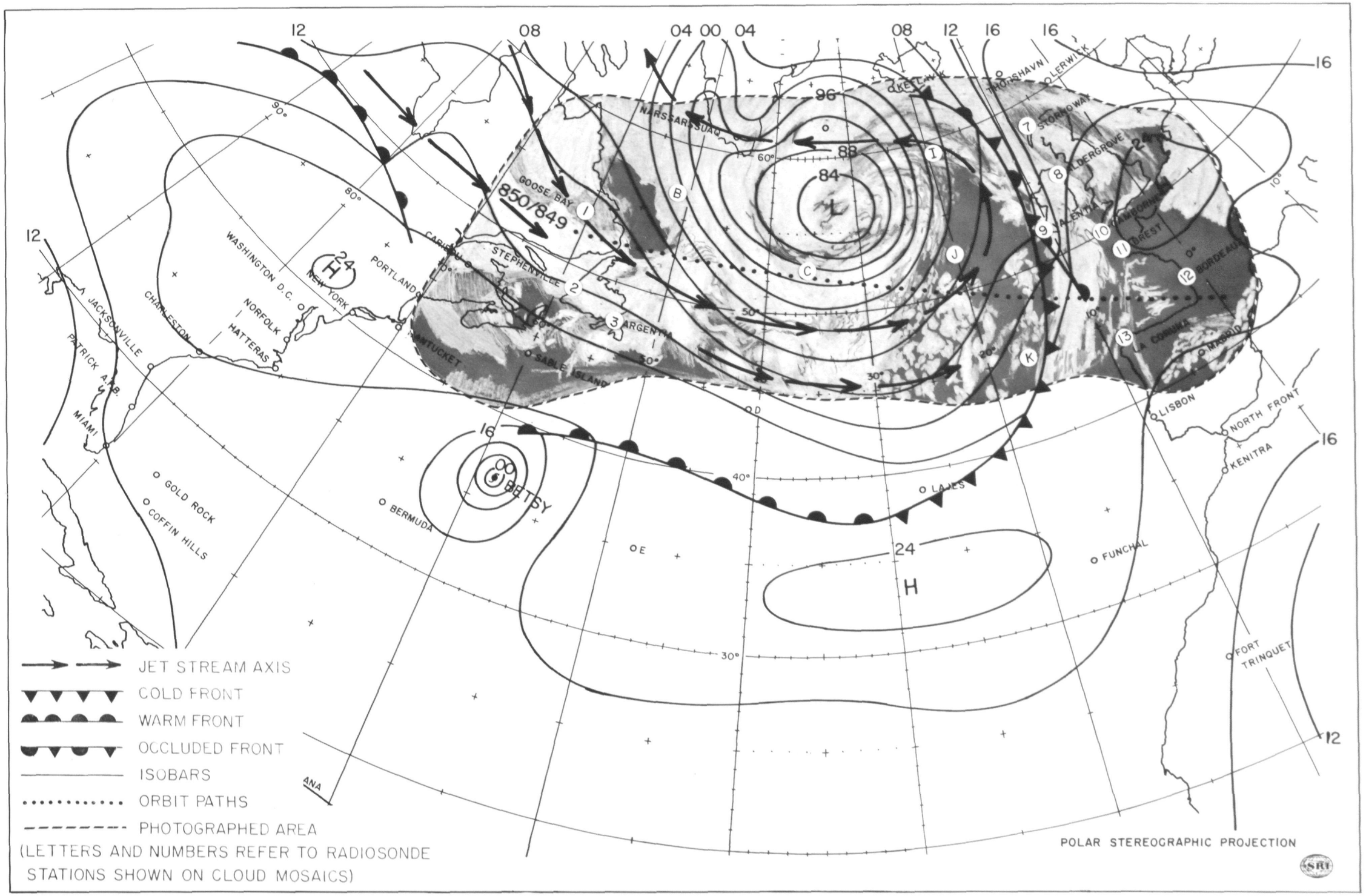

FIG. 13 (b) RECTIFICATION OF CLOUD PHOTOGRAPHS FOR 1200GMT, 9 SEPTEMBER 1961

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D. 10 September 1961

The analysis of the 1200 GMT surface chart, shown in Fig. 14, now contains the frontal system in eastern Canada and the Maritime Provinces that the cloud field seemed to indicate on the 1200 GMT chart of 9 September. Another interesting feature is the decided west-east elongation of the principal low pressure circulation southeast of Greenland. This is accompanied by the expansion of the subtropical high-pressure cell centered near Lajes Acores. In addition to these developments there has been a movement of the low pressure center off Greenland to the north-northwest.

Wave action has developed on the frontal system in the eastern Atlantic. Although this system continues to progress eastward, it is now doing so at a much reduced rate. The high pressure cell downstream continues to exist but is now somewhat weaker in intensity. Hurricane Betsy continues its northeasterly course.

The analysis of the 1200 GMT 300-mb level is shown in Fig. 15. Circulation changes noted on the surface chart are reflected at this level as well. For example, there is a corresponding west-east orientation of the cyclonic circulation in the central Atlantic, although the center of this circulation at the 300-mb level is located southward of the pressure minimum at the surface. South of the 45th parallel, the spreading Bermuda High in the central Atlantic is accompanied by the building of an anticyclonic circulation at the 300-mb level. Marked troughing is occurring where Hurricane Betsy enters the westerlies, indicating that this storm will probably accelerate in the next 24 hours. The trough, seen off Spain 24 hours ago, has retrograded, due to wavelength readjustments, while the ridge over Europe shows little change.

In general, there are only minor changes in the location and configuration of the jet stream complex from that of the previous day, particularly in the Atlantic. The deepening of the trough in the western Atlantic results in the shifting of the southern jet stream toward the base of this trough. This jet stream reforms again over the ridge downstream. Maximum isotach areas are located along the northern jet stream, near Goose Bay, at the southern limit of the strong cyclonic circulation and again on its eastern periphery.

A mosaic (Fig. 16) and rectification (Fig. 17) of the cloud distribution was constructed from Orbit 864/863, whose viewing time across the Atlantic began at 1347 GMT. The orbital path results in observations of the Atlantic north of the 43rd parallel.

Although the nadir angles are very high on the extreme left portion of the mosaic, the cloud field in this area appears to be quite dense and is presumed to be associated with the frontal system that extends from Caribou, Maine to Argentia. Weather stations under this frontal cloud shield report an overcast of stratiform low clouds, with precipitation. Although no frontal system was evident on the surface map of the 9th, a dense cloud mass was already discernible in this area at that time from the satellite photographs. This dense cloud mass may be an indication that active frontogenesis was already occurring.

A comparison of the radiosonde data at Goose Bay, Stephenville, Argentia, Sable Island, and Nantucket shows distinct temperature variations prevailing over this region. Goose Bay lies in fairly cold air with its sounding showing a tendency towards stability in the layer between 700 and 500 mbs, a tropopause at the 250-mb level, and a rather warm and stable stratosphere. Very strong winds are present above the 400-mb level. The dew-point curve shows appreciable moisture only in the levels below 700 mbs. Sparse cloud cover is reported, although low, middle, and high cloud types are reported by weather observations. On the mosaic the area around Goose Bay is almost cloud-free and even the coast line in this region is discernible.

The temperature soundings at Stephenville, Argentia and Sable Island are rather similar to (except for some small variations at and about the troposphere near the 250-mb level), but definitely warmer than that at Goose Bay. The dew-point lapse rate at these stations, however, are quite different. At Stephenville near saturation occurs only below the 850-mb level, with an overcast of cumulus-topped-by-stratocumulus

is indicated. At Sable Island, saturation extends only to the 980-mb level, and the cloud character is reported as stratiform, although coverage is only partial.

Nantucket, which lies farther to the west, shows both a warmer troposphere and a colder stratosphere than at the other stations (tropopause at the 150-mb level). Its dew-point curve shows rather dry air over the station, which correlates well with the report of clear conditions.

In the central Atlantic the cloud field in and around the pressure vortex (see north of OSV B, C, and I) does not present the clear-cut spiral appearance of previous days. This lack of cloud organization, undoubtedly, has an association with the decay and aging of the pressure system. The trajectories of the air parcels in this region apparently no longer trace the inflow spirals, as they did on the previous days. Cold air has been modified and recirculated in such a way that widespread desiccation has set in.

A chaotic and broken cloud field is found in the entire southeastern sector of the surface cyclone and continues as such to the limits of the picture to the southward (see OSV J and K and south of C). An elongated cloud mass lying parallel to the surface wind lies southwest of OSV J. Surface reports in the area show it to consist of swelling cumulus or cumulonimbus, with some shower activity, and suggests that this cloud system may be a squall line. Farther downstream, nearer the surface front, the wind field shows marked directional divergence and the cloud cover is considerably diminished.

Radiosonde data from this area are available from OSV B, C, I, J, and K. Ocean Station Vessels B and C lie in the southwestern sector of the low-pressure vortex in the mid-Atlantic and the soundings at these stations are characteristic of those found in modified cold air. The tropopause at Ship B is found at 280 mbs; the tropopause at Ship C is found at 230 mbs. The temperature/dew-point difference indicates that the air at OSV B is quite humid below the 700-mb level. The air at OSV C is somewhat drier at all levels. Both stations report swelling cumulus as the low cloud type along with altocumulus at OSV B and cirrus at OSV C.

Ocean Station Vessels I, J, and K are located in the post-frontal region, characterized by scattered to broken cloud fields. Ship I, however, lies in the eastern sector of the cyclone under the influence of southerly flow. Ship J lies in the southeast sector of the low. In the troposphere these soundings are comparable. The tropopause is lowest at Ship J (near the 300-mb level). Reference to the 300-mb chart shows the cold air aloft lies to the south of the surface minimum pressure position and near the area of Ship J.

Ship I reports near-saturated conditions below the 700-mb level and above the 500-mb level. Stratus with low ceilings, middle and high clouds are reported. Above Ship J, the air is much drier (showing near-saturated conditions only below the 800-mb level) but cumulonimbus, as well as middle and high clouds, are being reported.

Ship K also lies in the post-frontal region under the influence of the anticyclonic circulation. The sounding shows a stable layer between the 700-mb and 600-mb levels, which probably delineates the frontal interface over the station of the main frontal system to the south. The air is dry just above this stable layer, suggesting subsidence. The station reports sparse cloud cover--cumulus-topped-by-stratocumulus and altocumulus.

The frontal cloud band in the eastern Atlantic is well defined (see area east of OSV I, J, and K on the mosaics). The northern portion of the surface front is located within a broad cloud mass. Here, the surface wind flow is approximately parallel to the orientation of the front. In the southern portion of the front, the clouds lie in advance of the frontal system. Here, the winds in the post-frontal area are directed perpendicular to the front.

Radiosonde data in the frontal cloud system are available from Stornoway, Aldergrove, Valentia, Camborne, Brest, and La Coruna. Stornoway and Aldergrove lie in cold air at low levels, with indication of a frontal intersection over these stations at about 750 mbs. The

front also has just passed Valentia, which is now in the cold air, in the very low layers. Stornoway and Aldergrove show near-saturated conditions only in the layers below 750 mbs, whereas, at Valentia, this condition extends throughout the troposphere. Stornoway reports a near overcast of cumulus-topped-by-stratocumulus; Aldergrove shows broken coverage of stratocumulus and cirrus. Valentia, near the crest of the wave, shows moderate amounts of stratus and altostratus.

To the south, La Coruna lies in the frontal band, as well. The temperature/dew-point distribution on its sounding shows rather moist conditions throughout the troposphere, with the exception of a layer near the 500-mb level. This station reports a sparse amount of swelling cumulus, and large amounts of middle and high clouds.

Camborne and Brest lie at the edge of the frontal cloud shield. Camborne has rather moist conditions prevailing through most of its sounding, whereas Brest has substantially drier air in the lower layers. Cloud cover at Camborne is reported as an overcast of stratus, whereas Brest reports upper clouds only. Undoubtedly, these upper clouds exist over Camborne, as well as over Brest.

Nearer the center of the high-pressure area itself, the cloud cover is quite sparse. Bordeaux, which is located in this region, has a sounding which indicates extremely dry conditions. Only very small amounts of cumulus and cirrus are being reported.

At the 300-mb level the pattern-association between the jet stream complex and the gross cloud distribution is difficult to establish. Over Canada and the Maritime Provinces, the northernmost jet stream passes over the clear area southeast of Goose Bay. The southern jet stream passes over the cloudy area north of Caribou, Maine, and does not appear to be delineated by any unique cloud distribution. The surface reports indicate large amounts of upper cloud in this region, which may present an organization that is not evident in these pictures.

Through the central and eastern Atlantic, cloud distribution is quite chaotic and any tendency for clouds to line up with the upper winds is not apparent. The southern jet stream is re-established in the central Atlantic. Clouds appear to be aligned generally with the upper air flow near this jet stream, especially west of 25°W longitude. The northern jet stream turns northward before reaching the front, after which it roughly parallels the frontal cloud system.

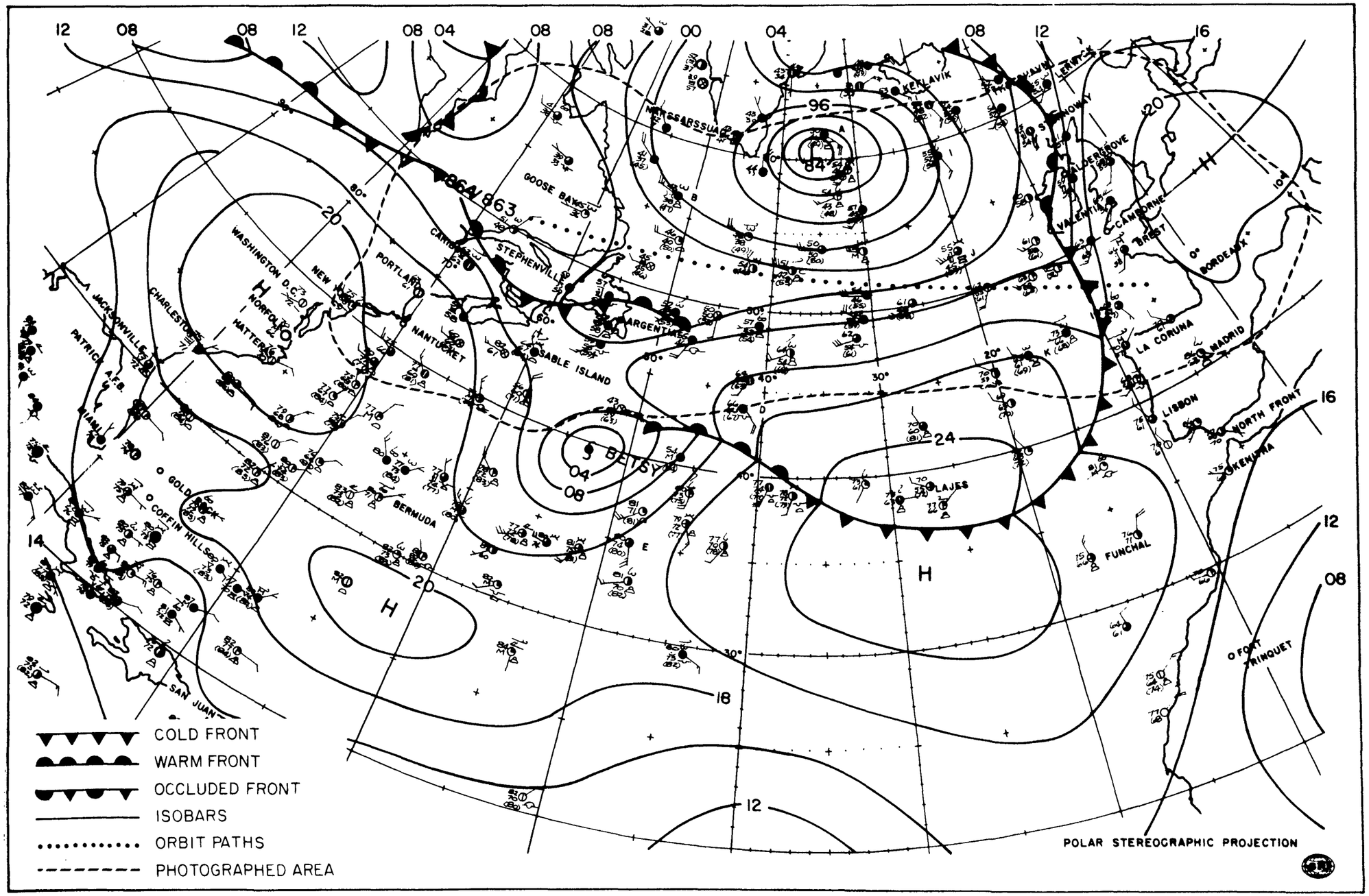

FIG. 14 SURFACE MAP, 1200GMT, 10 SEPTEMBER 1961

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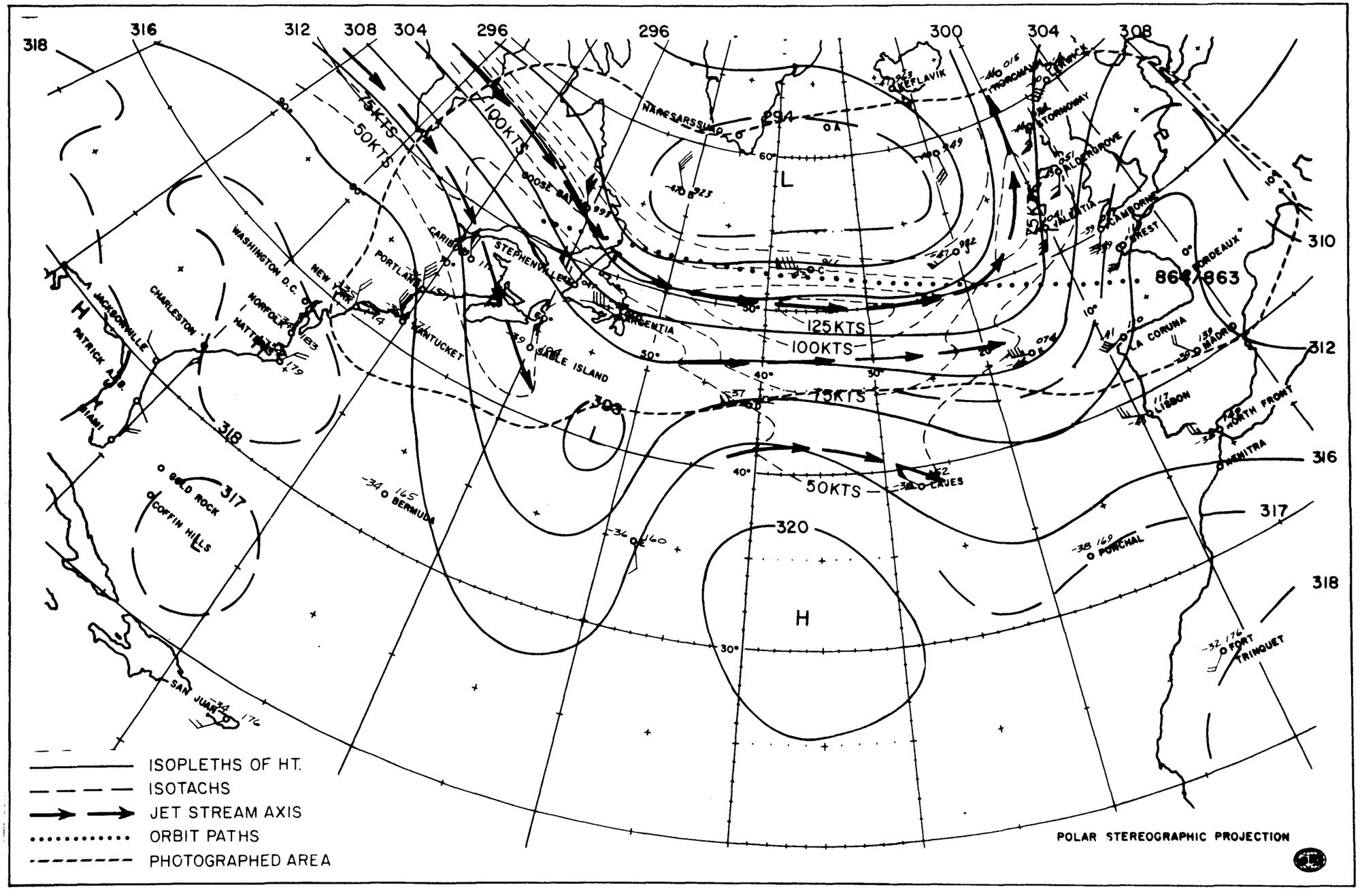

FIG.15 300-mb MAP, 1200GMT, 10 SEPTEMBER 1961

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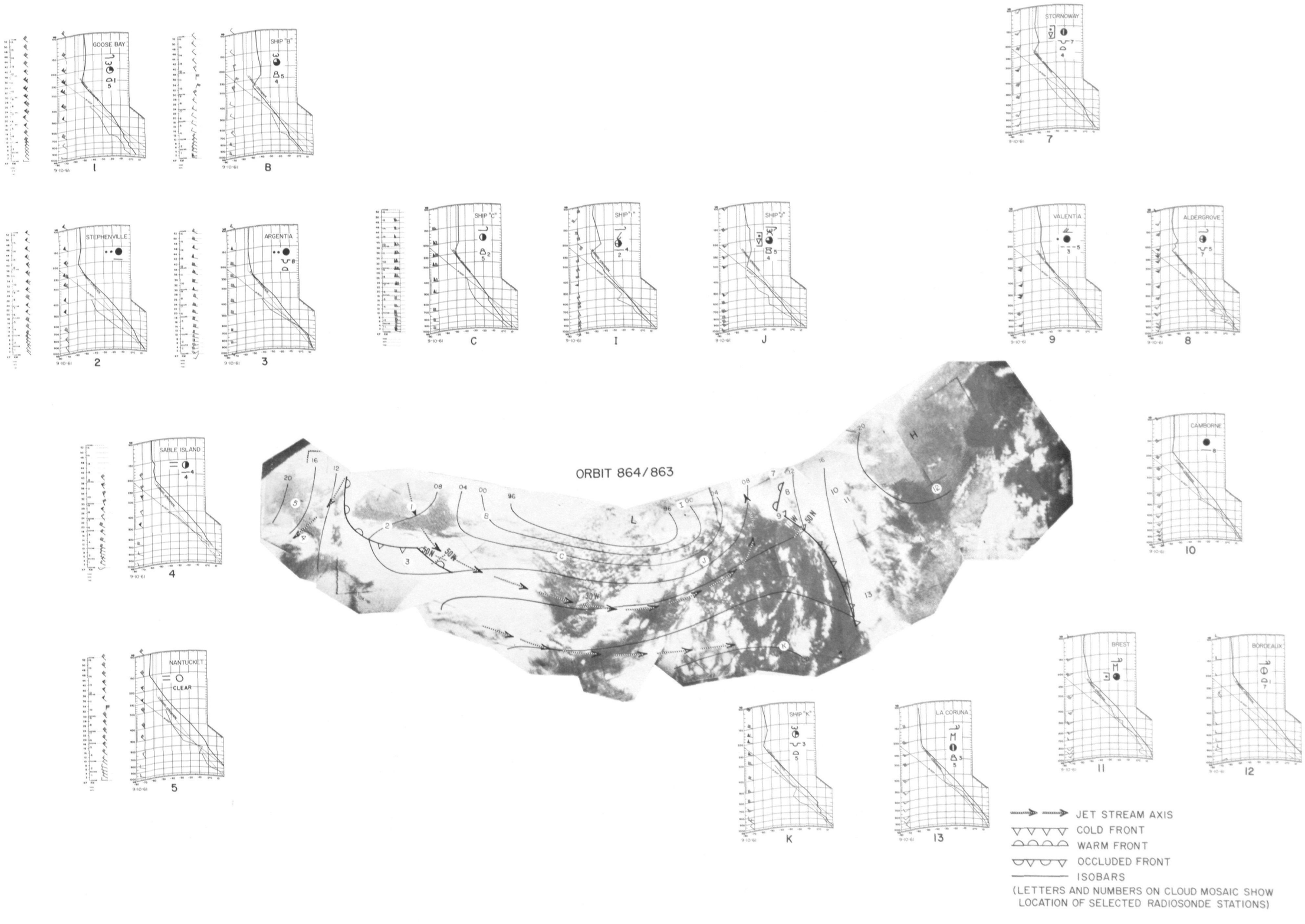

FIG. 16 CLOUD MOSAICS AND RADIOSONDE DATA FOR 1200GMT, 10 SEPTEMBER 1961

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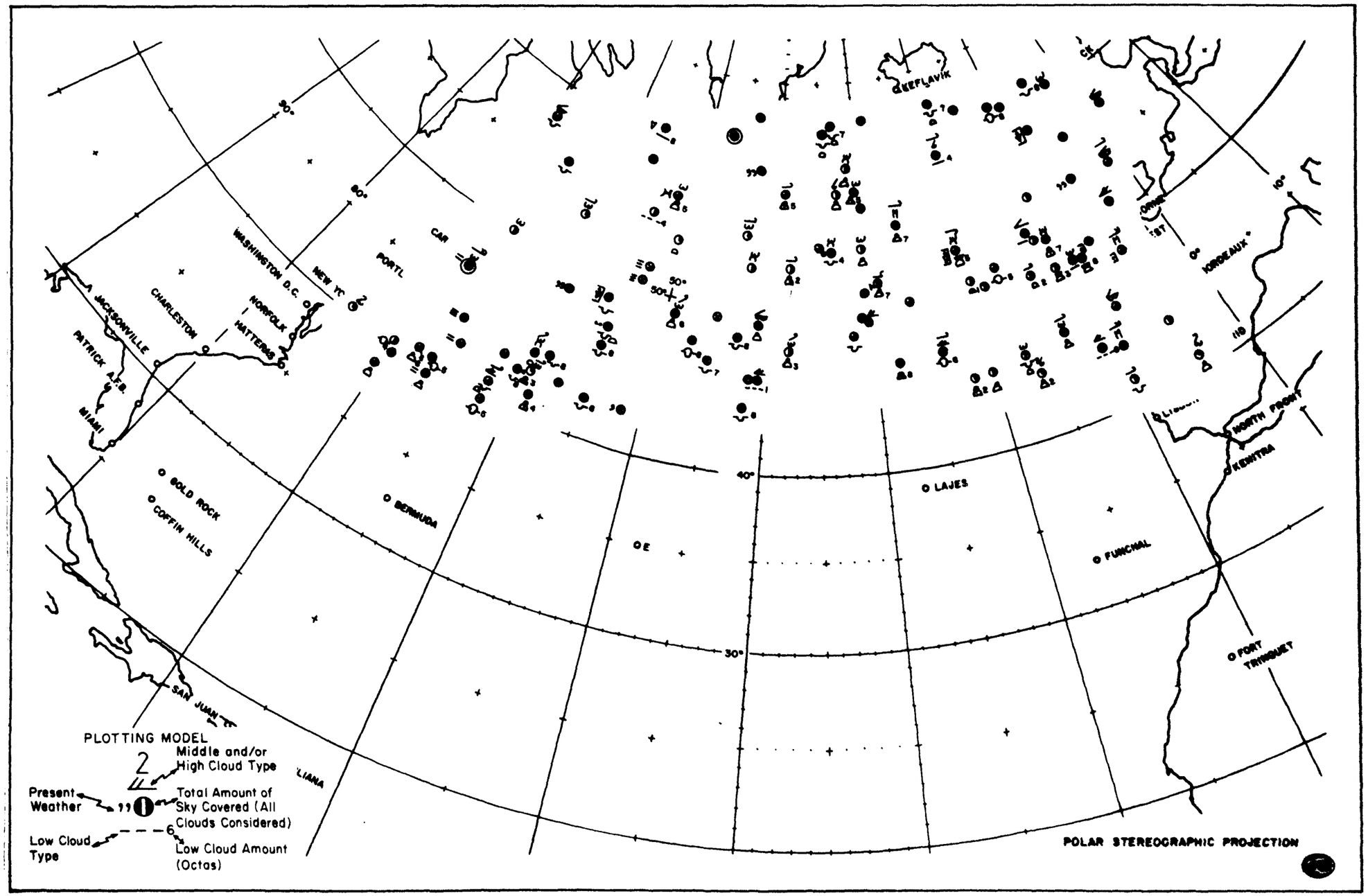

FIG.17(a) CLOUD REPORTS FOR 1200GMT, 10 SEPTEMBER 1961

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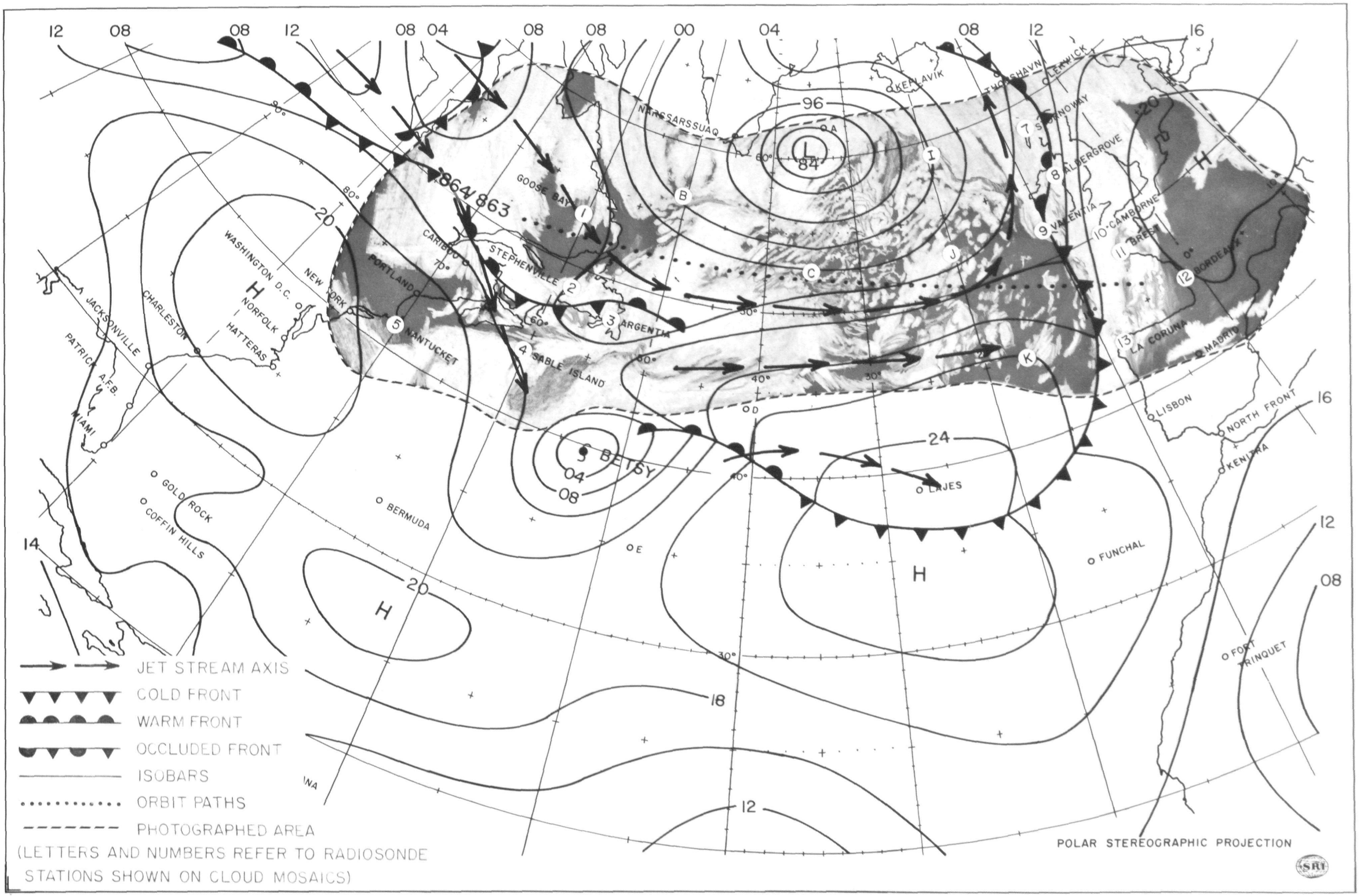

FIG. 17 (b) RECTIFICATION OF CLOUD PHOTOGRAPHS FOR 1200GMT, 10 SEPTEMBER 1961

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E. 11 September 1961

The analysis of the 1200 GMT surface chart is shown in Fig. 18. By this date Hurricane Betsy has moved to the central Atlantic and is in the process of becoming transformed into an extra-tropical storm. Concomitantly, advection of warm air is producing a large-scale open wave. Hurricane Debbie has been formed in the low latitudes. The warm front over the Maritime Provinces continues. A remnant of a filling low-pressure cell is still observed southeast of Greenland. Ridging predominates in the eastern Atlantic, as the old frontal system has moved into Europe. The over-all orientation of the isobars shows a meridional circulation being formed with warm air injection prevailing throughout the eastern Atlantic.

Two jet streams are apparent. The northern one is continuous and quite strong, particularly on the flanks of the developing trough in the western Atlantic. The southern jet stream is much weaker, being eroded around the base of the trough, and terminates in the upper air divergence field just west of Spain.

Three orbits over the North Atlantic were available on this day: Orbits 877/876, 878/877, and 879/878, which passed over the area at 1133 GMT, 1311 GMT, and 1456 GMT, respectively. Mosaics from these orbits are shown in Fig. 20. The bulk of the observed area lies north of the 40th parallel in the Atlantic dipping to the 30th parallel over Africa and Europe. A rectification of these three mosaics to a polar stereographic map is given in Fig. 21(b).

The dense cloud mass in the Maritime Provinces is identified with the frontal system that has existed there some 24 hours or more. Surface reports on Fig. 21(a) show overcast conditions in the area of the front. West of Sable Island, however, where the low cloud coverage permits their observance, there are middle and high clouds reported and these middle and high clouds undoubtedly extend over, and to the north of, the front itself. The frontal cloud band extends southeastward from the tip of the warm front and seems to be drawn into the cloud system associated with the circulation of the Hurricane Betsy.

Radiosonde data in eastern Canada are available from Goose Bay, Stephenville, Argentia, and Sable Island. The warm front across the Maritime Provinces southwest of Stephenville is causing considerable overrunning to the north. The frontal intersection aloft can be seen on the Stephenville, Argentia, and Goose Bay soundings near the 850-, 500-, and 400-mb levels, respectively. Goose Bay, at the northern extension of the front, reports sparse cloud cover of cumulus and altocumulus. Extremely strong upper winds prevail and the jet stream center is analyzed as being overhead at the station. At Stephenville a low overcast of stratocumulus is reported; at Argentia a near-overcast of stratocumulus is reported, but the few breaks allow the observation of cirrus as well. Sable Island lies on the warm side of the warm front and reports only cirrus clouds.

The cloud fields in the northerly latitudes of the western Atlantic contain numerous breaks, whose orientation appears to be fairly well correlated with the orientation of the surface isobars. This broken coverage extends as far south as the circulation of Hurricane Betsy. Most of the clouds in these breaks are of the low cumuliform variety.

A vast cloud sheet lies in advance of the huge open wave in the central Atlantic. The cloud population consists of low stratiform clouds, overridden by a shield of middle and high clouds. In the eastern Atlantic the edge of this dense cloud field transforms into a broken, chaotic condition. The location coincides with the ridge line. Some of this random appearance may be due to various orientations of low cloud clusters and middle or high cloud bands, all superimposed. The surface reports indicate that both varieties of clouds are present.

In the Atlantic, radiosonde data are available for Ocean Station Vessels B, C, D, I, J, and K. Ships B and I lie in the cold air associated with the parent surface low pressure center and well away from the jet stream. Both stations report low cumuliform cloud types, though overridden by middle and high clouds at Ship I. Ships C and J lie under the flow of warm moist air in advance of the open wave to the southwest. The upper winds are very strong at these stations; in fact,

the jet stream is located near Ship C. A near-overcast of low clouds is reported at Ship C while at Ship J the station reports scattered low cloud coverage and substantial amounts of middle and high clouds. The edge of this upper cloud field is seen near Ship C on the mosaic.

Ship D is located in the immediate post frontal area of Hurricane Betsy. The cold front interface is found at about the 700-mb level. A near-overcast of swelling cumulus is reported. Strong winds aloft are observed through a very deep layer.

Ship K lies in the area of ridging in the eastern Atlantic. Tropical air is found above the 750-mb level. Upper winds are fairly strong only above the 300-mb level. The station reports a small amount of swelling cumulus and moderate amounts of middle and high clouds.

The cloud field associated with the occluded frontal system over Europe is visible on the extreme northeastern portion of the viewed area. As far as is discernible, its position correlates fairly well with that of the occluded front.

The southeast sector of the high-pressure ridge off Spain is comparatively free of clouds. The mosaic shows this clearing extending through the front, presenting a rather abrupt end to the frontal cloud band near the point of occlusion. Here is an example where the surface analysis indicates the existence of a cold front through an area which the satellite pictures show to be completely inactive; almost no clouds are observed along it. This condition has also been observed in the midwest area of the United States during so-called "blue northers," which are frequently cloudless but very intense cold fronts.

The radiosonde data considered along the European coast include data from Stornoway, Aldergrove, Valentia, Camborne, Brest, Bordeaux, La Coruna, and Lisbon. Stornoway displays a sounding characteristic of polar air--the tropopause is found as low as 340 mbs. In general the air mass is fairly moist, particularly in the lower layers. Cumulonimbus is reported. The Aldergrove sounding is similar in the troposphere but has a slightly higher tropopause and a cold stratosphere. The clouds at this station are reported as cumulus topped by stratocumulus. Note the difference in the dew-point curves at Stornoway and Aldergrove. Neither of these stations show frontal evidence in the soundings.

Valentia shows strong winds above the 500-mb level. A frontal intersection is observed over the station at 600 mbs. A small amount of swelling cumulus and a moderate amount of cirrus are reported. The jet stream center is located just to the north of this station.

The Camborne, Brest, and La Coruna soundings are similar to that at Valentia. The cloud data are missing from Camborne, but Brest shows a small amount of swelling cumulus and cirrus. La Coruna shows a moderate amount of cumulus topped by stratocumulus and middle and high clouds. Bordeaux and Lisbon show no frontal evidence in the soundings, which would indicate that in this area the analysis has advanced the frontal system too far to the east.

The jet stream analysis on the western Atlantic shows that the maximum isotach area of the northernmost jet stream coincides quite closely with the clear area east of Goose Bay. A second maximum isotach area is found directly north of Hurricane Betsy. It completely transits the dense cloud shield associated with the open wave in the central Atlantic.

The southernmost jet stream extends over the frontal cloudiness between Caribou and Stephenville. In the central Atlantic, it transits quite close to the Hurricane Betsy and across the southern position of the dense cloud shield in advance of the open wave.

In the eastern Atlantic the buildup of the high-pressure ridge at the surface is reflected by a decreasing amplitude of the upper trough. The chaotic deployment of the clouds in this area does not seem to bear a clearly discernible relationship to the configuration and location of either jet stream, although some parallel alignment of the cloud fields with the upper flow is suggested on the rectification. The surface reports indicate the presence of the low cloud coverage, but the poor quality of pictures does not permit the identification of these upper clouds.

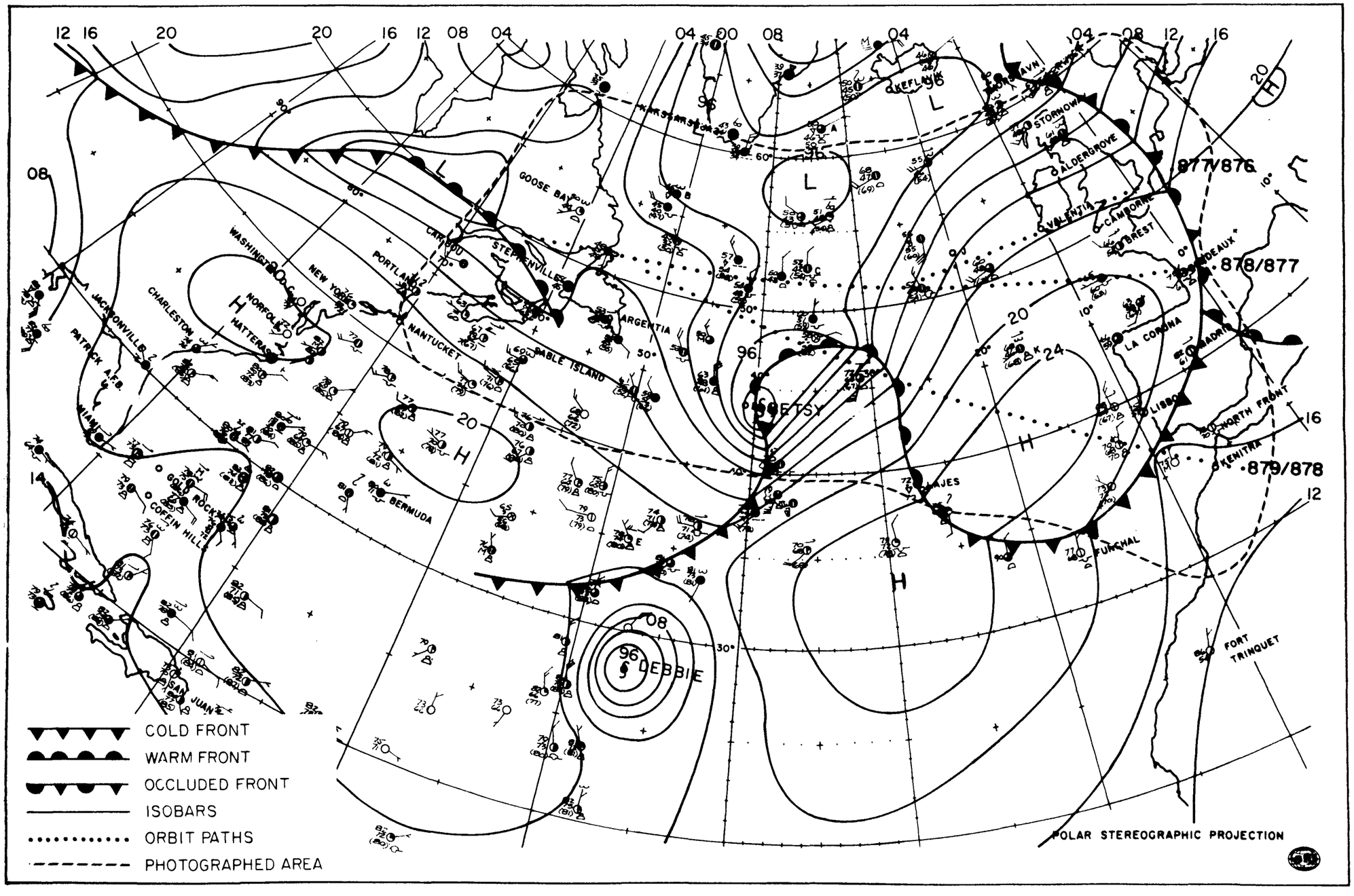

FIG. 18 SURFACE MAP, 1200GMT, 11 SEPTEMBER 1961

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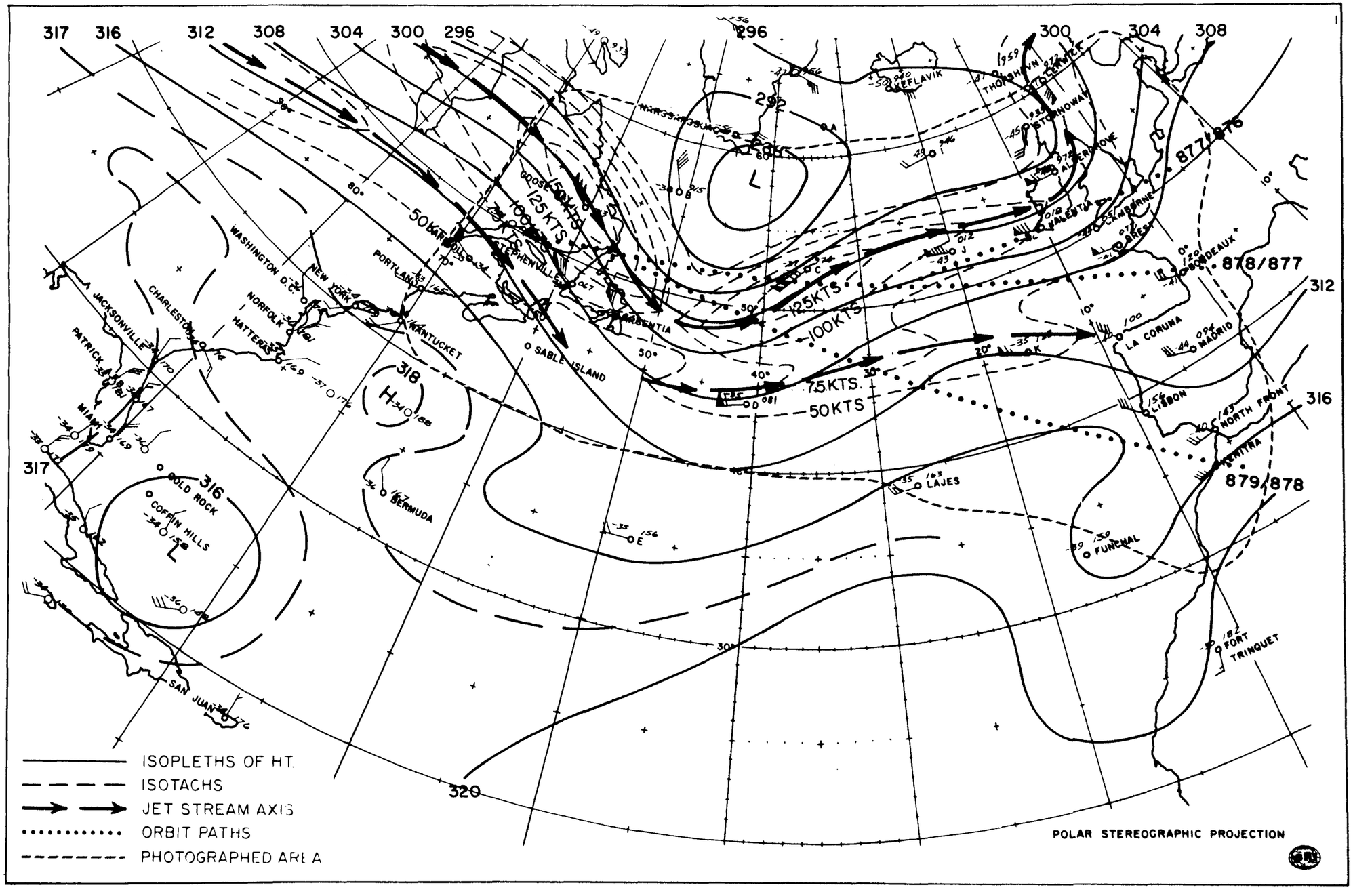

FIG. 19 300-mb MAP, 1200GMT, 11 SEPTEMBER 1961

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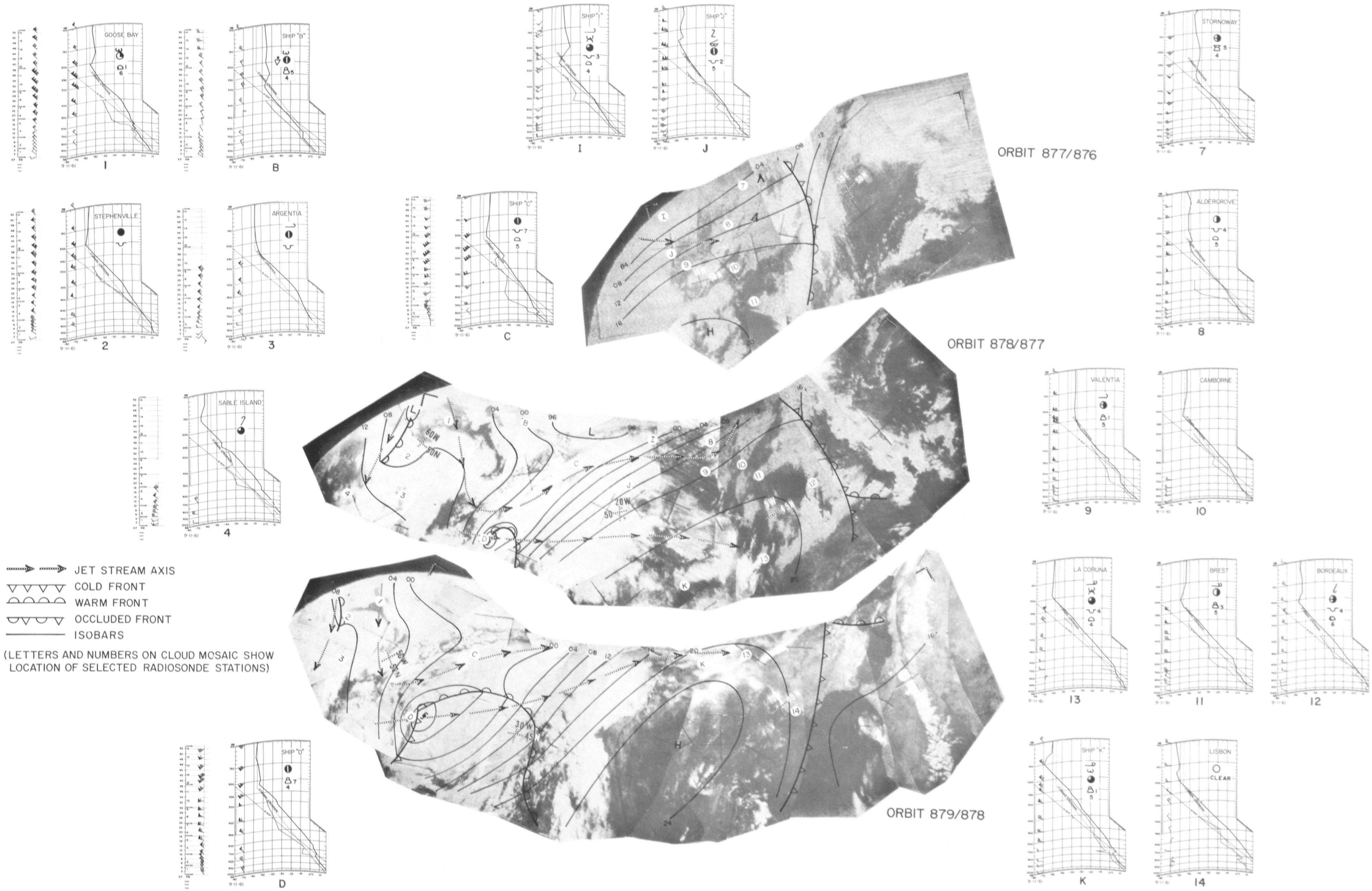

FIG. 20 CLOUD MOSAICS AND RADIOSONDE DATA FOR 1200GMT, 11 SEPTEMBER 1961

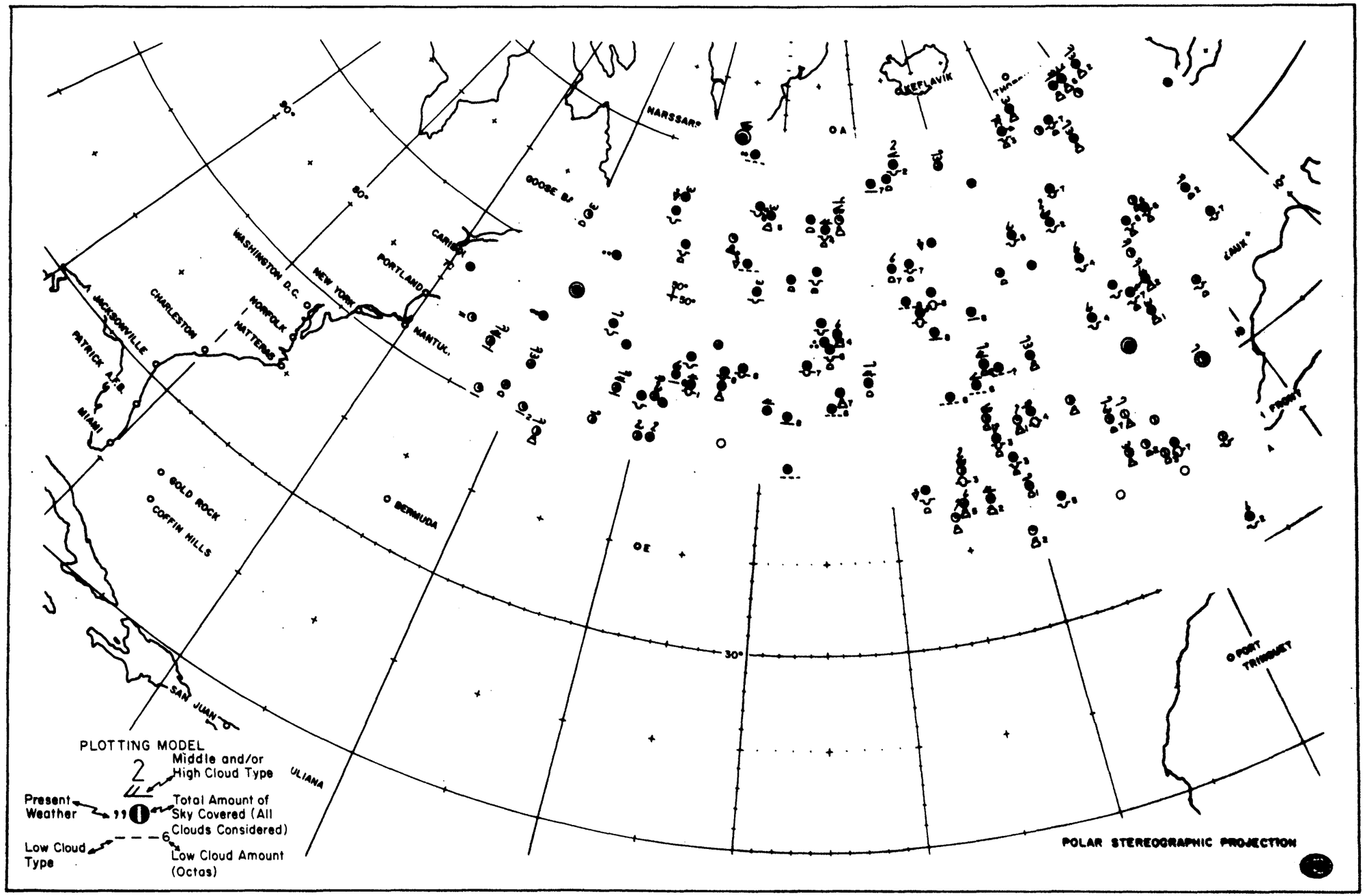

FIG. 21(a) CLOUD REPORTS FOR 1200GMT, 11 SEPTEMBER 1961

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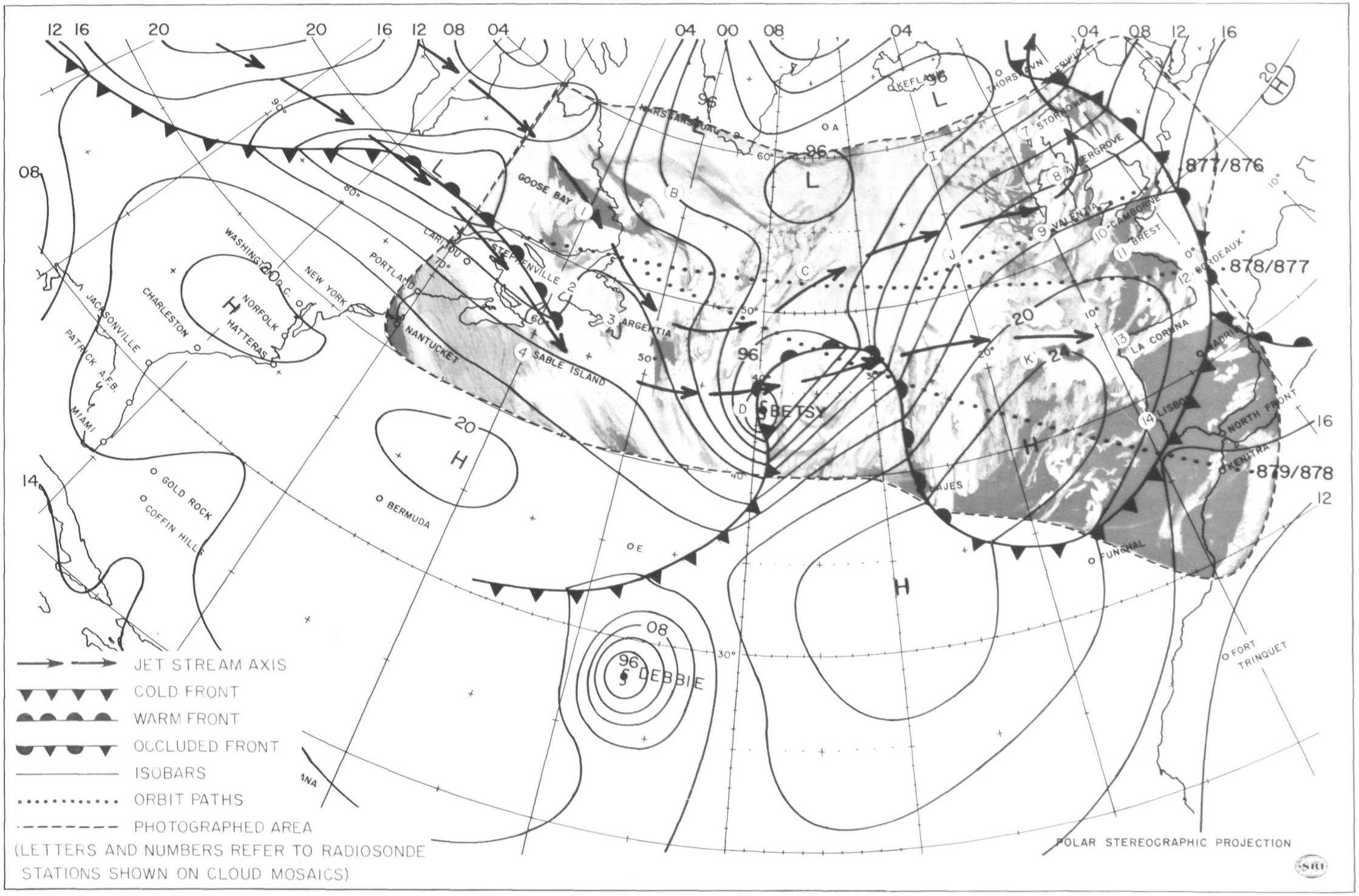

FIG. 21(b) RECTIFICATION OF CLOUD PHOTOGRAPHS FOR 1200GMT, 11 SEPTEMBER 1961

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F. 12 September 1961

The analysis of the 1200 GMT surface chart is shown in Fig. 22. The deep low-pressure cell, northwest of England, is the extra-tropical storm formed by Hurricane Betsy. Its passage under the jet stream westerlies within the past 24 hours has resulted in rapid acceleration and occlusion of the system; based on its analyzed location, it has moved approximately 1200 nautical miles in 24 hours. The associated frontal system extends southwestward to Hurricane Debbie.

A new high pressure cell is observed in eastern Canada, with a frontal system through the Maritime Provinces, culminating in an open wave in the western Atlantic.

At the 300-mb level (Fig. 23), strong westerly flow extends from Canada to the eastern Atlantic, north of the 40th parallel. Marked cyclonic circulation, which is a reflection of the deep low-pressure system at the surface, is present in the eastern Atlantic, showing a slope to the southwest with increasing altitude. Pronounced ridges are evident over Europe.

Two jet streams are analyzed across the north Atlantic. They are parallel in orientation as far as the eastern Atlantic, at which point they diverge. The maximum isotach area extends through most of the Atlantic and ends just to the east side of the upper-level cyclonic circulation.

Two orbits were utilized on this day, Orbits 892/891 and 893/892, which passed over the Atlantic at 1236 GMT and 1419 GMT, respectively. Both orbits viewed the Atlantic region north of the 40th parallel and as far westward as the Maritime Provinces. Mosaics from these orbits are given in Fig. 24. The rectification of both of these mosaics is given in Fig. 25(b).

In terms of the surface analysis, the broad expanse of cloud between Caribou and Argentia is associated with the zonally oriented frontal system in this region. Although the boudaries are ill-defined, there seems to be a spreading of the cloud field in the area of the developing wave. Surface observers (Fig. 25a) in the wave area, especially on its northeast side report low, middle, and high cloud types.

Radiosonde data in the viewed area over Canada and surroundings are available from Ocean Station Vessel B, Goose Bay, Stephenville, Argentia, and Sable Island. Of this group, Goose Bay and Ship B are located in cold air; the others are located in warm air. All stations except Sable Island report overcast low stratified clouds. Strong winds aloft are reported at Goose Bay, Stephenville, and Argentia, with Goose Bay located close to the center of the northern jet stream, and the other two stations located close to the southern jet stream center.

The dense cloud field associated with the zonally oriented frontal system through the Maritime Provinces apparently extends into the central Atlantic, as far as 30° west longitude. Radiosonde data in this area are available from Ship D, which is located at the eastern edge of the warm front as analyzed. The sounding shows a frontal intersection at about the 700-mb level, with tropical air aloft. The upper winds are quite strong, reflecting the proximity of a jet stream center to the north. Clouds at the station are shown as stratocumulus and cirrus; temperature/dew-point difference indicates the presence of considerable moisture throughout the sounding.

In the northeastern Atlantic the cloud distribution associated with the large surface cyclone has taken on a large-scale comma-like configuration. The head of the comma is located over the central part of the low, while the tail of the comma is formed by the frontal clouds south of the point of occlusion. East of the front, the pre-frontal clouds of the occluded portion extends through the weak ridge to the east, although it is relatively clear on the east side of the cold front portion. The point of occlusion is located at about the same latitude as the northern periphery of this clear area immediately downstream from the frontal clouds.

Clouds in the pressure vortex are reported as being of the low stratiform type; however, the copious amounts of rain that are being

reported in the area suggest thick layers of cloud aloft. These upper clouds are reported on the edges of the pre-frontal cloud shield, and they undoubtedly extend over the pressure vortex itself.

The post-front cloud field appears mottled and broken. In general the alignment of the cloud conglomerates is not particularly pronounced but the alignment of the very large cloud clusters seems to indicate a flow in towards the low-pressure center. Clouds in this area are mostly of the low cumuliform variety, although a few higher types are reported.

Ships C and J lie in the mottled post-frontal cloud field south of the surface cyclone. Radiosonde data from these stations show cold air in the troposphere and relatively low tropopause heights. Both stations report an overcast-with-breaks consisting of low cumuliform cloud types. The upper winds at Ship C are not given, but the wind distribution at Ship J shows the strongest winds in the lower levels, rather than at the customary jet stream altitudes. This is probably a reflection of its genesis from a hurricane.

Ship I lies in the eastern sector of the deep low-pressure system. Radiosonde data from this station confirm the presence of warm air being advected about the pressure vortex. Strong southeasterly winds are indicated from the surface to the 300-mb level. The station reports an overcast composed of low stratus and altostratus.

The analysis of the cold-front portion of the frontal system (see southwest of Ship K) places it between two elongated areas of cloud. In this area the cold front could be advanced to the east, with due regard for the surface data and, thereby, bring it into juxtaposition with the major cloud band. The cloud band to the west is perhaps a squall line or secondary front about to be caught up in the main frontal system. Ship K, which lies ahead of the front, provides the only radiosonde data in the immediate area. They show tropical air aloft and fairly moist air to the 300-mb level. The station reports an overcast-with-breaks composed of stratocumulus. Strong winds prevail from the surface to the 150-mb level.

Along the European coast, radiosonde data are available from Stornoway, Aldergrove, Valentia, Camborne, Brest, Bordeaux, La Coruna, and Lisbon. All these stations lie in advance of the frontal system in the eastern Atlantic, and all display soundings indicative of warm maritime air.

Stornoway, Aldergrove, and Camborne are located under the pre-frontal cloud shield and the dew-point trace displays near-saturated conditions throughout the soundings. All three stations report overcast coverage; Stornoway and Aldergrove report both low and middle clouds, but Camborne reports low cloud only.

Valentia is located quite close to the occluded front. Its sounding shows saturated conditions below the 750-mb level but rather dry air aloft. A very low stratus overcast is reported by the station.

Brest and Bordeaux lie in advance of the warm front but in the area of higher surface pressures. Both of these stations report cirrus clouds. In addition, Bordeaux reports middle clouds. The mosaic has a filmy appearance in this area, which is probably these upper clouds. Brest shows a sparse amount of swelling cumulus.

La Coruna and Lisbon are located in the warm sector, well away from frontal influence. The area around these stations appears clear on the mosaic. Lisbon reports clear skies and La Coruna a very small amount of low clouds.

A comparison of the cloud deployment with the jet stream analysis shows that in the western Atlantic the jet stream complex parallels the orientation of the frontal cloud band. The northern jet stream skirts the northern periphery of the cloud band, while the southern jet stream passes over it. In the eastern Atlantic, both jet streams lie in the area between the cloud mass in the pressure vortex and the frontal cloud band to the southeast. The jet streams diverge east of the low center near the northern penetration of the area of partial clearing behind the frontal system (see area just west of Valentia).

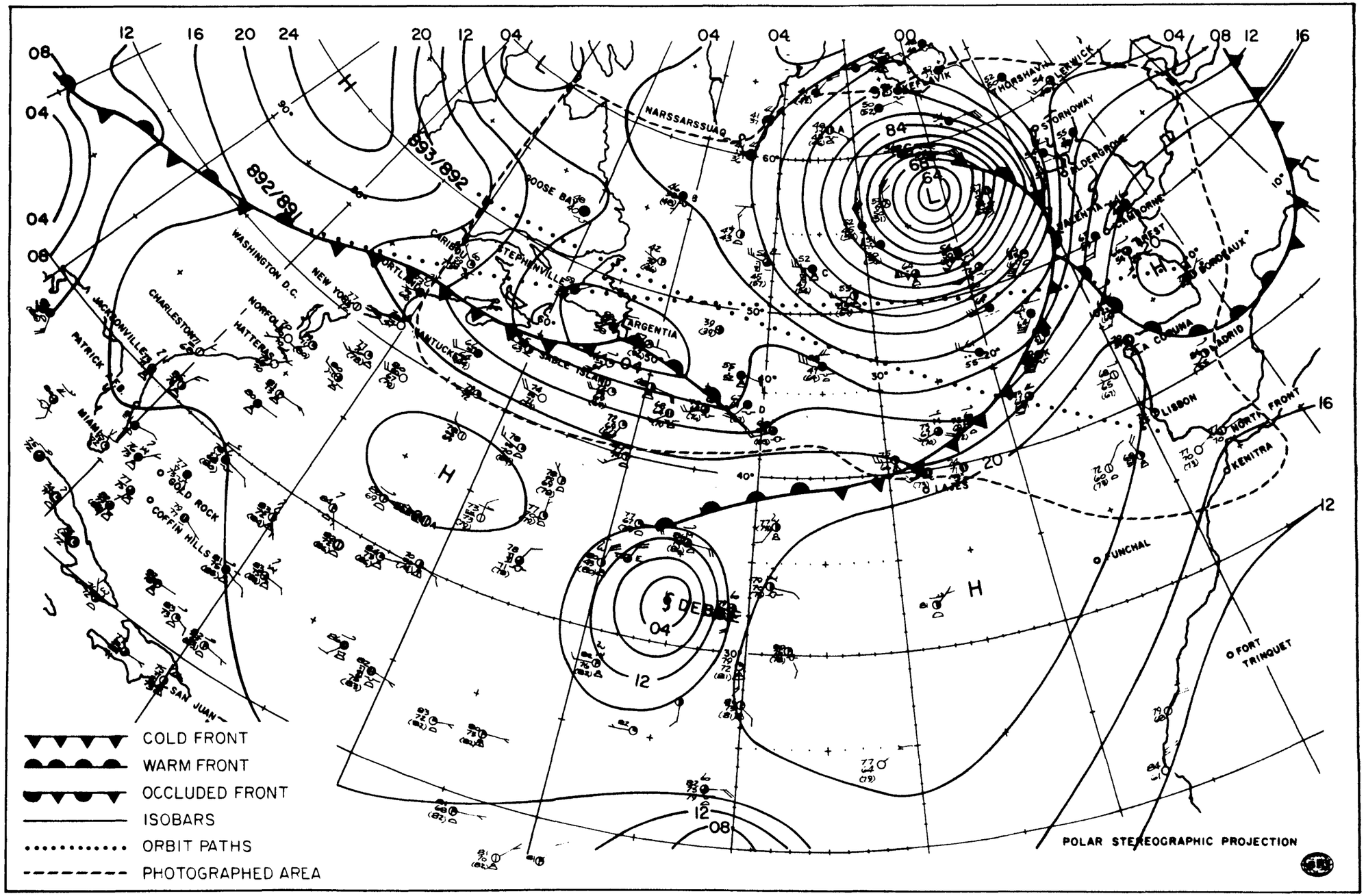

FIG. 22 SURFACE MAP, 1200GMT, 12 SEPTEMBER 1961

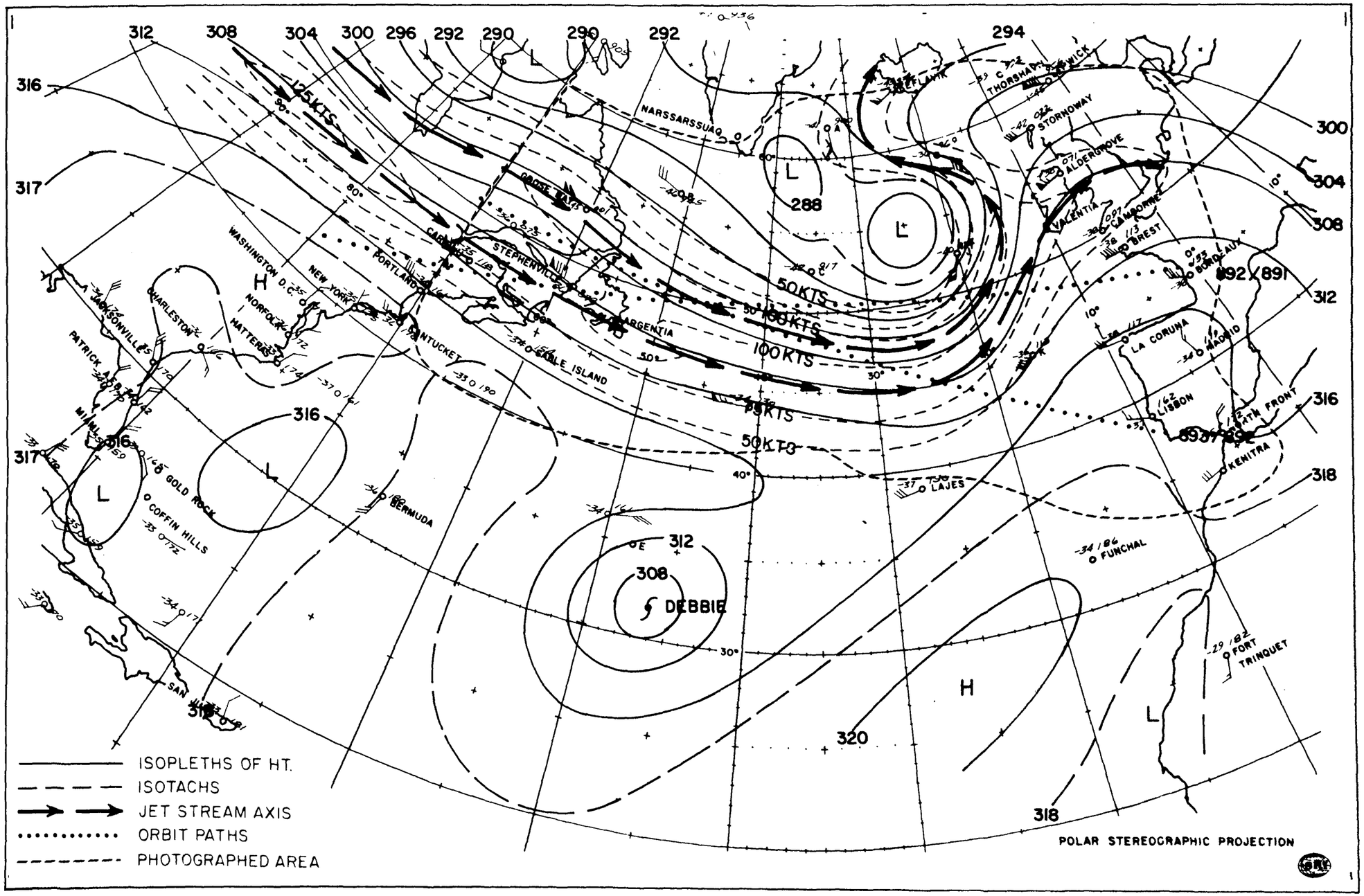

FIG. 23 300-mb MAP, 1200GMT, 12 SEPTEMBER 1961

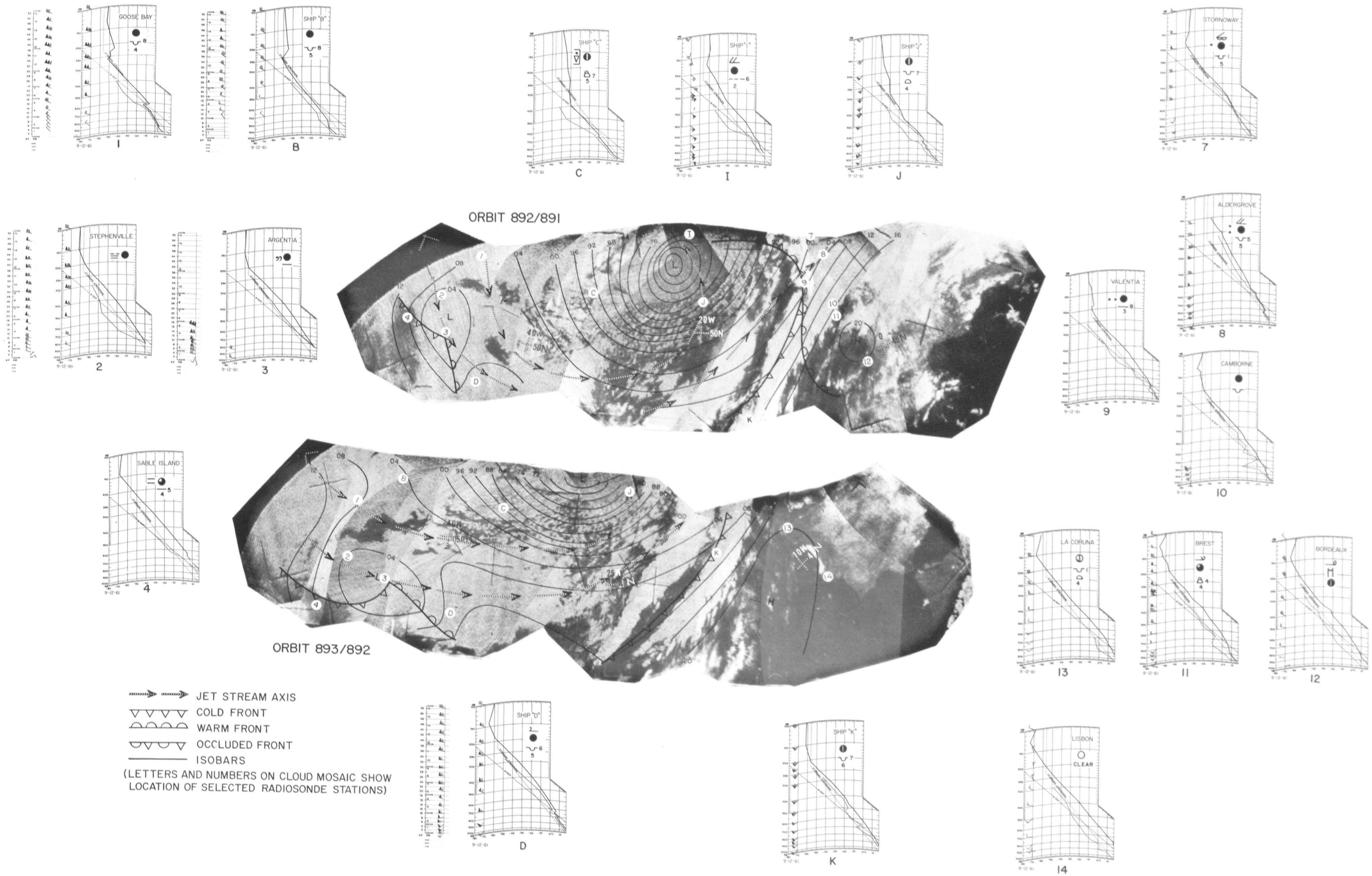

FIG. 24 CLOUD MOSAICS AND RADIOSONDE DATA FOR 1200GMT, 12 SEPTEMBER 1961

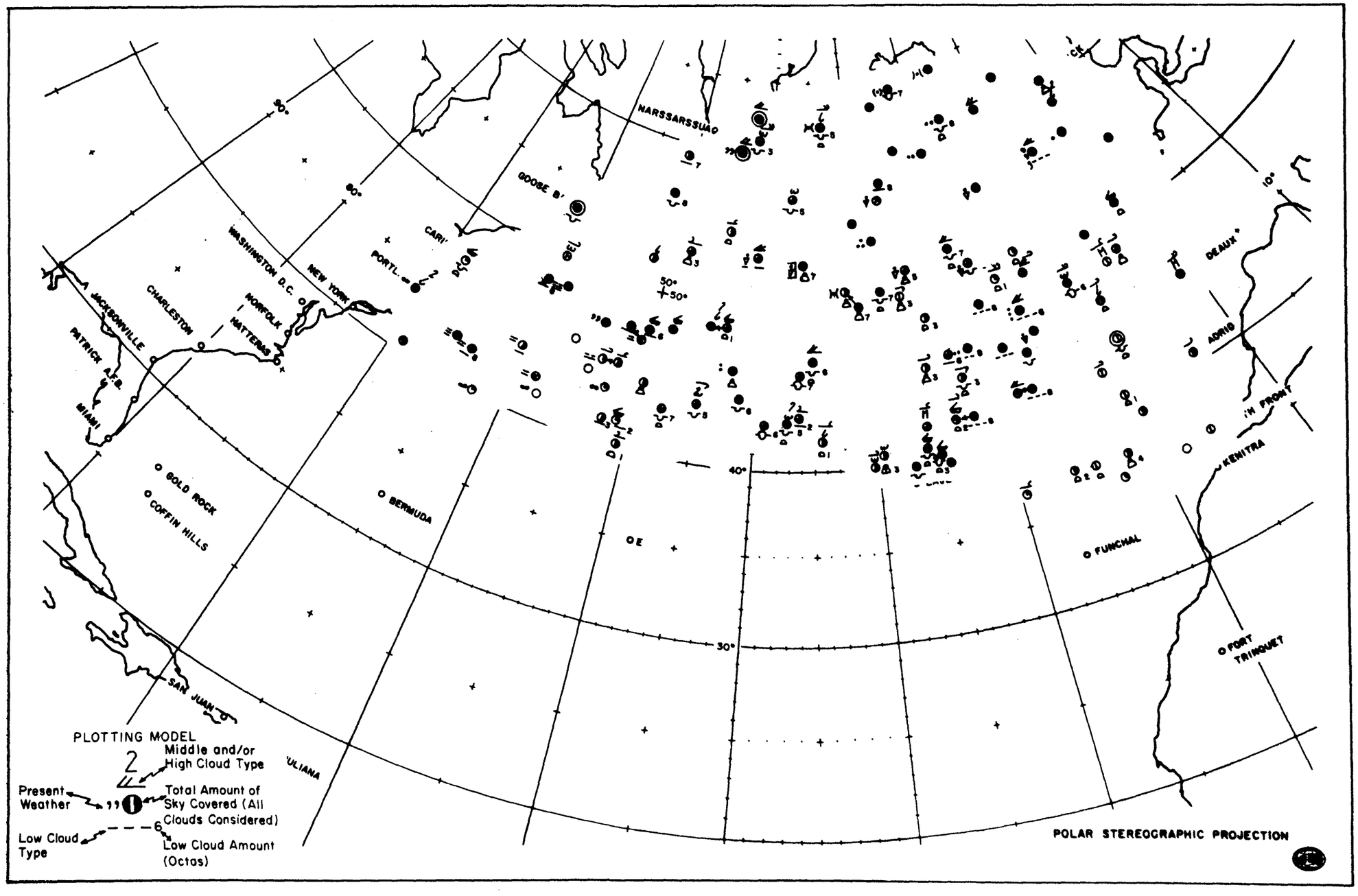

FIG.25(a) CLOUD REPORTS FOR 1200GMT, 12 SEPTEMBER 1961

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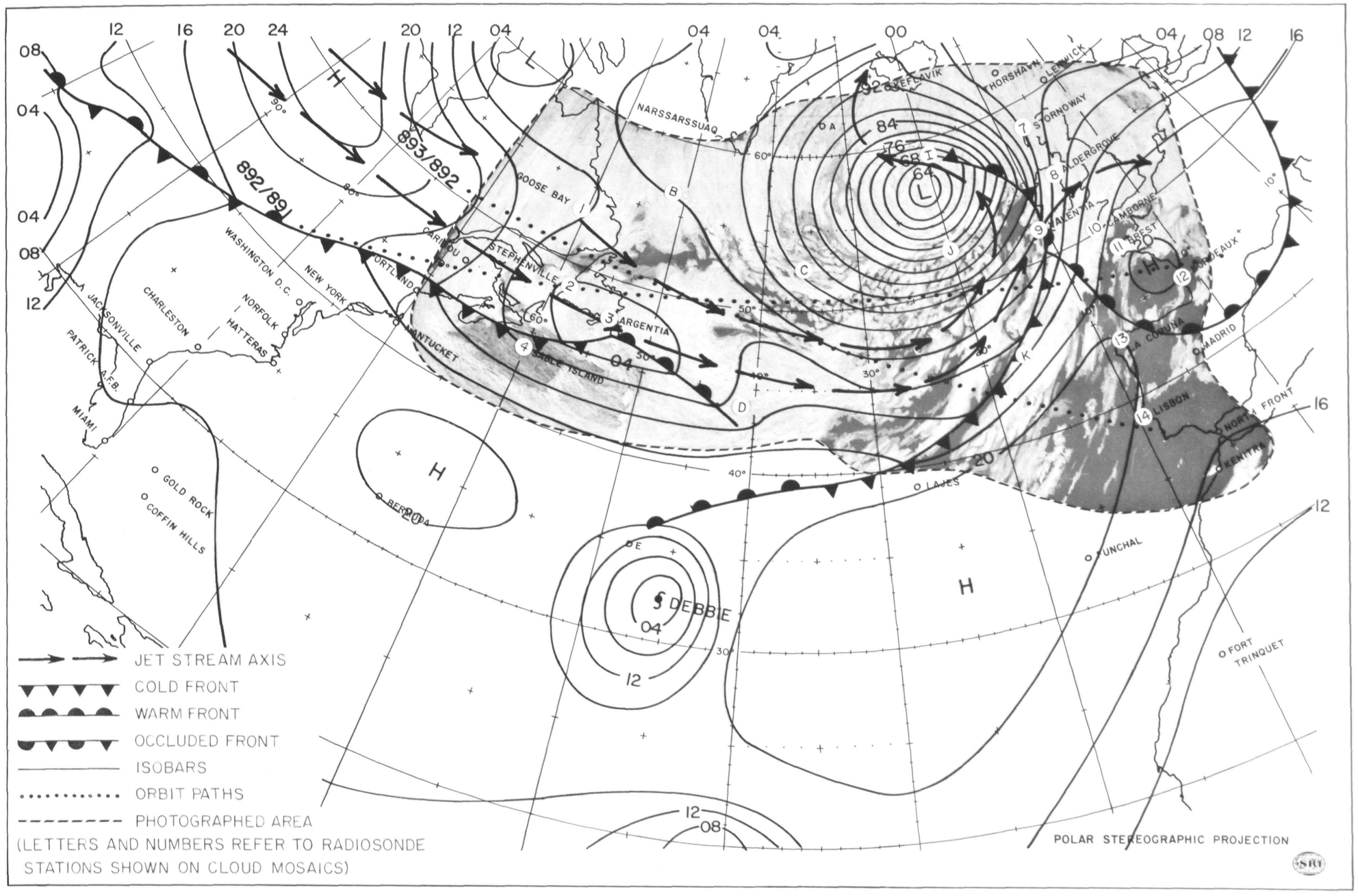

FIG. 25 (b) RECTIFICATION OF CLOUD PHOTOGRAPHS FOR 1200GMT, 12 SEPTEMBER 1961

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G. 13 September 1961

The analysis of the surface map (Fig. 26) is fairly similar to that of the previous day. On this date, however, the frontal system extends completely across the Atlantic, just north of the 40th parallel. The high-pressure cell over Canada has moved eastward slightly and a small low has developed east of the Maritime Provinces, with wave action on the front just to the east of the low. The main low-pressure cell in the eastern Atlantic remains intense and has moved northward. Hurricanes Debbie and Esther are observed in the southern latitudes. Two subtropical high cells are delineated, both fairly weak in intensity. Over the North Atlantic the pressure gradient between the main low near Iceland and the high cell over Canada is quite weak, which presages a readjustment of the wave length between the pressure centers and a development of a more meridional wave pattern.

At the 300-mb level (Fig. 27) the maps show strong zonal westerlies in the mid-latitudes, extending from central North America to England. The deep low at the surface is reflected in a closed cyclonic circulation at the 300-mb level. Weak troughing is present in the western Atlantic.

Two jet streams are analyzed across the Atlantic in rather close proximity. These jet streams diverge east of the closed cyclonic circulation.

Two orbits were utilized on this day, Orbits 906/905 and 907/906, whose orbit times were 1203 GMT and 1344 GMT, respectively. These orbits provide observation of the Atlantic north of the 40th parallel. In the eastern Atlantic, Orbit 906/905 views an area considerably north of Orbit 907/906. Mosaics from these orbits are shown in Fig. 28. The rectification of both of these mosaics is given in Fig. 29(b).

Considered over-all, the cloud pattern presents a picture of rather extensive coverage over most of the Atlantic. The dense cloud field surrounding the Maritime Provinces, however, may not be directly associated with a surface front as it was in previous instances. On this day the breaks in the clouds southeast of Goose Bay could be induced by offshore flow and orographic effects and, in fact, breaks in the cloud cover in this area have been noticed on several of the previous charts in this series under conditions of offshore flow.

Radiosonde stations within the field of view in the western Atlantic region include OSV B, Goose, Bay, Stephenville, Argentia, and Sable Island. Of these, OSV B and Goose Bay lie in the cold air north of the jet stream complex. The tropopauses at these stations are found at the 300-mb and 460-mb levels, respectively. Upper winds are weak over OSV B. The influence of the jet stream, which lies south of Goose Bay, is observed in the wind distribution over this station. Goose Bay reports an overcast with breaks consisting of scattered low cumuliform clouds and altostratus and cirrus clouds. OSV B reports an overcast-with-breaks comprised of cumulus congestus.

Stephenville, Argentia, and Sable Island show much warmer temperatures. At Stephenville and Argentia the tropopause is located at the 250-mb level; at Sable Island, it is at 140 mbs. Though no front is analyzed through the area, a definite change of air mass does exist between these stations and Goose Bay to the north. The poor picture quality and the high nadir angles involved mask any configuration in the cloud field that could be interpreted as frontal. Very strong winds aloft are observed at Stephenville and Argentia, due to the proximity of the jet stream complex.

The open wave in the central Atlantic lies in a field of extensive cloud cover. Analysis of the surface data indicates a closed low to the west and a minor trough (20°W longitude) to the east of this wave. The cloud pictures about the small closed low are indistinct but do show a broadening of the cloud field to the right of the minor trough, which could be interpreted to mean that a second open wave exists in this minor trough.

Ships D and K are located in this dense cloud field just discussed. Radiosonde data indicate tropical air overhead at both of these stations. Ship K reports a small stable layer near the surface,

which could delineate a frontal interface. The height of the interface would require the front to be closer to the station than presently analyzed. Strong winds are reported in the upper levels at both stations but much stronger at Ship K. Both stations report broken coverage of low stratocumulus along with upper clouds.

To the north, only a portion of the dense cloud field associated with the deep low-pressure system south of Iceland is visible on the mosaics and the rectification. The outer portion of the pressure vortex (roughly along the 960-mb contour) is occupied by a cloud field of broken coverage, the individual elements of which are cellular in shape. Surface reports of cumuliform clouds are prevalent in this area.

Ships C and J lie within this broken cloud field. Radiosonde data from both stations indicate the presence of cold air, with the tropopause at about the 300-mb levels. Although scattered cumuliform clouds are indicated by both stations, Ship C also reports middle clouds. The upper wind sounding shows fairly moderate speeds.

Ship I is located quite close to the barometric center within the denser cloud coverage. It reports an overcast-with-breaks comprised of cumulonimbus. Radiosonde data from this station show that it too, lies in cold air, though somewhat warmer than the air at Ship J. The tropopause is found at the 250-mb level. Moisture extends through a very deep layer. The winds aloft are fairly strong in the low levels, diminishing above.

The occlusion in western Europe is far removed from the barometric vortex and lies out of the area of view of the satellite. Clouds along the cold front portion of the system, however, are visible from western France southwestward through La Coruna. In its southern portion the cold front lies through a clear area between two dense cloud fields. Possibly two frontal systems are involved here; the cold front stemming from the occluded system could be advanced somewhat to bring it into juxtaposition with the elongated cloud field off Spain, and a second frontal system could account for the dense cloud field around Ship K.

Along the European and African coasts, the radiosonde stations of Stornoway, Aldergrove and Valentia lie on the low-pressure side of the jet stream complex towards the center of the pressure vortex. All the tropopause levels are located at the 300-mb level or below. Reference to the mosaic shows that these stations lie in the broken cloud field surrounding the pressure vortex, which agrees with their reports of rather sparse coverage of cumulonimbus and cirrus. The wind speeds aloft at these stations vary in direct relation to their proximity to the jet stream complex.

Camborne is located under the jet stream complex; very strong winds are reported near the tropopause at the 250-mb level. The temperature/dew-point spread shows fairly moist air in the lower and upper levels. An overcast, comprised of cumulus congestus, altocumulus and cirrus is reported at the station.

La Coruna and Brest lie between the cold front and the jet stream complex under a canopy of heavy cloud cover. Brest reports an overcast-with-breaks of low cumuliform clouds; La Coruna reports broken low cumuliform with middle and high clouds visible. Both soundings show fairly moist air to about the 300-mb level. Their tropopause is located at or above the 200-mb level. Although the upper wind reports are missing above the 400-mb level, wind speeds at both stations are shown to be fairly strong as low as the 700-mb level.

Bordeaux, Lisbon, and Kenitra are situated well south of the Polar jet stream complex. Troposphere temperatures are warm and the tropopause is found at 150 mbs. These stations lie well ahead of the cold front and report sparse cloud coverage.

In the western Atlantic the jet stream complex follows the band of dense cloud that stretches eastward from the Maritime Provinces. In the eastern Atlantic the most southerly jet stream, except for a small segment near England, is situated over the dense band, the

northerly jet stream extends across the broken cloud field, toward its southern edge. These broken cloud lines (which contrast primarily of low cloud types) follow a trajectory more closely approximating the surface flow than the 300-mb flow.

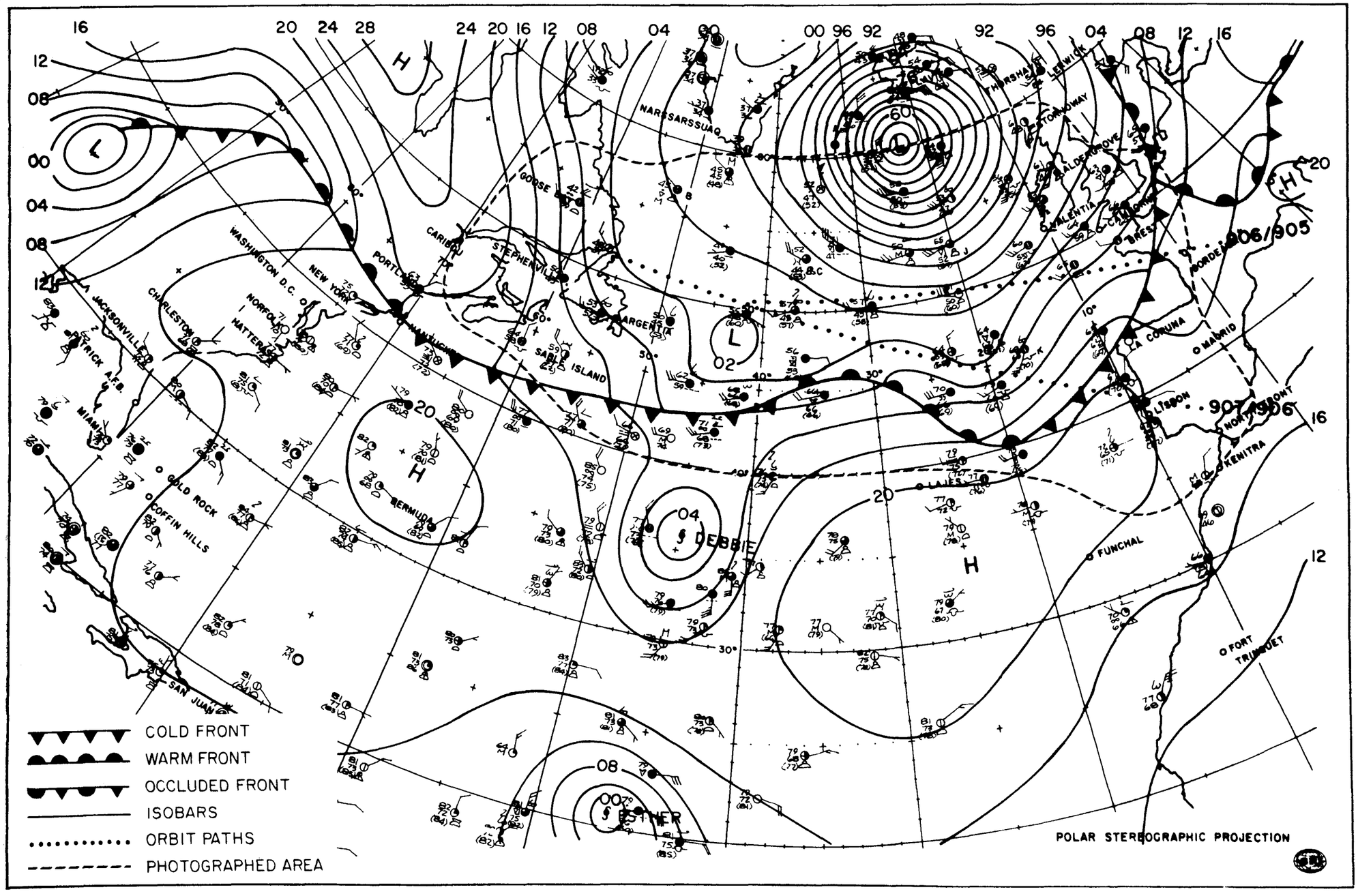

FIG. 26 SURFACE MAP, 1200GMT, 13 SEPTEMBER 1961

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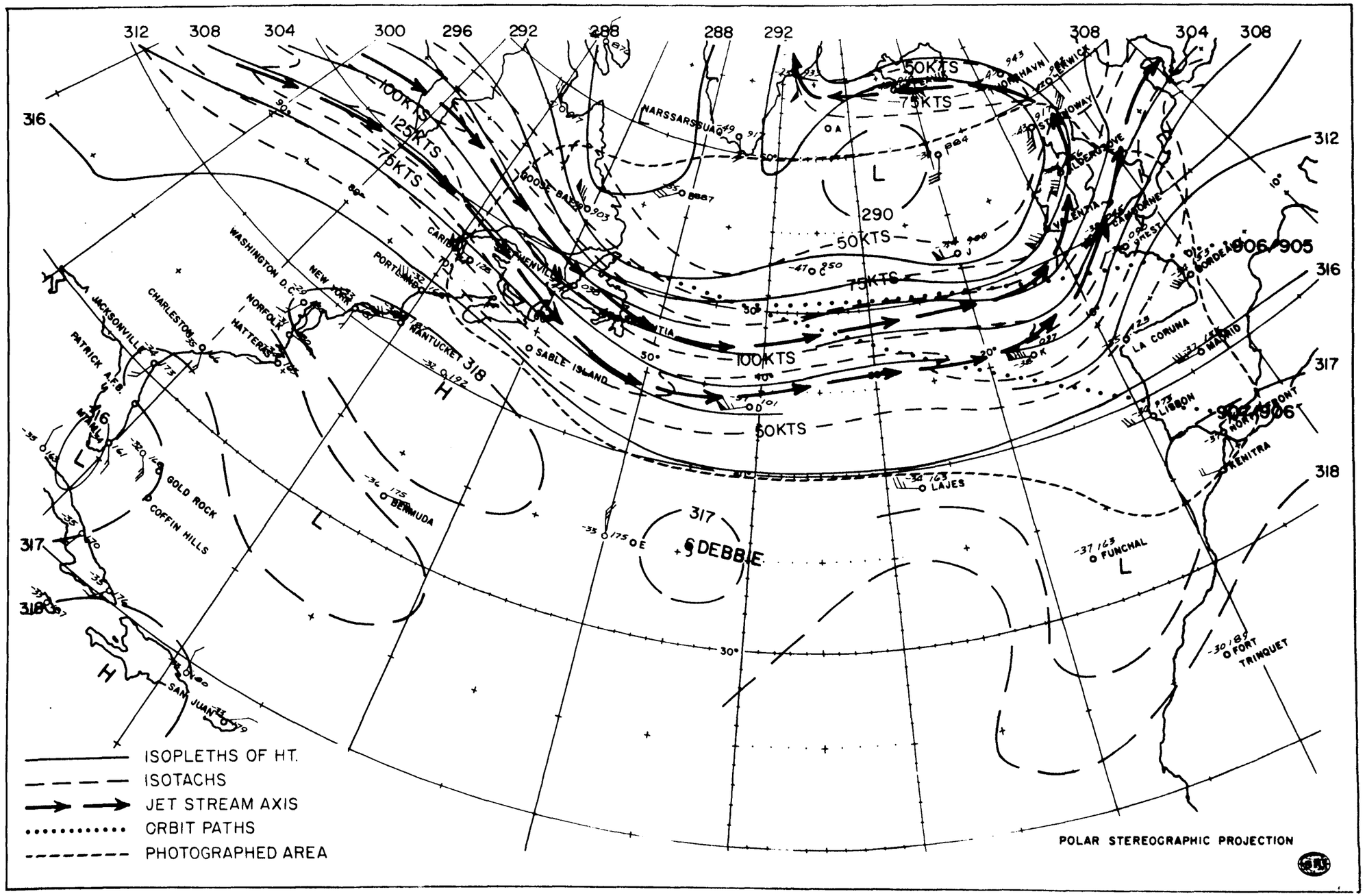

FIG. 27 300-mb MAP, 1200GMT, 13 SEPTEMBER 1961

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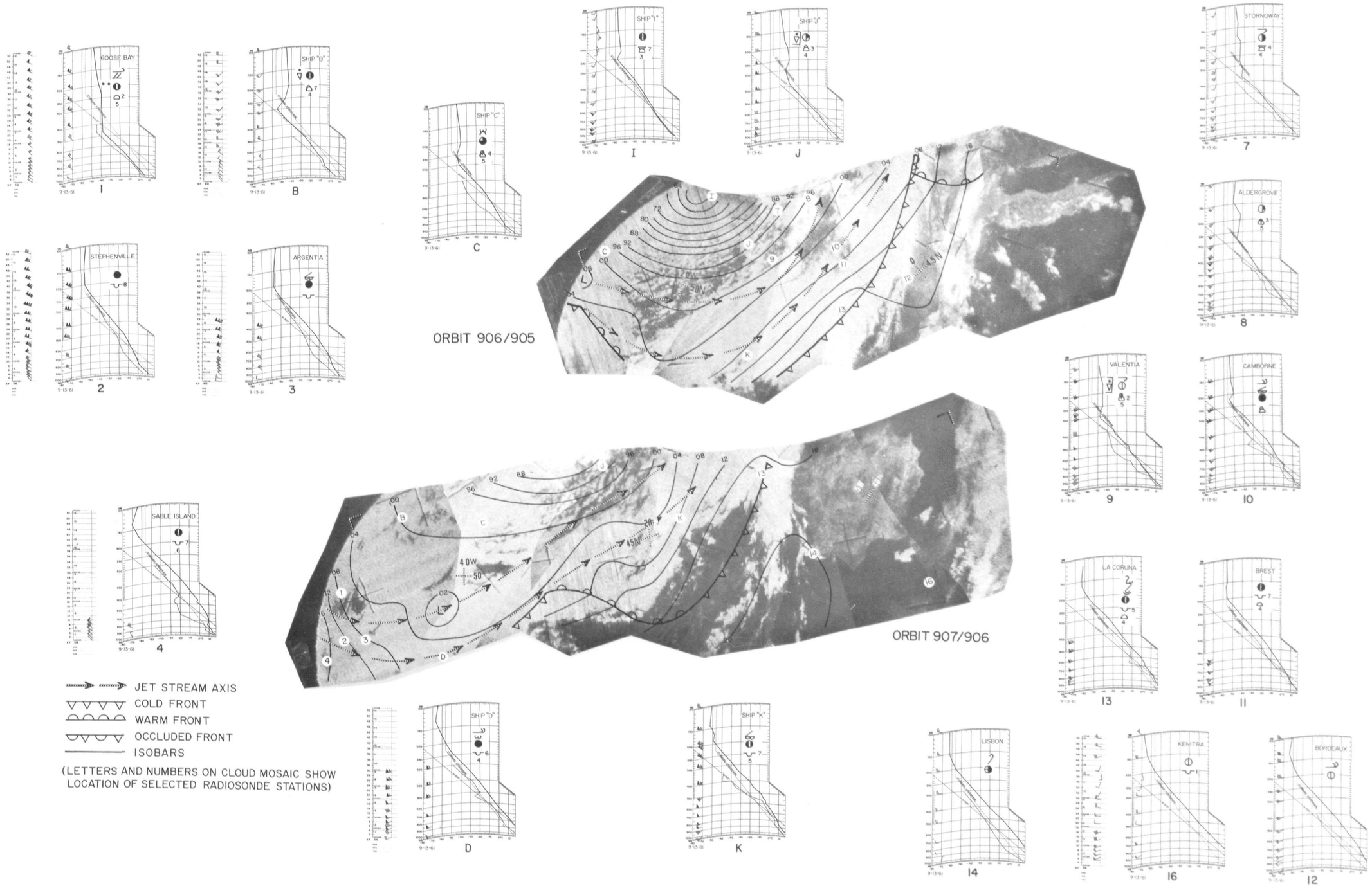

FIG.28 CLOUD MOSAICS AND RADIOSONDE DATA FOR 1200GMT, 13 SEPTEMBER 1961

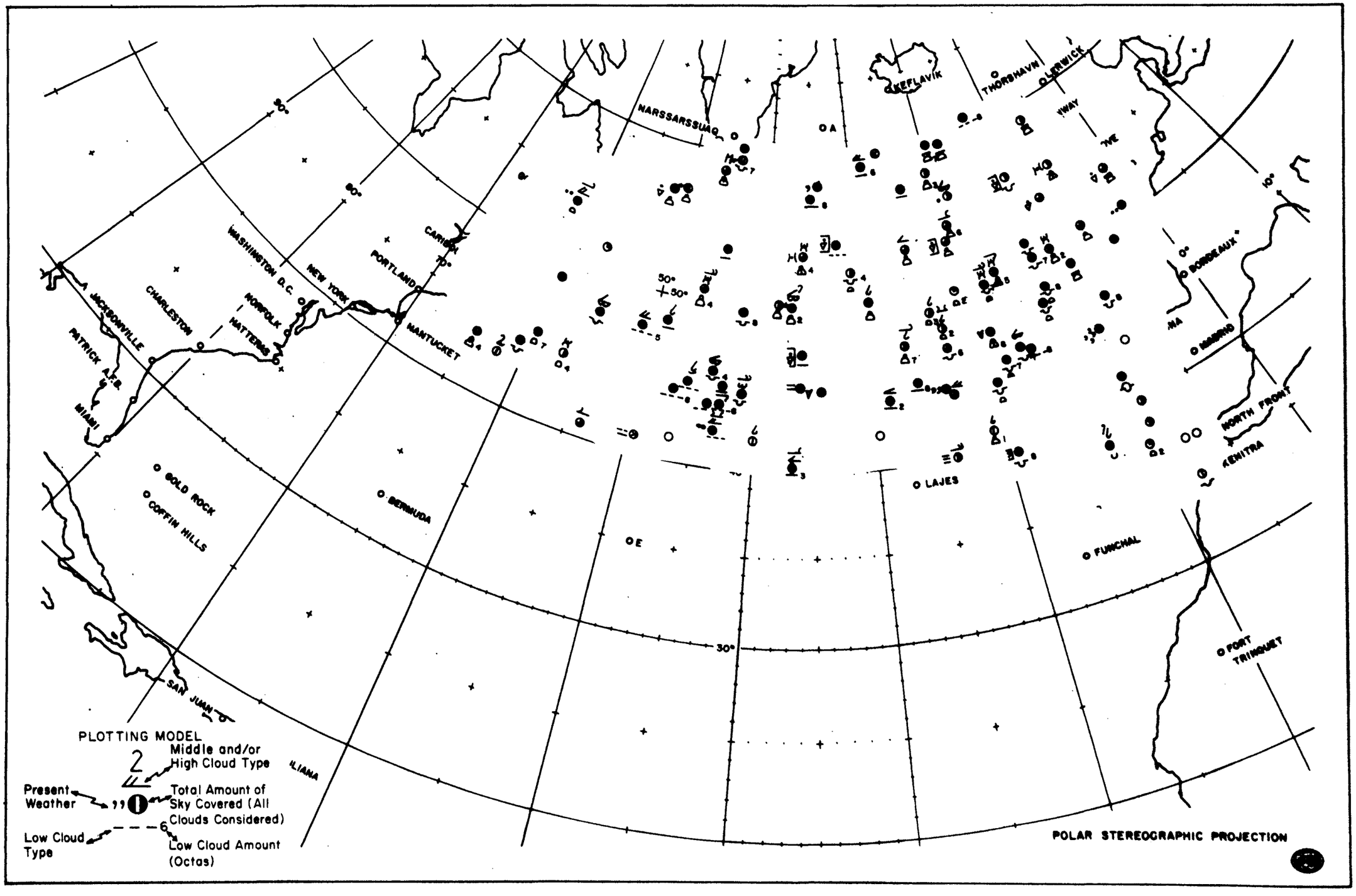

FIG.29(a) CLOUD REPORTS FOR 1200GMT, 13 SEPTEMBER 1961

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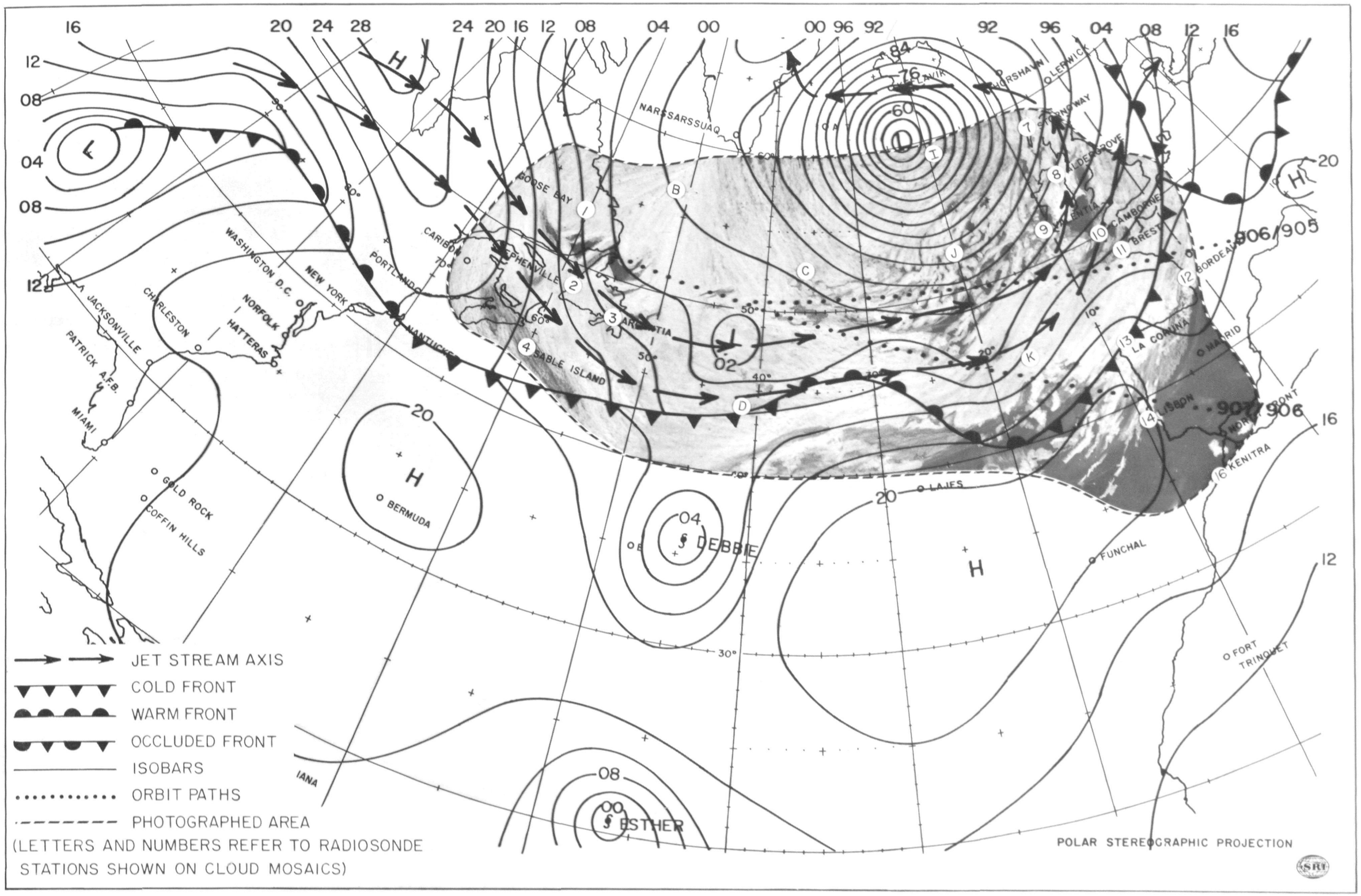

FIG. 29 (b) RECTIFICATION OF CLOUD PHOTOGRAPHS FOR 1200GMT, 13 SEPTEMBER 1961

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H. 14 September 1961

The analysis of the 1200 GMT surface chart is shown in Fig. 30. The wave system in eastern Canada has undergone considerable deepening in the past 24 hours. Hurricane Debbie has been captured by the mid-latitude flow along the principal frontal system across the Atlantic. The wave, seen previously on this latter frontal system, has occluded south of the old deep low center, creating a very pronounced meridional flow pattern. Concomitantly the subtropical high pressure cells have assumed a more north-south orientation, particularly the Bermuda anticyclone.

At the 300-mb level (Fig. 31) a long wave trough is beginning to deepen in the central Atlantic, with the closed circulation and trough line positioned to the west of the low pressure centers at the surface. Two jet streams are analyzed in the strong westerly flow over the Atlantic. Over the western and central portion of the Atlantic these jet streams lie rather parallel to one another but diverge in the eastern Atlantic. The northern jet stream follows the circulation around the low aloft, while the southern jet stream moves eastward across the newly developed occlusion and on into Europe.

Two orbits were utilized on this date, Orbits 921/920 and 922/921, which passed over the area at 1312 GMT and 1455 GMT, respectively. On this day the orbital paths have changed to more of a northwest-southeast orientation over the Atlantic. Mosaics of the pictures taken on these orbits are shown in Fig. 32. Rectification of these mosaics to a polar stereographic chart is shown in Fig. 33(b). In general the mosaic and rectification show extensive cloud cover north of the 40th parallel and a relatively broken cloud field to the south, except in the area of Hurricane Debbie.

The cloud cover about the Maritime Provinces appears as a continuous, featureless sheet on the mosaics. Stations in the southern portion report rain and an overcast sky condition consisting of low, middle and/or high clouds [Fig. 33(a)]. This cloud field is probably associated with the frontal system to the south. Stations in the northern portion have less-solid coverage, particularly around Goose Bay, consisting of low and middle clouds. Because of the high nadir angle, the satellite pictures do not clearly distinguish these less-covered areas.

The clear area east of Goose Bay is believed to be resulting from offshore flow from the continental area. Broken cloud cover which extends to the center of Hurricane Debbie, is occurring on the eastern side of the ridge.

The radiosonde stations on the western portion of the rectification include OSV B, Goose Bay, Stephenville, Argentia, and Sable Island. A perusal of the radiosonde data from these stations indicates two distinct types of air mass regimes. Ship B lies in the cold air, well north of the jet stream regime. Its tropopause is found at 300 mbs, with a decidedly warm stratosphere. The dew-point trace indicates the presence of moisture to the 400-mb level and the station reports an overcast-with-breaks comprised of stratocumulus and altocumulus.

Goose Bay, Stephenville, and Argentia are located under the jet stream complex, with extremely strong winds prevailing above the 400-mb level. All three stations have a tropopause near the 150-mb level. In the troposphere, however, there is a marked difference in the sounding at Goose Bay, compared with those at Stephenville and Argentia. At Goose Bay cold air is found below the frontal intersection at 350 mbs; at Stephenville and Argentia, this cold air is found below the frontal intersection near the 500-mb level. The air at Goose Bay is moist only below the 700-mb level; partial cloud coverage of stratocumulus and altocumulus is reported. At Stephenville the sounding is fairly moist up to the 200-mb level; overcast conditions of stratocumulus and altocumulus are reported. Argentia shows cumulonimbus, altocumulus, and cirrus. Sable Island lies south of the jet stream complex. The tropopause is very high, characteristic of tropical air above the 850-mb level. Overcast conditions of the stratocumulus are reported.

A broken, striated cloud field is located in the southwest sector of the main cyclonic circulation (see between OSV C and OSV D). The orientation of these lanes of striations is almost perpendicular to the orientation of the isobars. A secondary cold front may be present in this area, according to the synoptic data. This secondary cold front has been discussed on the previous day as possibly having been in existence near Goose Bay. Extrapolation would place it in the area of the leading edge of the breaks. These breaks would then signify a local change of air mass, accompanied by a wind shift.

Ocean Station Vessels C and D, which are located to the north and south of these breaks, respectively, present radiosonde data on this day. The radiosonde of Ship C shows rather cold air with a low tropopause height (300 mbs). That of Ship D shows warm air throughout the sounding above the 300-mb level, with the tropopause at 150 mbs. There is a stable layer between 500 and 400 mbs, which could be the interface of the front shown to the south on the map. The air above the 800-mb level is still very warm, compared to the same levels at Ship C. The stable layer at 800 mbs could be the interface of a cold front which has just passed Ship D. The upper winds at Ship D reflect the influence of the jet stream complex; Ship D reports an overcast sky comprised of scattered stratocumulus with cirrus. Ship C, in the cold air, reports a broken coverage of cumulus congestus with altocumulus and cirrus.

A widespread zone of cloudiness extends from Hurricane Debbie northeastward to the pressure vortex center and east of the occluded system. This cloud field appears as a continuous, essentially featureless, sheet on the mosaic. Surface reports in the area however, indicate that several layers of clouds make up this cloud sheet.

Radiosonde data are available from OSV K, Camborne, Brest, Bordeaux, and La Coruna, which lie at the southern edge of this cloud sheet and in advance of the warm front. The soundings at all of these stations exhibit a more or less similar lapse rate regime in the middle troposphere, with a tropopause at 200 mbs or higher. Camborne, Brest, and La Coruna report a distinct frontal inversion in the lower layers, stemming from the surface frontal system to the south. The satellite photographs in the La Coruna area show that few clouds are distributed along the weakened front, despite the overcast coverage at La Coruna itself, reported by the surface observer.

South of the warm front there are radiosonde data from Lajes Acores, Azores Is., Funchal, Madeira Is., and Lisbon. Soundings from these stations are of the type characteristic of tropical air. Weak upper wind speeds prevail. This area is populated by cloud bands and cells, typical of cumuliform development, located principally within the surface high pressure cell. The configuration of these bands is definitely curvilinear. The 300-mb chart indicates that cyclonic circulation prevails over this area aloft.

A comparison of the jet stream complex with the cloud patterns shows that the northernmost jet stream in the jet stream complex crosses the clear areas east of Goose Bay and extends through the center of the broken cloud field at the base of the trough aloft. The southernmost jet stream passes over fairly dense cloud cover across the entire Atlantic.

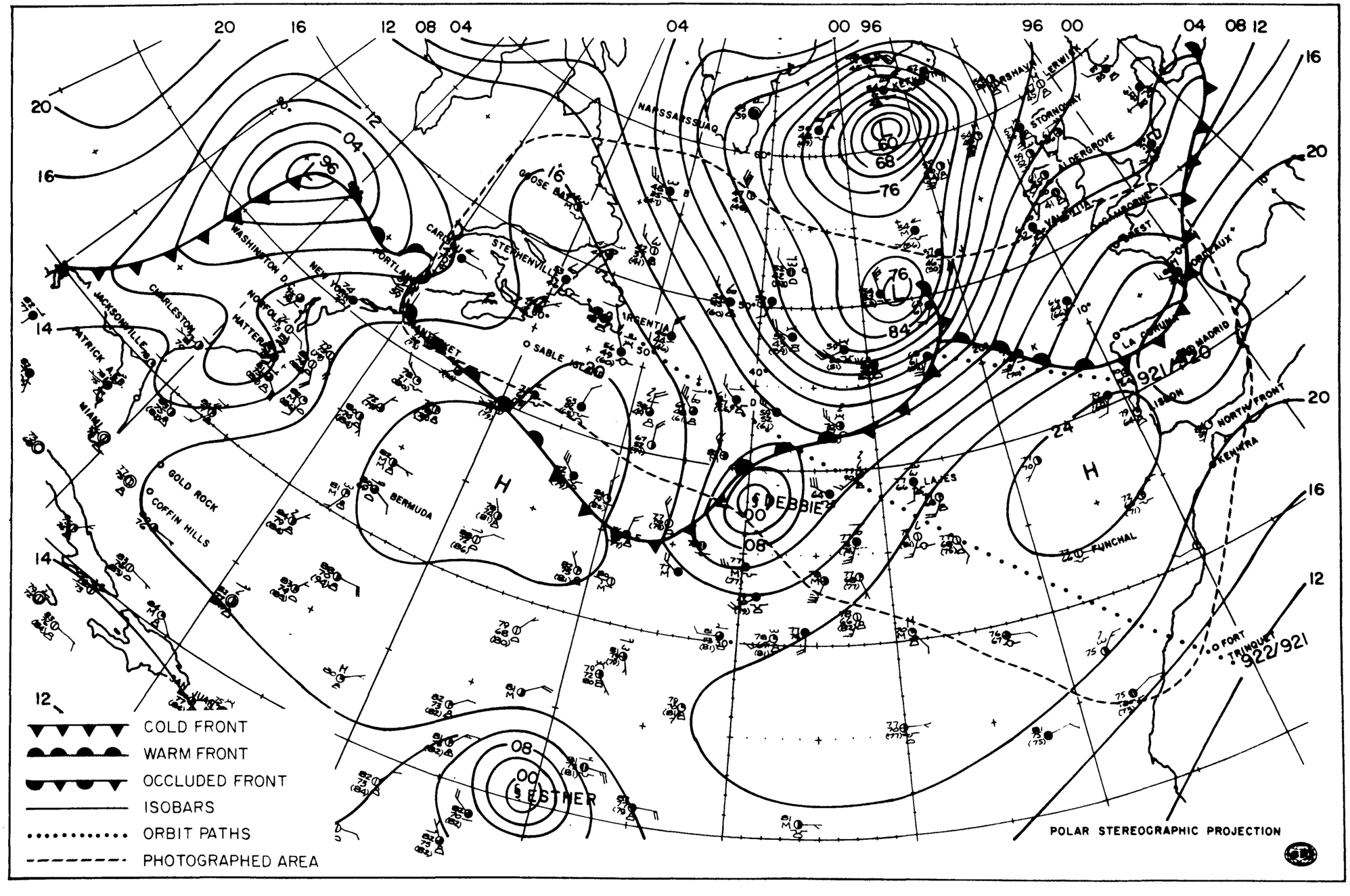

FIG. 30 SURFACE MAP, 1200GMT, 14 SEPTEMBER 1961

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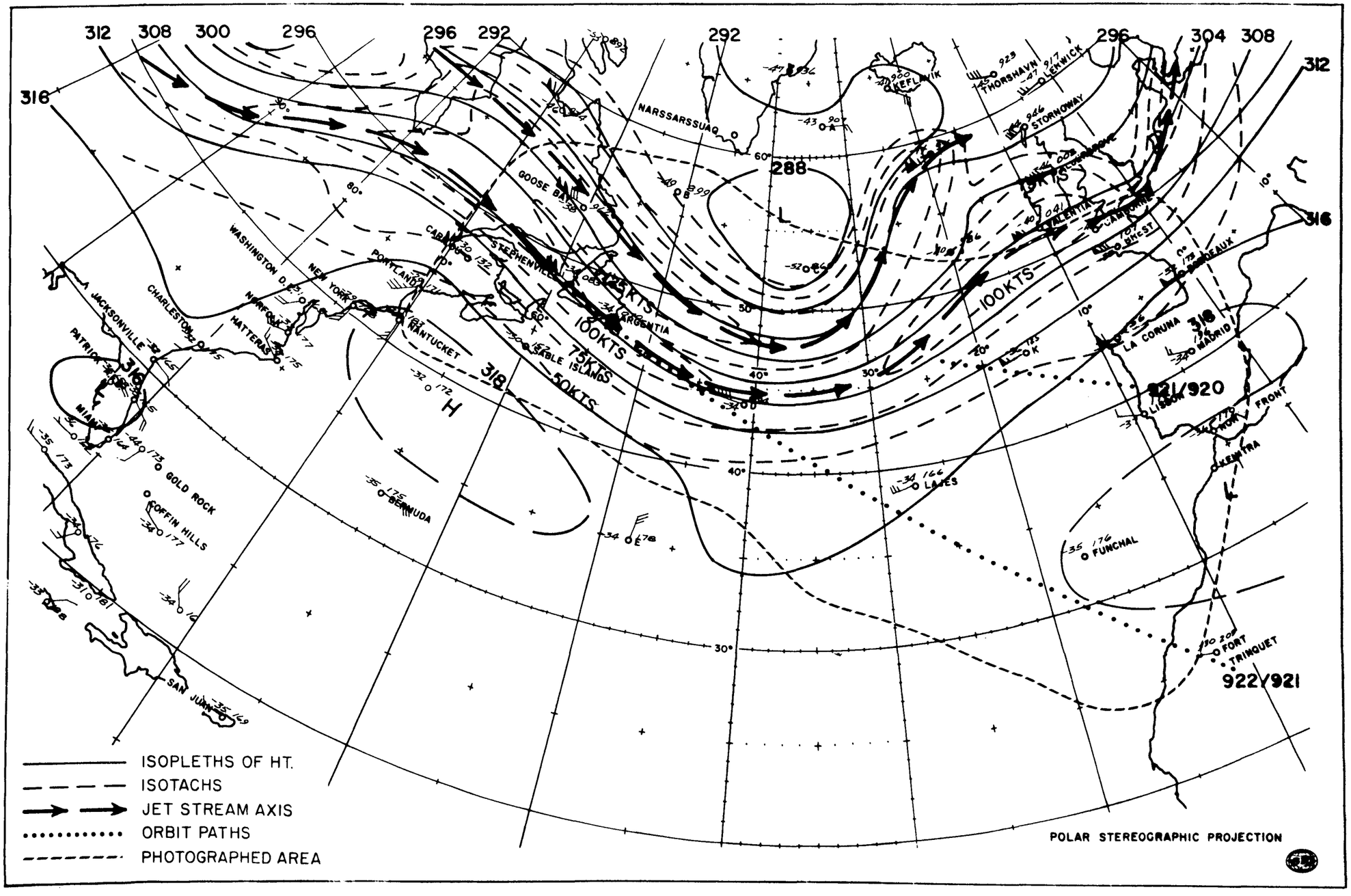

FIG. 31 300-mb MAP, 1200GMT, 14 SEPTEMBER 1961.

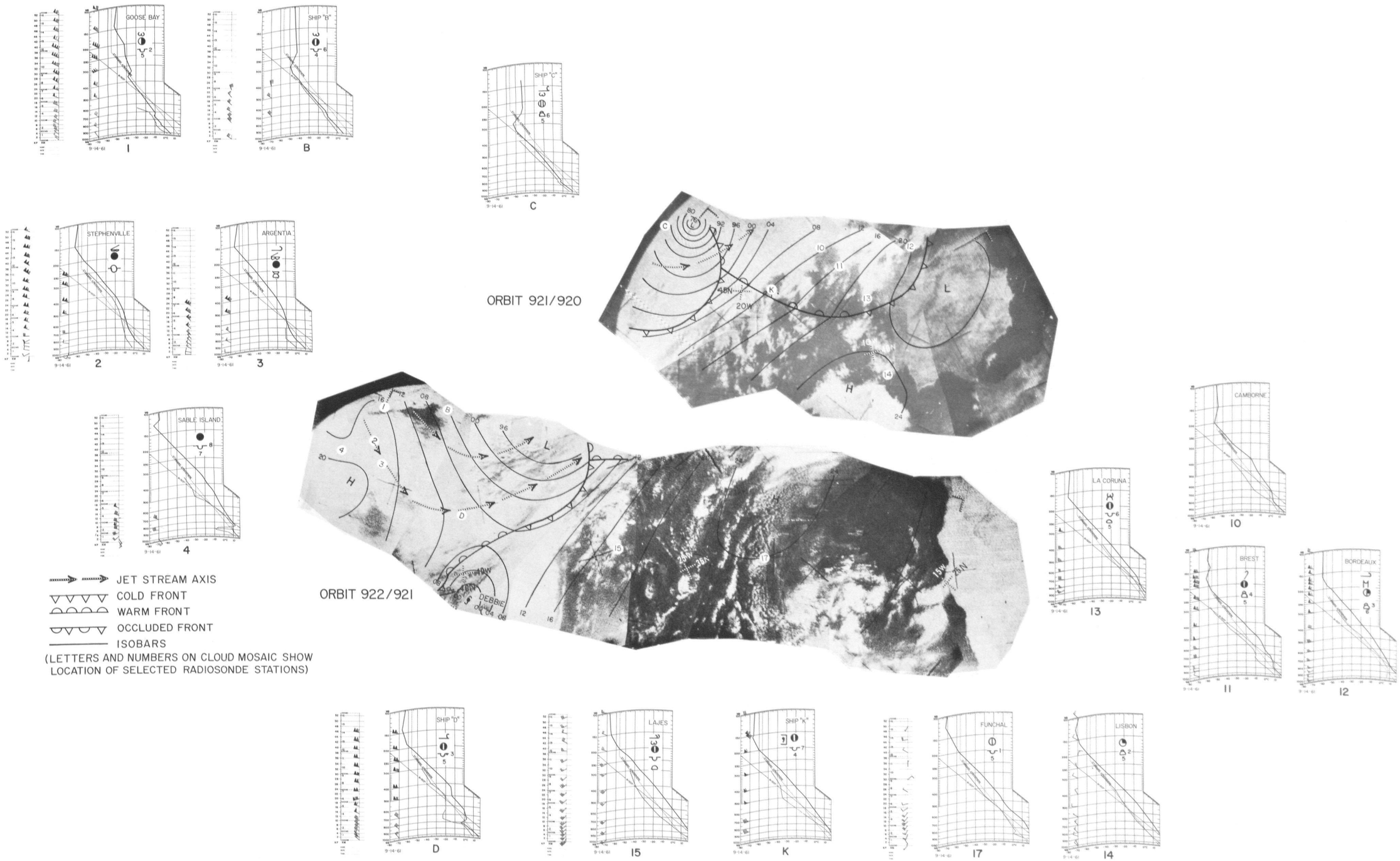

FIG. 32 CLOUD MOSAICS AND RADIOSONDE DATA FOR 1200GMT, 14 SEPTEMBER 1961

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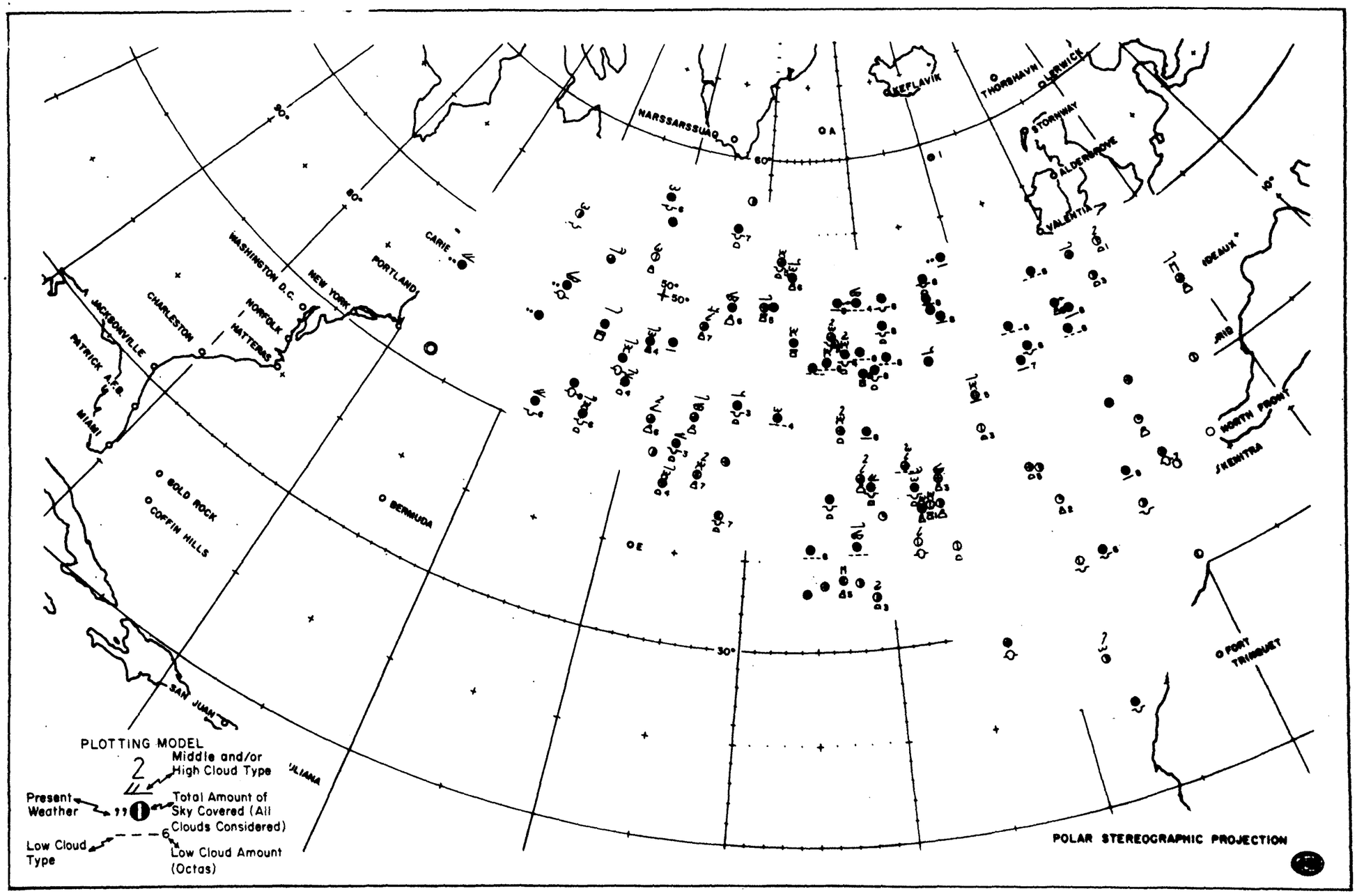

FIG.33(a) CLOUD REPORTS FOR 1200GMT, 14 SEPTEMBER 1961

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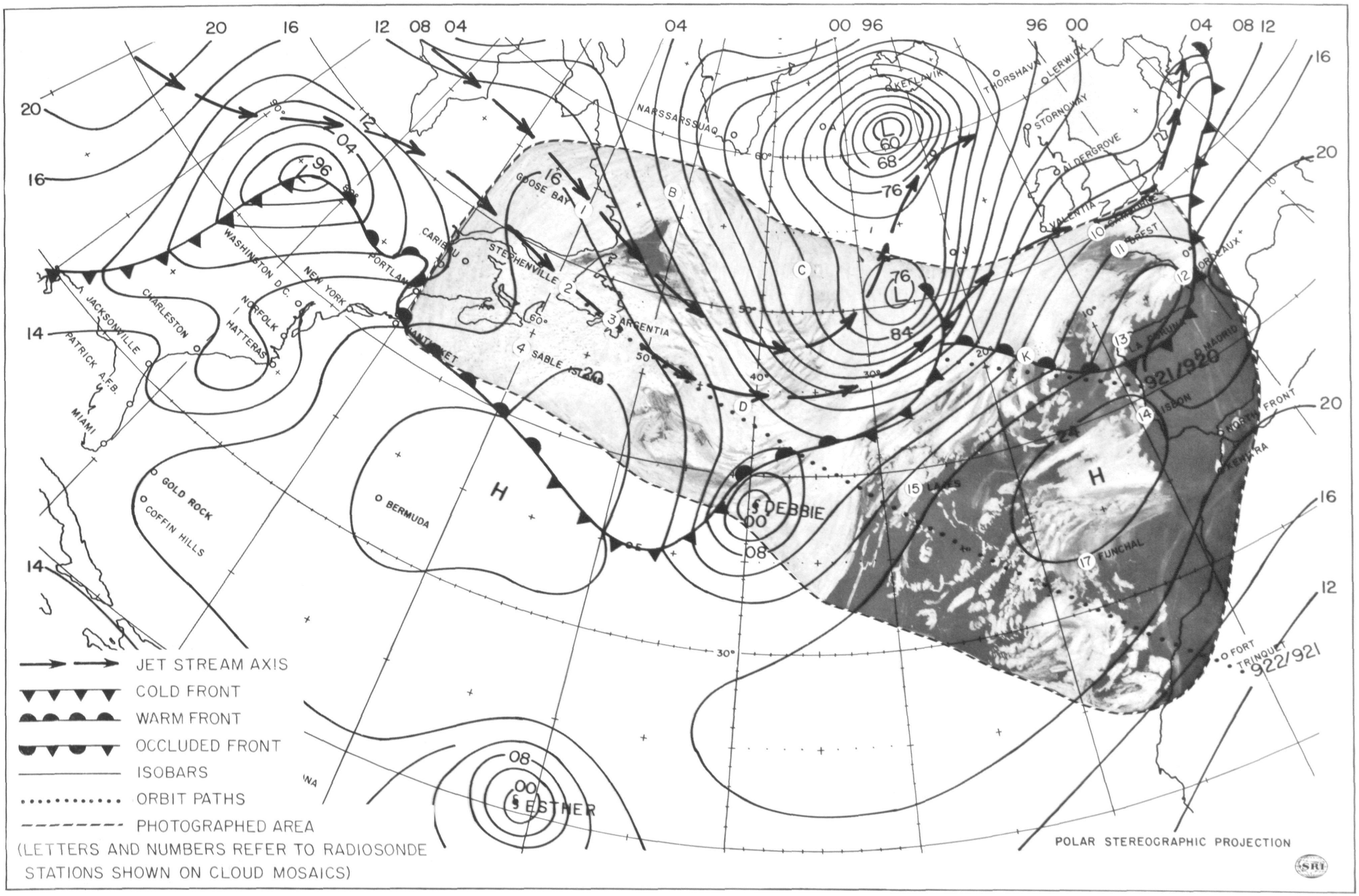

FIG. 33 (b) RECTIFICATION OF CLOUD PHOTOGRAPHS FOR 1200GMT, 14 SEPTEMBER 1961

I. 15 September 1961

The analysis of the 1200 GMT surface chart (Fig. 34) shows that by this date the trend toward a meridional circulation is quite advanced. In the eastern Atlantic, the parent cyclone has deepened and moved northward to the vicinity of Iceland. The occluded system associated with this low has advanced to the North Sea. An open wave is observed along this frontal system near the latitude of Spain. The low-pressure area accompanying this open wave is the remnant of Hurricane Debbie.

Considerable ridging is apparent in the western Atlantic, resulting from the intensification and eastward progression of the high pressure cell in that area. A large-scale occluding wave system is located on the western periphery of this ridge. The anticyclone, seen off Africa 24 hours previously, has collapsed.

At the 300-mb level (Fig. 35), a long wave trough has progressed to the eastern Atlantic where, 24 hours before, a ridge was present. This trough lies to the west of the surface low centers. A ridge of considerable amplitude is located over the eastern Atlantic and European area.

In the western Atlantic, the intensification of the surface ridging is reflected by a corresponding change in the amplitude of the upper flow.

The analysis indicates two jet streams, in rather close proximity, extending from Canada to Europe. A maximum isotach area penetrates through the long wave trough.

Two orbits were utilized on this date, Orbits 935/934 and 936/935, which passed over the Atlantic at 1231 GMT and 1419 GMT, respectively. Their orbital paths after passing off Canada are markedly different and, as a consequence, the pictures observe the same area only in the western Atlantic. Mosaics from these orbits are shown in Fig. 36; the rectification of both of these mosaics is given on a polar stereographic map as Fig. 37(b).

The cloud patterns on this date present a very clear-cut example of the difference between frontal and air mass cloud distributions. For example, dense cloud field in the western Atlantic is associated with the occluding frontal system in that area. Extensive coverage is evident within the warm sector and in the pre-frontal region. The eastern edge of this frontal cloud band ends rather abruptly along the surface ridge line, leaving a fairly cloud-free area just downstream from the surface ridge.

Radiosonde stations under view in the western Atlantic region include OSV B, Goose Bay, Stephenville, Argentia, Sable Island, Nantucket, and OSV D. Goose Bay, Stephenville, and Argentia lie under the pre-frontal cloud shield. Overcast cloud coverage is reported at all three stations. Upper clouds are reported at Stephenville and, judging by the distribution of moisture, are present at Goose Bay and Argentia, as well. The tropopause is found at high altitudes due to the influx of warm air. Strong winds aloft are indicated at Goose Bay, reflecting the presence of the jet stream complex.

Sable Island and Nantucket lie in the warm sector. The upper air soundings show warm tropical air, although the degree of moisture varies at these stations. Sable Island is relatively dry with partial cloud cover reported; Nantucket reports an overcast of stratus. The soundings however, show moisture through a deep layer.

Ocean Station Vessels B and D are located along the ridge line ahead of the frontal system. Both of these stations lie at the western periphery of the extensive broken cloud field in the central Atlantic. At Ship B, the surface report indicates a sparse cover of cumulus cloud. Moisture is confined to the layer below the 900-mb level. The tropopause is located at the 160-mb level, though there is a change toward stability in the lapse rate as low as the 250-mb level. Upper winds are very strong at this station, reflecting the proximity of the jet stream complex.

At Ship D, the overrunning warm air ahead of the frontal system is found above the top of the frontal surface near the 600-mb level.

Cumuliform low clouds and cirriform clouds are reported. The upper wind sounding shows that the strongest wind speeds are concentrated in a very narrow layer, just above the frontal surface near the 600-mb level. The cloud field around Ship D displays striations that are oriented parallel with the wind flow; clouds in the area are reported as cumuliform low clouds, together with cirrus.

A broken cloud field is found throughout the entire central Atlantic, though not always striated in appearance. Although surface reports in the post-frontal area indicate this region to be occupied by low cumuliform clouds that range from stratocumulus to cumulonimbus, some high and middle clouds are also reported.

Radiosonde data are available from OSV J and from Lajes Acores, which are located in this post-frontal broken cloud field. Although the sounding at OSV C is missing at this time, the station reports an overcast-with-breaks, comprised of low cumuliform clouds. Ship J is located at the base of the cyclonic circulation associated with the parent low-pressure cell, and on the immediate cold side of the jet stream complex. It reports a partial coverage consisting of cumulus and cirrus on the horizon. The sounding is typical of modified cold air (tropopause at the 250-mb level). Winds aloft at this station are rather strong, particularly at the tropopause.

In the southern portion of the viewed area in the central Atlantic the cloud elements become larger and appear to align themselves in a large-scale semicircular band of dense cloud. This cloud banding is associated with a "secondary" front, or is a reflection of the shallowness of the extensive cold air dome, probably the latter. Lajes Acores is located in this area of cloudiness. The radiosonde data from this station are incomplete in the lower layers; the stability evidenced below the 700-mb level might connote a frontal interface stemming from the cold front to the east, or it may be due to subsidence. The remainder of the sounding is in tropical air and the tropopause is seen near the 150-mb level. Moderate wind speeds are indicated above the 700-mb level, in keeping with the location of this station south of the jet stream complex. An overcast-with-breaks is reported, consisting of cumulus and stratocumulus, although cirrus is also reported.

The dense cloud band in the eastern Atlantic is well correlated with the analyzed position of the frontal system in this area; wave development along this front, however, is not reflected in a unique cloud-field disposition that can be seen on these pictures. The warm front portion of the open wave is embedded within the cloud field; along the cold front south of the open wave, the cloud mass lies in advance of the front.

Radiosonde data are available from Valentia, which lies in the dense cloud field on the cold side of the frontal system through England. In its sounding, the intersection of the front over the station is seen at the 700-mb level. Aloft, a stabilizing lapse rate change is noted between 400 and 300 mbs, with the tropopause at 200 mbs. The sounding is moist (almost near saturation) at all levels, and an overcast of stratus is reported. Judging from the depth of the moisture, this cloudiness is probably present to very great heights. Although no upper wind data were reported, wind speeds are undoubtedly strong, due to the proximity of the jet stream complex.

La Coruna, Lisbon, and Funchal are located well to the east of the frontal cloudiness and in the area of ridging. The over-all cloud cover in this area, as seen by the satellite, is rather broken. Radiosonde data at all of these stations show maritime tropical air throughout, with the tropopause above the 150-mb level. La Coruna and Lisbon report no clouds over the stations; Funchal reports some middle and high clouds. A large cloud patch is noted south of Funchal. One station in this area reports altocumulus of a chaotic sky. This patch was noted on the chart of the 14th and is believed to be associated with a low pressure circulation aloft, located just off northwest Africa. As currently analyzed, this patch lies on the western periphery of the low pressure cell at the 300-mb level. Data in this area are sparse, however, and a closed circulation may be directly over this field.

The jet stream complex passes over the pre-frontal cloud shield off Canada, and then passes in a southeasterly direction over the broken cloud field that lies under the east side of the surface ridge. The striations evident in these cloud bands are aligned with the upper flow. At the base of the trough in the central Atlantic, this association is less certain.

In the eastern Atlantic, the jet stream complex passes over that portion of the cloud field on the cold side of the frontal wave. The southernmost jet stream in this complex passes quite close to the tip of the developing wave.

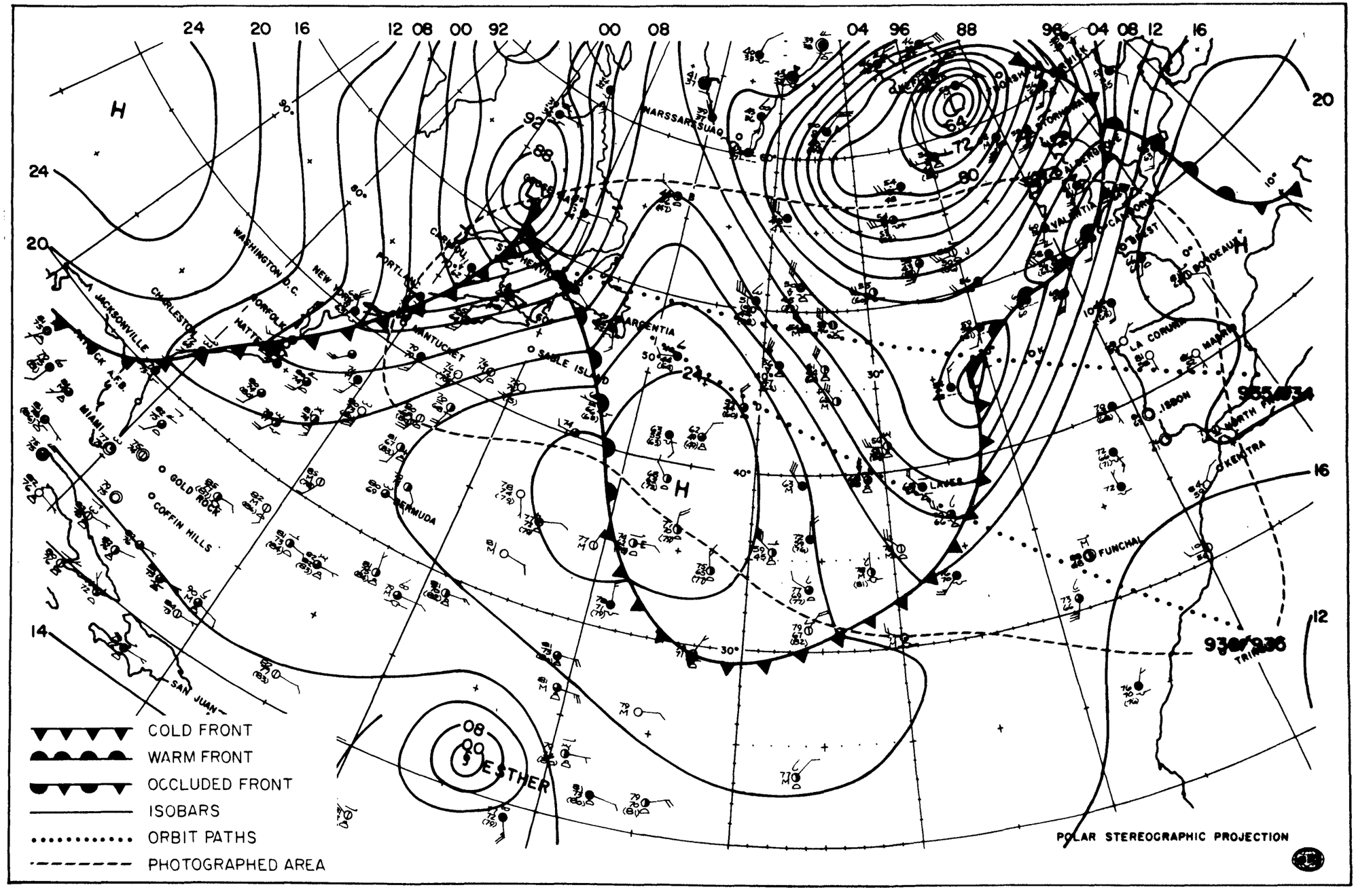

FIG. 34 SURFACE MAP, 1200GMT, 15 SEPTEMBER 1961

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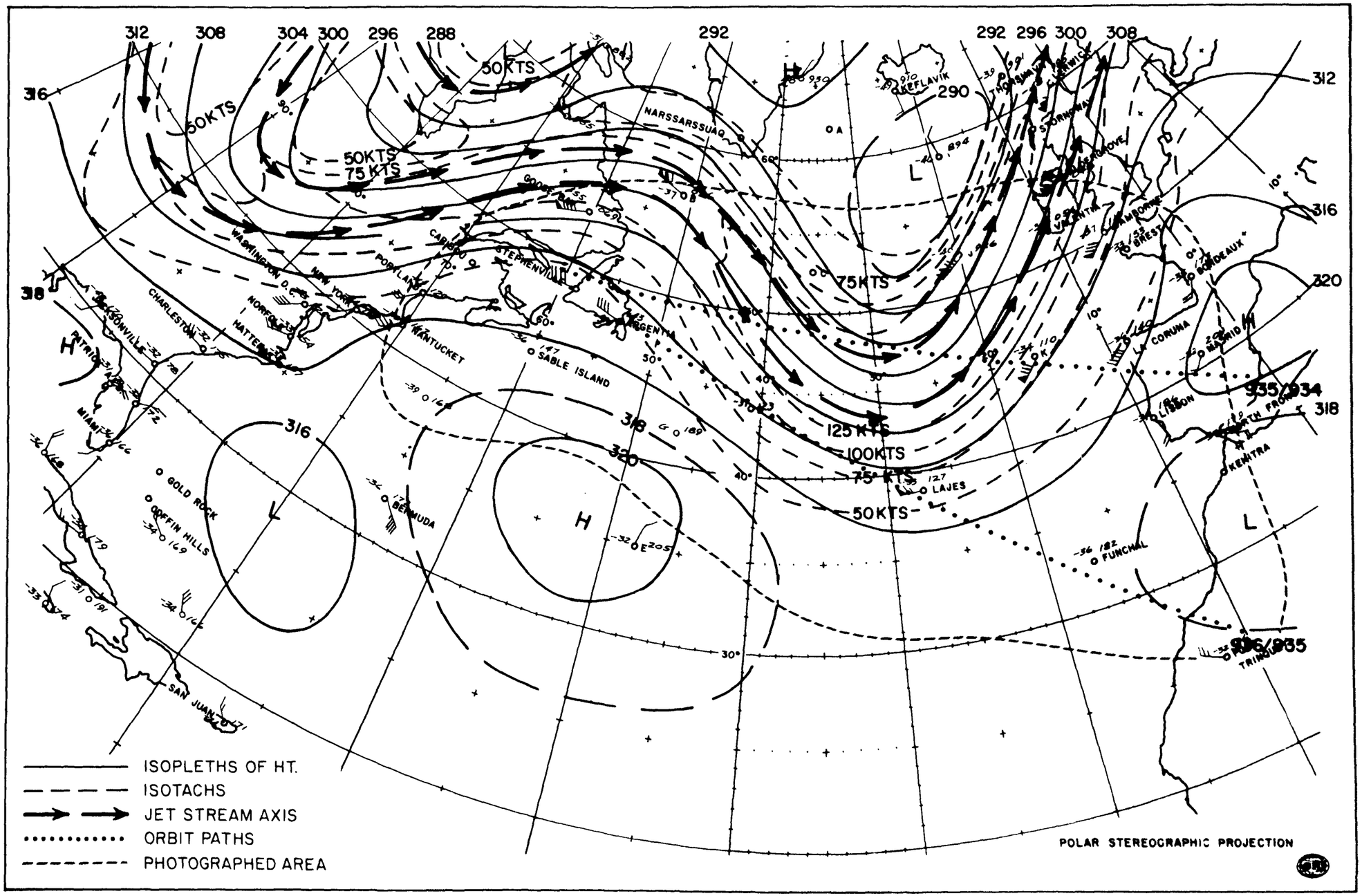

FIG. 35 300-mb MAP, 1200GMT, 15 SEPTEMBER 1961

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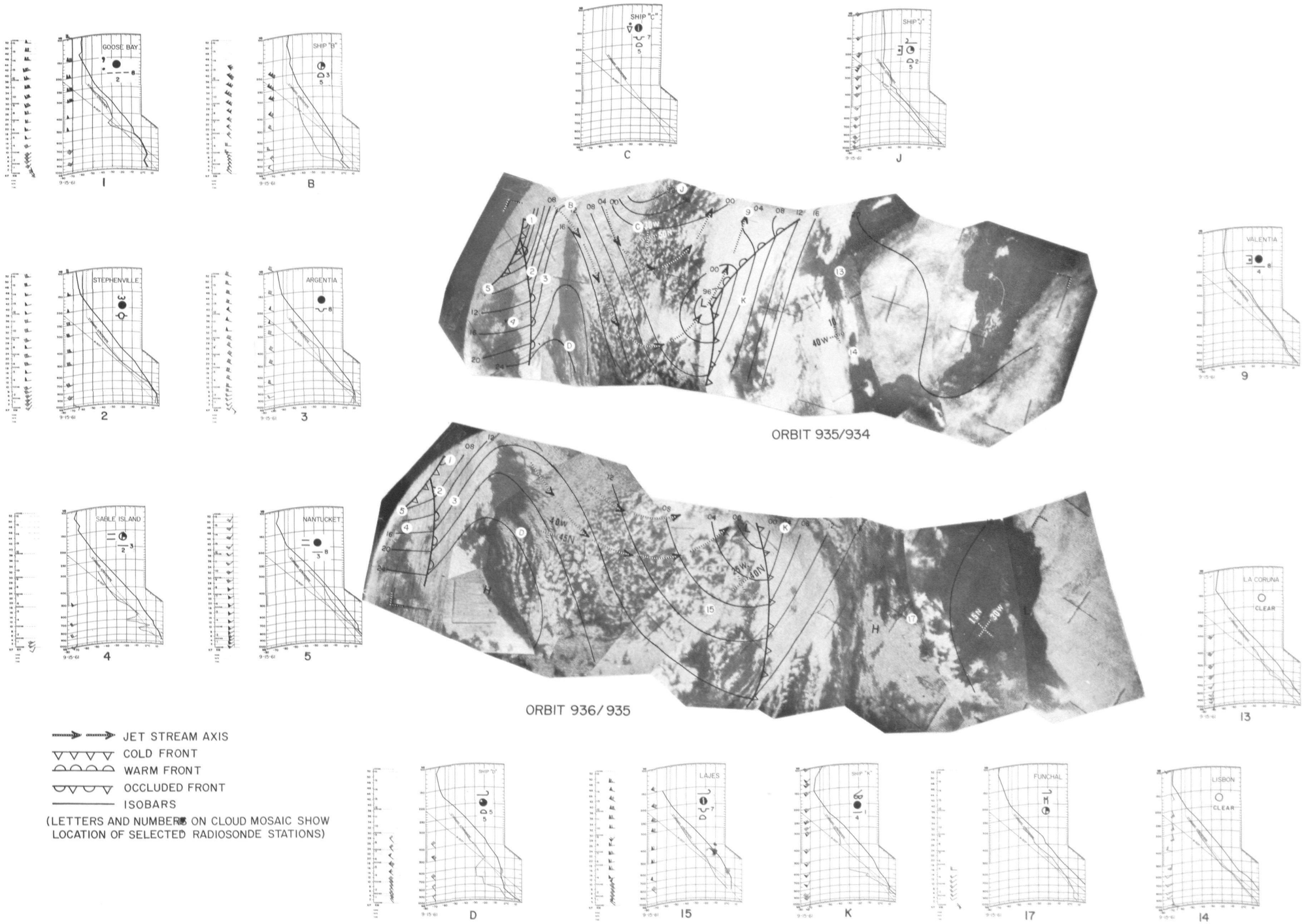

FIG. 36 CLOUD MOSAICS AND RADIOSONDE DATA FOR 1200GMT, 15 SEPTEMBER 1961

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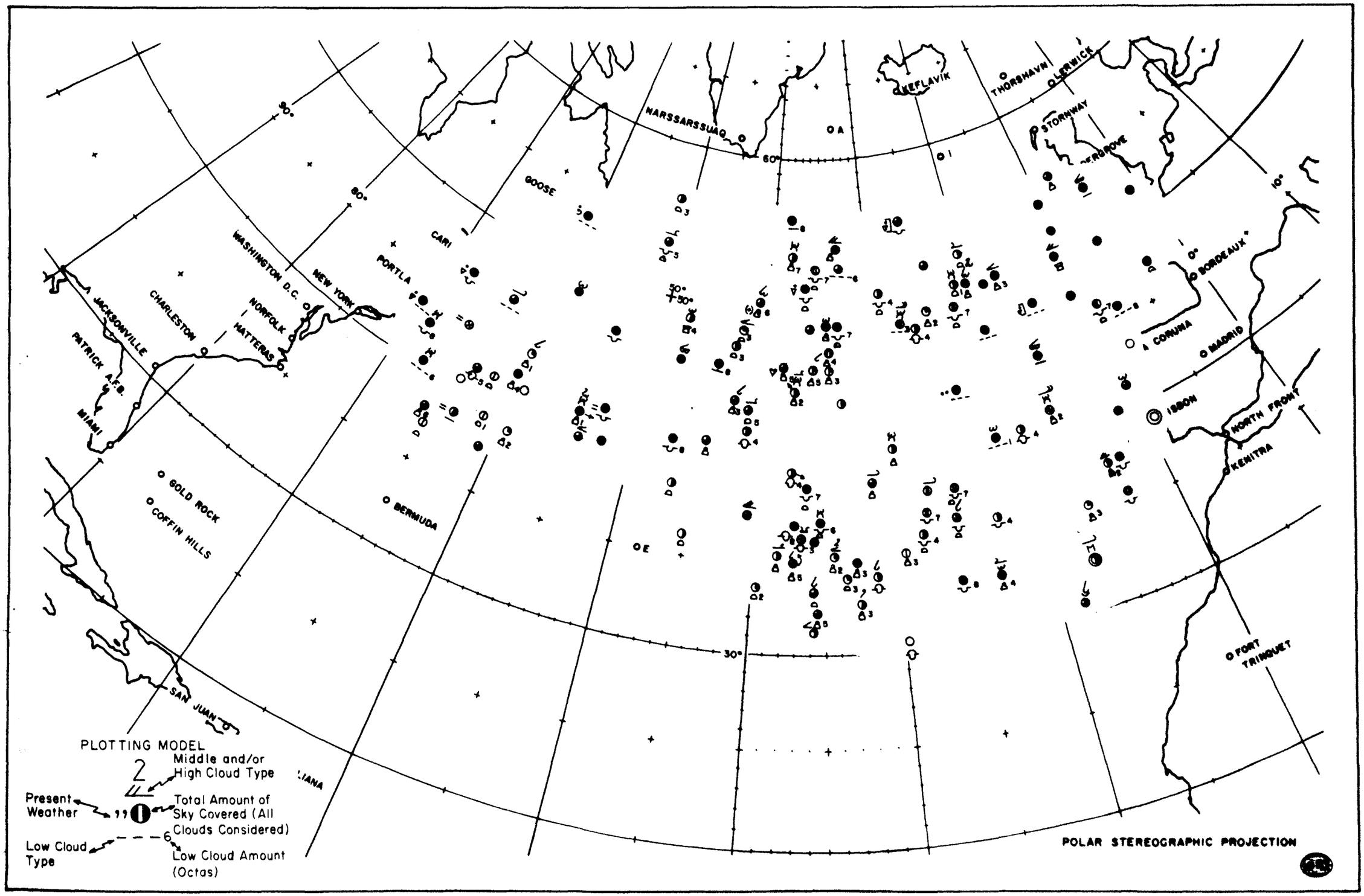

FIG. 37 (a) CLOUD REPORTS FOR 1200GMT, 15 SEPTEMBER 1961

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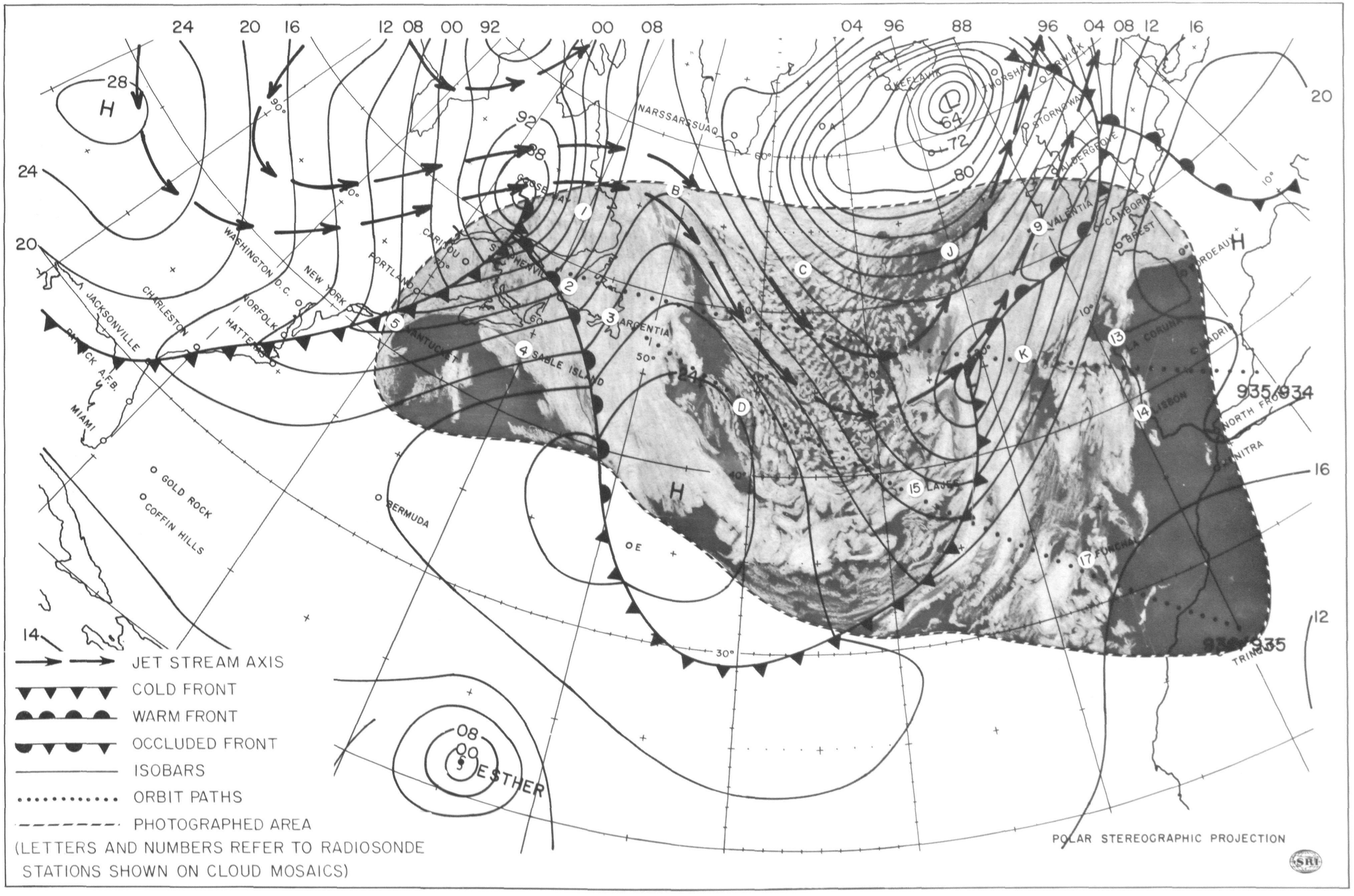

FIG. 37 (b) RECTIFICATION OF CLOUD PHOTOGRAPHS FOR 1200GMT, 15 SEPTEMBER 1961

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J. 16 September 1961

Pressure systems on the surface map (Fig. 38) remain well developed. The subtropical anticyclone has moved eastward, almost to the central Atlantic. Concurrently, the low pressure centers in Greenland and the British Isles continue to recede northward. The frontal system in the eastern Atlantic retains its meridional orientation seen on the previous day, though the wave development has reached the occluded stage. In the western Atlantic, the large-scale occluding wave system is breaking away from the parent low and moving into the Atlantic, passing north of the high-pressure cell in the process. Hurricane Esther remains in low latitudes.

At the 300-mb level (Fig. 39), the long wave trough is located in the eastern Atlantic. This upper trough still lags the surface low-pressure system; the closed cyclonic circulation at the 300-mb level is located some 10 degrees southwest of the surface low center. An upper ridge is located in the western Atlantic, again somewhat west of the corresponding feature on the surface chart. In this area the upper ridge lies completely over the wave system transiting the surface high pressure cell. A moderate trough is located along the east coast of the United States and Canada.

Considerable jet stream activity is indicated on this day; the major double jet stream complex extends across the entire north Atlantic. The isotach analysis shows the strongest winds along the southeastern sector of the low over Canada and on the eastern and western flanks of the low pressure trough in the eastern Atlantic.

Three orbits (Orbits 948/947, 949/948, and 950/949) were utilized on this date. Their viewing times over the area began at 1016 GMT, 1158 GMT, and 1344 GMT, respectively. Mosaics from these orbits are shown in Fig. 40. Rectification of the mosaics onto a polar stereographic map is shown in Fig. 41(b).

The dense cloud mass over the east of the Maritime Provinces is associated with the passage of the broad-scale wave system in that area. Surface reports in its warm sector [see Fig. 41(a)] indicate stratiform clouds with low ceilings, patches of fog, and some drizzle. While the coverage appears continuous in the northern part of the warm sector, some breaks are evident in the southern portion. Here, the surface reports indicate that the cloud types change to cumuliform varieties with some middle and high clouds present.

Surface reports in advance of the warm front indicate partial coverage of low, middle, and high cloud types. The mosaic, however, shows a continuous unbroken cover over this area. This discrepancy from the surface reports may be due to the high nadir angle of the pictures, which tends to mask any possible breaks in the cloud cover.

The center of the high cell is shown by the photographs to be fairly free of cloud development. This clear area coincides almost exactly with the analyzed surface position of the anticyclone.

Radiosonde stations in the field of view for the area just discussed include Argentia, OSV C, and OSV D. Argentia lies in the warm sector just in advance of the cold front. Maritime tropical air is indicated throughout the sounding, with the tropopause near the 150-mb level. Strong winds are reported above the 300-mb level. Although the station report at Argentia is missing, cloud reports in the surrounding area indicate considerable low stratus and fog, and the moisture distribution would suggest that these conditions probably apply to this station as well.

Ship C lies under the warm-front cloud shield and near the high-pressure ridge line. The extension of the warm front to the west is shown in the sounding near the 700-mb level. Maritime tropical air is indicated above this level, with the tropopause being found at the 130-mb level. Moisture is greatest above and below the frontal zone, with marked dryness within the frontal zone. The surface report indicates an overcast-with-breaks, consisting of stratocumulus, although middle clouds (altocumulus) are also visible. Winds are quite strong above the 500-mb level, as might be expected from the station location in relation to the jet stream complex just to the north.

Ship D lies just ahead of the warm front and just north of the clear area associated with the center of the subtropical high pressure cell. The front to the west is reflected in the sounding near the 750-mb level. Maritime tropical air is indicated aloft with a tropopause at the 120-mb level. The layer below the front is almost saturated and the surface report indicates an overcast of stratocumulus. The appearance of the cloud pattern in this area verifies the report of overcast conditions, although breaks begin to appear just to the south of the station.

In the central Atlantic the cloud mosaics and rectification give the impression of a rather continuous cloud cover in the northerly latitudes, giving way gradually to a broken and scattered coverage in the middle and southern portions. This broken and mottled coverage extends into the eastern Atlantic and occupies most of the post-frontal region, with the exception of the area of the low-pressure system off England. Minimum cloudiness occurs just west of the frontal cloud band, in a region where the isobars diverge.

Surface reports on Fig. 41(a) indicate that the bulk of the post-frontal area is occupied by cumuliform low clouds, though middle and high clouds are also reported. Some shower activity is indicated, particularly in the northerly latitudes.

Radiosonde stations in the broken cloud regime of the post-frontal area include Ocean Station Vessels I, J, and K, and Lajes Acores. The soundings at Ships I, J, and K are similar, and are characteristic of polar air--tropopause near the 300-mb level, and cold temperatures in the troposphere. Ship I reports warmer temperatures near the 500-mb level than the other two stations. This station reports an overcast-with-breaks comprised of cumulonimbus clouds. Ship J reports a partial cloud cover of cumulus and stratocumulus along with cirrus. Ship K reports a partial coverage of cumulonimbus with middle and high clouds visible. The upper wind speeds at these three stations are rather low.

The cloud-pattern distribution about the surface low off England is suggestive of the circular patterns often seen with deep lows, although admittedly only the southern portion of the cloud vortex lies in the picture area. The center of the surface low is covered by an extensive sheet of cloud without breaks. Whether or not the center of the cloud vortex would coincide with the low pressure center cannot be ascertained.

A dense band of cloud extends southward from the cloud vortex. The surface analysis delineates a frontal system that extends from the North Sea through the tip of Spain. If the premise is taken that this band of dense cloud is frontal, then it indicates that the frontal analysis through England has been advanced too far to the east.

Radiosonde data in the vicinity of the dense cloud mass mentioned above are available from Stornoway, Aldergrove, Valentia, Camborne, and Brest. In terms of the analysis, Stornoway lies in advance of an occlusion. Its sounding indicates a possible frontal intersection at the 500-mb level. Warm air is present aloft, with the tropopause at the 150-mb level. Moisture is present through a deep layer, and an overcast is reported by surface observations. This sky cover is made up of altostratus and cumulofractus (7/8th). Upper winds are rather strong above the 700-mb level, reflecting the close proximity of the station to the jet stream complex.

Valentia lies to the west of the frontal cloud band. Its tropopause is located at the 210-mb level. Reports of winds aloft are missing. Moisture is confined to the layers below the 650-mb level. A partial cloud cover of cumulus congestus and altocumulus is reported.

Aldergrove lies in the cloud field about the low pressure system and south of the analyzed position of the occluded front. Its sounding shows a frontal inversion over the station near the 700-mb level, with warm air present aloft. The tropopause is located near the 150-mb level, as was the case at Stornoway. Moisture is confined to the layer beneath the 800-mb level and above the 400-mb level. A partial cloud cover of cumulus, altocumulus, and cirrus fibratus floccus is reported. Although the upper wind reports do not extend above the 600-mb level, strong winds are reported.

Camborne lies within the frontal cloud band itself. Its sounding shows a frontal intersection near the surface, indicating that the front lies only a little to the east. Warm air is present aloft, with the tropopause at the 180-mb level. Near saturated conditions are indicated near the surface and again above the 650-mb level. Cloud cover, unfortunately, is not reported. The upper winds are quite strong above the 700-mb level.

Brest lies toward the eastern edge of the dense cloud band but west of the analyzed position of the surface cold front. Its sounding, however, shows warm air throughout, indicating that the cold front has not passed this station. Moist conditions are reported observed near the surface and, again, in a layer near the 600-mb level. A partial cloud cover of cumulus and altocumulus is indicated. Upper winds are fairly strong, but less than at the stations previously discussed.

Bordeaux lies in the clear air to the east of the frontal cloud band. The radiosonde data from this station show warm tropical air to high altitudes. The upper winds are strong to moderate, in keeping with Bordeaux's position to the east of the jet stream complex.

La Coruna and Lisbon lie within a dense cloud band along Spain. The analysis shows a cold front between these stations; however, the Lisbon sounding below the 800-mb level (not reproduced) shows an inversion, which represents a frontal interface, indicating that the front is just east of this station. The top of this front can be found over La Coruna at about the 500-mb level, though the frontal layer is delineated in the sounding only by a tendency for stability, rather than an actual inversion. La Coruna shows near-saturated conditions throughout the sounding, whereas Lisbon shows near saturated conditions in the 450- to 350-mb layer. Cloud cover at La Coruna consists of an overcast of cumulus fractus; upper clouds are undoubtedly present, in addition. Lisbon reports an overcast of altostratus, with scattered stratocumulus beneath. The upper wind soundings at both stations show high to moderate speeds, although the soundings do not extend to very high altitudes.

An interesting analytical feature presents itself in the area off North Africa. The cloud pictures show a dividing of the dense cloud system into two distinct cloud fields. One field continues southward to a point east of Funchal; the other field curves to the southwest (staying just to the north of Funchal). This latter cloud field is not as continuous in its coverage as the dense cloud field to the east, though the cloud elements in it are rather large. The surface reports in the area suggest that these elements are large patches of stratocumulus. A narrow band of clouds can be seen in the area of Funchal itself. These clouds appear to be of the cumuliform variety.

The cloud band east of Funchal appears to be quite continuous, with no extensive breaks evident. This cloud system consists of large amounts of low and middle cloud types.

The analysis indicates that the frontal system is associated with the broken cloud band just north of Funchal. The sounding at Funchal, however, does not seem to confirm this. Its sounding shows an inversion below the 850-mb level (due to illustration limitations this part of the sounding has not been reproduced), that appears to be frontal in origin, indicating that the surface position of the cold front lies to the south of the station, probably as far as the continuous dense cloud band to the east. Maritime tropical air is found above this front, with a tropopause located near the surface and fairly moist again above the 750-mb level. The station reports an overcast consisting of scattered cumulus with breaks and stratocumulus plus altocumulus and cirrus spissatus.

It is interesting to note that, qualitatively, the large stratocumulus patches (north of Funchal) occur where the depth of the cold air is shallowest; whereas, where the cold air is deepest (see around OSV K) the clouds are more of the vertically developed cumulus type, and appear in cloud pictures as small individual elements.

The jet stream complex in the central and eastern Atlantic enters the viewed area at the northeastern periphery of the warm-front cloud shield, plunges southeastward over the broken cloud field, reaching

its southernmost latitude in the eastern Atlantic, and returns northward, parallel to the western edge of the frontal band near Europe. The orientation of this frontal cloud band and the latitudinal extent of the broken cloud field suggests that the meridional flow is well pronounced. In general, the small individual cloud elements fall on the cold side of the jet stream complex and the large cloud patches on its warm side.

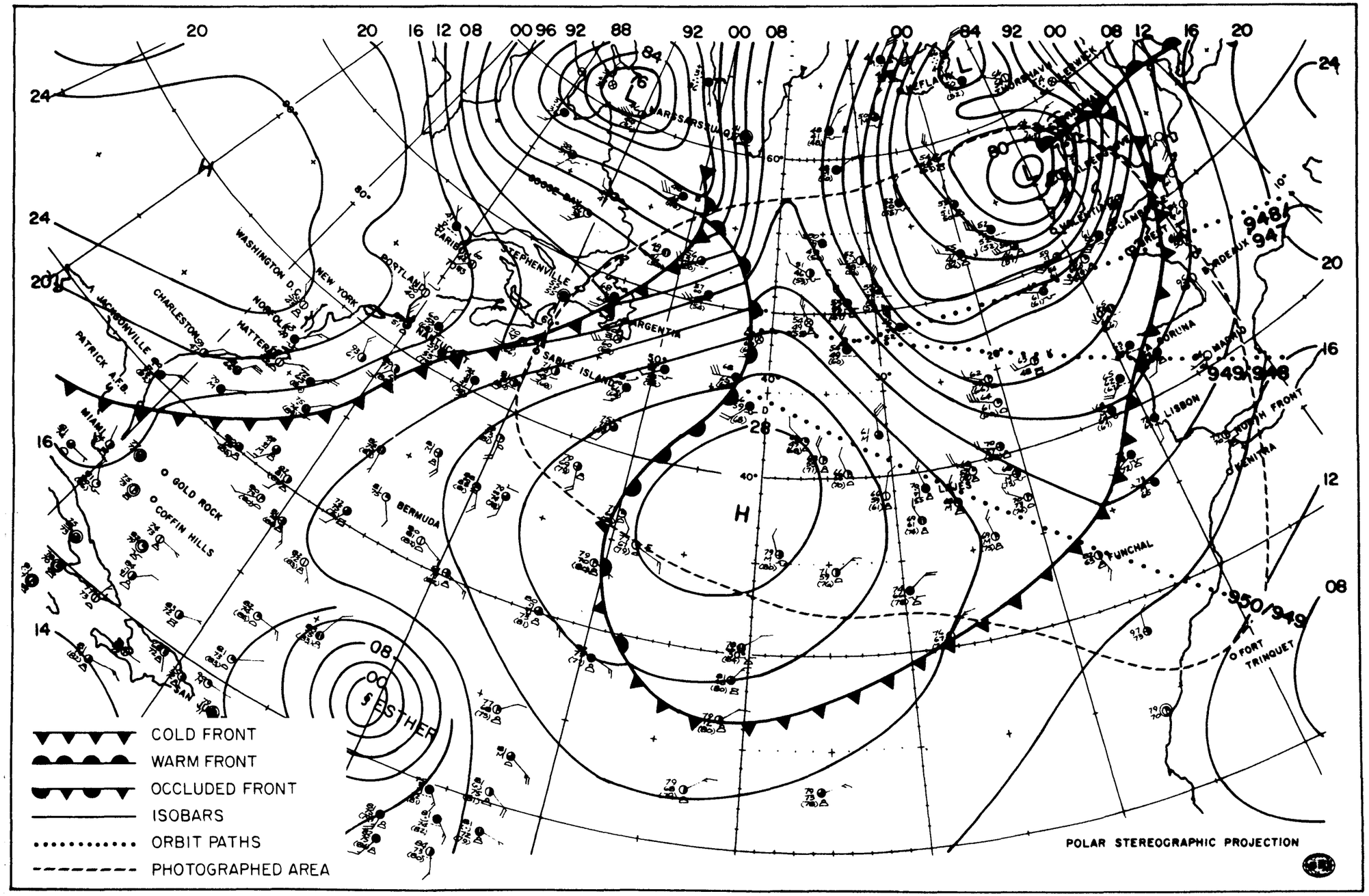

FIG. 38 SURFACE MAP, 1200GMT, 16 SEPTEMBER 1961

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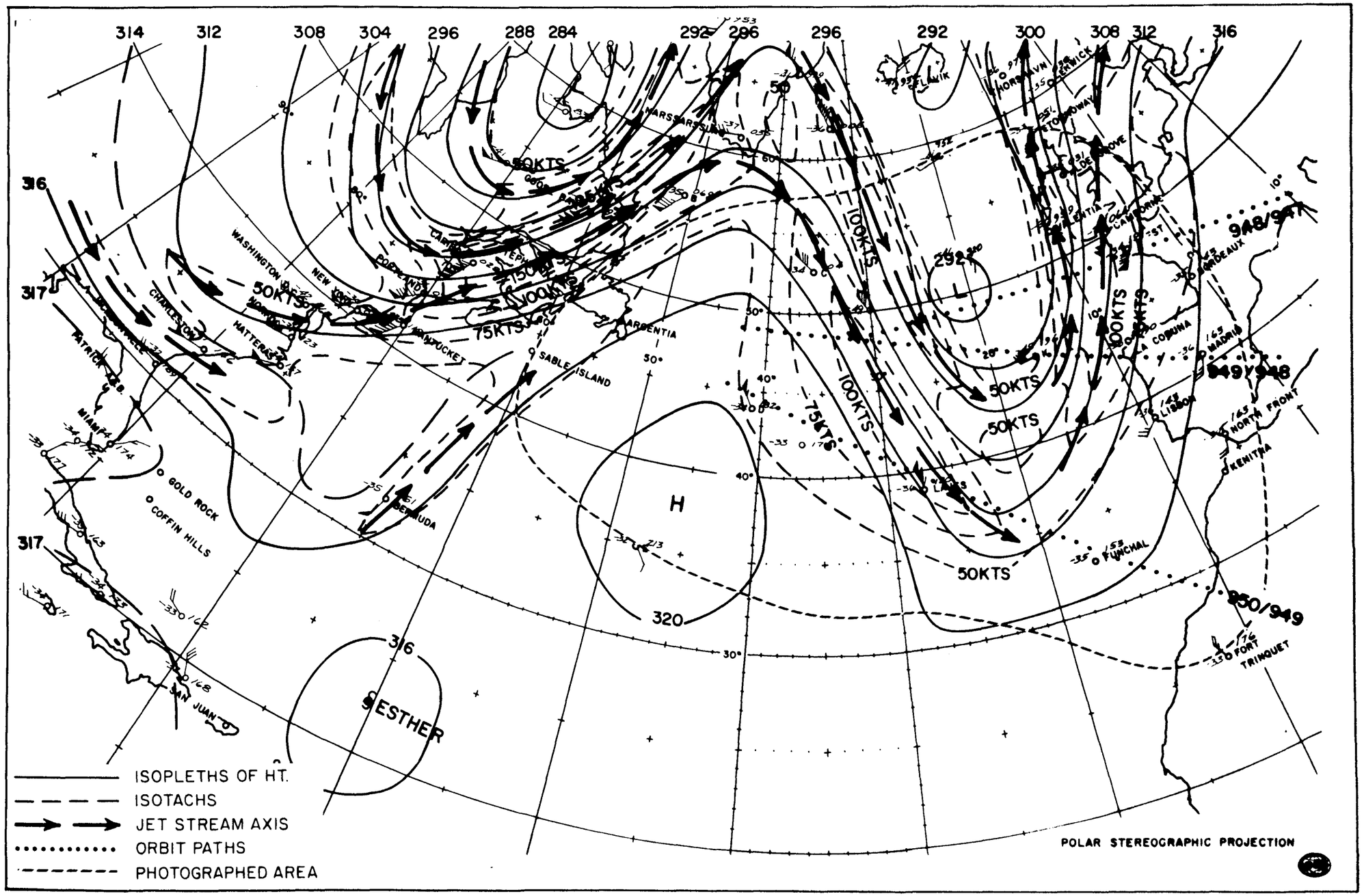

FIG.39 300-mb MAP, 1200GMT, 16 SEPTEMBER 1961

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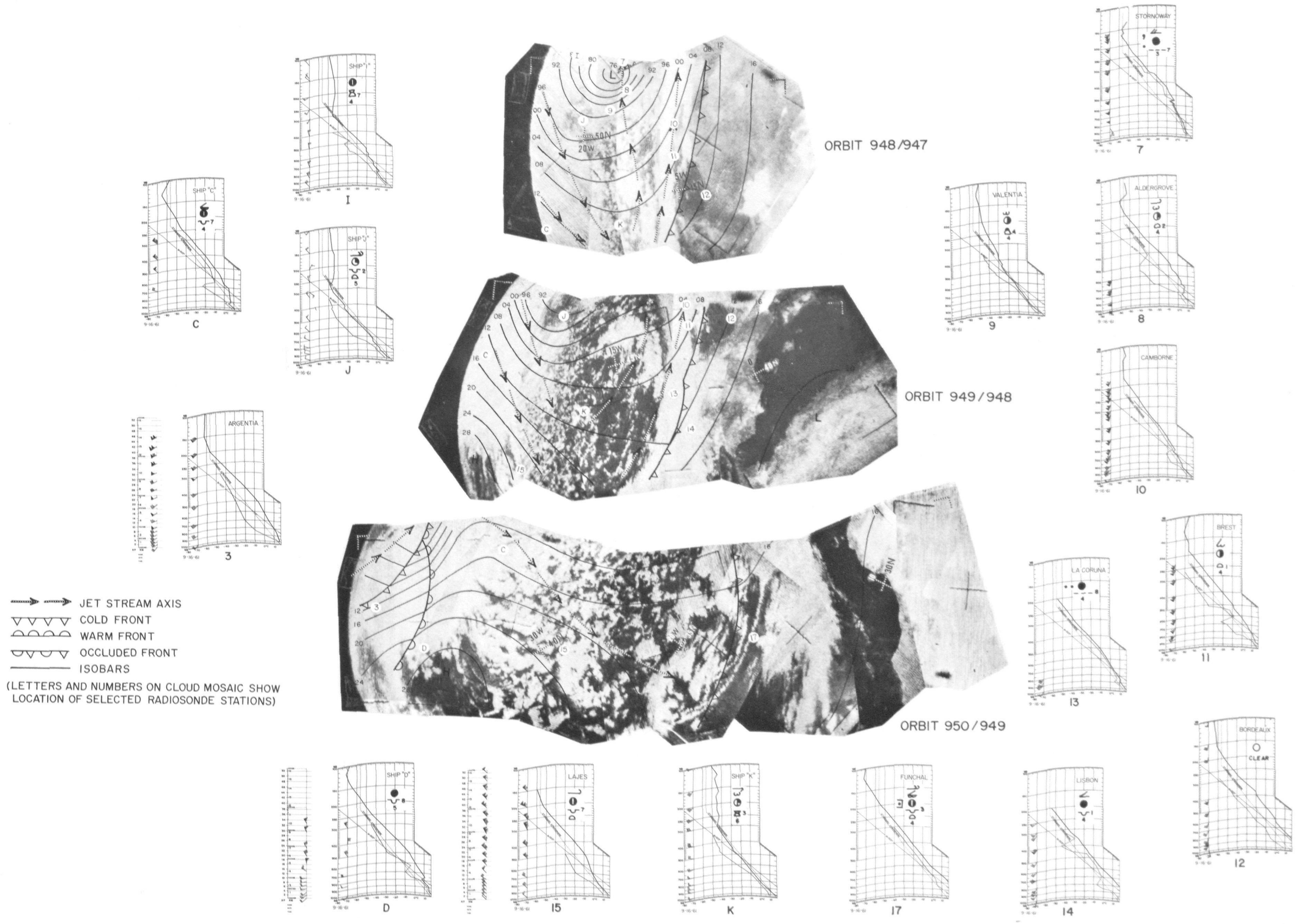


FIG. 40 CLOUD MOSAICS AND RADIOSONDE DATA FOR 1200GMT, 16 SEPTEMBER 1961

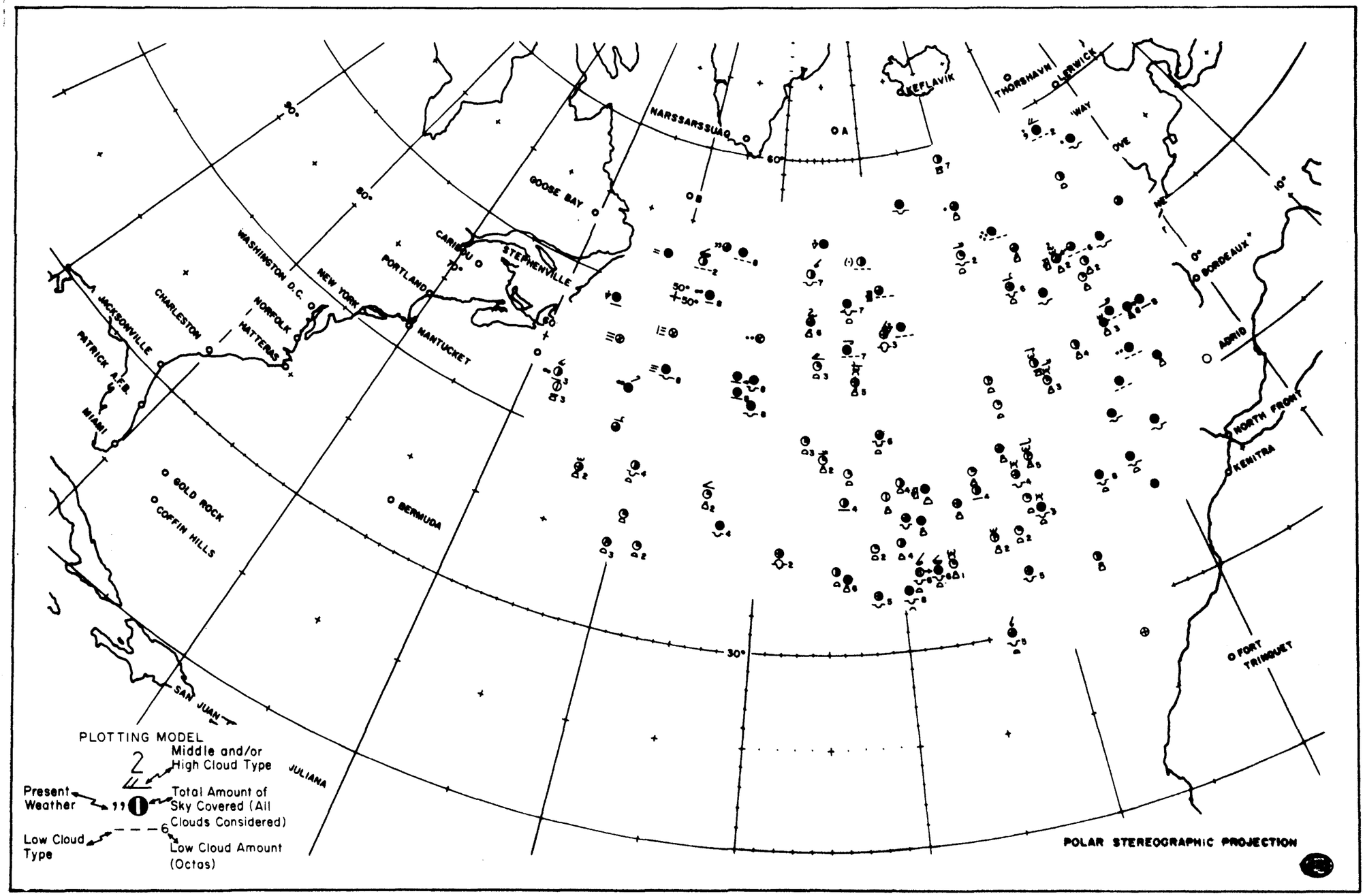


FIG. 41 (a) CLOUD REPORTS FOR 1200GMT, 16 SEPTEMBER 1961

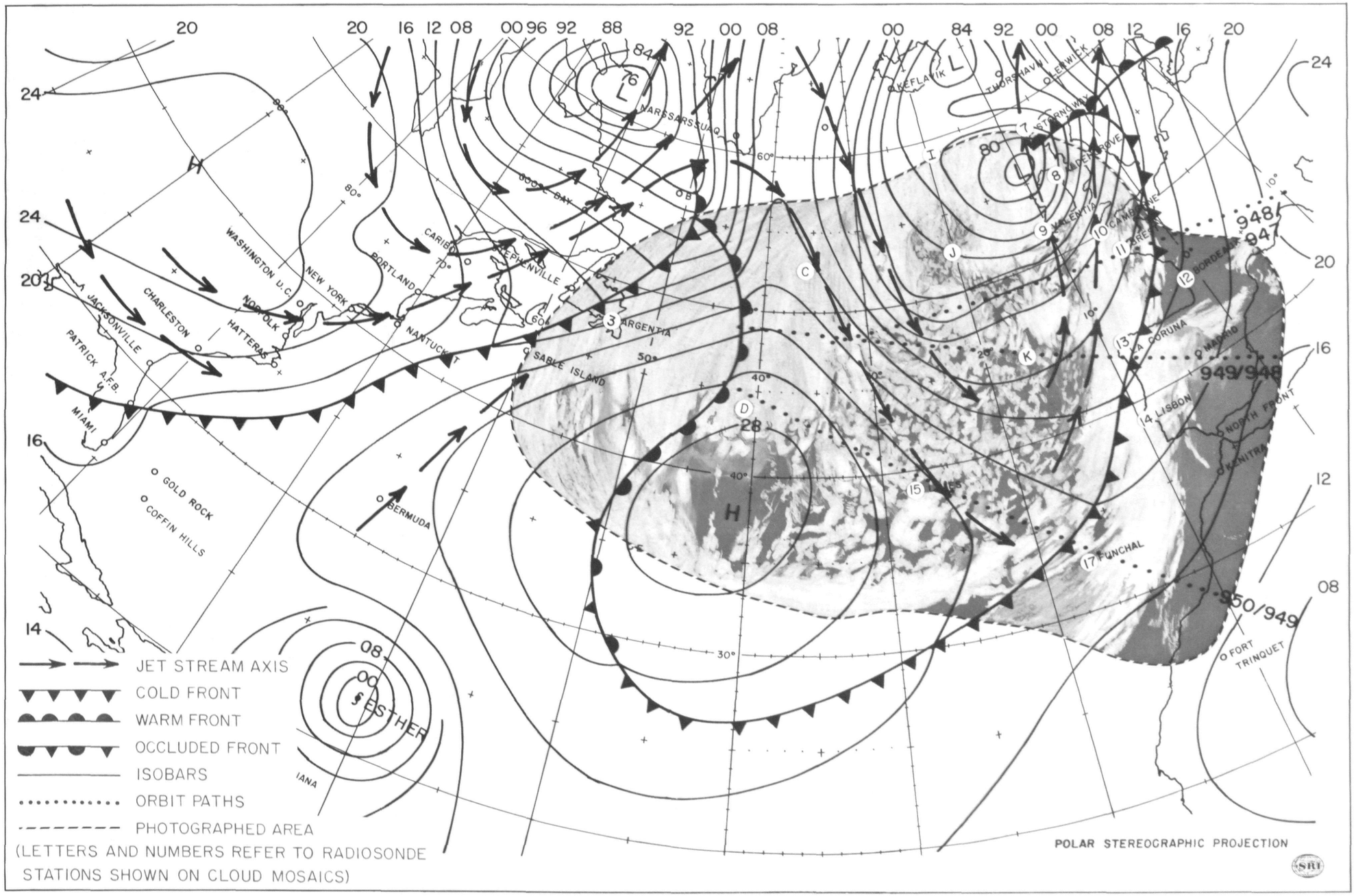


FIG.41(b) RECTIFICATION OF CLOUD PHOTOGRAPHS FOR 1200GMT, 16 SEPTEMBER 1961

III COMPUTED LARGE SCALE VERTICAL MOTION PATTERNS IN RELATION TO TIROS III SATELLITE CLOUD PHOTOGRAPHS AND SURFACE WEATHER REPORTS

A. General

Numerous studies in the meteorological literature relate patterns of computed vertical motion in the atmosphere to observed moisture patterns and to the existence and distribution of clouds. Characteristic patterns of vertical motion and moisture are associated with fronts, low-pressure cells, high-pressure cells, etc., as has been shown by various authors (viz., Sawyer 1955, Vuorela 1957, Elliot 1958, Newton 1959).

Serebreny, et al., in a 1962 study of TIROS I satellite observations made over the Pacific, have shown that large-scale patterns of computed vertical motion can be related to the cloud cover as seen by the satellite. In this study, relationships between patterns of computed vertical motion and cloud patterns are investigated for the Atlantic, using TIROS III satellite cloud photographs.

The adiabatic method of computing large-scale vertical motion has been used in this, as in the previous, study in the manner introduced in 1942 by Arnason, who obtained the following expression for the vertical motion:

$$w = \frac{-\frac{\partial T}{\partial t} - \frac{fT}{g} v^2 \frac{\partial \psi}{\partial Z}}{\gamma_d - \gamma} \qquad (1)$$

where w is the vertical velocity, γ_d the adiabatic lapse rate, γ the actual lapse rate, $\frac{\partial T}{\partial t}$ the local temperature change, f the Coriolis parameter, T the absolute temperature, g the acceleration of gravity, v the observed windspeed, and $\frac{\partial \psi}{\partial Z}$ the observed turning of the wind in the vertical. It is assumed that the wind is geostrophic.

Vertical motions computed with this formula have also been presented by Vuorela in 1957 and by Hubert in 1953.

However, it is feasible to make this equation more amenable to computation by using the well-known relation between temperature and potential temperature, and changing height, as the vertical coordinate, to pressure. Equation (1) then takes the form:

$$w = \frac{-\left.\frac{\partial T}{\partial t}\right]_P + \frac{f}{R_d} v^2 \frac{\partial \psi}{\partial \ln P}}{T \frac{\partial \ln \theta}{\partial P}} \qquad (2)$$

where $w = \frac{dP}{dt}$ is the vertical motion in mb sec^{-1}

$\left.\frac{\partial T}{\partial t}\right]_P$ is the local change of temperature on the pressure surface

f is the Coriolis parameter in sec^{-1}

R_d is the gas constant for dry air ($287 M^2 sec^{-2} {}^\circ K^{-1}$)

v is the mean wind speed in the layer ∂P in $msec^{-1}$

$\frac{\partial \psi}{\partial \ln P}$ is the turning of the wind in the vertical in radians (positive for winds backing with height)

T is the mean temperature in the layer ∂P

$\frac{\partial \ln \theta}{\partial P}$ is the deviation of the actual lapse from the dry-adiabatic lapse rate.

Using Eq. (2), vertical motions, representative on the scale of the geostrophic wind, can be computed for a station over a given time period for which vertical soundings of temperature and wind are available. A vertical time-section analysis of temperature, based on radiosonde data taken at 12 hour intervals, will provide the local change of temperature, which can be determined as a mean value over a period extending from 6 hours before to 6 hours after the radiosonde observation. Both the vertical windshear term ($v^2 \frac{\partial \psi}{\partial \ln P}$) and the stability term ($T \frac{\partial \ln \theta}{\partial P}$) can be evaluated from the instantaneous

soundings over layers of 100-mb thickness up to the 300-mb level and over layers of 50-mb thickness above the 300-mb level.

Vertical motion computations using Eq. (2) have been made for two Atlantic weather ships, OSV C and OSV D for the period 7-17 September 1961.

The stability term, which is the denominator of Eq. (2), is always less than zero, except when the measured lapse rate is adiabatic or super-adiabatic. For the cases investigated, such lapse rates were only found between the surface and 850 mbs. Assumption of adiabatic motion is, on the average, least acceptable below 850 mbs and the vertical motion computations have only been considered valid above this pressure level (where the stability term was always found to be negative).

The computations in this investigation showed that the sign of those vertical motions, whose magnitude $\leqq 2$ cm sec^{-1}, could frequently be reversed by changing the analysis of the isotherms on the vertical time section within their limits of uncertainty; for magnitudes of vertical velocity > 2 cm sec^{-1}, the vertical shear term $(v^2 \frac{\partial \psi}{\partial \ln P})$ was frequently the dominant term, by far, in the numerator of Eq. (2); hence, the turning of the wind in the vertical could have been used alone to determine the sign of the vertical motion, such that a backing wind with height corresponded to downward motion and a veering wind with height corresponded to upward motion.

Near frontal surfaces, the local change of temperature with time was often large but, in this instance, the wind speeds were also frequently large, which meant a large value for v^2 in the vertical shear term of Eq. (2). This large value for v^2 combined with the presence of a change of wind direction across the frontal boundary, made the vertical shear term, again, the dominant term in the numerator of Eq. (2).

Except in the vicinity of fronts, vertical motion obtained by considering only the backing or veering of the wind with height and neglecting the local temperature closely approximated the patterns obtained by using both terms. Some results will be presented below.

B. Time Sections of Large Scale Vertical Motion Patterns at Two Ocean Station Vessels

1. Ocean Station Vessel C (52.5N, 35.5W)

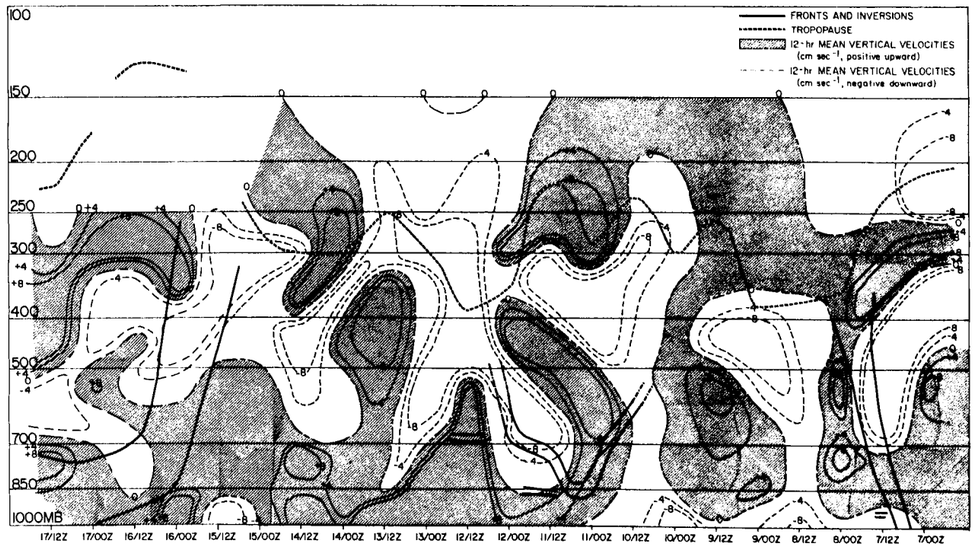
Panel (a) of Fig. 42 shows the time section of vertical motions computed by evaluating both terms in the numerator of Eq. (2).

Only the 0000 GMT and 1200 GMT winds obtained at the radiosonde observation have been used in the computations, although the intermediate pilot balloon winds have been included in the illustration of Panel (d) to provide a more complete synoptic history.

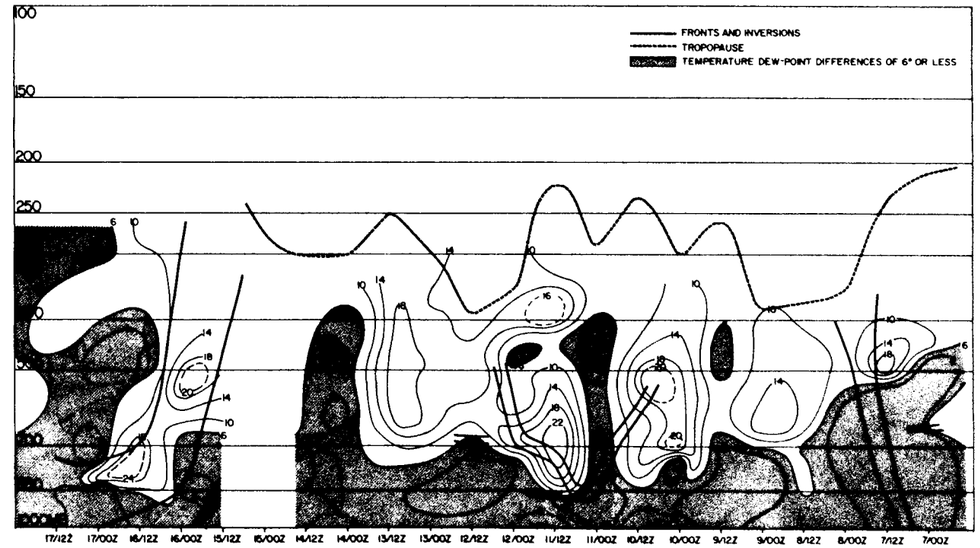
No vertical wind soundings were available between 12 September, 0000 GMT and 16 September, 0000 GMT and no temperature soundings between 14 September, 1200 GMT and 15 September, 1200 GMT. For these periods of missing data, vertical motions have been computed using the temperature and/or the geostrophic wind as obtained from the U.S. Weather Bureau upper-air contour analyses.

Upward motion is evident at the beginning of the time period (7 September 0000 GMT) when Ship C is located in a pre-frontal area. Downward motion prevails along a large portion of the cold frontal boundary, while upward motion is found again behind the cold front at 8/0000 GMT.

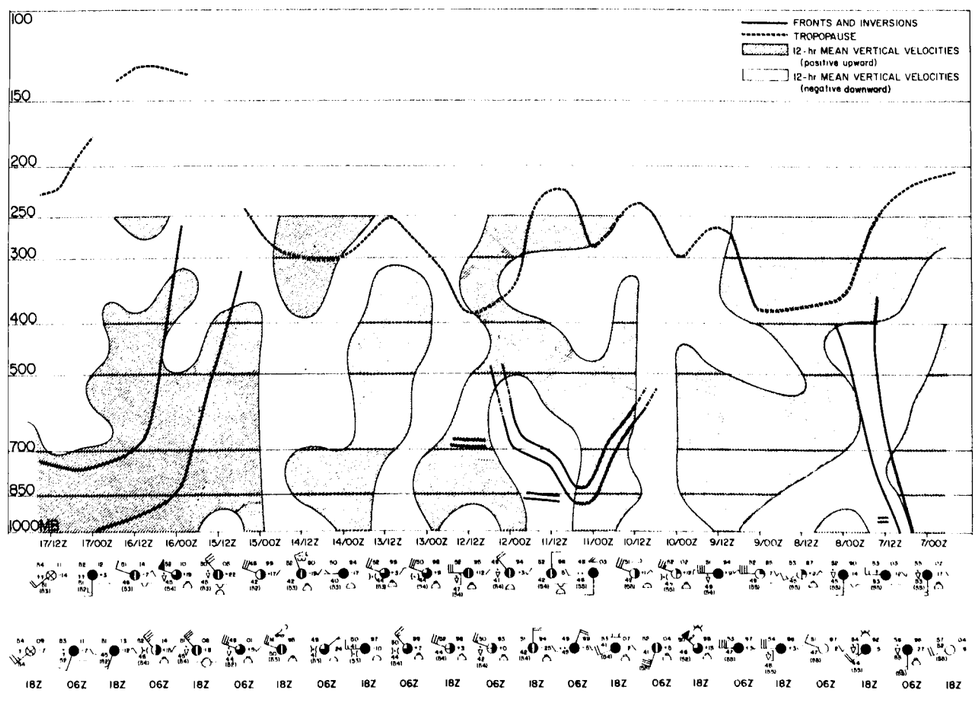
Synoptic surface observations [plotted under Panel (b)] show that this vertical motion distribution is manifested in the rain showers in the pre-frontal area at 7/0000 GMT and 7/0600 GMT, and in the post-frontal area at 7/1800 GMT and 8/0000 GMT. Intermittent drizzle is reported at 7/1200 GMT, when the frontal boundary is over the station. Thus, the computed downward motion along the frontal boundary may be reflected in the precipitation pattern through a change from slight rainshowers to intermittent slight drizzle.



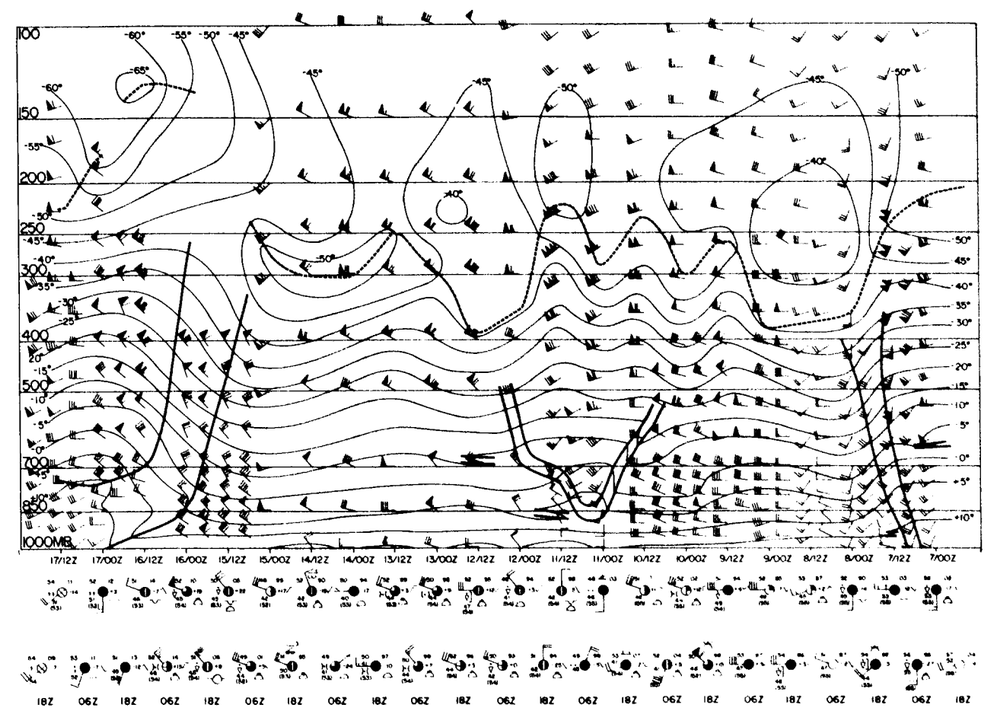
(a) Vertical Motion Considering Thermal Stability and Wind Shear



(c) Isopleths of Temperature Dew-point Difference



(b) Vertical Motion Considering Wind Shear Only



(d) Upper Winds and Isopleths of Temperature

FIG. 42 VERTICAL DISTRIBUTION OF SELECTED ATMOSPHERIC PARAMETERS AT OSV "C" (52.5N, 35.5W), SEPTEMBER 7-16, 1961. . . . . .

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Downward motion, extending to lower levels in the troposphere, is computed under the low tropopause around 8/1200 GMT. Around this time Ship C is located near the center of a cold low aloft (see Fig. 7). Upward motion, extending up to the middle troposphere, is computed again at 9/0000 GMT. The surface observations during the period of downward motion show a definite clearing of the sky, with no middle or high clouds reported.

Within the period discussed so far (7/0000 GMT-9/0000 GMT), TIROS III cloud photographs, that include the location of Ship C, are available at three different times.

Cloud photograph (a) on Fig. 44 (valid for 7/1723 GMT) show Ship C to be in the immediate post-frontal area. The extensive cloudiness shown in this cloud picture to the east of OSV C is undoubtedly the frontal and pre-frontal cloudiness. A narrow clear band is shown immediately to the west of this frontal cloudiness.

Cloud photographs (b) and (c) (valid for 8/1504 GMT and 8/1648 GMT, respectively) show Ship C past this band of clearing and located within the northeastern boundary of an extensive area of air mass cloudiness. The cloudfree band noted in picture (a) is still apparent to the east of OSV C.

The vertical motion patterns computed for the period covering the times of the three satellite cloud photographs suggest that the narrow clear band marks the lowering of the tropopause level behind the cold frontal boundary (see Fig. 42). Since downward motion, extending throughout most of the troposphere, is computed under the low tropopause, the cloudiness seen in the clear band (and possibly also the cloudiness shown in photographs (b) and (c) to the west and southwest of OSV C) must be predominantly low cloudiness, developing from convection in the post-frontal cold air mass under the low tropopause. These convective clouds must form in the low level northwesterly flow behind the center of the surface cyclone. Thus, the clear band, shown in photograph (a) can be thought of as the eastern boundary of a low-level convective cloud regime.

Between 10/1800 GMT and 12/0600 GMT there is a period of upward motion extending throughout the troposphere followed by pronounced downward motion. This computed vertical motion pattern appears to be associated with the passage of Hurricane Betsy to the east of Ship C. Note the sharp drop in the tropopause level which accompanies this event. The surface observations between 10/1800 GMT and 11/1200 GMT show extensive middle cloudiness, with continuous slight rain. At 11/1200 GMT the sky condition is no longer reported as overcast; precipitation has ceased and no middle or high clouds are visible. At this time downward motion is shown in the vertical time section.

TIROS III cloud photographs, which would give a good view of the area in which OSV C is located, were not available for this period.

A deep layer of upward motion follows again toward the end of 13 September, when Ship C comes under influence of a frontal wave disturbance. Surface observations at 13/1800 GMT and 14/0000 GMT show an overcast sky condition of low clouds and some precipitation is reported at 13/1800 GMT. The vertical motion computations would either imply that clouds extend to high altitudes or that additional middle and high clouds are also present above the reported overcast. Middle and high clouds as well as towering cumulus are reported at 14/1200 GMT and 14/1800 GMT.

Cloud photograph (h) (valid at 13/1532 GMT) show Ship C at the very edge of the picture, which makes consideration of the cloudiness surrounding OSV C in relation to the computed vertical motion pattern too uncertain.

A sharp rise in tropopause level, starting around 15 September, marks the arrival of a warm ridge of high pressure from the west. Downward motion is computed along the broad warm frontal boundary. Surface observations are consistent with this downward motion in that no middle or high clouds are reported.

Panel (b) in Fig. 42 shows the vertical motion patterns obtained by considering only the turning of the wind with height. Since

above 850 mb the stability term in Eq. (2) was always negative, a backing wind with increasing height corresponded to downward motion, while a veering wind with increasing height correspond to upward motion.

As in the analysis of Panel (a) in Fig. 42, only the 0000 GMT and 1200 GMT radiosonde observation winds have been entered. The veering of these winds with height indicate upward motion in the pre-frontal area at the beginning of the time period, which is in agreement with the upward motion on Panel (a). There is downward motion along the cold frontal boundary, but it extends to lower levels than is shown in Panel (a).

Downward motion (subsidence) is present under the low tropopause behind the cold front, but it does not extend throughout the troposphere, as is suggested by Panel (a). These discrepancies indicate that the local temporal change of temperature is a dominant factor near the cold frontal boundary.

There is generally good agreement between the patterns of up and down motion in Panel (a) and Panel (b) during the period 9 September to 16 September. However, toward the end of this time period there is some disagreement near the warm frontal boundary, where downward motion in the frontal boundary is only apparent above 500 mbs on Panel (b) compared to Panel (a).

In summation, the vertical time section of computed vertical motion at this station illustrates that the patterns of up and down motion correspond to the synoptic weather patterns affecting Ship C, and that they are consistent with the surface observations and the cloud cover in the few available cloud photographs.

Patterns of up and down motion were associated with a cold frontal passage, the near passage of a hurricane, and a frontal wave development. Marked downward motion was computed along a large portion of the cold frontal boundary at the beginning of the time period, and the broad warm frontal boundary towards the end of the time period. This is in agreement with previous investigations regarding the direction of vertical motion along frontal boundaries (see Serebreny, et al., 1962). All the synoptic features were associated with significant changes in the tropopause level.

Downward motion computed under the low tropopause near the beginning of the time period appears associated with an area of clearing seen in the cloud photographs. This relatively cloudfree area can be thought of as the eastern boundary of a convective cloud regime which develops in the northwesterly flow behind the surface cyclone center.

Patterns of vertical motion computed with Eq. (2) were reproduced quite accurately by considering only the turning of the wind in the vertical, except in areas where sharp frontal boundaries extended throughout the tropopause.

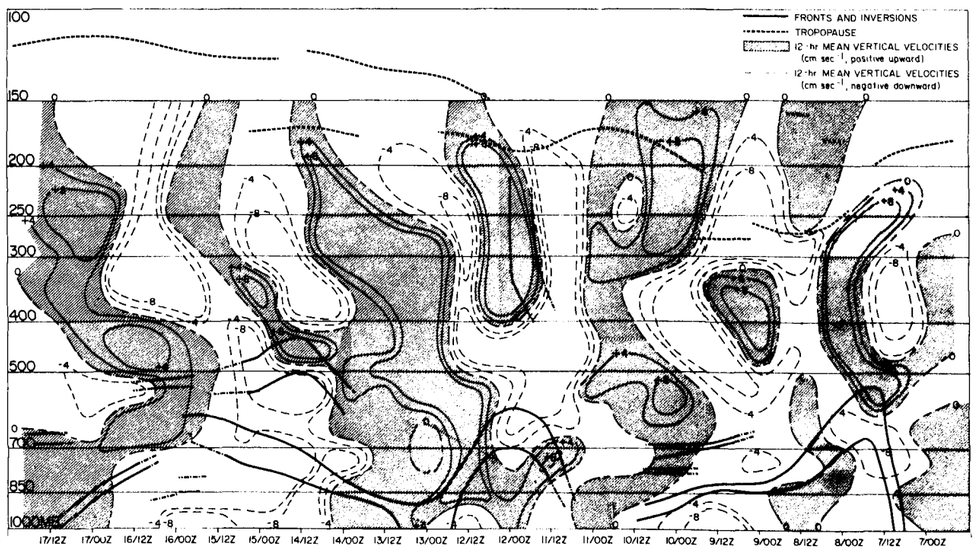
2. Ocean Station Vessel D (44.0N, 41.0W)

The vertical motion patterns for Ship D computed by evaluating both the local change of temperature and the vertical wind shear term are shown in Panel (a) of Fig. 43.

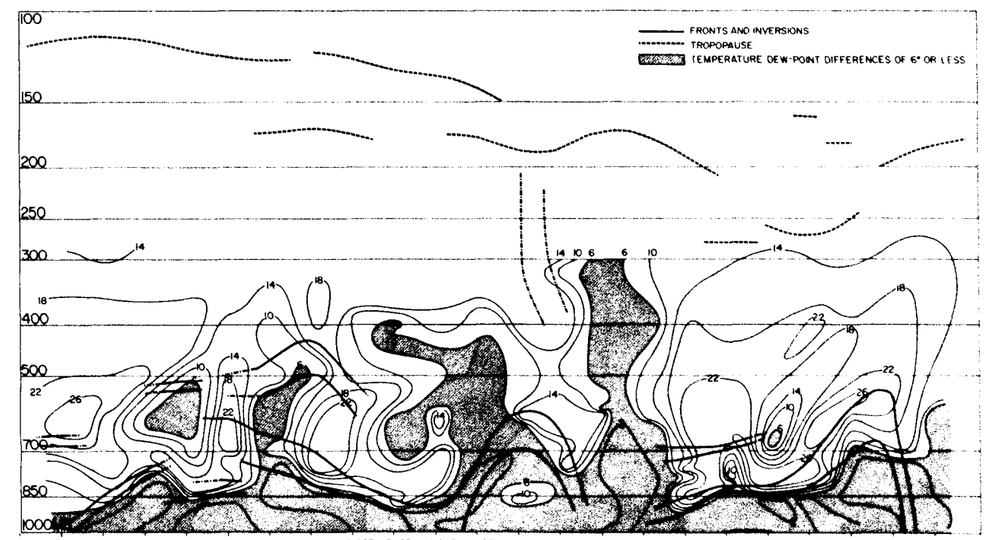
Soundings of Ship D, located approximately 8 degrees of latitude farther south than Ship C, does not show the sharp variations in tropopause height as did those at Ship C. However, the computer vertical motion patterns are identified with the same synoptic features.

The cold frontal passage near the beginning of the time period shows the same vertical motion distribution as in the case of Ship C, even though the cold frontal boundary is confined to the lower troposphere. There is downward motion in the frontal boundary, and upward motion again in the post-frontal area. This upward motion in the pre-frontal area is connected with a deep layer of upward motion in the upper troposphere.

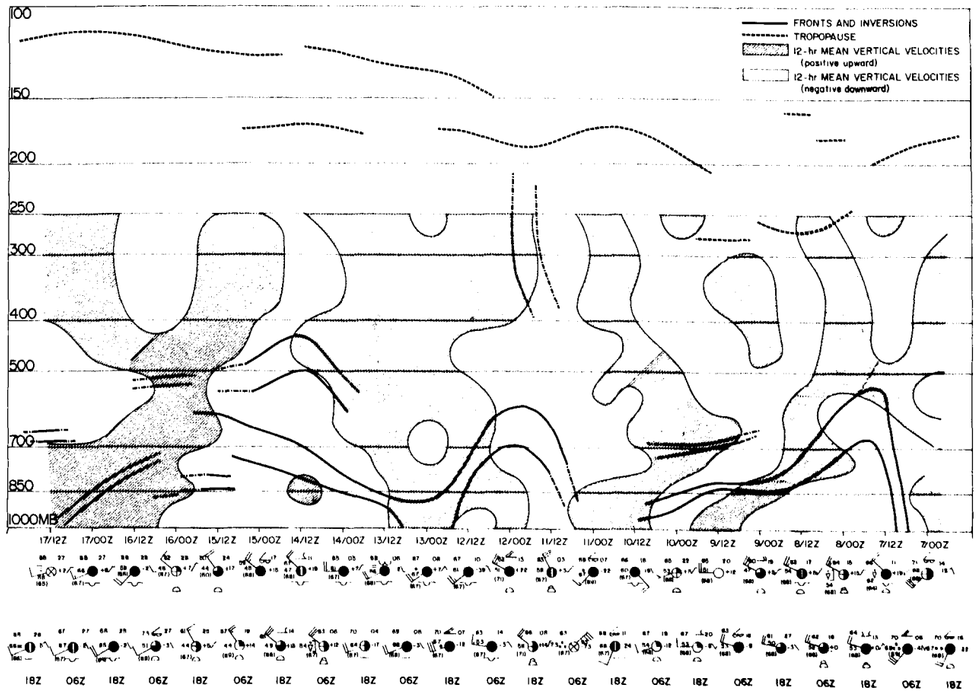
In the pre-frontal area the surface observations show continuous slight to moderate rain from thick, middle clouds. The effect of the downward motion computed along the cold frontal boundary is not reflected in the reported sky cover although the reported precipitation changes from continuous rain to rainshowers. The surface observation



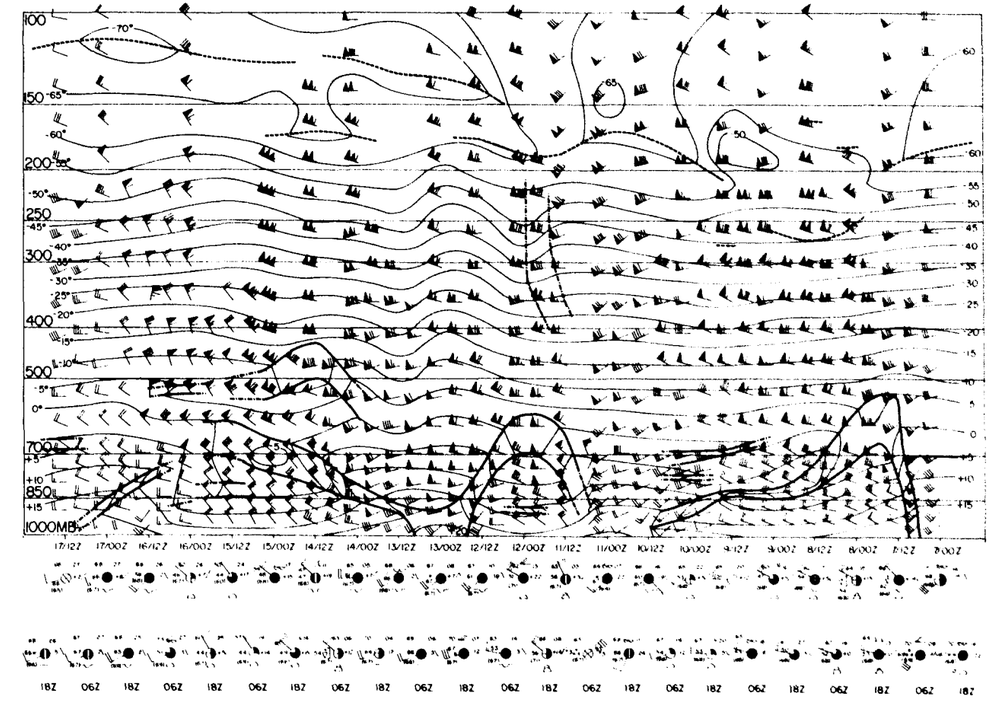
(a) Vertical Motion Considering Thermal Stability and Wind Shear



(c) Isopleths of Temperature Dew-point Difference



(b) Vertical Motion Considering Wind Shear Only



(d) Upper Winds and Isopleths of Temperature

FIG. 43 VERTICAL DISTRIBUTION OF SELECTED ATMOSPHERIC PARAMETERS AT OSV "D" (44.0N, 41.0W), SEPTEMBER 7-16, 1961. . . . . .

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at 8/0000 GMT reports only low clouds at which time there is a deep layer of upward motion computed in the upper troposphere.

A low tropopause is evident at 8/0000 GMT and this condition persists through 9/1200 GMT, accompanied by predominantly downward motion throughout the troposphere.

Except for two reports of high and middle cloudiness at 9/0000 GMT and 9/1200 GMT, the surface reports for OSV D indicate a tendency for decreasing cloudiness during this period of low tropopause and downward motion.

TIROS III cloud photographs a and c of Fig. 44 show the area in which Ship D is located. Picture (a) (valid at 7/1623 GMT) shows Ship D in the post-frontal area immediately to the southeast of a narrow cloudfree band and to the west of an extensive area of cloudiness, which represents the area of frontal and pre-frontal cloudiness, respectively.

Picture (c) (valid at 8/1648 GMT) shows Ship D at the southern edge of an extensive area of cloudiness, which can be seen to the north of the clear band in Picture (a). The vertical motion pattern for Ship D seems to support the possibility that the clear area signifies the eastern boundary of a low level convective cloud regime.

There is a lowering of the tropopause shortly after the time of Picture (a). At the time of Picture (c) the tropopause is still low, and downward motion begins to set in throughout most of the troposphere.

Thus, as was concluded for OSV C, the band of clearing shown in Picture (a) marks the beginning of a period of low tropopause, accompanied by downward motion throughout most of the troposphere. The extensive area of cloudiness, shown to the north of OSV D in Picture (c), can now again be interpreted as a low cloud regime which is developing due to convection in the cold air mass in low level, northwesterly flow.

Between 10 September and 11 September there is warm frontal activity associated with the passage of Hurricane Betsy to the south. A deep layer of upward motion is computed for this period. Panel (a) in Fig. 42 shows this layer of upward motion computed for OSV C about a day later. In both cases downward motion immediately follows the deep layer of upward motion.

Surface observations for OSV D show an overcast sky condition at 10/1200 GMT. At 11/0000 GMT intermittent slight rain is reported from an overcast of thick middle clouds. Six hours later the sky is obscured in continuous moderate rain. At 11/1200 GMT precipitation has ceased and breaks begin to appear in the overcast. Thus the surface observations are consistent with the pattern of computed up and down motion.

Cloud Picture (d) shows a large portion of the western Atlantic including the location of Ship D at 10/1721 GMT. The cloud mass associated with Hurricane Betsy is easily identified and approaches Ship D from the southwest.

Cloud Photograph (e) shows Ship D at 11/1644 GMT, when Hurricane Betsy has moved to the northeast and downward motion is computed throughout the middle and high troposphere. The clouds shown in this picture must be predominantly low clouds; this is confirmed by the surface reports. Numerous breaks are apparent in the cloud photograph in the extensive area of post-hurricane cloudiness. Unfortunately, the cloud photographs available for this study are of poor quality and not much more can be said, though, up till now, the cloud pictures have been consistent with the discussion of the vertical motion patterns.

The frontal wave development, mentioned in connection with a deep layer of upward motion computed for Ship C toward the end of 13 September, also affects Ship D and shows up as a deep layer of upward motion between 12 September and 13 September.

The upward motions computed between 13 September and 14 September are associated with the development of Hurricane Debbie to the south of Ship D. (Ship C appears to have been located too far north to have been affected by the upward motion pattern associated

with this hurricane.) The surface observations for Ship D show considerable low and middle cloudiness, with occasional slight rain between 12/0000 GMT and 14/0000 GMT. TIROS III cloud Photographs (f) and (g) show different angles of view of the area of Ship D at approximately the same time: 12/1600 GMT. On the time section of computed vertical motion, this time coincides with the beginning of a one-and-a-half-day period of upward motion throughout the troposphere. In both satellite cloud pictures, Ship D is seen to be located in an extensive area of cloudiness. Again the quality of the pictures is poor and no deductions about cloud type or cloud top height can be made. Only the presence or absence of clouds can be determined. However, in this latter respect the cloud photographs are consistent with the surface observations and the computed vertical motion pattern.

Between 14 September and 15 September, Ship D was found to be under the influence of a high-pressure area. Downward motion is shown on the vertical time section for this period. However, the surface observation at 15/0000 GMT, showing an overcast of thick middle clouds, is not consistent with the downward vertical motion computation. Since this reported middle cloud layer is not present in the observations 6 hours before and 6 hours after, it must, therefore, be attributed to a disturbance on a scale much smaller than considered in this study.

Panel (b) in Fig. 43 shows the patterns of up and down motion obtained by considering only the veering or the backing of the wind direction with height in Eq. (2). There is an excellent agreement between Panel (b) and Panel (a) with respect to the patterns of vertical motion. This excellent agreement is probably due to the fact that frontal boundaries are confined to the lower troposphere. Thus the possibility of the local temperature change carrying much weight in the computations is considerably reduced.

In conclusion it can be stated that, for both Ships C and D periods of up or down motion are associated with the large-scale synoptic features affecting these weather ships. The patterns of vertical motion are consistent with the surface observations and may even explain some general features in the cloud patterns shown in the TIROS III cloud photographs.

It also has been shown that, except near sharp frontal boundaries, the patterns of vertical motion as computed from Eq. (2) can be obtained by considering the turning of the wind in the vertical only, such that a backing wind with height corresponds to downward motion and a veering wind with height corresponds to upward motion. There is uncertainty near frontal boundaries, since in this case the local change of temperature with time can be large.

C. Comparison of the Patterns of Large-Scale Computed Vertical Motion and Temperature/Dew-Point Difference

The patterns of large-scale vertical motion, shown in Panel (a) Fig. 42 and Panel (a) Fig. 43 for Ships C and D, respectively, will now be compared with the patterns obtained from an analysis of the differences between temperature and dew point on the same vertical time-section.

Temperature/dew-point differences were taken from the individual radiosonde soundings at all levels for which both temperature and dew point were reported. Few dew-point data are available above 400 mbs.

Panel (c) in Fig. 42 shows the patterns as analyzed for Ship C. The shaded portion refers to temperature/dew-point differences less than 6°C. Except for the cold frontal area at the beginning of the time period, there is a good correspondence between patterns of vertical motion and patterns of moist and less-moist air as expressed through the temperature/dew-point difference. The temperature/dew-point differences are generally large during periods of computed downward motion; deep tongues of moist air (temperature/dew-point difference of less than 6°C) correspond to the deep layers of upward motion. Examples of the latter in connection with Hurricane Betsy (11 September, 0000 GMT) and the frontal wave development (13 September, 1200 GMT).

Relatively dry air (temperature/dew-point difference greater than 6°C) is found in the warm frontal boundary toward the end of the time

period throughout the entire layer where downward motion was computed. Downward motion is computed along the cold frontal boundary at the beginning of the period between 700 mbs and 400 mbs. However, it is accompanied by large temperature/dew-point differences only at 500 mbs and above.

The deep tongue of moist air associated with the frontal wave disturbance around 13 September lags the deep layer of computed upward vertical motion with respect to time. Some of this lag may be attributed to the fact that during this period geostrophic winds obtained from upper-air constant-pressure maps had to be used to compute the vertical shear term because of missing wind data on the radiosonde soundings.

Panel (c) on Fig. 43 shows the vertical time section analysis of the temperature/dew-point differences for Ship D. Again the shaded parts refer to differences less than 6°C.

The moisture patterns can again be compared with the patterns of computed vertical motion, shown in Panel (a) of Fig. 43. Deep layers of moist air are associated with the layers of upward motion computed for the periods 10-11 September and 12-14 September.

The moisture distribution connected with the cold front at the beginning of the period is not very consistent with the distribution of computed vertical motion. Here, the downward motion along the cold frontal boundary does not appear as a large temperature/dew-point difference. Similarly at 8/0000 GMT and 8/1200 GMT, even though vertical motion is computed throughout the entire troposphere, temperature/dew-point differences of 6°C or less are confined to levels below 700 mbs.

As in the case of Ship C, the layer of downward motion computed along the cold frontal boundary did not correspond with the layer of large temperature/dew-point difference (i.e., greater than 6°C). This lack of correspondence near the cold frontal boundary may be explained with a knowledge of the air parcel trajectories and the spatial field of vertical motion.

A layer of moisture is found in the mid-troposphere at 15/0000 GMT at which time the vertical motions were computed as downward. As was mentioned under the discussion of the vertical motion pattern, the surface observation for that time indicated an overcast of thick middle clouds. However, the absence of this middle cloud layer in the surface reports of 6 hours before and 6 hours after seems to suggest that the 15/0000 GMT observation reflected a disturbance on a scale much smaller than that for which the vertical motion computations are valid.

One can conclude that, except near frontal boundaries, there is a good correspondence between the patterns of upward and downward motion and patterns of moist and less moist air, respectively, where moist air is expressed as a temperature/dew-point difference of 6° or less.

Clouds are associated with layers of small temperature/dew-point difference and, by inference from the foregoing time sections, layers of upward motion are associated with cloudiness of large vertical extent and also with areas where the wind direction tends to veer with increasing height. Where no cloud is observed, there generally is downward motion and the wind direction tends to back with height. (These relationships between cloudiness and the turning of the wind direction with height are only valid on the scale of the vertical motion computations, i.e., on the scale of the geostrophic wind.)

Since a satellite cloud photograph displays large-scale clear and cloudy patterns in the troposphere, it provides a means of assessing on a given cloud photograph, at least qualitatively, the wind structure over a wide area with respect to possible veering and backing with increasing height.

Large-scale clear areas on satellite pictures may be considered as regions where downward motion is prevalent and where the wind would tend to back with increasing height. In areas of cloudiness a determination of the tropospheric layer through which the clouds extend would have to be made; where these are determined to be low clouds only, then downward motion and backing of the wind with height is most probable through most of the troposphere. However, when the large-scale cloud pattern is

determined to be thick clouds through a deep layer, then upward motion, accompanied by a veering of the wind with height, is most probable throughout the troposphere.

Once the vertical extent of the cloud fields is determined, either by very high resolution in gray-scale or concurrent satellite radiation data, then the subsequent deduction of the fields of backing and veering of the wind in the vertical could provide inferences concerning the upper wind flow pattern above the low tropospheric layer for which the flow direction would normally be known from land stations or ship reports.

For example, over ocean areas there are many more surface wind reports than upper wind reports and these are usually sufficient to establish the low-level wind flow to a reasonable degree. An analysis of the satellite cloud photograph, using the foregoing relationships, could provide some estimate of the direction of the upper wind flow.

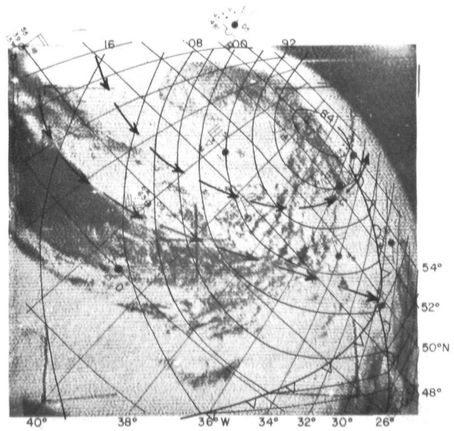
The following TIROS III cloud photographs in Fig. 44 can be used to illustrate the principles involved. Cloud Picture (a) was discussed earlier in connection with the vertical motion computations. It was concluded that the band of clearing, seen in this picture to the west of OSV C and OSV D, marked the eastern edge of a low-level cloud regime. This area of low clouds would most probably be an area of downward motion and a backing wind with height through most of the troposphere.

The sea-level flow pattern based on ship reports, indicates northwesterly flow. Since the low-level flow is northwest and the wind backs with height, the flow direction must become gradually more westerly as higher levels in the troposphere are approached. The direction of the 300-mb wind flow (superimposed on the picture) shows that this is the case; significant backing of the wind with height takes place.

Picture (e) presents a similar case for the area around Ship D in which low clouds are observed, indicating a backing of the wind with height. Cloud Photograph (d) shows extensive cloudiness in advance of Hurricane Debbie. The cloudiness has large vertical extent as can be deduced from the plotted surface reports. The 300-mb wind flow direction indicates a veering of the wind with height. Cloud Photograph (g) shows a large area of cloudiness in advance of a frontal-wave disturbance. Surface observations again show middle and high cloudiness in addition to the low cloud cover. A veering of the wind between sea level and the 300-mb level is found over this area of cloudiness.

Low clouds such as shown in Photographs (a) and (e) and thick prefrontal cloudiness such as shown in Photographs (d) and (g) could probably be identified with concurrent infrared radiation data. The general direction of low-level wind flow could be determined from an analysis of surface wind reports. Then a qualitative statement about the wind direction aloft could be made.

To determine from some given photograph exactly how much the wind backs or veers with increasing height requires further study. It would probably depend on the strength of the wind aloft (i.e., on the proximity of a jet stream and also on the areal extent of the cloudiness.



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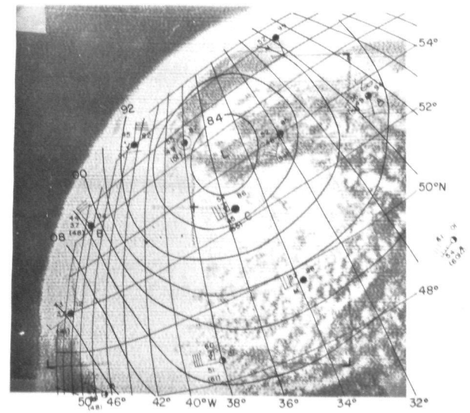

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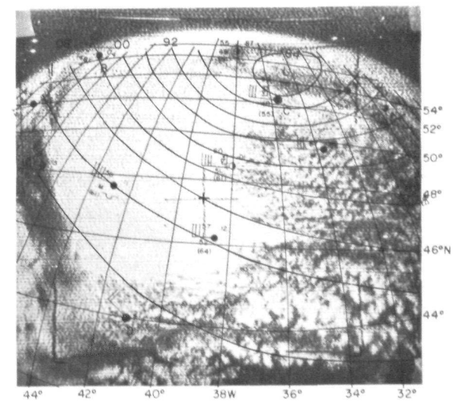

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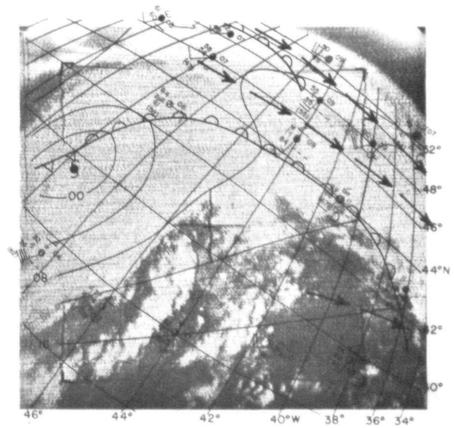

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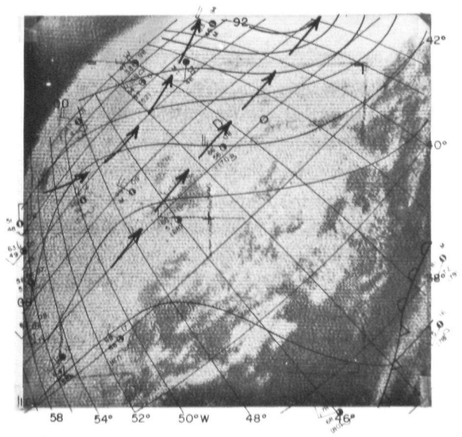
JET STREAM AXIS



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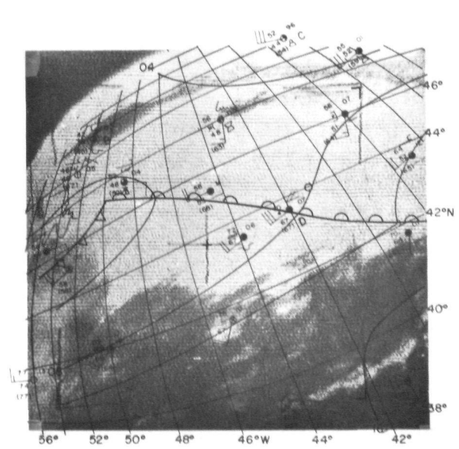

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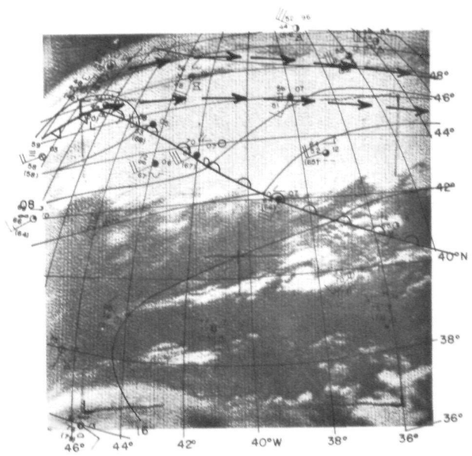

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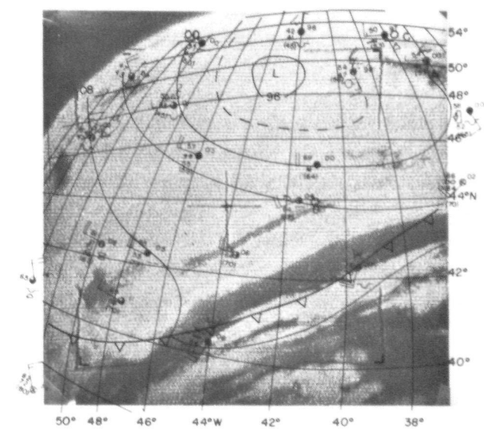

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FIG. 44 SELECTED SATELLITE CLOUD PHOTOGRAPHS SHOWING OSV "C" AND "D"

IV SUMMARY AND CONCLUSIONS

Photographs from the wide angle camera of TIROS III gave good day-to-day coverage of the gross cloud patterns, although the resolution of the pictures were poor. Between 7 and 11 September 1961, the synoptic weather situation in the North Atlantic was characterized by a slow moving large-scale low pressure cell and occluding frontal system. Between 12 and 16 September, the weather situation was highlighted by the entrainment of two hurricanes into the westerlies and culminated in a well-developed meridional circulation toward the end of the period.

Throughout the series there were three distinct synoptic regimes that produced unique large-scale cloud cover patterns, (see Fig. 45) as follows:

(1) Regime A--characterized by an occlusion in a mature state, a high-pressure cell south of the trailing cold front and a pronounced ridge east of the occlusion.

(2) Regime B--characterized by an old occlusion whose associated frontal system has moved eastward out of the primary circulation.

(3) Regime C--characterized by strong meridional flow between two frontal systems of about equal amplitude. A well-developed high pressure cell is north of the connecting cold front. There is no subtropical high pressure cell in the low latitudes.

Regime A is depicted by the synoptic examples of the 8th, 9th, 12th, and 13th September 1961. The generalized association of the cloud pattern and certain synoptic elements is shown in Panel (a) of Fig. 45.

For Regime A, dense cloud cover is concentrated along the cold front, with very broad pre-frontal cloud shield east of the occlusion and around the pressure vortex. This particular cloud pattern assumes a comma-like appearance. In some instances it is possible to observe a spiral arm structure in the clouds about the vortex. The width of the area of partial cloudiness in the post-frontal zone widens as the occlusion matures.

When the occluded stage is relatively young, the point of occlusion is found at about the same latitude as the clear northern periphery of the clear area downstream. This relationship is contained in the cloud model presented by Bergeron (1951) and by Serebreny, et al. (1962) in a study of TIROS I photographs in the Pacific. Apparently this is characteristic of a certain stage in the vortex development of an extra-tropical storm in the middle latitudes. Bergeron (1951) indicated in his model that this cloudfree "patch" is located between a point of occlusion and a surface high cell immediately downstream. On this day the cloudfree zone lies approximately midway between the point of occlusion and the ridge line.

The studies in the Pacific showed that this zone of clearing, while definitely present, was centered closer to the surface high pressure center than to the point of occlusion upstream and the northern edge of the clearing.

In the jet stream complex the northernmost jet stream is located near the southern periphery of the vortex cloud shield and recurves to the north, entering the dense cloud shield near the tip of the region of partial clearing. Even the southern jet stream is located northward of the cold front and crosses the dense frontal cloud band near the point of occlusion. The amount the jet stream penetrates the ridge downstream is a function of the amplitude and intensity of the ridge. As the ridge downstream builds, the jet stream has less penetration into the ridging area and sometimes is deflected northward completely around this area of ridging. An indication of the ridge amplitude is given to some degree by the amount of cloud coverage and patterns under the ridge. In general, large-amplitude ridges are populated by sparse cloud cover near the center and long, striations or breaks in the cloud cover in the north, due to the large subsidence taking place in the ridge. Most of the time these long striations are meridionally oriented.

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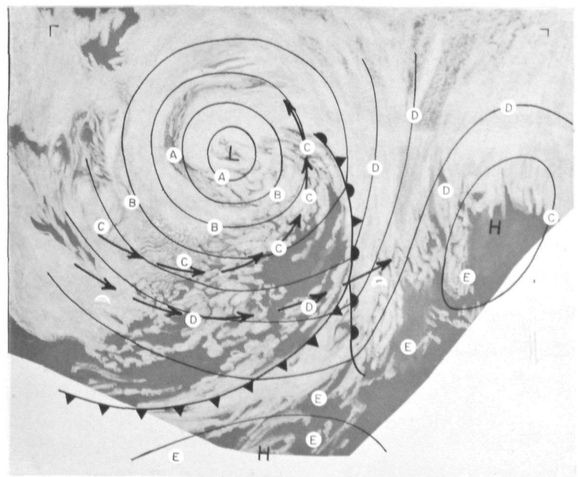
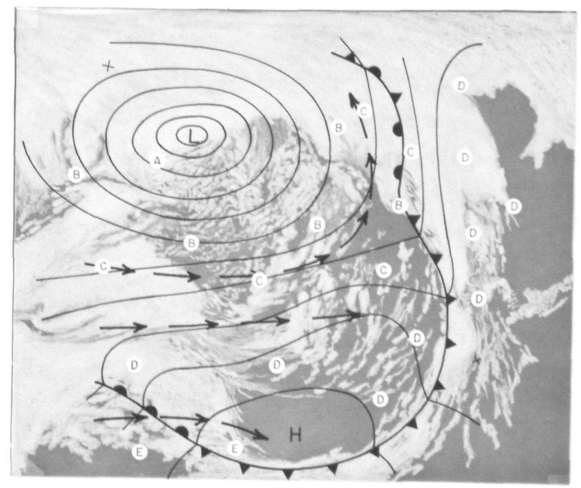
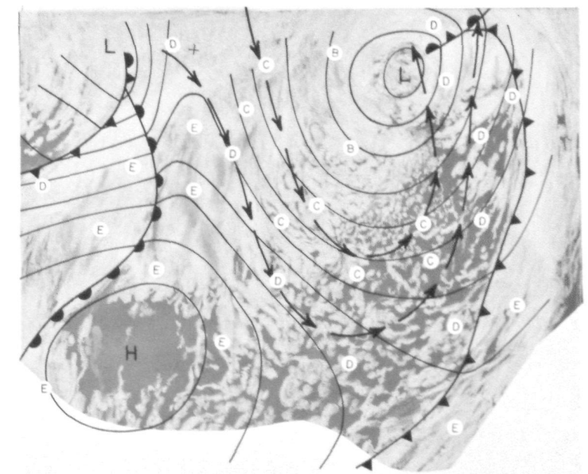


Pressure Regime A

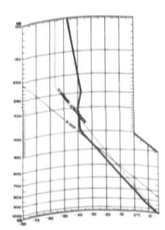


Pressure Regime B

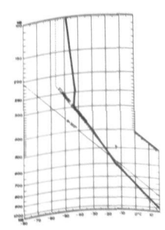


Pressure Regime C

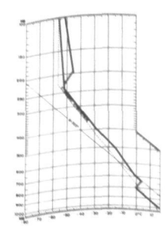
JET STREAM (300-mb)
SURFACE ISOBARS
A B .... E LOCATION OF GENERALIZED TEMPERATURE SOUNDINGS



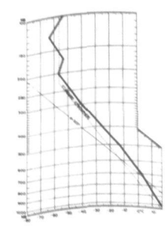
A



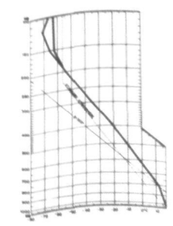
B



C



D



E

FIG. 45 DISTRIBUTION OF JET STREAM, TEMPERATURE SOUNDINGS AND CLOUD PATTERNS FOR SELECTED PRESSURE REGIMES - GENERALIZED

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Regime B is depicted by the synoptic situation of the 10th of September. Although it is a variant of the previous regime, it has certain significant differences. The pressure distribution shows a general relaxation of the gradient compared to Regime A, and the major axis of the pressure system shifts to an east-west orientation. Generalized features of this regime are shown in Panel (b) of Fig. 45.

The cold front has moved far enough south to be embedded in the anti-cyclonic circulation. The cloud distribution, in Regime B, shows less organization in the post-frontal area than in Regime A, although the vortex cloud does have a pronounced circular shape and the frontal cloud band remains identifiable. Post-frontal mottled clouds occupy the south half of the pressure vortex.

South of the low pressure center, both jet streams cross the post-frontal area of broken clouds. Their passage across this area is not characterized by any unique cloud arrangement. While the northernmost jet recurves to the north in the zone of major clearing behind the front, the southernmost jet stream terminates far short of the front itself.

Regime C is shown by the situations on the 15th and 16th of September. Features of this regime are shown in Panel (c), Fig. 45.

The circulation pattern for Regime C is somewhat akin to that used by Bergeron in 1951 when he presented his frontal cloud model. Pre-frontal overrunning around the vortex is quite extensive. The contrast between the frontal and post-frontal cloud patterns is rather marked. The mottled-appearing cloud area, characteristic of cumulus development in the cold post-frontal air, extends to rather low latitudes. In the area immediately north of the cold front where the depth of the cold air is shallow, the cloud elements appear rather large, characteristic of clouds of limited vertical development (stratocumulus). North of this zone, where the air is much deeper, the clouds present a smaller cell-like structure and are probably cumulus of greater vertical development. The center of the high pressure cell is generally free of clouds.

In this synoptic situation the upper trough lags the surface vortex and is centered over the mottled cloud field. The vortex cloud field in the post-frontal area extends to about the trough line. The pre-frontal clouds extend to the ridge line or a little beyond.

In this regime the jet stream complex lies over the northern portion of the pre-frontal clouds. It leaves these clouds north of the anti-cyclonic curvature in the isentropic flow about the pressure vortex. In the post-frontal area the northern jet stream in the complex lies over the small, broken cloud elements. These elements may be in streets or bands or may be chaotic in distribution. The southern jet stream also lies over these clouds but reaches its lowest latitude around the trough just to the north of the large clusters of stratocumulus behind the cold front. The jet stream complex on the east side of the long wave trough lies parallel to, but west of, the clouds along the cold front.

The various temperature soundings that were reported during the ten-day period were classified into five generalized categories, based, primarily, on the lapse rate configuration above the 300-mb level (see Fig. 45):

Type A--found in cold air, usually near the center of polar vortices and long wave troughs. The tropopause is generally located between the 400- and 300-mb levels, but may, on occasion, be found as low as the 500-mb level. The low levels may indicate inversions or isothermal layers.

Type B--found along, or just north of, the Maritime Arctic jet stream. In general, the tropopause is located about the 300-mb level, with isothermalcy or inversions above. If the sounding is within the wind maximum, the tropopause delineation is apt to be indistinct due to the presence of a frontal interface near the tropopause.

Type C--found over the Polar jet stream complex. The tropopause is found, approximately, at the 250-mb level.

with a pronounced inversion in the lower stratosphere--particularly at those times when the sounding is taken through the wind maximum. In the southern part of the jet stream complex there may be indications of a tropopause at the 150-mb level, as well. Since these soundings are in, or south of, the maritime Arctic jet stream, the lower levels of the soundings frequently display frontal inversions.

Type D--found at the subtropical side of the Polar jet stream complex, near the Polar jet stream. The tropopause is located at about the 200-mb level, although in some cases two tropopauses are evident: one at 200 mbs or lower, and another above the 100-mb level. In the latter instance, the lower tropopause is minor and depicted rather like a weak front (small inversion). It marks the leading edge of the subtropical air and is often found in ridges at fairly high latitudes.

Type E--found in subtropical and tropical air. The tropopause is located at or above the 150-mb level, for the most part, with the tropopause itself rather well-defined. In the low levels trade wind inversions are evident at stations in the low latitudes.

The distribution of these generalized soundings in the various pressure regimes are shown on Fig. 45. In general, temperature soundings of Type A and B were located over the broken cloud field of the post-frontal area. In the central and western portions of the pressure vortex, where the cold air is deep, the soundings are of Type A, rather moist conditions extend to moderate or high altitudes, and the typical cloud reported was "cumulus of vertical development." In the immediate post-frontal area where the cold air depth is shallow, the soundings are of Type B or C (depending on wave amplitude), and show high humidity only in the lower layers. Here the clouds are reported as cumuliform but of limited vertical development.

In the area of pre-frontal overrunning, where multiple decks of clouds prevail, the soundings are most often of Type C or D, with moisture in lower levels and again in upper levels, separated by drier air through the frontal interface. When pronounced meridional flow is indicated, as in Regime C subtropical air is thrust to high latitudes and may extend far over in the post-frontal clouds.

These tropopause/frontal-slope relationships are well known from previous meteorological experience. In cloud pictures the delineation of tropopause regime is dependent on identification of cloud character and cloud pattern--i.e., the ability to distinguish clouds of marked vertical development from those of limited vertical development. Some of this difference in vertical development is expressed in cloud pattern (viz., the large cumulus buildups are shown as larger clusters than, say, fair weather cumulus or stratocumulus). However, distributions of cloud patterns alone are not sufficient for use without consideration of cloud character, which requires pictures of high resolution, or perhaps infrared information. This area of meteorological interpretation needs further research.

In Sec. III, vertical time sections of the large-scale vertical motions computed with the adiabatic method, constructed from data at Ocean Station Vessels C and B show that patterns of up and down motion in the troposphere were related to the large-scale synoptic features found in the western Atlantic during the time period considered.

Except near frontal boundaries, the computations of vertical motion indicated that these tropospheric vertical motion patterns could be obtained by considering only the change of wind direction with increasing height, such that a backing wind with increasing height corresponds to downward motion and a veering wind with height corresponds to upward motion.

An analysis of the vertical distribution of the temperature/dew-point difference for the same period suggests that, as a first approximation, periods of computed upward motion coincide with periods of moist air, small temperature/dew-point difference (less than 6°C) while

periods of computed downward motion generally coincide with periods of large temperature/dew-point difference (greater than 6°C).

Since clouds are necessarily associated with layers of small temperature/dew-point difference, this study suggests that layers of cloudiness with large vertical extent are layers of upward motion, and also layers in which the wind direction tends to veer with increasing height. On the other hand, layers in which no clouds are observed can be thought of as layers of generally downward motion, and layers in which the wind direction would back with increasing height. This suggested relationship between cloudiness and change of wind direction with increasing height is, of course, only valid on the scale of the vertical motion computations; i.e., on the scale of the geostrophic wind.

Since satellite cloud photographs show the large-scale clear and cloudy patterns in the troposphere, they provide a means of qualitatively assessing the vertical wind structure over a wide area per given photograph. For example, large-scale clear areas on a given photograph may now be thought of as areas of downward motion, and also areas where the wind would tend to back with increasing height.

In areas of cloudiness a further analysis would have to be made to determine the tropospheric layer through which the clouds extend. When the satellite photograph shows low clouds only, then downward motion may be found throughout most of the troposphere with generally a backing wind with increasing height. However, when a large-scale cloud pattern is identified as consisting of thick clouds with high tops, then upward motion would persist throughout the troposphere, accompanied by a veering of the wind direction with increasing height.

In order to identify the vertical extent of the large-scale clouds shown on the cloud photograph, either a very high resolution in gray scale or concurrent satellite infrared radiation data would be required. Of the two radiation data would probably provide the most reliable tool.

Once the vertical extent of the clouds has been determined, the subsequent knowledge of the change of wind direction in the vertical could provide the large-scale wind-flow direction above a low tropospheric layer for which the flow direction is known. For example, over oceanic areas there are many more surface wind reports than upper-level wind reports. Thus, the general direction of flow in the lowest layers could be obtained from ship reports. An analysis of a satellite cloud photograph, in the manner suggested above, could then provide some qualitative estimate of the direction of the wind flow aloft, provided the satellite photograph is of sufficient resolution to depict the cloud patterns and character.

Since cloud systems derive from various synoptic scale weather entities, which move, impinge upon, and interact with one another, there is much to be said for obtaining satellite cloud coverage over as large an area as possible, so that these various major clouds systems can be identified and the correct meteorological interpretation made. Full coverage of this sort would be most necessary, if the cloud field only were being used as the basic analytic tool.

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