The Behavior of Jet Streams over Eastern North America during January and February 1948

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Abstract

A graph of the latitude of jet streams at 80° W longitude for a 49-day period in the winter of 1947—8 shows that the jet stream undergoes changes which appear as discontinuities on such a graph. Several cases are discussed which illustrate the manner in which these discontinuities appear. The new jets so formed then appear to experience a southward displacement before their disappearance. Accompanying the southward displacement at this longitude is a disappearance of the solenoidal field accompanying the jet in the lower troposphere, and an increase of the potential temperature in the center of the jet.

Introduction

Most previous detailed studies of the so-called "jet stream" (PALMÉN and NEWTON 1948, RIEHL 1948, HOVMÖLLER 1948) have been concerned primarily with the structure of the jet and its relation to other atmospheric phenomena *in selected situations*. However, even in some of these studies there are indications that the jet is not a simple phenomenon. PALMÉN and NEWTON (1948) averaged conditions at 80° W for selected cases, using the polar front as a moving reference point to obtain a meridional cross section. There is definite evidence on their mean cross section of a secondary wind maximum south of the primary maximum associated with the front — this in spite of their method of averaging, which would tend to suppress any but the primary maximum. There is also some evidence in RIEHL's study (1948) (e. g. fig. 2 b therein) of a double maximum of wind.

Some phases of this more complicated nature of the jet stream have been discussed recently by CRESSMAN (1950). He found that (at least during certain periods) there seemed to be a tendency for a hemispheric jet stream to move from high to low latitudes with a new current forming in the North as the previous maximum moved southward. He also found that there was a tendency for the individual jets to attain their maximum strength as they reached middle latitudes and to increase their elevation and potential temperature as they moved southward. The rate of southward progression was of the order of one-half degree of latitude per day.

In connection with an attempt to compute the transfer of energy from west to east across the longitude of 80° W, Dr. H. L. KUO and the writer analysed twice-daily meridional cross sections for that longitude for the 49-day

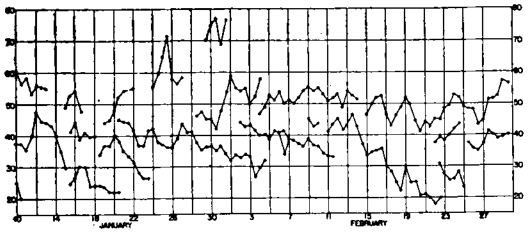

Fig. 1. Graph of the latidude of jets at longitude 80° W as a function of time for the period 10 Jan.—29 Febr. 1948.

period 10 January — 29 February 1948. These cross sections included an analysis of the wind field normal to the cross section, using both observed and gradient winds (geostrophic winds corrected for path curvature). Although the unavoidable errors in the energy transfer calculations rendered those computations meaningless, it was soon found that a southward shift of the wind maxima seemed to be indicated by the successive cross sections. Because of the interesting results uncovered by CRESSMAN at that time, it was decided to re-examine this material with CRESSMAN's results in mind. The continuity of the various maxima from day to day was then put on a more definite basis by further analysis and examination of the twice-daily 500- and 300-mb charts for the region of North America during the entire period. In some cases additional cross sections were analysed in other regions of the continent.

The latitudinal movement of the wind maxima at 80° W during the period is summarized in fig. 1. Each dot on this diagram represents the location of a jet at 80° W on the cross section for that time; solid dots are used where the existence and location of the maxima are relatively certain, open circles are used where the existence or location of the jets are less certain. Connecting lines are drawn between the dots when it appears from the cross sections and upper air charts that the individual wind maximum would have moved continuously from one position to another if charts had been available at very frequent intervals. It is to be expected that in some situations the continuity of the wind maxima between two successive 12-hr periods is difficult to determine; no connecting lines have been entered on fig. 1 in these cases. The most striking fact shown on the graph is the predominance of a double wind maximum throughout the period. During some periods there are three or even four jets, but these periods are relatively short-lived. Another feature of the chart is a tendency for some of the systems to gradually move southward, ultimately disappearing at low latitudes. The three most regular of these are the jets which disappear on February 4, 12, and 23.

An examination of the 300- and 500-mb charts indicated that the appearance of new wind maxima at 80° W was often associated with the development of large disturbances to the west. Furthermore, a comparison of the movement and location of the jets with the frontal systems on the surface weather chart indicated that a close connection between the two often existed in the sense that each of the successive jets tended to be associated with an individual polar front in the vicinity of the Atlantic coast of North America. The remainder of this article will be devoted to a description of these phenomena as illustrated by several of the more clear-cut cases.

The period 21 Jan.—4 Feb.

This period begins with the appearance at 80° W of a new maximum at about 45° N. This maximum subsequently moves southward and disappears by the end of the period at about 30° N. Fig. 2 contains schematic diagrams showing the relative location of the surface frontal systems and the principal jets at various intervals during this 15-day period. On January 21st the newly formed weak wind maximum at 80° W is seen to be closely connected with the unusually well-developed "arctic front" in the middle of the continent.[1] The "older" jet to the south is seen to be associated with a weak frontal system on the surface. By January 23 the southern frontal system has become very weak on the surface weather chart, and the arctic front now contains the principal contrast between the cold continental air and the warm sub-tropical air — i. e. the arctic and polar fronts are merging into a new strong polar front. This is shown in

[1] The name "arctic front" is commonly used by American meteorologists to denote the (usually) shallow frontal system found in winter between the extremely cold surface air over the northern part of the continent and the more temperate polar air (often from a maritime source) to the south.

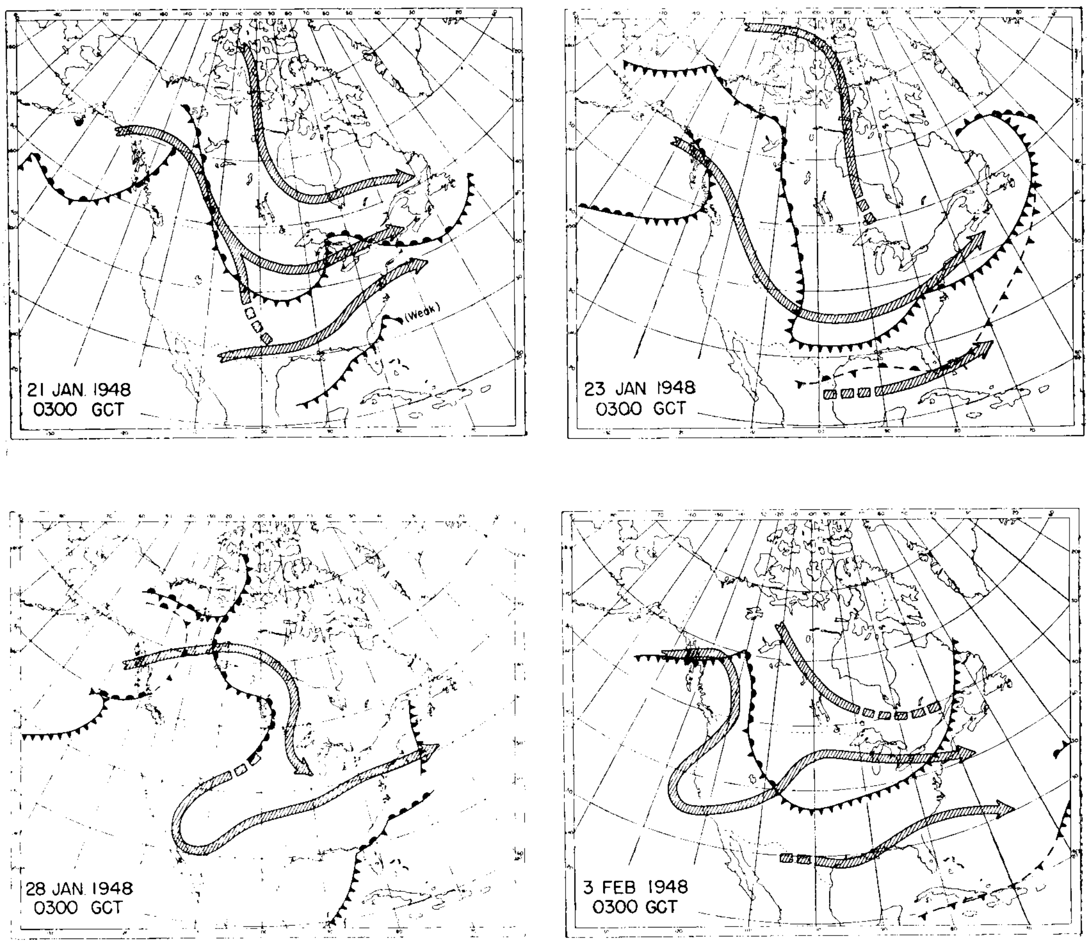

Fig. 2. Location of jet streams and surface frontal systems 21 Jan.—4 Febr. 1948. A jet stream is indicated by a hatched arrow, broken segments of the arrow indicating a diffuse jet. Conventional symbols are used to indicate the surface frontal positions.

the cross section for 1/23/0300 (fig. 3)[1]. This cross section shows definitely the existence of two wind maxima and shows particularly well the essential difference in the structure of the two systems. The southern jet, associated with a frontolysing surface frontal system, has its solenoidal field well developed only in the middle and upper troposphere, while the intensifying jet to the north has a greater portion of its solenoidal field in the lower troposphere.

The southern jet disappears at 80° W shortly after 1/23/0300 and on Jan. 28 there is only one jet stream with its associated front crossing the meridian. The jet and the front are very strongly developed, as shown in the corresponding cross section in fig. 3. The schematic chart in fig. 2 for 1/28/0300 suggests that the strong current entering the continent from the Gulf of Alaska will no longer flow around the trough in the southwestern United States but will cross the 80th meridian as a current distinct from that now crossing the longitude. This does occur and several days later a deep disturbance again develops in the western part of the United States (as shown on the schematic chart for 2/3/0300) with a new

[1] For brevity, a symbolism such as "1/23/0300" will be used to denote the date and time of a chart, the quoted figures referring to 0300 GCT on the 23rd of January.

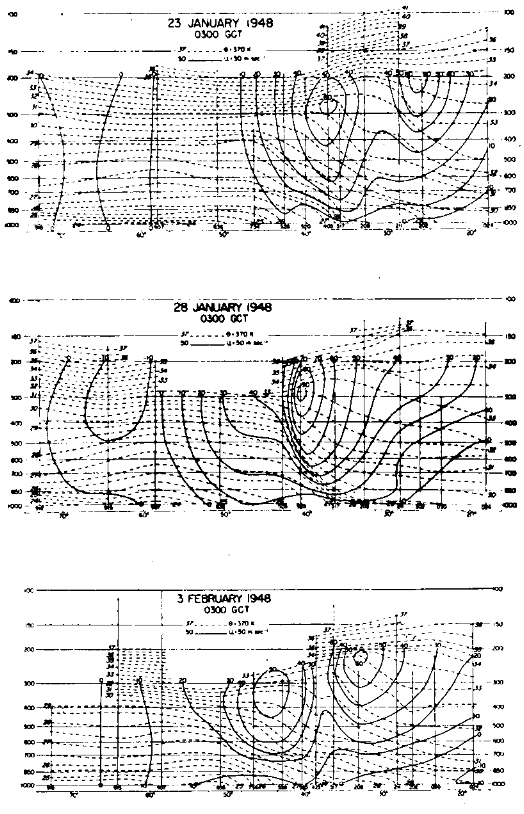

Fig. 3. Meridional cross sections at 80° W for 1/23/0300, 1/28/0300, and 2/3/0300 1948. Isentropes are entered in dashed lines, isolines of zonal wind speed in solid lines. Straight vertical lines show the location and height of the ærological soundings used in the analysis.

jet crossing the 80th meridian. In the meantime the jet and frontal system shown so well on the cross section for 1/28/0300 have moved southward and their intensity has decreased. However, a new Atlantic polar front is in the process of being formed by the frontal system associated with the new jet stream and a new cycle is beginning. In this light the general similarity of the cross sections and schematic charts for 1/23/0300 and 2/3/0300 is rather striking.

The synoptic events indicated in a rough manner by the schematic charts and cross sections in figs. 2 and 3, and their correspondence to the type of synoptic development frequently found in eastern North America, suggests that there is often an intimate relation between the formation and southward displacement of the jet at this fixed longitude and the southward displacement and subsidence of a mass of cold air in this region. The example described here took rather long (two weeks) to go through a "cycle". It is not believed that this case is necessarily representative in this respect; there are indications in the remainder of the period studied that the same process may occur at other times on a smaller and more rapid scale (and therefore more difficult to detect). It is also not suggested that the same sequence of appearances, displacements, and disappearances of a jet stream would be encountered at all longitudes in the same manner (e. g. a chart corresponding to fig. 1 for the meridian of 120° W would have been quite different from that for 80° W during this 49-day period).

The variations of potential temperature in the center of this jet are summarized in the top portion of fig. 4. There is a definite tendency for the current to be found at higher potential temperatures as it moves southward, although superimposed on the general trend are rather pronounced short-period fluctuations, the result of either errors in analysis or actual short-period changes in the jet at 80° W. If these latter are present, they are presumably connected with disturbances which are not sufficiently intense to appear as discontinuities

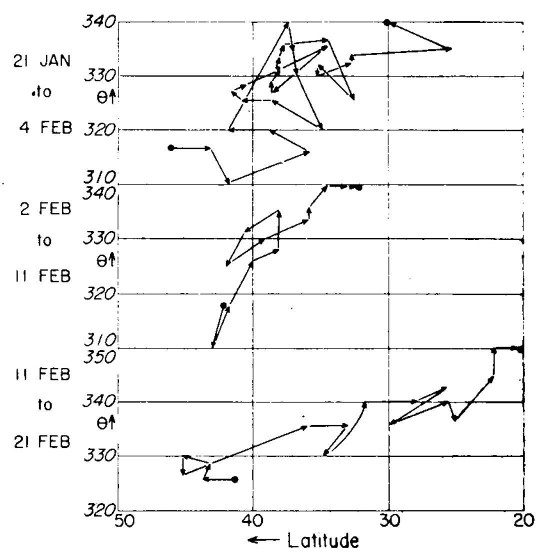

Fig. 4. Potential temperature (degrees Absolute) in the center of three jets at 80° W as a function of latitude of the individual jet. Each arrow represents either 12 or 24 hours.

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of the jets on fig. 1. Some suggestion of the reality of these short-period fluctuations is contained in the first part of the recent article by BERGGREN, BOLIN, and ROSSBY (1949).

The latitudinal shear (anticyclonic) of the zonal wind along the isentropic surfaces to

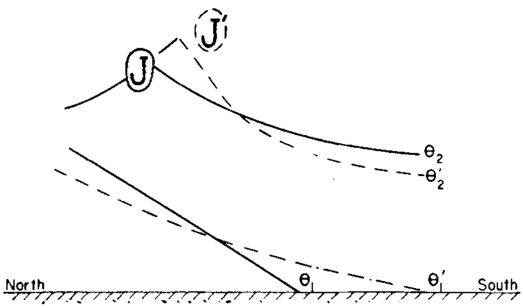

Fig. 5. Deformation of isentropic surfaces accompanying a shift of a jet to higher potential temperature.

the south of the jet in many of the analysed cross sections reaches a magnitude almost equal to that of the Coriolis parameter. Professor C.-G. ROSSBY has suggested to the writer that this may perhaps have something to do with the movement of the jet to higher elevations and potential temperatures. The process is indicated schematically in fig. 5. The near approach to inertia instability immediately to the south of and below the jet would presumably imply a greater freedom of meridional movement along the isentropic surfaces in this region than in the region farther to the south where the isentropic surfaces are more horizontal. If this meridional movement is primarily northward, the resulting net transport of air along the isentropic surfaces would tend to deform them in the manner indicated in fig. 5, and, *ceteris paribus*, cause a movement of the jet to a higher potential temperature. A study of the several cross sections reproduced in fig. 3 shows that the isentropic surfaces have been deformed in this manner (e. g. the surfaces $\Theta = 295$ and 310) but the importance of these meridional motions and their associated vertical motions in producing the observed isentropic deformation at a fixed longitude is impossible to decide until the effects of longitudinal (zonal) advection and non-adiabatic processes are eliminated. Unfortunately this is virtually impossible at the present time.

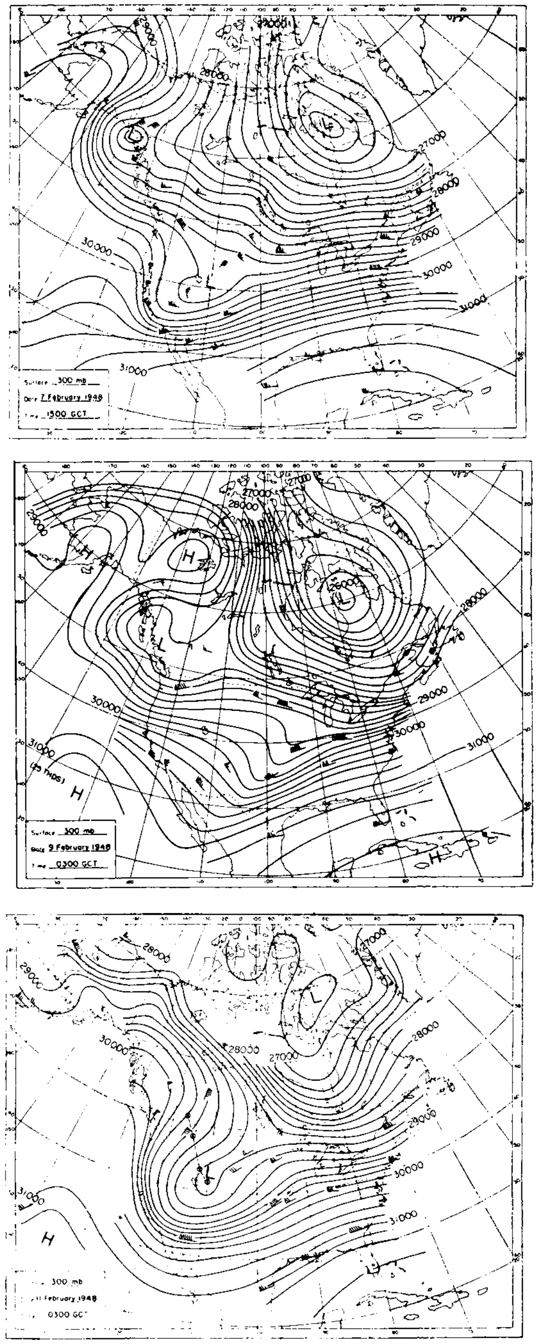

Fig. 6. 300-mb charts for 2/7/1500, 2/9/0300, and 2/11/0300 1948. Contours are for 200-ft intervals. Observed winds at this level are plotted with the following convention: solid triangular barbs = 50 mi hr^{-1}, full straight line barb = 10 mi hr^{-1}, half straight line barb = 5 mi hr^{-1}. Observed winds at a level 5000 ft lower are indicated by open triangular barbs.

The period 7—22 February

At the beginning of this period a new jet stream made its appearance at longitude 80° W at about 45° N (fig. 1) and subsequently moved southward and finally disappeared. However, the relation between the jet and the polar front on the surface was not as simple as in the case described above. The outbreaks of arctic air associated with the new jet occurred over the western part of the United States and therefore there was no replacement of the previous Atlantic polar front on the surface by a new frontal system at the beginning of the period. Also, the jet maintained its existence at a southerly latitude for some time after the surface frontal system had disappeared.

Fig. 6, containing the 300-mb charts for 2/7/1500, 2/9/0300, and 2/11/0300, shows rather clearly how the appearance of the new jet at 80° W was closely associated with the development and southward movement of a cyclonic vortex over the western part of the continent. In this type of development the cold arctic air in the lower levels is brought far to the south over the region of the Southwestern United States and occasionally even into California. This is apparently the reason why the behavior of the surface polar front over eastern North America did not correspond to that during the earlier period described above. The cross sections for the 9th and 11th of February (fig. 7) show the development of the new jet (very weak at 2/9/0300, 45° N — stronger at 2/11/0300, 40° N) and the weakening of the previous maximum (strongly developed at 2/9/0300, 39° N — barely discernible at 2/11/0300, 34° N).

The 300-mb charts for 2/9/0300 and 2/11/0300 seem to indicate that the new jet at 80° W is continuous with the strong current curving anticyclonically over Alaska. The 300-mb chart for 2/12/0300 (fig. 8) shows that this connection has been broken and the jet at 80° W will in the future be more connected

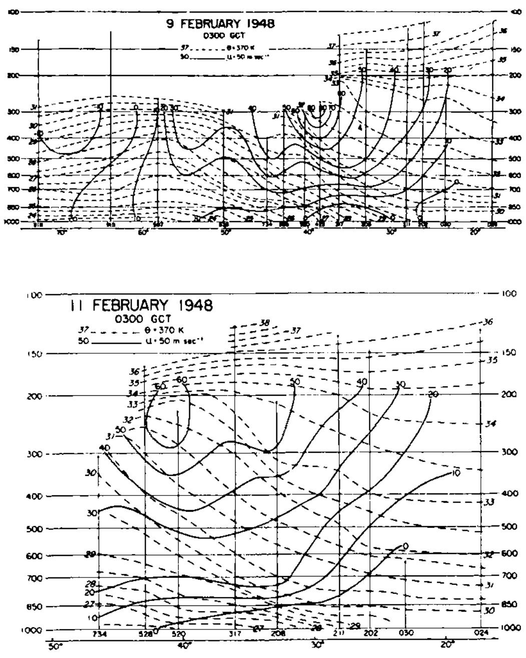

Fig. 7. Meridional cross sections at 80° W for 2/9/0300 and 2/11/0300, 1948. (See legend to fig. 3.)

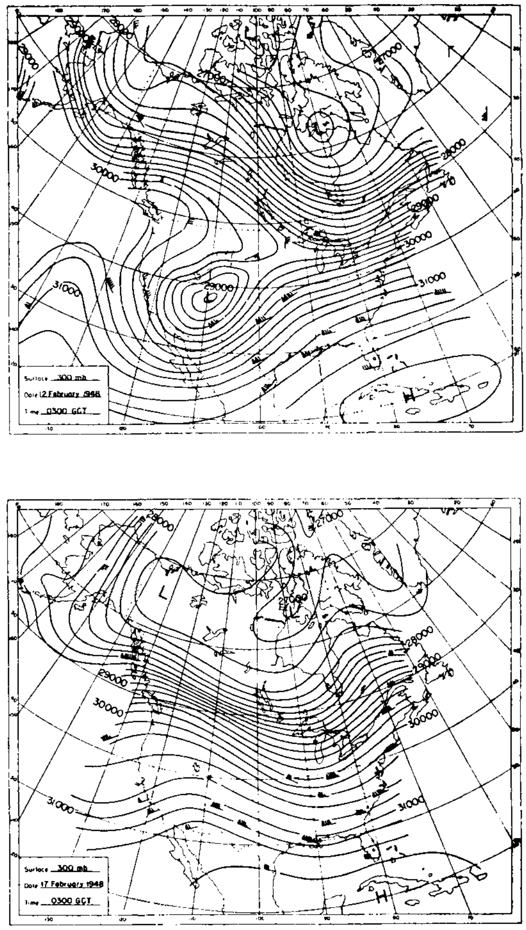

Fig. 8. 300-mb charts for 2/12/0300 and 2/17/0300, 1948. (See legend to fig. 6.)

with what appears to be another current in the Pacific, south of the current in the Gulf of Alaska. Scattered wind and radiosonde reports from the Pacific (not reproduced) indirectly support this conclusion — which on the reproduced 300-mb charts for 2/12/0300 rests rather heavily on the single ship rawin west-southwest of San Francisco.

The cross section along the 80th meridian for 2/12/0300 (fig. 9) is interesting in that it is taken in a region of pronounced *confluence*, which according to NAMIAS and CLAPP (1949) is of some importance in the development of jet streams. In this respect it is interesting to note that the 300-mb chart for 2/12/0300 shows that the two jets exist upstream of the confluence region in as fully developed a state as they do in the confluence region.[1] Hydrostatically this requires a more-or-less longitudinally-constant cross stream temperature gradient in each current (in the middle and lower troposphere). Synoptically this in turn requires the southern jet in its southernmost position to flow around a cold low (trough) and the northern jet in its northernmost position to flow around a warm high (ridge). In the writer's opinion these conditions are usually found in cases of pronounced confluence. This suggests that the conclusion of NAMIAS and CLAPP that confluence necessarily causes an increase of the temperature gradient rests on a streamline-isotherm relationship which in many cases differs *in the essential features* from the streamline-isotherm relationship actually existing in regions of confluence. In other words, the process described by NAMIAS and CLAPP may actually occur in the atmosphere, but the conditions for its occurrence need not always exist in regions of streamline confluence.

The 300-mb chart for 2/17/0300 (fig. 8) shows that at this time there were still two maxima existing across the continent, in agreement with the indications of the chart for 2/12/0300. The existence of the southern current between 30° N and 35° N is also borne out by rawin reports at higher levels from stations in that latitude belt, these winds being stronger than those reported in the latitude belt 35—40° N. The cross section for 2/17/0300

[1] A computation of the mean gradient wind at the 300-mb level shows that in both currents the values are the same ($\pm$ 2 m sec^{-1}) before (over the western part of the continent) and at confluence (80° W).

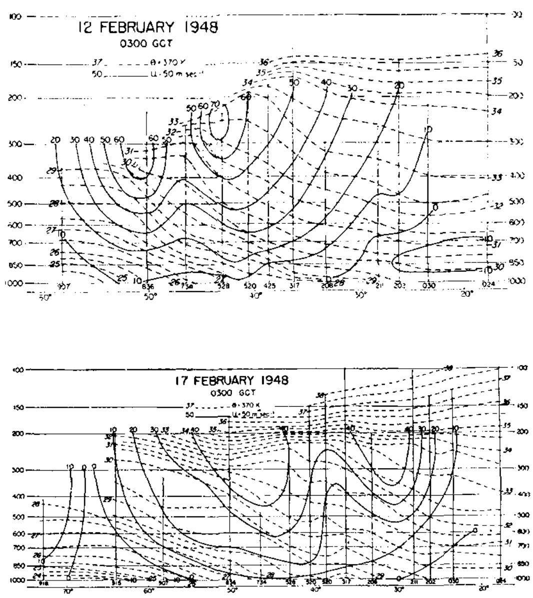

Fig. 9. Meridional cross sections at 80° W for 2/12/0300 and 2/17/0300, 1948. (See legend to fig. 3.)

(fig. 9) shows that the same changes have occurred in the structure of the southern jet since its first appearance at 80° W on the cross section for 2/9/0300 that occurred in the case of the jet studied above for the period 21 Jan. —4 Feb. However, the solenoid field in the lower troposphere associated with the southern jet on the cross section for 2/17/0300 seems to be somewhat stronger than the almost non-existent solenoid fields in the lower troposphere which accompanied the earlier jet in those latitudes (fig. 3). The surface frontal system which was associated with the jet as it developed in this case disappeared by the 15th of February.

The movement of the southern maximum between 2/17/0300 and 2/21/0300 was not as clear as it had been up until this time, but at 2/21/0300 there were still two maxima in existence, as shown by the 200-mb chart for that time (fig. 10) The general zonal orientation of the contours south of 30° N in this figure indicates, in an indirect and qualitative manner, that the current shown on that figure and on the cross sections in fig. 11 is not a local phenomenon but probably exists over a wide band of longitude. Unfortunately no observations were available to test this at other longitudes. However the 500-mb charts

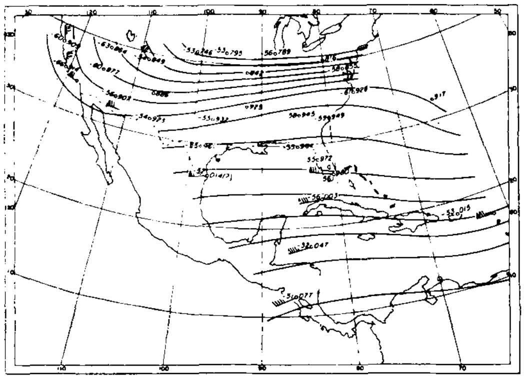

Fig. 10. 200-mb chart for 0300 GCT, 21 February 1948. Winds are plotted as stated in the legend to fig. 3 except that the winds for Havana (23° N, 82° W) and Swan Island (17° N, 84° W) are winds at 40 000 ft (~ 200 mb) and 35 000 ft (~ 250 mb) respectively, at 1500 GCT on the 21st (12 hrs after map time). Observed heights of the 200-mb surface are plotted in tens of feet with the first number (either 3 or 4) omitted, e. g. 003 = 40 030 ft. The observed height of 40 140 ft at Brownsville was considered incorrect. Temperatures are also plotted in °C; height reports unaccompanied by temperature reports are extrapolations made where the sounding terminated between 250 and 200 mb.

reproduced in the article by BERGGREN, BOLIN, and ROSSBY (1949), some of which are for this same period, indicate that a double maximum would also be found in the vicinity of the Greenwich meridian. Because of the low latitude, geostrophic wind computations are very

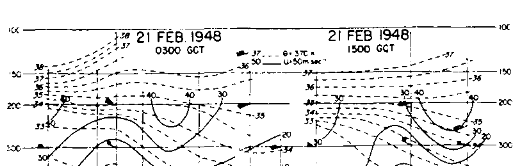

Fig. 11. Meridional cross sections at 80° W for 0300 and 1500 GCT, 21 February 1948. Winds are plotted in mi hr⁻¹ (see legend to fig. 6). West winds are plotted horizontally as if coming from the North.

sensitive to small errors in the pressure field and therefore too much reliance cannot be placed on the numerical value of either the maximum speed in the center of the jet of fig. 11 or on the horizontal shear indicated by the isolines of *u*. To demonstrate that the existence of the current on the maps and cross sections does not depend on the existence of a systematic error in the observed pressure field, observed pibal and rawin reports have been included on the cross sections for 2/21/0300 and 2/21/1500 in fig. 11. The geostrophic (gradient) and observed winds are in fair agreement except for the last wind observation reported above Managua (085) at 2/21/0300. No trace of this southern current could be found after 2/22/1500. The continued existence of this jet for a week after the surface frontal system had disappeared (in contrast to the case of Jan. 21—Feb. 4) agrees with the observation that this jet was reinforced, so to speak, by the existence in the Pacific of a strong current at low latitudes.

The variation of the potential temperature in this jet is summarized in the lower portion of fig. 4, which shows the same type of variation of potential temperature as did the jet of 21 Jan.—4 Feb. A similiar graph for the jet which moved southward during the period 2 Feb.—12 Feb. shows the same changes.

It appears likely from the time scale indicated by fig. 1 that the phenomena represented thereon are not identical with those reported by CRESSMAN (1950). In the writer's opinion the southward displacement of hemispheric jets reported by CRESSMAN to occur during some periods must in some fashion be the statistical result of the processes shown in fig. 1 occurring at several longitudes around the hemisphere more-or-less simultaneously.

Acknowledgment

The writer wishes to especially acknowledge the large contribution made by Dr H. L. KUO with his participation in the primary phases of this project.

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