Quasi-periodic Cyclogenesis in Relation to the General Circulation

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Abstract

A striking case of recurring cyclogenesis at ten day intervals during February 1953 with a tendency to continue until mid-May has been studied against the background of the planetary circulation averaged over periods up to thirty days. The data suggest a periodicity-producing mechanism whose period may be defined by the underlying long period (e.g., 30-day) mid-tropospheric wave pattern.

In this particular case the patterns of waves observed on 5-day mean charts oscillated about certain more stable centers of action in a manner consistent with vorticity considerations. These oscillations recurrently deployed continental polar and maritime tropical air masses into juxtaposition and set the stage for cyclone growth. The movement and development of these cyclones strengthened the westerlies, thereby temporarily permitting increase of the planetary wave length. After the energy of thermal contrast was tapped and the cyclones moved off or filled, the regional westerlies declined leading to long wave retrogression and the initiation of the cycle anew.

The annoying "change in phase" which has beset workers in periodicity for years is shown to be associated with abrupt though logical rearrangements of the mean planetary circulation incident to change of season.

1. Introduction

The search for periodicity in meteorological elements has commanded the attention of many research workers during the past century. Because of the obvious application of such studies to extended forecasting many papers on the subject are listed in the Bibliography on General and Extended Forecasting published in the January 1951 issue of the American Meteorological Society's Meteorological Abstracts and Bibliography. While most of these papers appear to be empirical and the authors try to unravel the tangled skeins of nature's records, some attempts have been made to compute from theoretical considerations natural periods of oscillation in the atmosphere. In such oscillations the atomospheric envelope, once disturbed, presumably fluctuates about its normal in a rhytmic manner. SHAW (1936) has aptly termed this phenomenon "resilience".

In spite of the numerous researches on periodicity over the past century, the only periodic phenomena which are unqualifiedly accepted by meteorologists the world over, and which appear to be capable of physical explanation and detection year in and year out are the diurnal and annual cycles. Other so-called periods, while seemingly valid for limited time intervals, have a distressing way of failing when examined in the light of new samples of data. These failures are often attributed to "change of phase," a convenient phrase in any periodologist's vocabulary.

The tendency to recurrence of synoptic weather map patterns for differing time intervals led the Russian School (PAGAVA, 1940) to define a "natural periodicity". This "natural period" is not a fixed interval of time in the usual sense, – rather, it is an interval during which the lines of synoptic activity (the tracks of cyclones and anticyclones, for instance) are much the same. The interval, or natural period, may last for five, six, seven or even up to sixteen days, after which another type of activity takes place and lasts about the same length of time as its predecessor. During one so-called "synoptic season", however, the interval of common synoptic activity tends to remain about the same, changing abruptly by two days or more with the onset of another "synoptic season". This is apparently another way of expressing the "change of phase", and presumably indicates that some new impulse or feature has been added to or subtracted from the circulation that formerly was not of importance.

Fresh interest in periodicities has been evoked by the striking weekly recurrences in rainfall pointed out by LANGMUIR (1950, 1953), who attributed them to periodic cloud seeding, and by subsequent work or BRIER, HALL (1950) and HAWKINS (1952), who revealed 7-day periodicities for intervals during which no comparable periodic cloud-seeding was performed. The lay public is occasionally aware of periodic weather phenomena before the forecaster, who may be overly preoccupied with the daily weather map.

The author's interest in periodicity stems largely from long experience in making 5- and 30-day forecasts of general circulation and weather, for in this work one cannot escape the fascination of recurring weather regimes (NAMIAS, 1953). Since 30-day mean maps of atmospheric circulation characterize quite effectively the average and prevailing weather of the month, it is possible that the length and character of atmospheric periodicity are closely associated with the patterns of the general circulation. In such a case the underlying planetary circulation depicted by a mean over a period of a month or so, may not only reflect or predetermine the paths and behavior of

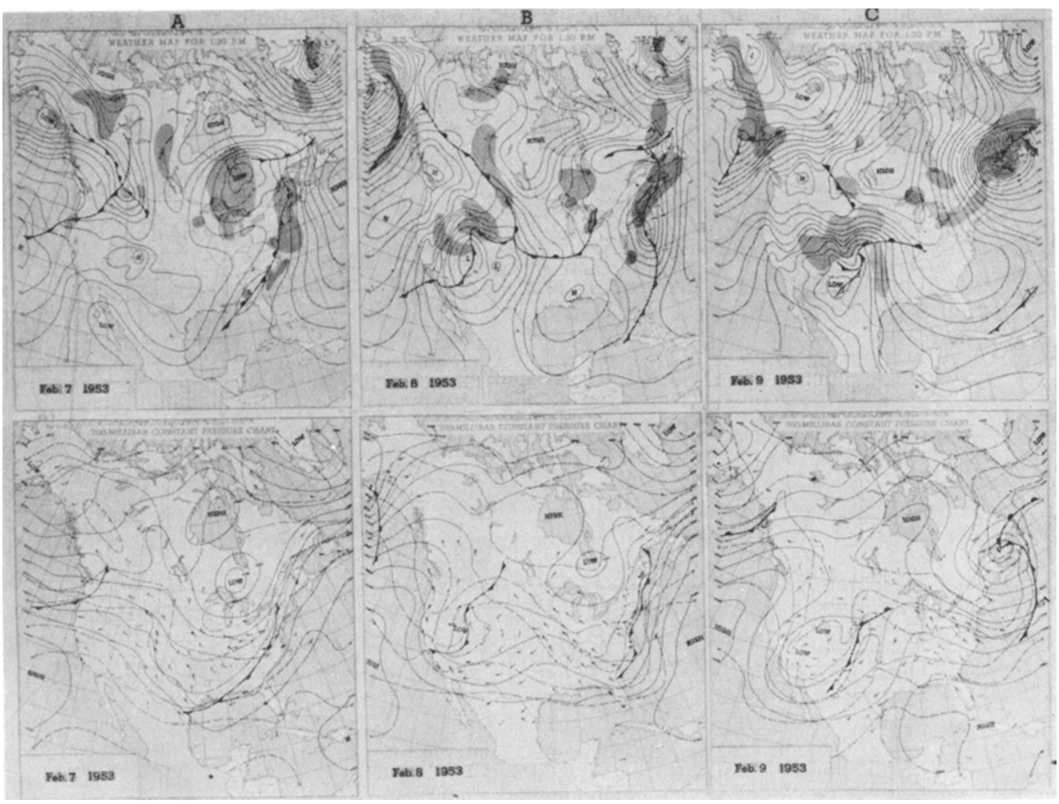


Fig. 1. Sea level (upper) and 700 mb (lower) charts for 1830 Z and 1500 Z respectively on 7, 8, and 9 February 1953.

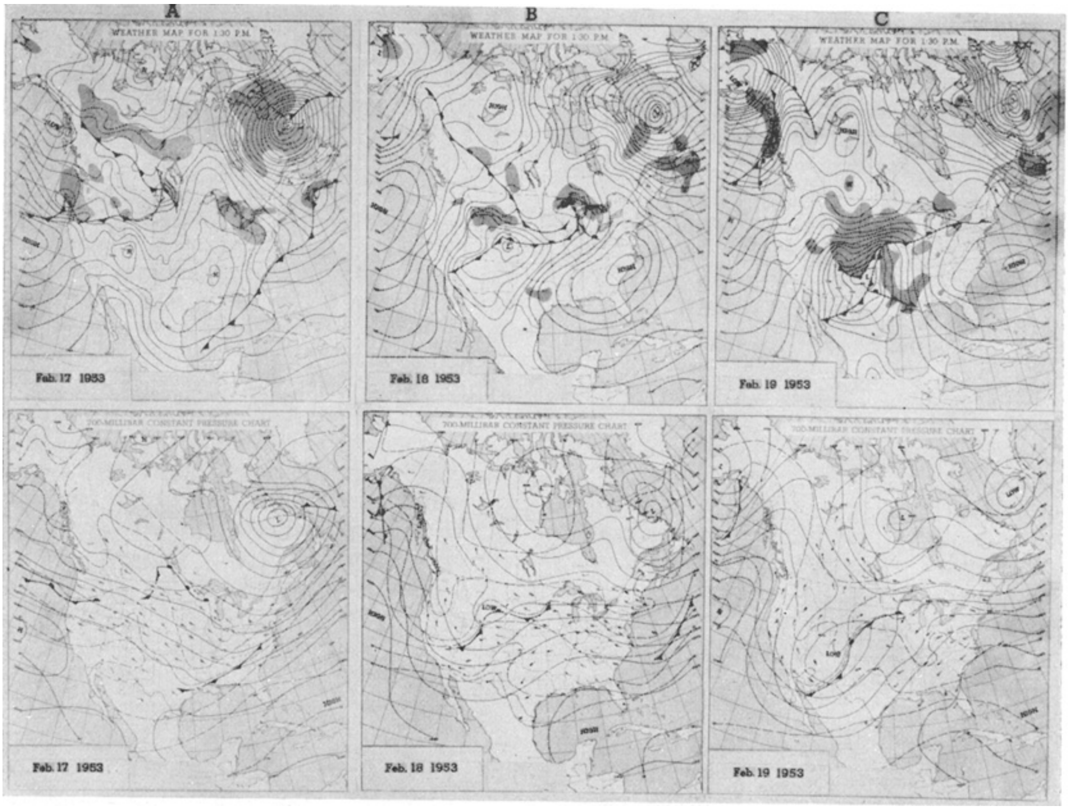


Fig. 2. Sea level (upper) and 700 mb (lower) charts for 1830 Z and 1500 Z respectively on 17, 18, and 19 February 1953.

cyclones and anticyclones, but also may serve as a sort of calendar from which predominant periodicities can be determined. In this paper an effort will be made to demonstrate how a chain of events leading to quasi-periodic cyclogenesis may be associated with the form of mean planetary circulation patterns.

2. Periodic cyclogenesis during February 1953

During February 1953 three unusually rapidly developing cyclones moved into the western plateau of the United States at intervals of ten days. The series of sea level and 700 mb maps reproduced from official printed maps of the U.S. Weather Bureau for these periods are shown in Figs 1 to 3. In each series a high pressure area at sea level (on the 7th, 17th and 27th) rapidly vanishes and is replaced by a deep cyclone within 24 to 48 hours. Similarly, ridge conditions aloft give way to the rapid development of closed cyclonic circulations. The great effect of these developments on regional weather shall not be discussed here, except to mention that these storms produced extensive areas of rain, sleet, and snow and affected much of the country in the course of their life history. One of them (the second of the three) was responsible for high winds, blizzards, dust storms, tornadoes and abnormal freezes.

Detection of the wave disturbance which plunged into the western plateau was by no means easy for the analyst, and in the series from 7–9 February only a minor ripple had been found in the polar front off Oregon on 7 February. Subsequent to this map pressures began falling with amazing rapidity along the west coast (4 mb per 3 hours at 2130 Z), and later the pressures over the plateau did likewise. Similar features attended the later two

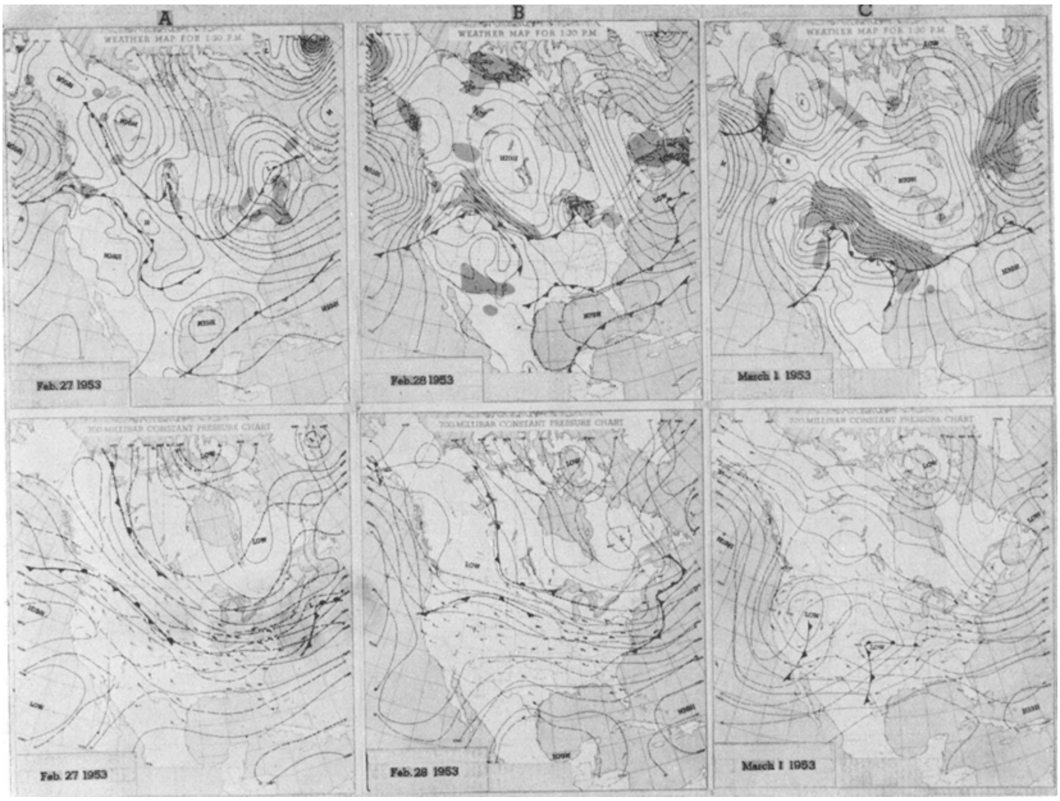


Fig. 3. Sea level (upper) and 700 mb (lower) charts for 1830 Z and 1500 Z respectively on 27 and 28 February, and 1 March 1953.

cases, when the analysts were apparently more alert to the possible existence of a nascent wave off the west coast. However, in all three cases the development was so spectacular that the official 30-hour and medium range prognostic charts appreciably underestimated the deepening.

The regularity, similarity and abruptness of these three storm developments is graphically illustrated by the plot of 700 mb height variations at 40°N, 110°W (near Salt Lake City) shown in Fig. 4 (top).

From this figure it will be noted that also in the period from March through the first half of May there was some suggestion of a continuation of sharp minima occurring about each ten days. This matter will be discussed at greater length later on. Meanwhile attention shall be focussed on other pertinent features of the February cyclogenesis.

Following the classical work of Rossby (1939), modern synoptic meteorology lays much stress on the planetary wave trains in the upper westerlies as governors of cyclonic activity at sea level. In fact, these concepts have for many years furnished the basis of preparing 5-day prognostic charts (Namias, 1947). The detection of the long planetary waves as opposed to the short cyclone waves has been effected by the use of time-averaged mean maps which usually filter out the short waves quite effectively. Five-day mean maps for the 700 mb level for periods just preceding the plateau cyclogenesis are shown in Fig. 5. In all three cases the wave lengths between the troughs over the western Pacific and United States (or western Atlantic on the 23rd to 27th) are uncommonly long in temperate latitudes. [Wave lengths are here measured between longitudes where the contours reach a mini-

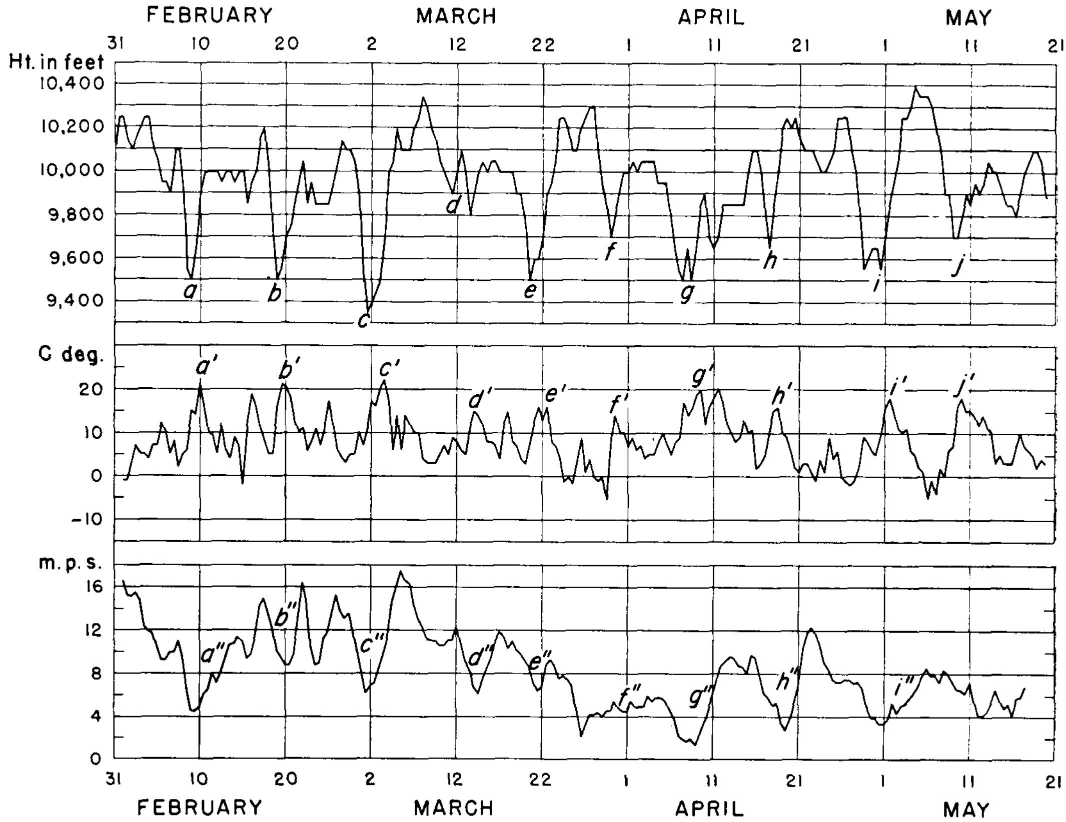
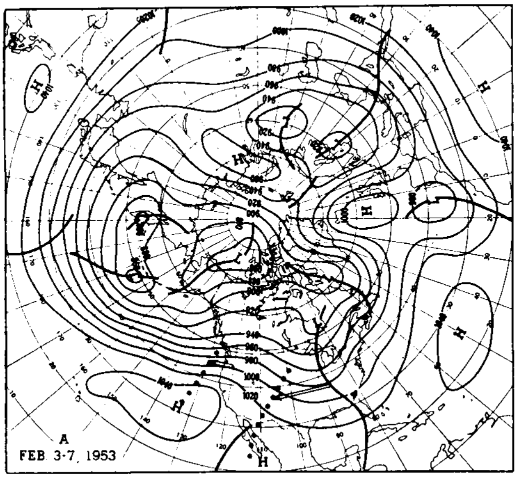


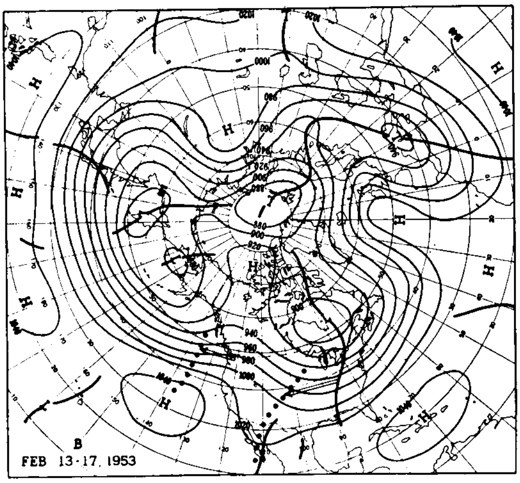
Fig. 4. Twice daily (0300 Z and 1500 Z) values of 700 mb height at 40° N 110° W (top), temperature difference at 700 mb between 30° N 100° W and 40° N 110° W (middle), and North American zonal index (bottom) (computed for latitude belt 35° N—55° N between 65° W and 125° W), all for the period February through early May 1953. Letters refer to quasi-periodic fluctuations usually associated with plateau cyclogenesis.

mum (troughs) or maximum (ridges) latitude.] At 40°N, for example, they are:

3— 7 February – 97 degrees of longitude
13—17 February – 138 " " "
23—27 February – 144 " " "

Since these waves are asymmetrical, the distance between the trough in the western Pacific and the ridge over western United States accounts for much of the great wave length. These values at 40°N for the three periods in chronological order are 65 degrees of longitude, 92 degrees and 59 degrees. Studies of 5-day mean charts over North America (NAMIAS and CLAPP, 1944) have indicated the average wave length during winter to be about 83 degrees of longitude at 45°N latitude and the stationary wave length 98°, although these statistics refer to twice the distance between trough and ridge over the United States. From this comparison as well as from forecasting experience it is concluded that the planetary wave in which the ensuing cyclone becomes embedded has become unusually extended — a condition well-known to favor retrogression of the eastern trough of the wave train or perhaps development of a new trough at a position in more harmony with wave length (vorticity) considerations. The subsequent adjustment of the planetary wave as observed from the 5-day mean maps just subsequent to those in Fig. 5 (that is for the periods 8—12 February, 18—22 February, and 28 February—4 March) is shown by the ridge and trough lines extracted from these maps. Here the "retrogression" of both ridge and trough are clearly indicated.





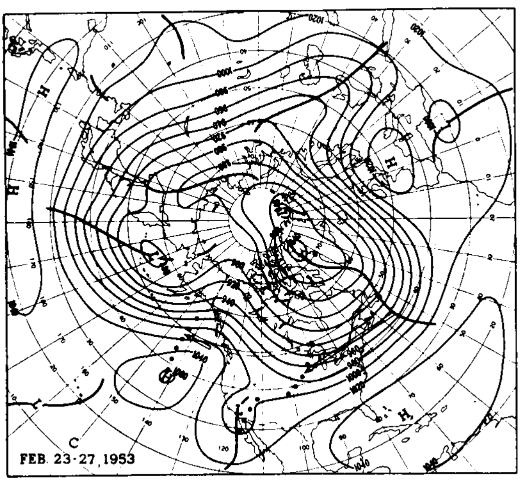


Fig. 5. 5-day mean charts of 700 mb contours (in tens of feet) for periods just preceding abrupt cyclogenesis over western plateau. (a) 3—7 February 1953 (b) 13—17 February 1953 (c) 23—27 February 1953. Trough lines (solid heavy) are drawn for minimum latitude of contours. Arrows denote displacements of major U.S. troughs and ridges to next 5-day mean where dotted lines indicate new positions.

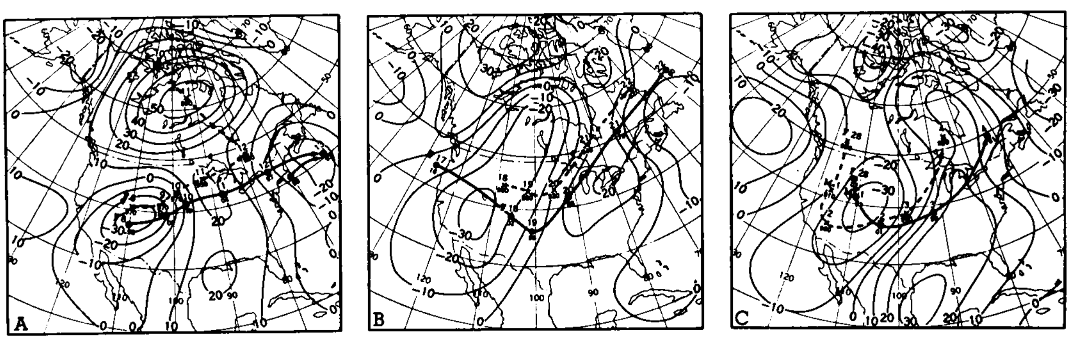


Fig. 6. Departure from normal of thickness (in tens of feet) between 1000 mb and 700 mb subsequent to cyclogenesis over western plateau (a) 1500 Z, 10 February 1953 (b) 1500 Z, 19 February 1953 and (c) 1500 Z, 3 March 1953. Heavy curved arrows connect points giving daily positions (by day of month) and intensities of primary cyclone centers at sea level (in mbs) and 700 mb (in tens of feet) which emanated from plateau cyclogenesis.

Thus the pronounced cyclogenesis over the western plateau appears to have originated in an over-extended planetary wave, which favored the development of the west coast perturbation in order to bring about the necessary shortening of the long waves. To what extent the cyclone developments were barotropic or how much contribution came from the baroclinicity in the vicinity is not possible to determine without laborious computations much easier done by electronic machines. However, inspection of the thermal fields preceding the development (lower charts in Figs 2a, 3a, and 4a) suggests that the barotropic contribution was the principal one,—at least in the initial stages of the first and third cases.

Coincident with each deepening cyclone and formation of the upper cold low, polar air masses were advected southward into the trough and tropical air masses northward ahead of it. This differential advection soon led to an abnormally large temperature difference between the western plateau and the central plains region. The departure from normal of the layer isotherms (thickness anomalies) between 700 and 1000 mb just subsequent to the western cyclogenesis are shown in Fig. 6.

The subsequent history of the principal perturbation which emanated from the plateau trough is also indicated in Fig. 6 by curves showing the 24 hr positions and intensities of cyclone centers at sea level and the corresponding center or short wave trough aloft. At the few times when the sea level continuity was not straightforward, a great deal of help was derived from the course of the 700 mb perturbations and the suggestion of steering afforded by the 5-day mean 700 mb pattern (not reproduced) in which they were embedded,—a procedure which might be used profitably where official storm track charts are published.

While the general trajectories of the cyclones in Fig. 6 seem to be governed chiefly by the concurrent 5-day mean steering patterns of their respective periods (not shown), the differences in deepening after leaving the plateau area are related to the pre-existing thermal fields. The cyclones of 19—21 February and 2—4 March underwent very strong deepening as they left the plateau area (998 mb from 20 March to 975 mb on 21 March, and 998 mb on 3 March to 981 mb on 4 March), while the cyclone from 9 February to 12 February was much weaker, reaching an intensity of only 997 mb on 12 February. These differences are apparently associated with the extent and orientation of the thermal anomalies. In the two cases of the strong cyclones (21 February and 4 March) the preceding anomalous temperature contrast extended in a general meridional direction for great distances, while in the case of the weak cyclone (11 February) the thermal contrast is limited to more southerly latitudes whereas warmer than normal air existed in Canada. Consequently, the cyclones moving away from the plateau area (generally northeastward) in the two later cases could continually draw upon the potential energy of mass distribution along much of their paths while in the first case the cyclone had access to a much more limited supply of thermal energy.

The initial temperature contrast associated with the plateau cyclogenesis occurs between Texas and the central plateau where warm maritime tropical and cold polar air masses are brought into juxtaposition. An index of this temperature contrast at 700 mb as a function of time has been plotted in Fig. 4 (middle). Here again the periodicity shows up; in this case as sharp peaks of maximum temperature contrast which lag the 700 mb height minima about a day.

As the cyclones proceed northward and increase in intensity a regional increase in zonal wind speed occurs over the United States, as shown by the zonal wind speeds in the latitude belt 35°N to 55°N observed between 65°W and 125°W and plotted in Fig. 4 (bottom). The increasing bursts of upper westerlies are shown as a″, b″ and c″ which follow on the heels of the plateau trough development (the height minima) and peaks of temperature contrast. The failure of sharp bursts of zonal wind speed to materialize from mid-March to early April resulted from a strong wave of blocking which effectively depressed the storm track (and westerlies) south of the latitude band (35°—55°) in which this index was measured. In fact, the peak speeds of the westerlies at 700 mbs prevailed between 35° and 40° during this period of blocking. It is probable that the periodicity in zonal wind speed would be more pronounced in an index which measured the peak speed independent of latitude.

3. The mechanism underlying the February periodic cyclogenesis

Thus far a description of some of the prominent synopic features attending the plateau cyclogenesis has been offered. In order to assist the reader in placing these into the perspective of longer timescale, Figs 7 and 8 have been constructed. The former gives 700 mb height profiles at 40°N extracted from routinely computed 5-day mean maps which are prepared twice a week from twice-daily analyses. Troughs and ridges are indicated by lines marking the lowest and highest contour heights (respectively) reached along the latitude. Areas of the curves are shaded where heights are above the base line of 10,000 feet. These base lines are exactly 1000 feet apart, thereby facilitating a quick visual estimate of height difference from 10,000 feet and of height changes from one period to the next. The ordinate of the graph is also an approximate time scale since the distance between successive base lines is about one half-week. In Fig. 8 are shown the mean positions of the eastern Pacific anticyclonic center at 700 mb for 5-day and 30-day periods.

Fig. 8 shows that from 8 February to 8 March the eastern Pacific upper level anticyclone was

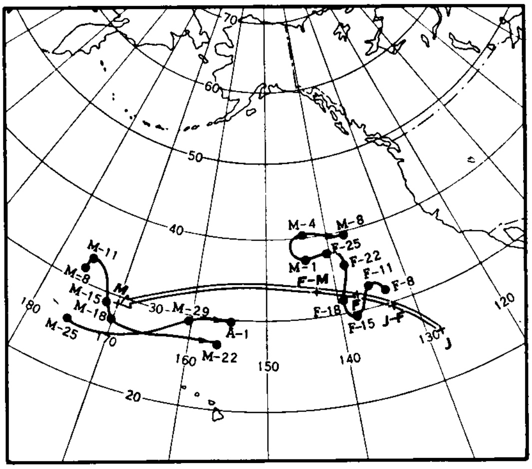


Fig. 8. 5-day (solid circles) and 30-day (crosses) mean positions of principal center of Pacific anticyclone at 700 mb level. Dates are indicated by monthly initials and numbers, e. g. F-11 means 5-day period ending 11 February, J-F means mid-January to mid-February, etc.

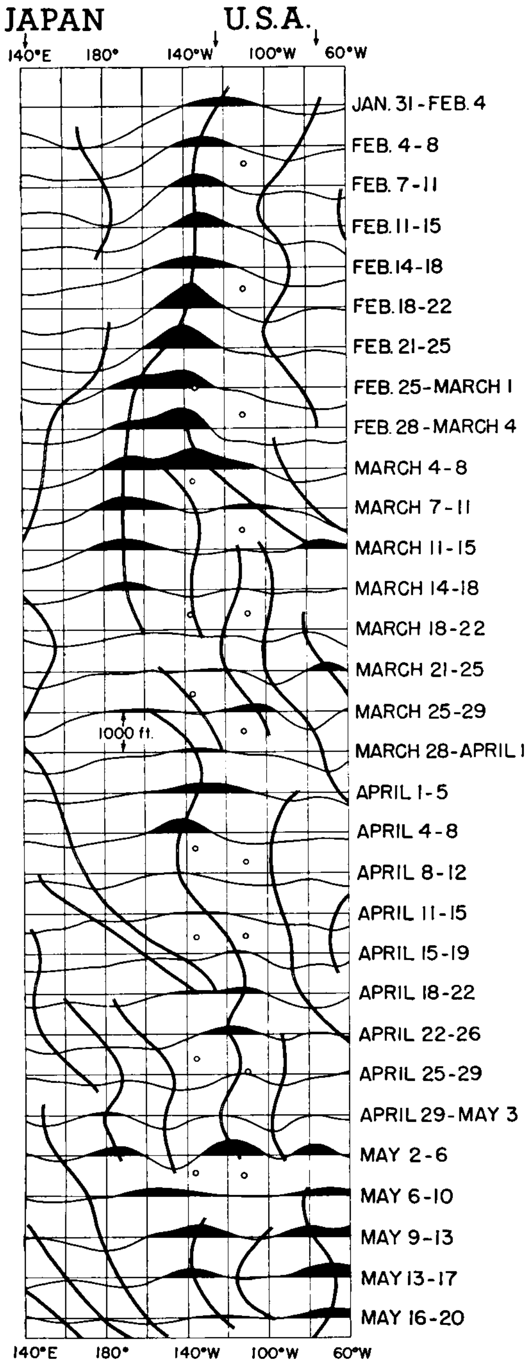


Fig. 7. Profiles of the 700 mb surface at 40° N foı 5-day means during the months February through early May 1953. Heavy vertically oriented curves give positions of principal troughs and ridges. Open circles indicate roughly the periods indicated by minima in Figs 4 and 11. Shaded portions of curves show areas where 700 mb height exceeds 10,000 feet. Base lines of curves are equally spaced as indicated in the dimensional marker in the middle.

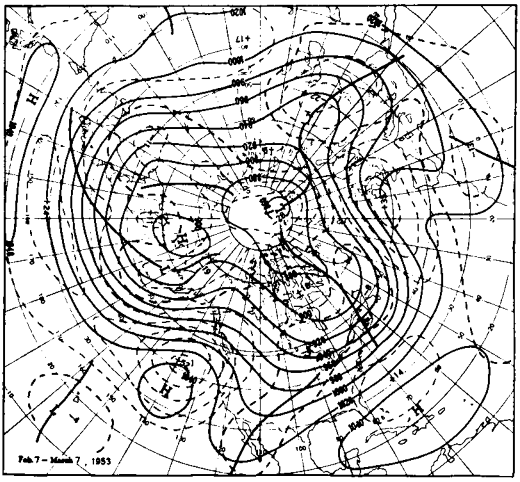


Fig. 9. 30-day mean 700 mb contour chart (in tens of feet) and its anomaly (broken lines) for the period of most pronounced 10-day periodicity, 7 February—7 March 1953.

a prominent and quasi-stationary feature of the planetary wave train. It is important to note, however, that although moving rather erratically it gyrated about a generally northwestward path. This mean component of motion is also indicated in the path of the 30-day mean center from January through mid-March. The main habitat, as well as the character of the fundamental mid-tropospheric center of action during the period of cyclogenesis, is perhaps best shown by the 30-day 700 mb chart for 7 February to 7 March, Fig. 9, on which the height anomalies are superimposed.

The quasi-stationary, though slowly retrogressive nature of the ridge during February and early March is also evident in the profiles of Fig. 7. Each burst of cyclogenesis over the western plateau was preceded by a long wave length between the quasi-stationary east Pacific ridge and the eastern U.S.A. trough, or also between the two troughs on either side of the ridges. During these periods of long wave length preceding cyclogenesis and retrogression of the major long wave troughs, the zonal flow over the half-hemisphere 0° long. westward to 180° was high, subsequently falling to lower values attending and following the cyclogenesis, as indicated in Table 1.

The above description of synoptic events makes it possible to suggest the mechanism producing periodic cyclogenesis.

Table 1. Zonal flow at 700 mb at 40°N (from 0° westward to 180° taken from wind speed profiles)

	Period	Geostrophic Wind Speed (mps)
preceding cyclogenesis	31 Jan.—4 Febr.	14.0
following »	7—11 February	12.0
preceding »	14—18 »	15.0
following »	18—22 »	13.0
preceding »	21—25 »	13.0
following »	28 Febr.—4 March	9.0

In February, the fundamental pattern (the 30-day mean shown in Fig. 9) indicates that the strongest anomaly (520 feet) lies in the area dominated by the eastern Pacific upper level anticyclone whose semi-permanence has already been mentioned (see Fig. 7). Other anomalies in the Pacific or over North America and the western Atlantic appear relatively weak so that the most anomalous component of the planetary wave train, the eastern Pacific ridge, seems to be the more stable feature of the general circulation, while other adjacent and more remote areas largely respond to its dictates. The manner of this response brings us back to the sequence of events associated with the cyclogenetic periodicity.

During periods of high zonal flow the long-wave trough over the United States is permitted to reside east of the 30-day mean position, although the eastern Pacific ridge remains essentially in the preferred position indicated by the longer period mean. This fact agrees with the wellknown barotropic wave-equation where the stationary wave length is directly proportional to the square root of the zonal wind speed. The periods of high index, particularly over North America, are those subsequent to the northeastward movement and deepening of the great cyclones which emanate from the western plateau and feed on the thermal contrast initially established by planetary wave retrogression.

In other words, there appears to have been an intertwined series of events: A quasi-stationary and abnormally strong eastern cell of the Pacific High developed early in February. This anticyclone regulated the downstream pattern in a manner depending upon the strength of the westerlies. During an initial period of weakening circulation and greater growth of the anticyclone the downstream trough was favored over the plateau, not far from the ridge. The development of this trough proceeded as a small perturbation appeared on the Pacific coast and deepened with amazing speed. In so doing it induced strong flows of polar and tropical air on its west and east sides respectively (see Fig. 6) since the geographical location of this deepening storm lay fairly proximate to sources of both continental polar and tropical Gulf air. Having developed such a strong and extensive thermal contrast, further cyclogenesis of one or more cyclones along the Polar Front was favored, for these cyclones could feed upon the rich diet of thermal energy as they proceeded northeastward. The increased kinetic energy fed into the westerlies by the northward migration of the deepening cyclones created high index periods thereby permitting the planetary trough over the United States to occupy a position farther east of the quasi-permanent Pacific ridge than in the longer period mean. After the major source of energy for the cyclones, the thermal contrast, was used up in the cyclogenetic process and friction set in to decrease the westerlies after the cyclones left the area or filled, the stage was set for retrogression of the long wave trough into the plateau, when the chain of events once again repeated.

With our present meteorological knowledge it would be difficult if not impossible to compute the time involved in this cycle of interdependent events. Ten days, the observed time, appears long in view of the many claims for periods lasting from five to seven days. However, NAGAO (1952) maintained that a 10-day period in air pressure is often found in the neighborhood of the Kanto district of Japan, particularly from April to June and from September to October. In a study of natural periods in Russia during 1926—1935 PAGAVA (1940) gave the frequency of 10-day periods as occurring there only 7 % of the time while six to eight day periods occurred 65 % of the time.

Before leaving the February case, 10-day periodic cyclogenesis in another area shall be described. This occurred in the vicinity of the Hawaiian Islands where an easterly wave appears in the underlying pattern of the 30-day mean (Fig. 9). The 5-day mean maps or daily maps during this period show that this low latitude trough becomes active more or less in sympathy with the eastern Pacific upper level high and the southwestern plateau trough. It does this as the westerlies in the Pacific fluctuate in strength and position, so that the easterly wave periodically builds up into the westerlies, splitting the narrow zonally-oriented semipermanent ridge to its north (Fig. 9). The 10-day periodic nature of the activity of this trough and its association with the lower latitude portion of the western plateau trough are shown in Fig. 10. The slight lag in these curves suggests that there was some contribution to the enhancement of the Pacific High by the Hawaiian trough.

4. Termination of the February regime

While the general circulation during February oscillated about a fairly stable position, it was pointed out that there was a slow westward drift of the eastern Pacific anticyclone. This drift is evident in Figs 7 and 8 and is associated with a comparable retrogression of the central and western Pacific trough. The

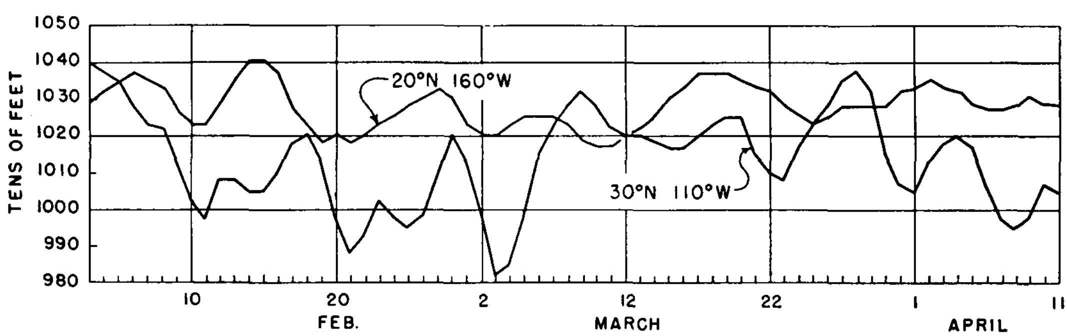


Fig. 10. Daily 700 mb heights (upper) at 20° N 160° W (near Kawai in the Hawaiian Islands) and (lower) at 30° N 110° W at the base of the western plateau trough. Note the periodicity and resonance during February which abruptly terminates in March.

major westward shift in this trough occurs between 18 February and 15 March during which period it gradully retrogrades from 180° to a position just west of Japan. Simultaneously, there is the marked increase in height between 160°W and 180°, the area which ultimately becomes the seat of the major ridge (after 8 March) while the ridge farther east progresses and declines. This is the usual manner in which retrogression operates. The downstream trough subsequent to the retrogression is now favored just off the west coast of the United States—a position in harmony with the new seat of the central Pacific ridge. Note that this new wave train is out of phase with the pattern which occupied the same area during most of February. The break in regime along the west coast occurred abruptly between the 5-day periods ending 8 March and 11 March, when, in spite of the overlapping character of the periods the 700 mb heights at 130°W fell more than 600 feet.

Before discussing the repercussions of this change in regime upon cyclogenetic periodicity an attempt will be made to explain its evolution, or at least to cite some factors which are apparently important in the development. In the "self-developmental" hypothesis advanced by the author (NAMIAS, 1953) to account for changes in long period mean patterns of atmospheric circulation, there was assumed to be some inertia in mean circulations. Because of this, changes in insolation incident to change in season can operate differentially upon the centers of action and their component planetary waves which have prevailed during a period of say two weeks to a month. These changes then introduce displacements and distortions in the centers of action which are amplified, suppressed or in some way brought into greater harmony through the great teleconnections operating between the various troughs and ridges (operating primarily through vorticity flux) of the general circulation.

In the present situation it appears that the initiation of the retrogression may be largely ascribed to the marked weakening of the Asiatic monsoon anticyclone which normally occurs from late winter to early spring and the consequent retrogression of the upper level Asiatic coastal trough which is also a climatological feature at this time. For example, normal monthly maps (U.S. Weather Bureau, 1952) show that the semipermanent Asiatic anticyclone at sea level falls away from about 1033 mb to 1028 mb at its center from February to March. Concurrently, the normal trough at the 700 mb level at 40°N recedes from 160°W to 150°W with a similar retrogression of the central Pacific ridge. In February and March of 1953 the changes were as follows:

	1953	Normal
Change in Intensity of Sea Level Asiatic High	− 15 mb	− 5 mb
Retrogression of Asiatic Coastal Trough	25° long.	10° long.

It is also interesting to compare in Table 2 the changes in 700 mb contour height at 40°N over the Pacific from February to March as normally observed with the changes in 1953.

Table 2. Changes in 700 mb height along 40° N from February to March

	140°E	150°	160°	170°E	180°
Normal change (tens of feet)...	+ 9	+12	+19	+22	+19
1953 Change	+16	+22	+37	+52	+67

	170°W	160°	150°	140°W
Normal changa (tens of feet)	+18	+15	+11	+ 6
1953 Change	+68	+44	+ 8	−19

It appears that during 1953 the changes in circulation from February to March over Siberia and the Pacific followed the general course of normal seasonal change *but with much greater intensity*. In other words, in 1953 an amplification of the normal change occurred: —the Siberian High fell away faster, the coastal trough retrograded more and the Pacific ridge increased more than normal. These amplifications of the normal change appear even more striking when one notes from Fig. 7 that a large portion of this change took place between the periods 21—25 February and 25 February —1 March. Precisely why and how this amplification came about is presently impossible to answer. However, if one assumes some form of carry over (inertia) of the anomaly of the eastern Pacific ridge as the retrogression takes place, the large rises in the central Pacific may be accounted for. The greater reduction in the strength of the Asiatic high than normally occurs is associated with the increase in

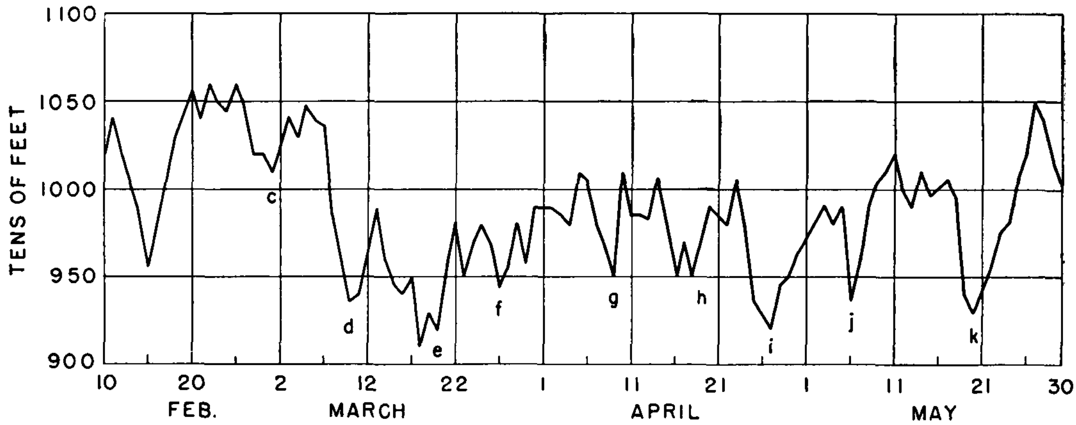


Fig. 11. Daily (1500 Z) height of 700 mb surface at 45° N 135° W showing the establishment of 10-day cyclogenetic periodicity off the west coast during March and April.

westerlies over it in March compared to February. This increase, in turn, is associated with the strong northeast-southwest tilt of the trough over western Russia.

(a) *Effect of the change in regime on periodicity*

With the sudden appearance of a trough off the west coast of the United States in place of a ridge, the clear-cut nature of the periodicity observed in February vanishes, as indicated in Fig. 4 (top). However, one can still find a suggestion of the re-establishment of ten-day periodicity, especially beginning with the abrupt drop around 20 March and continuing with successive deep minima through 9 May. These reasonably periodic minima are believed to be secondary phenomena induced by emanations from the primary trough off the west coast which was a quasi-permanent feature of the March and April circulations. The primary storms leading to a 10-day periodicity appear to have developed in advance of the upper level ridge of the mean underlying pattern in a manner somewhat similar to the storms over the plateau in February. Thus a 10-day cyclogenetic periodicity can be detected in the site of the trough (e.g. at 45°N, 135°W) in March and April as indicated in Fig. 11. Note that this periodicity did not appear until the west coast trough became established (after the first week in March) although a weak forerunner appeared around 1 March. This forerunner was not due to a separate cyclogenesis off the west coast, but to strong deepening of the plateau cyclone, which, responding to the long-period retrogression of the planetary wave, could for the first time influence this area (45°N—135°W). Thus it would seem that the nature of the periodicity is linked primarily to the fundamental pattern of the general circulation and not to the orography.

The disturbances which plunge into the planetary mean trough off the west coast in Spring are seldom stationary but travel embedded in a generally westerly flow aloft onward to the western plateau. They usually undergo redevelopment just east of the Continental Divide, perhaps in response to the creation of a trough to the lee of the Divide under selected wind conditions. This redevelopment often results in a very short wave length between troughs on either side of the plateau. The recurrence of such troughs during March was so prominent that they show up in the 30-day mean (Fig. 12).

The break in regime beginning after the first week in March is much more effective in destroying the periodicity observed in the vicinity of the Hawaiian Islands (see Fig. 10) than over the western plateau. The reason for this and also for the abrupt cessation of resonance between the Hawaiian trough and the southern portion of the plateau trough seen in Fig. 10 is due to the retrogression of the strong Pacific ridge. As may be seen from the mean flow pattern for March (Fig. 12) this retrogression relegates the Hawaiian trough entirely to the role of an easterly wave, with no opportunity to enter into the circulation of the westerlies as it could in February when the neck of ridge to its north was very tenuous (Fig. 9). In other words, the strong anticyclone north of the Hawaiian area in March shielded the area from quasi-periodic variations associated with the westerly wave train to the north. Here is an excellent example of how changes in phase in periodicity at a point can be brought about by very large scale features of the general circulation.

5. The mean circulation after April and the termination of the 10-day periodicity during May

The mean flow pattern initiated after the first week in March prevailed more or less until the end of the month, particularly with respect to the recurrence of trough activity off the west coast. However, strong seasonal effects accompanying the transition to Spring produced later modifications in the 5-day mean wave patterns. For example, as the zonal index at 700 mb fell from an average of 9.4 mps in March to 7.3 mps in April (a somewhat greater drop than normal) an increase in wave number was favored leading to another quasi-permanent trough in the central and eastern Pacific. In general, as may be seen from Fig. 7, the 5-day mean flow patterns were in a state of transition during most of April and did not become stably organized until late in the month after which time there were only minor fluctuations through the first week of May. In spite of the April transition the 10-day character of the periodicity in 700 mb height continued as shown in Figs 4 and 11. When considered against the background of the longer period (30-day) mean, the continuation of the periodicity is perhaps not so surprising since April's pattern (not shown) resembled February's (Fig. 9) (when the periodicity was most pronounced) in the general nature of the westerlies and positions of troughs and ridges over the Pacific and North America.

Another sharp break in pattern occurred after 2—6 May with the new stable pattern (9—13 May) quite out of phase with the original. Here the abrupt transition was due to the insertion of a new trough, formerly existing only at high latitudes, into the temperate latitude westerlies over east Asia. The effect of this abrupt change in planetary circulation

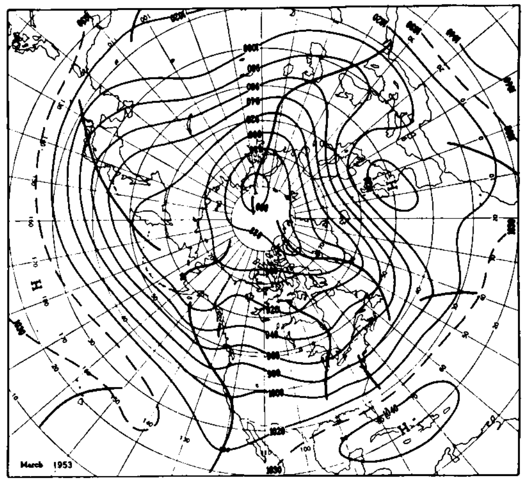


Fig. 12. Mean contours of the 700 mb surface (in tens of feet) for March 1953.

upon the periodicity is quite evident in Figs 4 (top) and 11 where the 10-day characteristic vanishes, and more complex fluctuations set in. Perhaps the variations in Fig. 11 are assuming a longer period.

6. Other periodicities in relation to the general circulation

In some recent articles dealing with periodicity it has been customary to devote considerable time and effort to statistical analysis in order to buttress the reality of the periodicity suggested. Extensive work of this character has not been performed in connection with the present work because the author feels that the periodicity of the minima in Figs 4 and 11 is sufficiently clear from inspection, and besides, no claim is made that the periodicity is exact. It is a "quasi-periodic" cyclogenesis. Neverthless, a few of the more common statistics have been computed for those to whom numbers have a stronger appeal than graphs and maps.

A 10-day sine-wave was fitted to the height values at 40°N 110°W shown in Fig. 4 (top) for the period 4 February to 14 May. This embraced 100 days and 10 waves. The correlation of the observed data with the fitted sine-curve turned out to be 0.52 with an amplitude of 154 feet. A similar analysis of the data in Fig. 11 from 4 March to 10 May (70 days and 7 waves) gave a correlation of 0.42 and ampli-

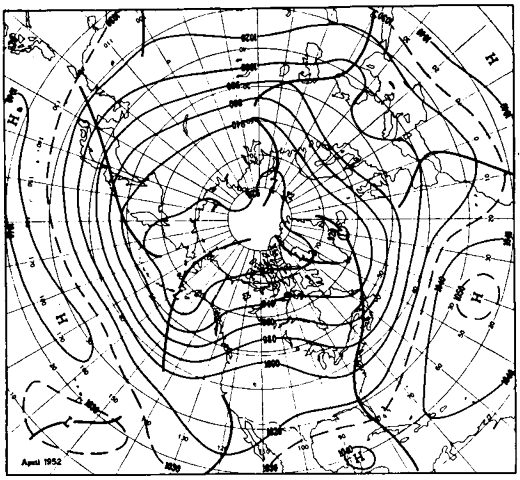


Fig. 13. Mean contours of the 700 mb surface (in tens of feet) for April 1952.

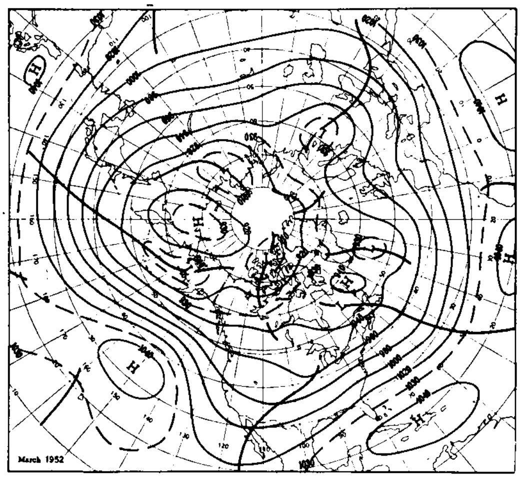


Figure 14. Mean contours of the 700 mb surface (in tens of feet) for March 1952.

tude 182 feet. While these values are not overwhelming they are perhaps comparable to those obtained for 7-day periods (LANGMUIR, 1950) computed for similar lengths of time. It is noteworthy from Fig. 4 (top) that a sine-curve is not the most appropriate description of the variation. Rather, the 700 mb values appear to fluctuate in a minor way about a constant value for several days before plunging precipitously to low values as the cyclogenesis sets in. In other words, if one wished to obtain a higher correlation he could fit some other type of curve to the data.

In order to see how frequently 10-day periodicities in the height of the 700 mb surface over the western plateau occur during late winter and spring, daily values at 40°N 110°W were plotted for the twenty years beginning 1933. From these graphs it was concluded (by an independent worker) that:

1. The 10-day wave is not common at this place and season, and none could be found as striking as the one investigated.
2. The period during which the plots most resembled those investigated (i.e. had a 10-day periodicity of good amplitude) was from 25 February to 15 May 1952.

The 30-day mean 700 mb maps associated with this latter period are reproduced in Figs 13 and 14. The similarity of the April 1952 pattern over the Pacific to March 1953 (Fig. 12) is apparent. The similarity of March 1952 (Fig. 14) with February 1953 (Fig. 9) is even more striking. However, a fairly rapid transition to the April regime took place in late March of 1952, and this did not permit the 10-day periodicity to be as striking as in February 1953.

Once again the suggestion arises that the length and character of the periodicity may be inherent in the long-period (e.g. 30-day) mean circulation pattern. It is unlikely that the relatively uncommon 10-day periodicity would appear in maps bearing similar patterns (and similar anomalies) unless such a connection existed.

Another indication that there may be an intimate relationship between periodicity and the long period mean planetary wave pattern is afforded by a chart published by HALL (1950), showing amplitudes and phases of the clear-cut 7-day periodicities which occurred in April 1950 and were first brought to light by LANGMUIR (1950). Hall's chart is reproduced in Fig. 15, along with the 700 mb 30-day mean for the same period (Fig. 16). Comparing these two figures it seems clear that where the amplitude of the 7-day cycle reaches a maximum the curvature of the 700 mb contours is greatest (in ridges or troughs). The phases on Hall's chart also suggest that the 7-day periodic components may have similar phase in the troughs of the planetary wave train (e.g. off Japan, the west coast of United States and the east coast). The tendency to resonance of this

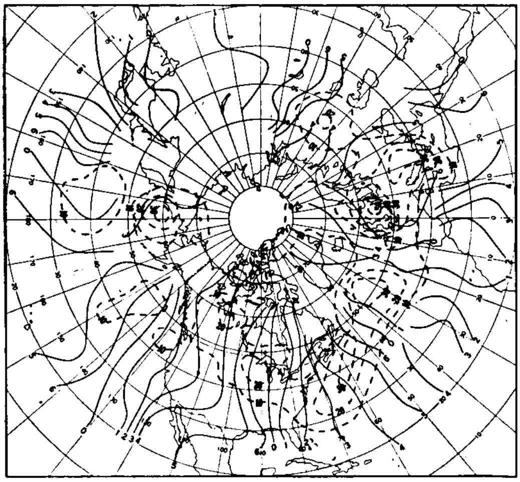


Fig. 15. Amplitude (dashed lines, in tens of feet) and phase (day of maximum height [solid lines] where 0 is for Sunday, 1 for Monday, etc.) of 7-day periodic component during 2—29 April 1950 [reproduced from Hall (1950)].

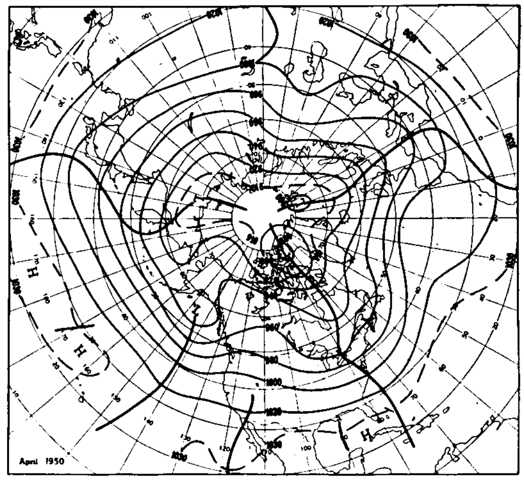


Fig. 16. Mean contours of the 700 mb surface (in tens of feet) for April 1950.

type was mentioned in connection with the Hawaiian and southern plateau troughs in the 1953 case. These suggestive connections between amplitude, phase and long period mean pattern will require further research.

The tentative conclusions which may be drawn from the above few paragraphs are that the character of periodicities in mid-tropospheric pressure (which, of course, are also associated with periodicities in other elements, including weather) may be inherent in long period mean flow patterns. These patterns reflect the underlying positions and intensities of the centers of action, which in turn may condition the life history of storms and anticyclones, setting the stage for their birth, growth and movement. Insofar as the mean ong period (e.g. 30-day) flow pattern remains unchanged with time, the evolution of day to day storms may proceed similarly and periodically. However, owing to seasonal changes, and perhaps other phenomena, the long period mean patterns are themselves gradually changing form, thereby leading to changes in periodicity. When the mean patterns abruptly change, signaling great changes in the weather regime, the periodicity is also apt to change phase and length abruptly.

To the extent that correct 30-day prognoses of mean planetary flow patterns can be made (NAMIAS, 1953) these conclusions suggest the possibility of predicting the spells of weather within a month as well as its average characteristics.

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