THE WEATHER AND CIRCULATION OF SEPTEMBER 1959

Quasi-Periodic Oscillations in Zonal Index and Centers of Action

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1. HIGHLIGHTS

One of the weather highlights of September 1959 was the striking of the South Carolina coast by hurricane Gracie near month's end. Due to the timely warnings and evacuation of coastal areas, there was no reported loss of life from drowning although more than 20 deaths occurred in the storm. A few days earlier, September 26, one of the most catastrophic typhoons of modern history struck Japan near Nagoya. Deaths were reported in excess of 4,000, with 1,700 missing, many thousands injured, and enormous property damage.

In the United States surprisingly large contrasts in weather occurred. Record temperature extremes were common. North Platte, Nebr., reported a maximum temperature of 102° F. on the 7th, the highest on record for so late in the season, and a minimum of 29° F. on the 10th. At Hartford, Conn., three temperature minima and two maxima set new records for individual days. Los Angeles had the warmest September of record (average temperature 72.8°). The hottest day of the year at Buffalo, N.Y., was September 9 when 95° F. was recorded, the highest ever reported so late in the season. Binghamton, N.Y., had the warmest September since records began in 1891, while Idaho Falls, Idaho, had the coldest September of record. Grand Junction, Colo., had a freeze on the 28th, the earliest in 51 years.

Excessive precipitation occurred this month in many areas. For example, Boise, Idaho, reported 2.54 in., exceeding all September totals since 1864. Other cities reporting record amounts were Kalispell, Mont. with 3.84 in.; Sexton Summit, Oreg., 2.81 in.; Seattle, Wash., 4.60 in.; and Oakland, Calif., 3.27 in., the previous record being 0.82 in. in 1939. Record snowfall hit areas in the lee of the Colorado Rockies. Colorado Springs received 34.1 in. of heavy wet snow on September 28, 29, and 30, with damage to property reported in excess of a million dollars.

By way of contrast this was the driest September on record at Lexington, Ky., Milton, Mass., Providence, R.I., Oak Ridge, Tenn., and Brownsville and El Paso, Tex. Philadelphia, Pa. had its longest consecutive period without rain, from the 4th to the 27th.

This was the windiest September on record at many places on the west coast from Sacramento, Calif. northward to Olympia, Wash.

2. MONTHLY CIRCULATION AND WEATHER

The largest abnormalities of the Northern Hemisphere's circulation in September 1959 occurred in western Europe (fig. 1). A strong anticyclone persisted in the vicinity of Great Britain throughout the month, bringing a succession of warm, dry, and brilliant days and nights to the British Isles, following four consecutive months of unequalled dryness, sunshine, and warmth combined. Closely allied with the strength of this anticyclone were the intense negative height departures from normal to the east, over northern Russia, a manifestation of persistent storminess and below normal temperatures over eastern Europe during the month.

Over North America, however, there were no unusually strong circulation anomalies in the monthly average. Figure 1 shows lower than normal heights in the western United States and above normal heights in the Northeast. These height departures were associated with lower than normal temperatures in most of the west and north-central sections, while the Northeast, the Mississippi Valley, and the Southern Plains averaged warmer than normal (fig. 2A). Within the month, however, some violent temperature fluctuations occurred, and record temperatures at both extremes were not uncommon.

The departures from normal of this month's precipitation are shown in figure 2B. September was a wet month over most areas except the Northeast and Southwest, in line with the prevailing height anomaly pattern which reflected stronger than normal flow of moist air from source regions in the Gulf of Mexico, Pacific, and Atlantic. Very heavy precipitation occurred in the West north of northern Nevada and Utah, with many places in this region reporting this month the wettest or near wettest September on record. Most of the heavy precipitation from the Mississippi Valley westward occurred in the second half of the month when the deep mean trough migrated from near the west coast to the Continental Divide and became stationary there in the latter part of the month.

Although the average circulation for the month over North America was not greatly different from normal, an intramonthly upheaval in the broad-scale flow occurred, resulting in considerable variability in the circulation and weather within the month. This evolution will be considered in some detail below.

3. THE INDEX CYCLE

An interesting aspect of this month's weather was the oscillation of the speed of the 5-day mean 700-mb. westerlies at temperate latitudes in the Western Hemisphere (fig. 3). This was a continuation of a rhythmical variation in the strength of the westerlies which started in early August with the first substantial weakening of wind speeds since June 20. The next low point in the index

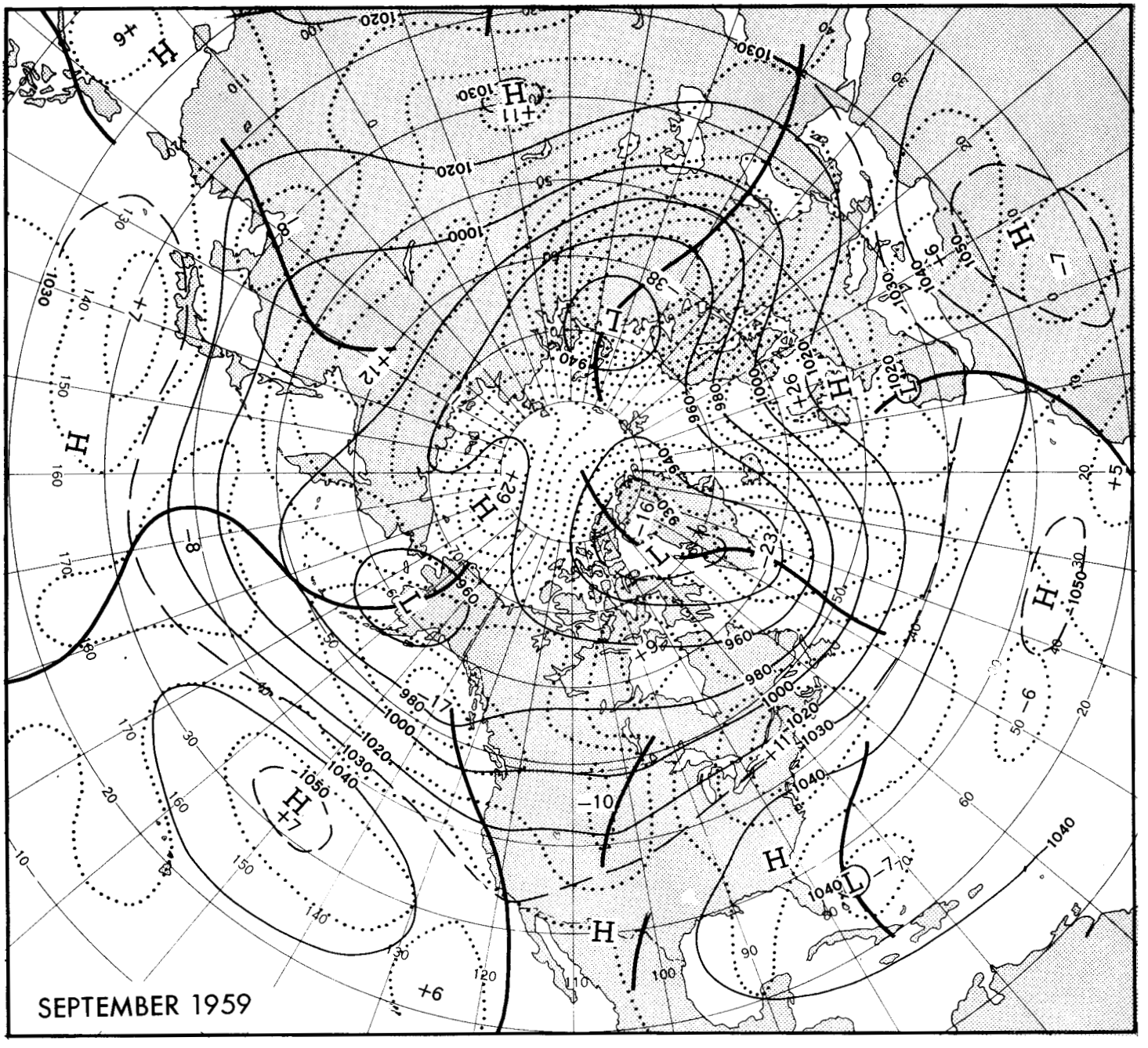


FIGURE 1.—Mean 700-mb. contours (solid) and height departures from normal (dotted) (both in tens of feet) for September 1959. The westerlies averaged near normal, being somewhat depressed in western North America but north of normal in the East.

(4.8 m.p.s.) was reached at the end of August, after which the westerlies increased until the 5-day period ending September 7, when the first maximum of September (9.3 m.p.s.) occurred. This was followed by a decrease to 6.5 m.p.s. a week later, after which a new high of 10.4 m.p.s. was reached on the 26th. Following this peak, another decrease set in, which was still in progress at month's end.

Figures 4 to 7 are presented to illustrate the sequence of 5-day mean circulation and weather anomaly patterns associated with this rhythm in the strength of the westerlies.

4. FIRST WEEK—HIGH INDEX

The high index at the end of the first week was due primarily to a deep Low over northwestern Canada (fig. 4A) which maintained stronger than normal westerlies over North America. Five-day mean Lows in September have not been observed this far west in Canada in the last decade or more, since in this area a ridge normally prevails. With the mean Low in this position (see also the sea level mean, fig. 4B) the regime was unfavorable for anticyclonic activity in Canada. As a result, most of

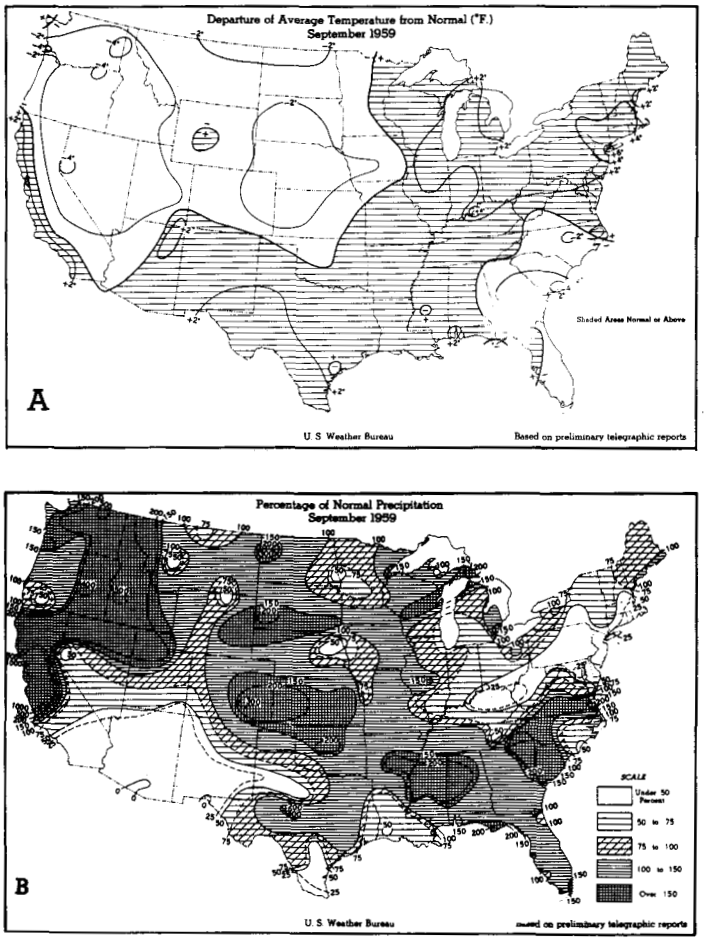


FIGURE 2.—(A) Departure of average surface temperature (° F.) from normal for September 1959. (B) Percentage of normal precipitation for September 1959. (*From Weekly Weather and Crop Bulletin, National Summary*, vol. XLVI, No. 40, October 5, 1959, and No. 41, October 12, 1959.

the United States remained warmer than normal except for the Far West (fig. 4C). Here cooler than normal Pacific air predominated, largely due to stronger than normal westerlies along the west coast. The abnormal strength of the westerlies can be deduced from the height departures in this area (fig. 4A), which totalled 820 feet of contour gradient in excess of the normal, between the positive center off lower California and the negative center in western Canada.

Figure 4B, which depicts the average sea level flow during the first week, shows the predominantly southerly flow from the southern Rockies eastward which kept this area warmer than normal. Also, the southeasterly drift of tropical Atlantic air which favored showery conditions along the Atlantic Seaboard may be inferred from the abnormal location of the Bermuda High near the Maritime Provinces.

The tracks on figure 4B show that only one High crossed the country during the week, and this of Pacific origin.

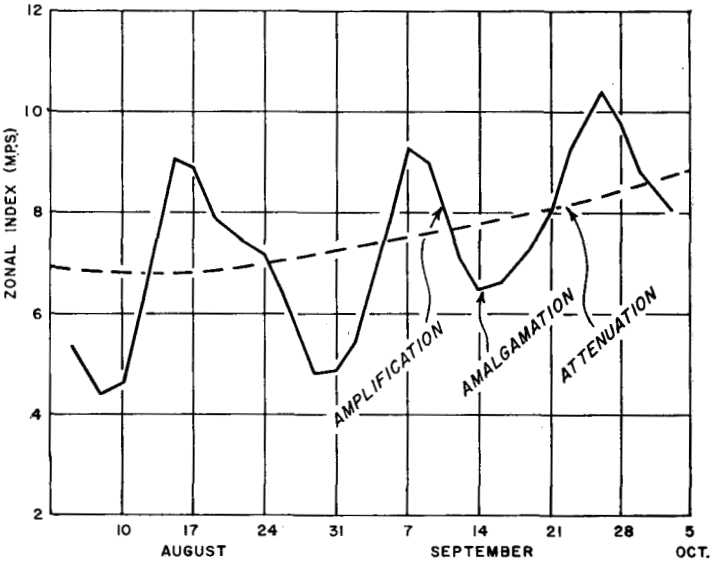


FIGURE 3.—Time variation of 5-day mean values of the zonal index in meters per second, plotted on the last day of the period. The index is computed from 35° to 55° N. for the Western Hemisphere. The dashed line represents the variation of normal index. Arrows indicate approximate stages of the index cycle when amplification, amalgamation, and attenuation of the planetary wave train occurred.

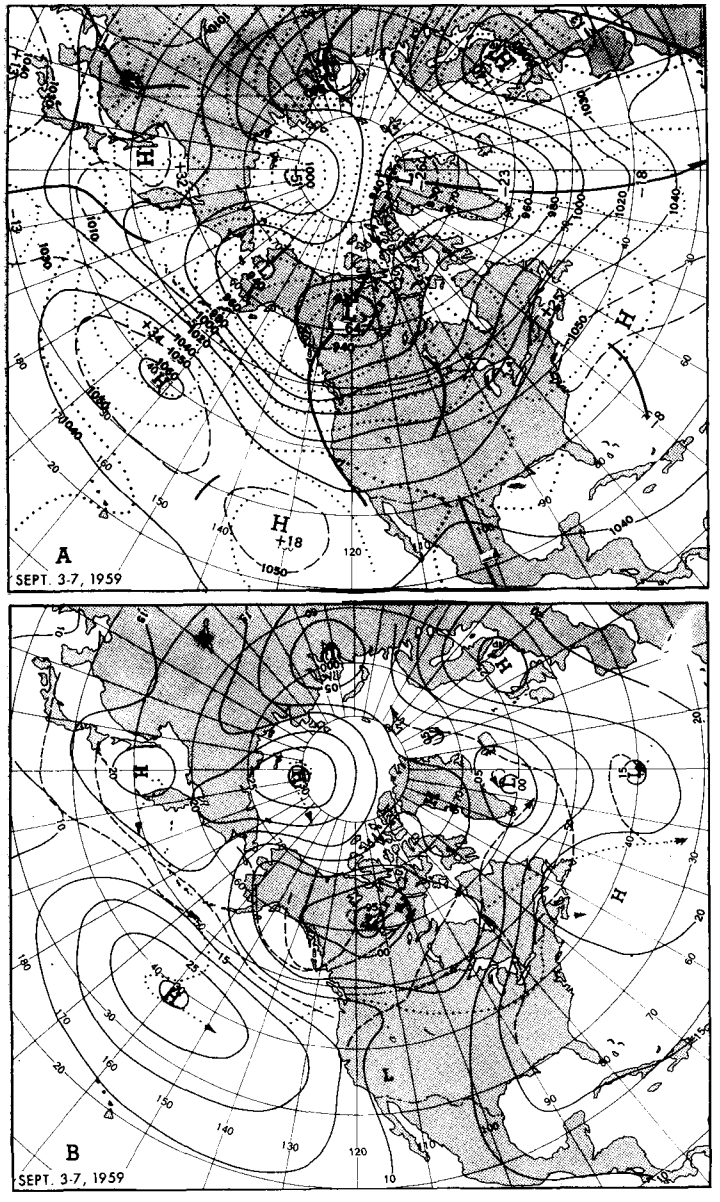
It slowed down over the Northeast and maintained easterly flow over the western Atlantic as far north as 40° N. This flow kept the Southeast wet through much of the week (fig. 4D).

Considerable storminess occurred over western Canada with practically no anticyclonic activity. Over the United States the only significant cyclonic activity was a weak Low which traversed the lower Mississippi and Ohio Valleys early in the week, spreading heavy rains through much of this area.

5. SECOND WEEK — AMPLIFICATION AND RETROGRESSION OF THE LARGE-SCALE WAVES IN THE WESTERLIES

During this week the speed of the westerlies dropped sharply in the Western Hemisphere, reaching a minimum at week's end. This was a manifestation of marked amplification of the large-scale waves in the westerlies over the Pacific and North America.

Associated with this amplification was an almost complete phase shift of the major waves over North America from the first week. Figure 5A shows the strong upper-level High that developed over the Rockies in consonance with deepening south of Alaska. This reversal of phase might be viewed as a retrogression of the large-scale height anomalies over North America and the Atlantic. Comparing figures 5A and 4A, it may be seen that the Scandinavian positive anomaly retrograded to Iceland,



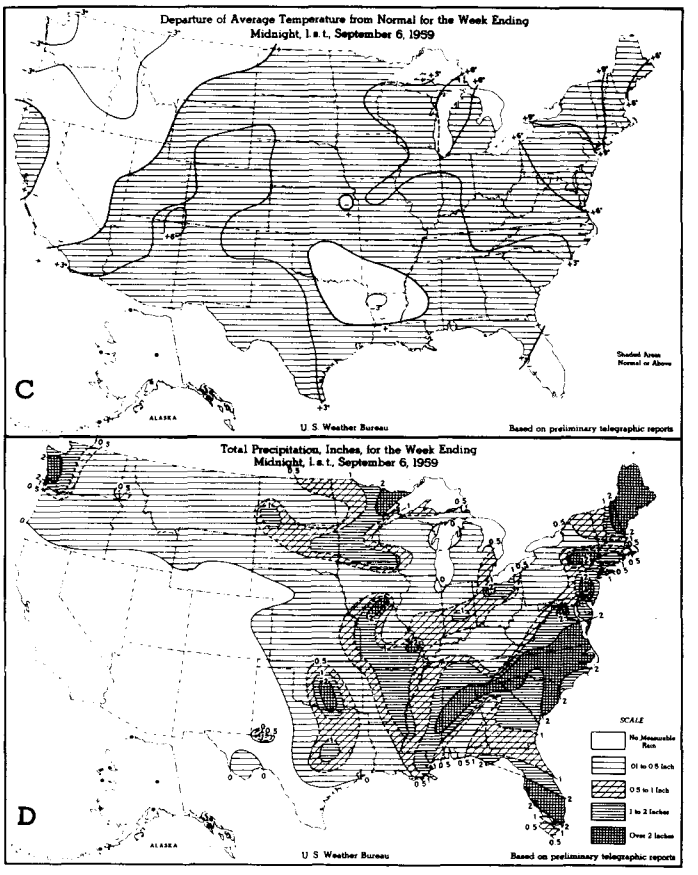


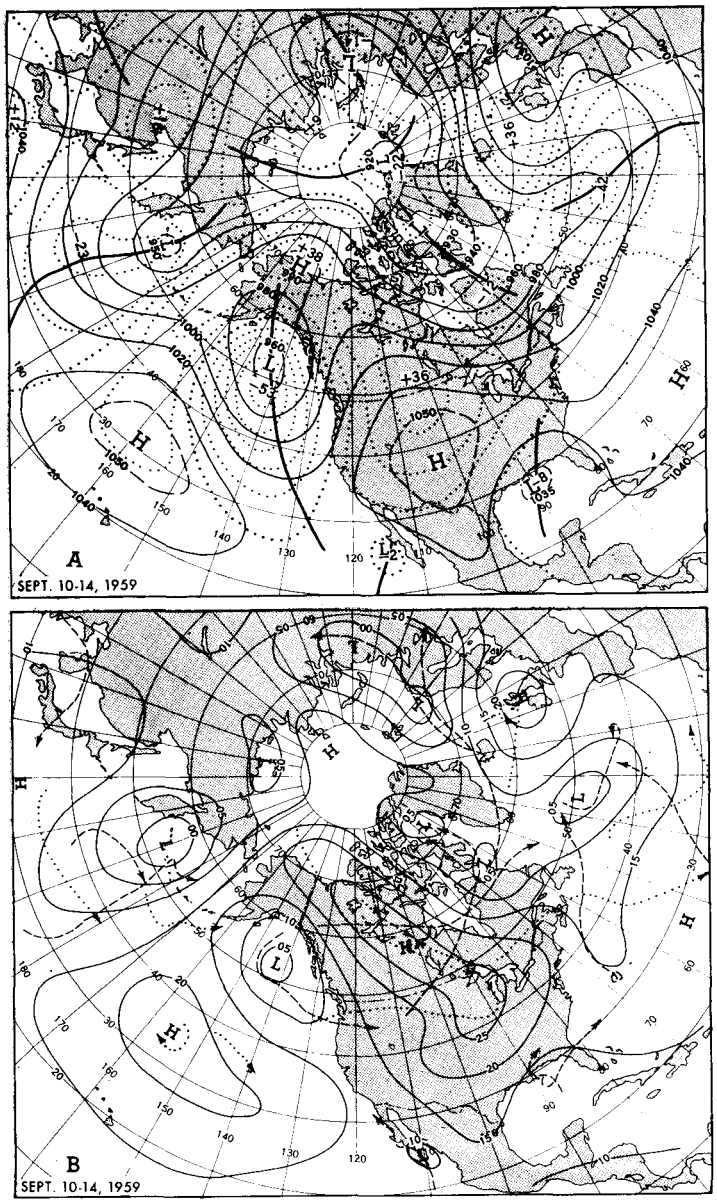
FIGURE 4.—(A) 5-day mean 700-mb. contours (solid) and height departures from normal (dotted) (both in tens of feet) for September 3–7, 1959. (B) Mean sea level isobars (solid) (millibars—hundreds omitted) for September 3–7, with smoothed tracks of migratory cyclones (dashed) and anticyclones (dotted) for week ending September 7, 1959. (C) Departure of average surface temperature from normal (° F.), and (D) total precipitation (inches) for the week ending September 6, 1959. (C and D from *Weekly Weather and Crop Bulletin, National Summary*, vol. XLVI, No. 36, Sept. 7, 1959.)

the positive center over the Maritime Provinces retreated to middle North America, and the western Canadian negative center backed off into the northeastern Pacific.

The amplification of the ridge in western North America occurred almost explosively between September 9 and 10, with simultaneous deepening of the troughs near Kamchatka and the Gulf of Alaska. During this period typhoon Patsy (fig. 5B) emerged from the subtropics and contributed its energy to the developing Kamchatka vortex. At the same time an upper-level anticyclone from north of the East Siberian Sea drifted southeastward and merged temporarily with the intensifying central Pacific ridge about midweek (fig. 5A) before continuing southeastward to reamalgamate with the amplifying ridge in North America.

The ridge development in the western United States was accompanied by strong warming over that area while at the same time it deployed cool air into the East as the southerly flow of the previous week gave way to northerly flow in this region. This is clearly portrayed by the mean sea level chart (fig. 5B). The front which ushered the cold air into the Eastern States from the 9th to the 11th dropped temperatures 20°–40° in a few hours, ending the late-season heat and humidity which had prevailed for a month or more. This heat wave was climaxed by record maxima on the 8th and 9th, such as 96° at Sheridan, Wyo., 103° at Rapid City, S. Dak., 94° at Cleveland, Ohio, and 98° at Rochester, N.Y. Despite the cooling, northern sections still averaged above normal for the week due to the large surplus built up in the early part of the week (fig. 5C).

Rains were light over most of the country this week (fig. 5D) since the location of the High in the West prevented moisture from entering most areas. The subsid-



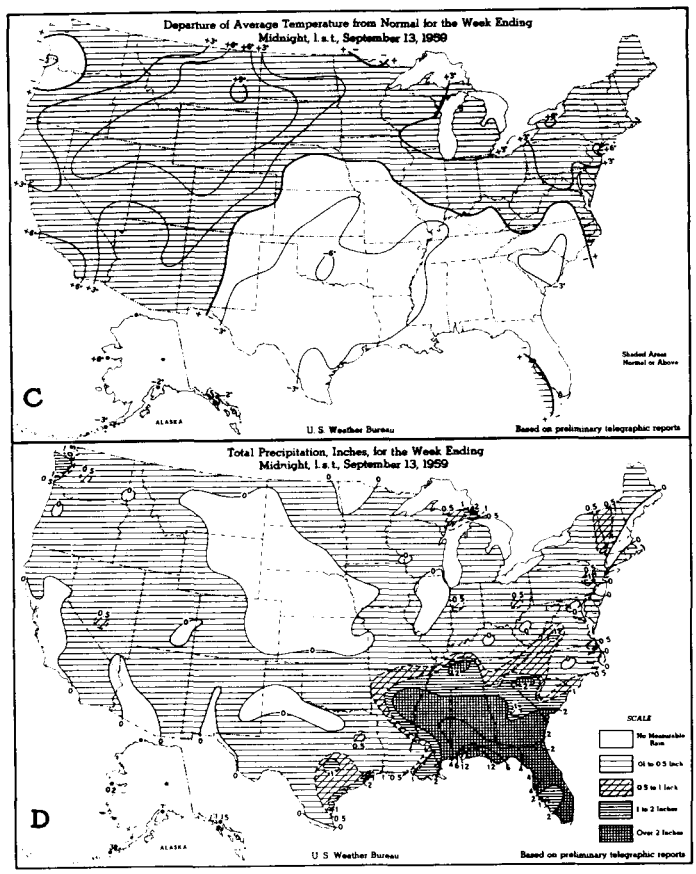


FIGURE 5.—(A) 5-day mean 700-mb. contours (solid) and height departures from normal (dotted) (both in tens of feet) for September 10–14, 1959. (B) Mean sea level isobars (solid) (millibars—hundreds omitted) for September 10–14, with smoothed tracks of migratory cyclones (dashed) and anticyclones (dotted) for week ending September 14, 1959. (C) Departure of average surface temperature from normal (° F.) and (D) total precipitation (inches) for the week ending September 13, 1959. (C and D from *Weekly Weather and Crop Bulletin, National Summary* vol. XLVI, No. 37, September 14, 1959.)

ing motions associated with anticyclonic curvature of the flow provided an additional desiccating mechanism.

However, in the Southeast, conditions were quite different. Here cyclonic flow associated with a Low near the mouth of the Mississippi River maintained ascending motion over the East Gulf States, overrunning the wedge of cooler than normal air. This produced excessive rains in the East Gulf States and the Carolinas, with totals in excess of 4 inches over a large area. Both Pensacola and Appalachicola, Fla., reported over 11 inches, with almost 10 inches falling at Pensacola in one 24-hour period on the 12th and 13th.

A comparison of figure 5B with 4B reveals further highlights of the dramatic reversal of the circulation from the first week to the second week. The cyclone tracks reflect the absence of cyclonic activity over the United States except in the Gulf of Mexico and in the extreme West. Here the Low from the Gulf of Alaska plunged southeastward toward the Pacific Northwest as the amplification neared its climax.

The anticyclone track from the Pacific Northwest to the Great Lakes was also a symptom of the extreme amplification process going on at upper levels. For one thing this High intensified as it moved across the northern Plains, and its northward recurvature along Lake Michigan on the 12th was probably one of the most unusual anticyclone tracks on record for this area. The southward movement of the Gulf of Alaska Low and the northward movement of the High were both compatible with diminishing westerlies at middle latitudes.

6. THIRD WEEK—AMALGAMATION OF ANTICYCLONES OVER CANADA

Early in the third week the large-scale waves reached their greatest amplitude. At this time the southeastward-moving anticyclone from the East Siberian Sea

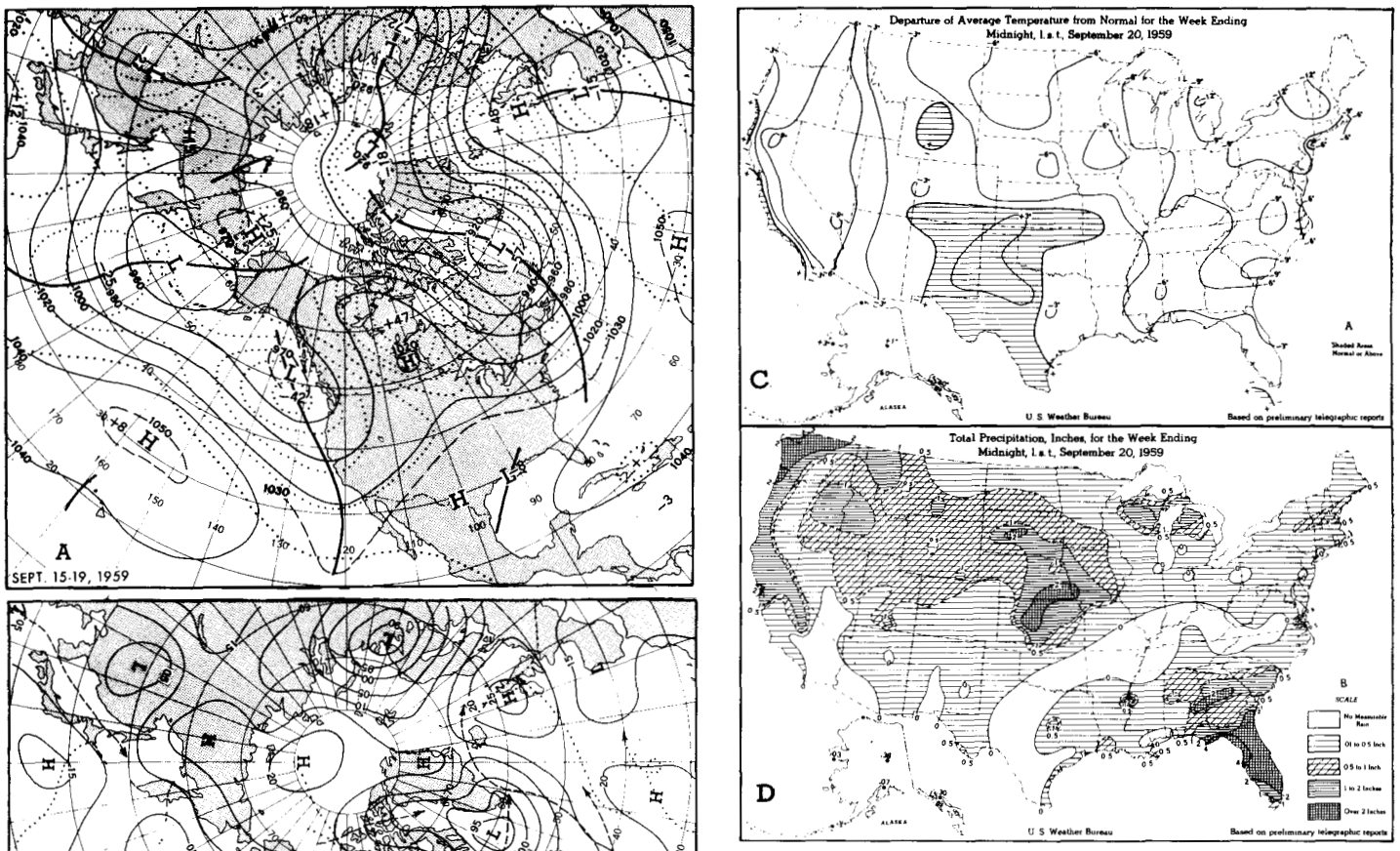


FIGURE 6.—(A) 5-day mean 700-mb. contours (solid) and height departures from normal (dotted) (both in tens of feet) for September 15–19, 1959. (B) Mean sea level isobars (solid) (millibars—hundreds omitted) for September 15–19, with smoothed tracks of migratory cyclones (dashed) and anticyclones (dotted) for week ending September 21, 1959. (C) Departure of average surface temperature from normal (° F.), and (D) total precipitation (inches) for the week ending September 20, 1959. (C and D from *Weekly Weather and Crop Bulletin, National Summary*, vol. XLVI, No. 38, September 21, 1959.)

merged over central Canada with the northward-moving anticyclone from the western United States. This was followed by severing of the anticyclone over central Canada as a new branch of westerlies broke across the central United States to its south. This evolution proceeded in concert with further deepening of the west coast trough as the Low from the Gulf of Alaska migrated toward the Pacific Northwest. Figure 6A shows the average circulation at 700 mb. for period September 15–19, with the height departures from normal highlighting the blocking character of this stage of the cycle; i.e., a positive departure area over central Canada flanked by negative areas to its southeast and southwest. This period is a classic example of the forecaster's rule that blocking in Canada is generally associated with cold and wet conditions in the United States, shown by figures 6C and 6D.

The mean sea level chart (fig. 6B) reflects the storminess which dominated the Pacific Northwest during this period. The mean Low off the west coast averaged 15 mb. below normal, and was largely a reflection of an intense winter-type storm which attained a minimum pressure of at least 985 mb. near the Oregon coast on the 18th. This storm brought high winds and practically all the month's record rainfall to northern California. San Francisco received 2.30 inches within 24 hours, more than twice the previous September record and 24-hour record. San Francisco airport also reported high winds of 48 m.p.h. on the 18th, 5 m.p.h. higher than the previous record.

In the East, the week was featured by the southeastward migration of an unusually intense Arctic anticyclone from the Lakes Region across the Middle Atlantic States, as shown by the track on figure 6B. This track was a symptom of the early stages of attenuation of the extreme amplitude of the large-scale flow of mid-month. This slowly-moving High produced record-breaking low temperatures in the Northeast, from the Great Lakes to New

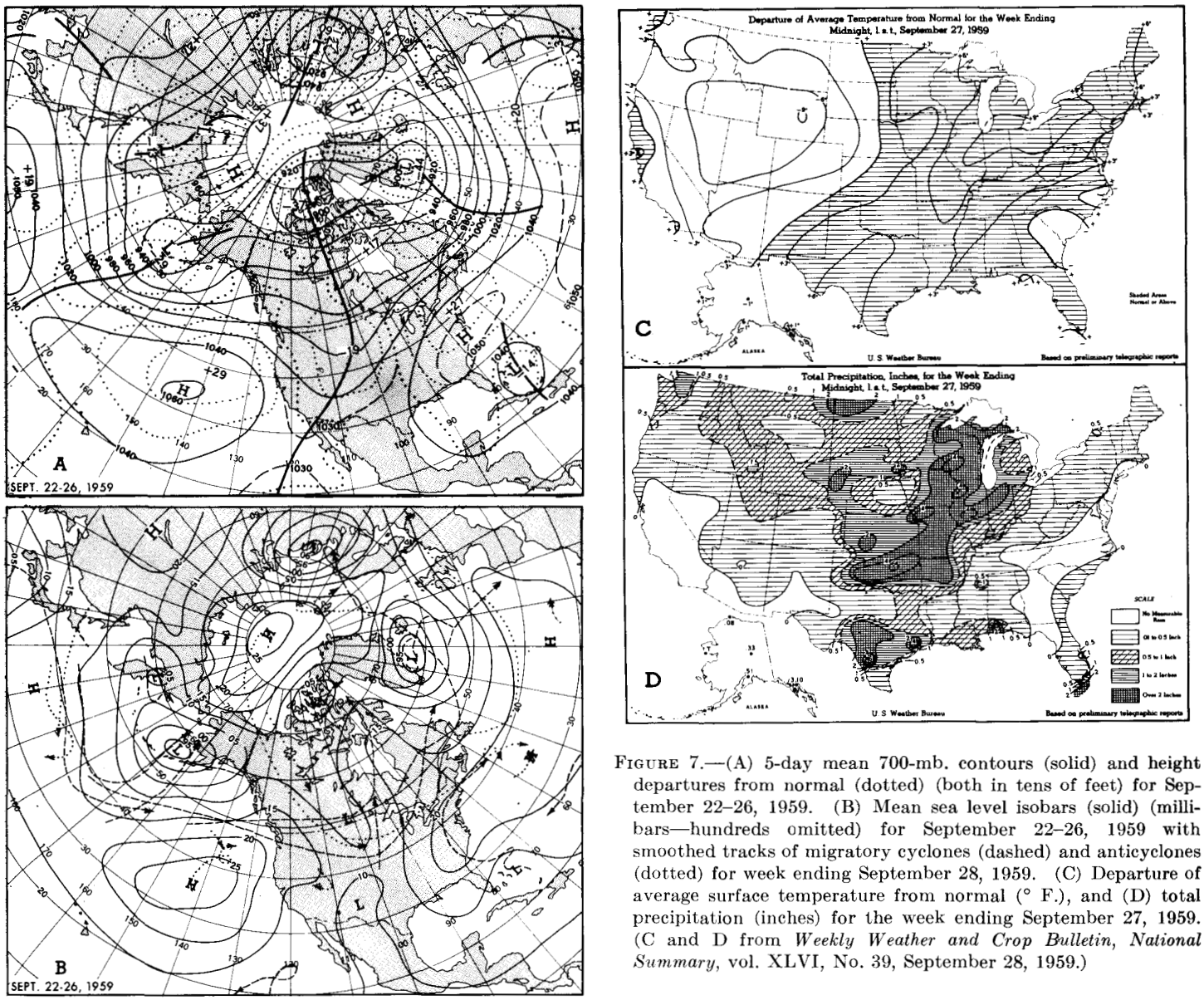


FIGURE 7.—(A) 5-day mean 700-mb. contours (solid) and height departures from normal (dotted) (both in tens of feet) for September 22–26, 1959. (B) Mean sea level isobars (solid) (millibars—hundreds omitted) for September 22–26, 1959 with smoothed tracks of migratory cyclones (dashed) and anticyclones (dotted) for week ending September 28, 1959. (C) Departure of average surface temperature from normal (° F.), and (D) total precipitation (inches) for the week ending September 27, 1959. (C and D from *Weekly Weather and Crop Bulletin, National Summary*, vol. XLVI, No. 39, September 28, 1959.)

England, a marked reversal from the record high temperatures of the early part of the second week. A few examples of the cold accompanying this High are: Lansing, Mich., record minima of 32° and 31° on the 16th and 17th, respectively; Toledo, Ohio, minimum temperatures in the 30's on four consecutive days from the 16th to the 19th; and Pittsburgh, Pa., record minima in the 30's on the 17th, 18th, and 19th.

Heavy rains this week spread eastward across the Rockies to the Great Lakes Region as the southwesterly flow of moist air that prevailed aloft (fig. 6A) overran the cold Arctic air as far east as the Upper Mississippi Valley, with Kansas receiving ½ to 3 inches over most of the State. A similar overrunning pattern existed in the Southeast, producing excessive precipitation amounts of 8 to 10 inches at scattered places in Florida.

7. FOURTH WEEK—ATTENUATION AND PROGRESSION OF THE LARGE-SCALE WAVES IN THE WESTERLIES

The fourth week saw the culmination of this remarkable 3-week cycle of development and decay of the large-scale wave pattern aloft. The attenuation of the major ridge over central North America was characterized by an almost complete phase shift over this continent, similar to, but in reverse of, the retrogressive shift which accompanied the amplification stage of the cycle in the second week. This week's reversal saw the ridge of the third week give way to a trough over central North America (fig. 7A). This may be viewed as a progression of the Pacific coastal trough eastward in response to increasing westerlies. Similarly, the collapse of the block over Canada may be viewed as a southeastward progression of this feature to the Middle Atlantic States. In terms of height anomalies, the negative anomaly off the Pacific

Northwest coast moved eastward to the Continental Divide, while the Canadian positive center migrated southeastward into the eastern United States.

This evolution set the stage for intensification of cooling over the central Rockies, while temperatures in the East returned to record warmth (fig. 7C) in many places, due to the return of abnormally strong southerly flow. New maximum temperature records were set at Akron, Ohio, with 88° on the 28th and Pittsburgh, Pa., with 90° on the 28th and 89° on the 29th, and were equalled at Albany, N.Y. on the 24th and 28th with 87° and 83°, respectively.

The persistent southerly flow during the week from eastern Texas to the Northern Plains and Upper Mississippi Valley brought excessive precipitation, high winds, and severe local storms to the Midwest, with weekly rainfall totals of 1 to 3 inches over a large area (fig. 7D). Local precipitation amounts of more than 10 inches in Oklahoma, 6 inches in southern Texas and Kansas, and 5 inches in Iowa, Minnesota, Illinois, and Michigan were recorded.

The strength and persistence of the meridionally oriented polar front associated with the mean trough in the center of the country can be assessed by the average temperature anomaly gradients for this period in figure 7C. This strong baroclinic zone bred a number of vigorous frontal waves, one of which produced the lowest September pressure of record, 989 mb., at Dubuque, Iowa on the 26th. This front, overrun by very warm and moist tropical Gulf air, spawned several tornadoes in Missouri, Wisconsin, Illinois, Kansas, and Iowa, on the 26th and 27th. Figure 7B shows the mean sea level pressure pattern characteristic of the week, with the associated cyclone and anticyclone tracks.

Late in the week the polar front moved eastward as cold Arctic air flowed southward into the northern Rockies and the high Plains. Overrunning of this wedge of cold air produced damaging snowfalls of record intensity in eastern Colorado. Pueblo reported a record 14 inches of heavy, wet snow which fell on the 29th and 30th with heavy damage to trees and shrubs.

Also near month's end hurricane Gracie moved inland across the South Carolina coast about 11 a.m. EST, September 29, a little south of Charleston. Winds were estimated near 120 m.p.h. and tides up to 9.7 ft. above mean low water in the Charleston area. Heavy rains along the storm path (fig. 8) totalled over 6 inches in most of South Carolina, 8 inches in western North Carolina, 10 inches locally in Virginia, 6 inches in western Maryland, 4 inches in West Virginia, and from 1 to 2 inches in the New England States. Figure 7D does not reflect this rainfall since the hurricane had not moved inland until the last two days of the month.

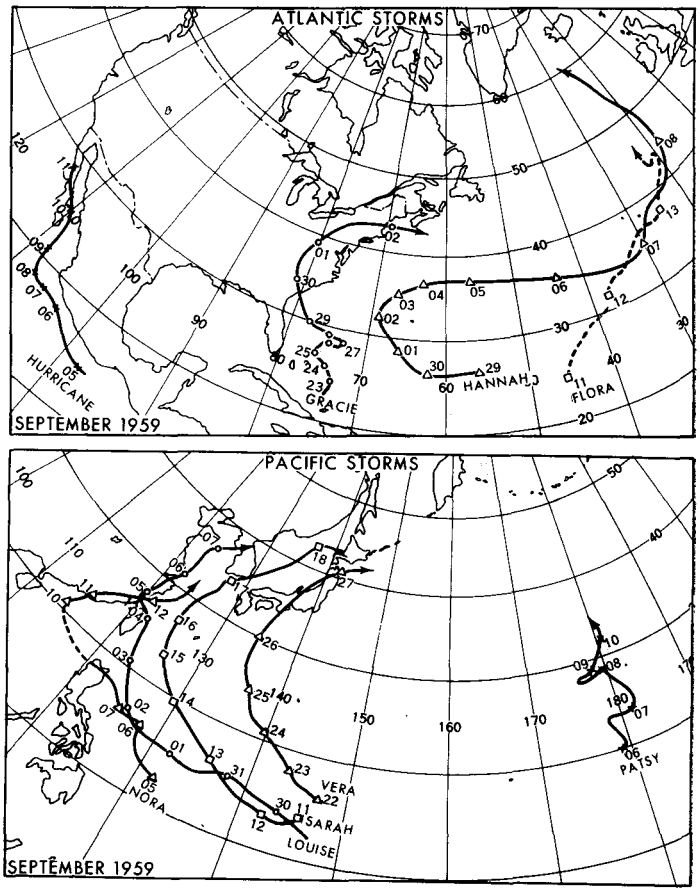


FIGURE 8.—Selected tropical storm tracks for September 1959. All attained hurricane force except Nora. Dates represent approximate 0000 GMT positions.

8. HURRICANES AND TYPHOONS

ATLANTIC

Three hurricanes developed in the Atlantic during the month. All three developed hurricane winds north of 20° N., which is unusually far north except for storms which originate near the Bahamas as hurricane Gracie did. Flora may have originated south of this latitude, but Hannah clearly appeared to have originated north of 26° N. All three developed close to the stage of the index cycle considered most propitious for hurricanes; i.e., at times of high index, when the westerlies were farthest north and the subtropical easterlies strongest. Hurricane Flora developed around the 9th, Gracie on the 22d, and Hannah on the 27th, which were times when the index was close to its maximum. The development of Gracie and Flora appeared to be associated with the well-known shearing process, in which the southern portions of full-latitude major troughs become disassociated from the more rapidly moving northern portions near times of high index [1].

These storms traced widely diverse paths as shown in figure 8. Hurricane Flora followed a very unusual path, heading rapidly for the Azores after detection on the 9th, with highest winds reported near 65 knots. The eastward component of this motion throughout its entire duration may be attributed to the sharp drop in the speed and lati-

tude of the westerlies between September 9 and 12 (fig. 3). The latter circumstance occurred in consonance with retrogression of the blocking anticyclone from near the United Kingdom to a position south of Iceland during this period. As a result the depressed westerlies in the eastern Atlantic swept hurricane Flora rapidly northeastward.

Hurricane Gracie, on the other hand, had its inception in the ascendant phase of the index. Thus the westerlies were increasing their latitudinal separation from the storm, and it drifted slowly northwestward. Around the time of the index maximum, from the 25th to the 27th, the hurricane wallowed indecisively while blocked by a High which moved eastward across New England. The hurricane resumed its northwestward course toward the coast on the 27th as the High center moved east of the storm's meridian. This was also about the time hurricane Hannah put in its appearance about 1400 miles farther east. Between October 1 and 2 both Gracie (now an extratropical Low), and hurricane Hannah recurved sharply eastward as the index dropped below the normal.

Thus it appears that the Atlantic hurricanes this month were spawned when the speed of the temperate westerlies (and the subtropical easterlies) was above normal, at which time westward motion prevailed. When the zonal index declined below the normal, eastward motion and/or recurvature to eastward occurred.

PACIFIC

In the North Pacific, 12 tropical cyclones were observed this September. In the eastern Pacific, two hurricanes developed off the west coast of Mexico, and one tropical storm occurred east of Hawaii. The first eastern Pacific hurricane (fig. 8) was detected near 14° N., 98° W. on September 4, about the time the index rose above the normal. It apparently disintegrated over Baja California on the 11th when the index was dropping sharply. The second hurricane (not shown) was detected near 17° N., 119° W. on the 21st and, after following an irregular path, apparently dissipated on the 26th near 20° N., 130° W.

Tropical storm Wanda, east of Hawaii, was shortlived, as was tropical storm Opal and depressions Marge, Ruth, and Thelma (not shown). Tropical storm Nora (Sept. 5–12) moved from east of the Phillipines across Luzon and passed near Hong Kong into the Yellow Sea (fig. 8). Highest winds were estimated at about 35 knots.

In addition to typhoon Patsy in the central Pacific, and typhoon Louise which developed late in August but hit Formosa early in September, two other severe typhoons wreaked widespread destruction in the Far East. These were typhoon Sarah and typhoon Vera, whose tracks are shown in figure 8.

Typhoon Sarah, first detected on September 11, reached typhoon intensity on the 12th, passed over the Ryukyus on the 15th, and swept across southern Korea into the Sea of Japan. Winds well over 100 knots brought considerable destruction to Korea and southern Japan, and heavy casualties in the fishing fleets.

About 10 days later typhoon Vera, a monstrous storm in both size and intensity, after originating near the Marianas, moved northwestward and then northward along the 135° E. meridian, striking central Honshu on the 26th. Winds well over 100 knots plus excessive precipitation and tides resulted in enormous casualties and destruction, placing it in the category of one of the greatest natural catastrophies in the modern history of Japan.

REFERENCE

1. J. Namias "Long Range Factors Affecting the Genesis and Paths of Tropical Cyclones," *Proceedings of the UNESCO Symposium on Typhoons, 9–12 November 1954*, Tokyo, pp. 213–219.

Weather Note

A REPORTED SEA LEVEL PRESSURE OF 877 MB.

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[Manuscript received September 8, 1959; revised September 14, 1959]

A dropsonde observation made in the eye of typhoon Ida at approximately 0500 GMT, September 24, 1958 showed a sea level pressure of 877 mb. (25.91 in.) which is believed to be the lowest sea level pressure ever recorded.[1, 2] This is about 10 mb. lower than the generally accepted minimum pressure of 26.185 in. (886.7 mb.) which was observed in a typhoon in 1927 by the steamship *Sapoeroea* east of the Philippines, and about 15 mb. lower than the lowest Western Hemisphere reading of 26.35 in. (892.3 mb.) which was observed at Lower Matecumbe Key during the Florida Keys hurricane of September 1935 (cf. [2]).

The dropsonde observation cited above was made from the 700-mb. level by a U.S. Air Force reconnaissance aircraft of the 54th Weather Reconnaissance Squadron. At the time of this observation, typhoon Ida was located

[1] The value of 873 mb. reported for this typhoon in the 1958 *Climatological Data—National Summary* (p. 93) represents an estimate of the sea level pressure based on the last reported information from the dropsonde. The pressure-height computation from this sounding, which was made 8 hours earlier than the one considered in this note, gave 878 mb. as the sea level pressure.

[2] Spectacular photographs of the eye of this storm taken from very high levels have been presented by Bundgaard, Fletcher, and Smith [1].