DETAILED ANALYSIS OF THE 1962 COLUMBUS DAY WINDSTORM IN OREGON AND WASHINGTON

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ABSTRACT

The most destructive windstorm of recorded history in the Pacific Northwest occurred on October 12, 1962. With a method between that of mesoanalysis and ordinary synoptic analysis, detailed reanalysis was made of the structure of the storm over Oregon and Washington, including isobaric patterns and frontal positions at 1-hr. intervals. The significant features of the storm are described. Comparison is made with other notable windstorms in the region. The pressure pattern is used to determine location and magnitude of maximum winds.

1. INTRODUCTION

The windstorm of October 12, 1962, caused more destruction in the Pacific Northwest than any other windstorm in recorded history. In Oregon and Washington, 31 persons were killed, and property damage was estimated conservatively at $225 million to $260 million. Numerous accounts [2, 4, 7, 9, 14, 17, 18, 19] describe events during the storm, details of destruction, and maximum winds; a few include a brief synoptic description. The blowdown of timber in western Oregon and western Washington amounted to more than 11 billion bd. ft., approximately equal to the annual cut in the two States. Nearly 98 percent of the blowdown was on the west side of the Cascade Range [13]. Wind damage to forests is a serious problem in this area where the forest industry is foremost in the economy. In addition to the immediate destruction of timber, there are associated longer term problems of increased fire danger and bark beetle epidemics [1, 5, 15].

Despite their impact, the meteorological features of previous windstorms have received scant investigation. The descriptions of past storms are vague. No detailed synoptic analysis of a violent windstorm in Oregon or Washington has heretofore been published. Even statistics on maximum winds are extremely limited [20] as a result of the sparse distribution of wind gages, most of which are located in valleys protected from the strongest wind. Wind records seldom include the speed of peak gusts. Furthermore, during violent storms, instruments are often damaged by flying debris or become inoperative because of power failure.

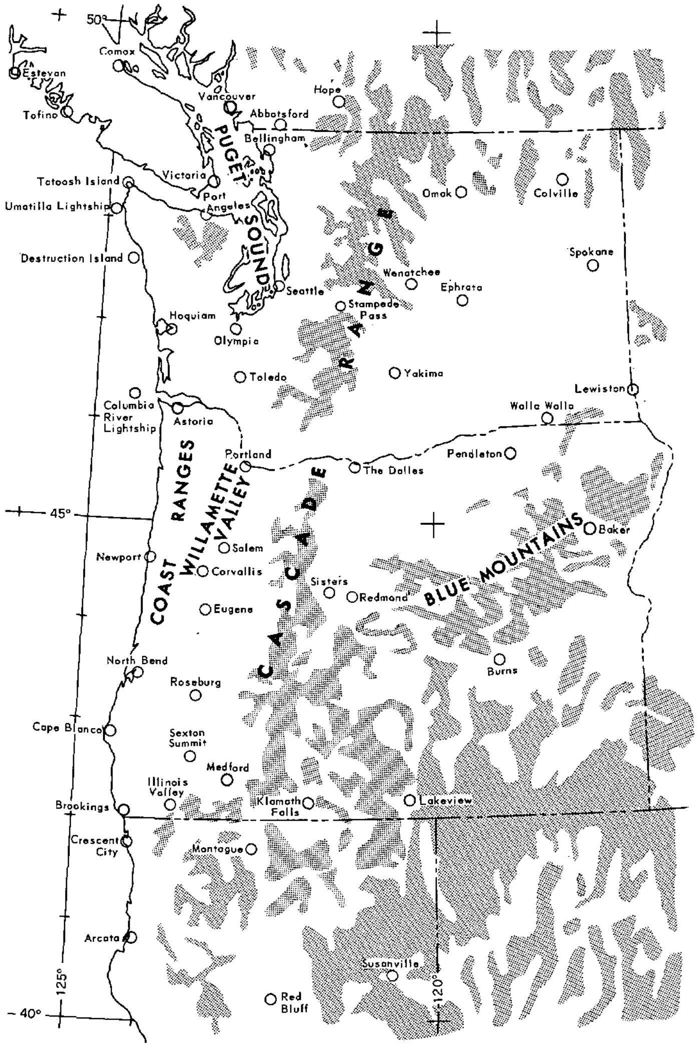

FIGURE 1.—Geography of the area struck by Columbus Day storm, 1962. Shading indicates elevations over 5,000 ft.

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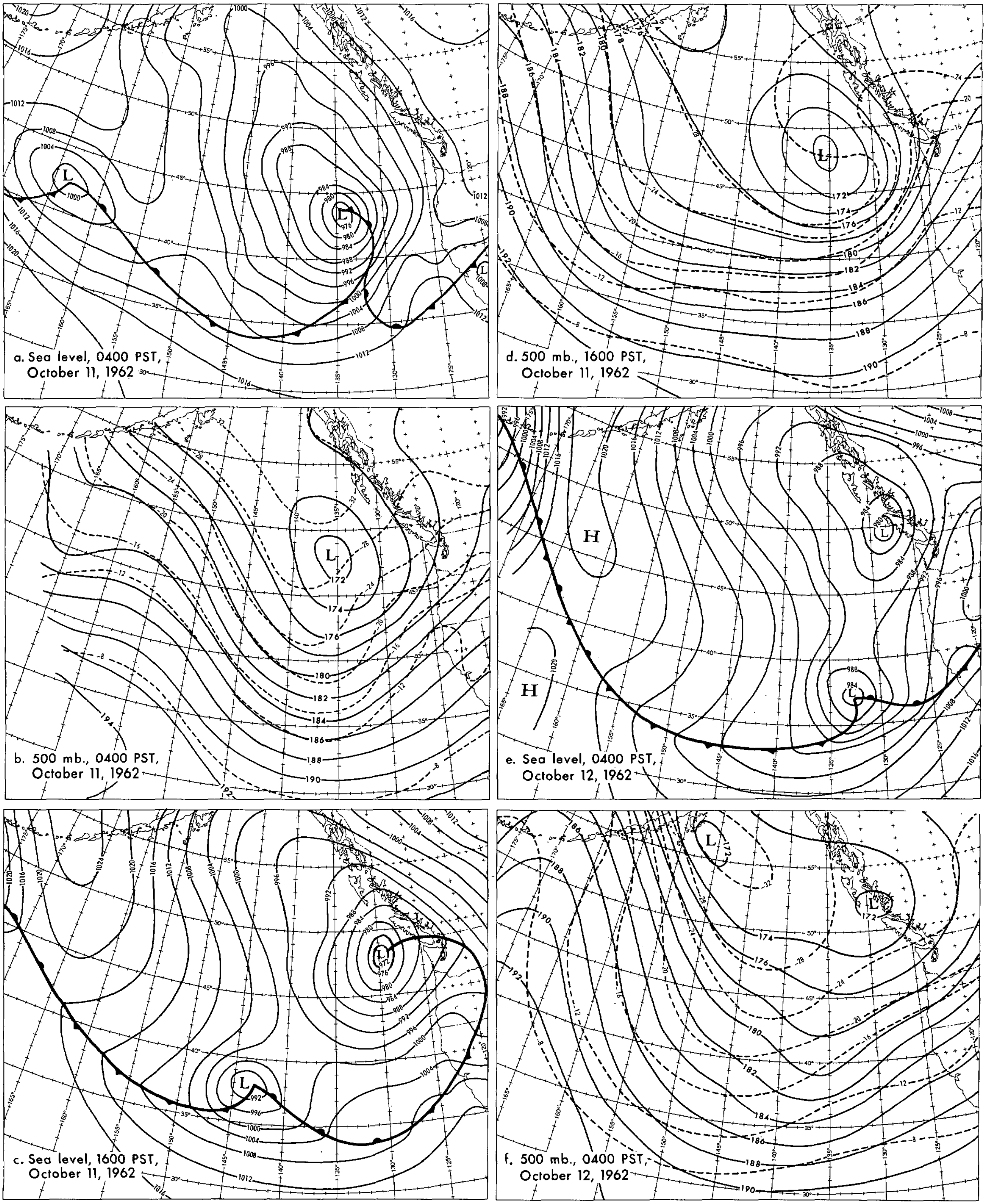


a. Sea level, 0400 PST, October 11, 1962

b. 500 mb., 0400 PST, October 11, 1962

c. Sea level, 1600 PST, October 11, 1962

d. 500 mb., 1600 PST, October 11, 1962

e. Sea level, 0400 PST, October 12, 1962

f. 500 mb., 0400 PST, October 12, 1962

FIGURE 2.—(a–i) Sea level and upper-air charts for October 11 and 12, 1962 (PST), from microfilm by San Francisco Weather Bureau Office. (j) Path of low center across eastern Pacific (time, date, and central pressure); inset: graph of central pressure vs. time.

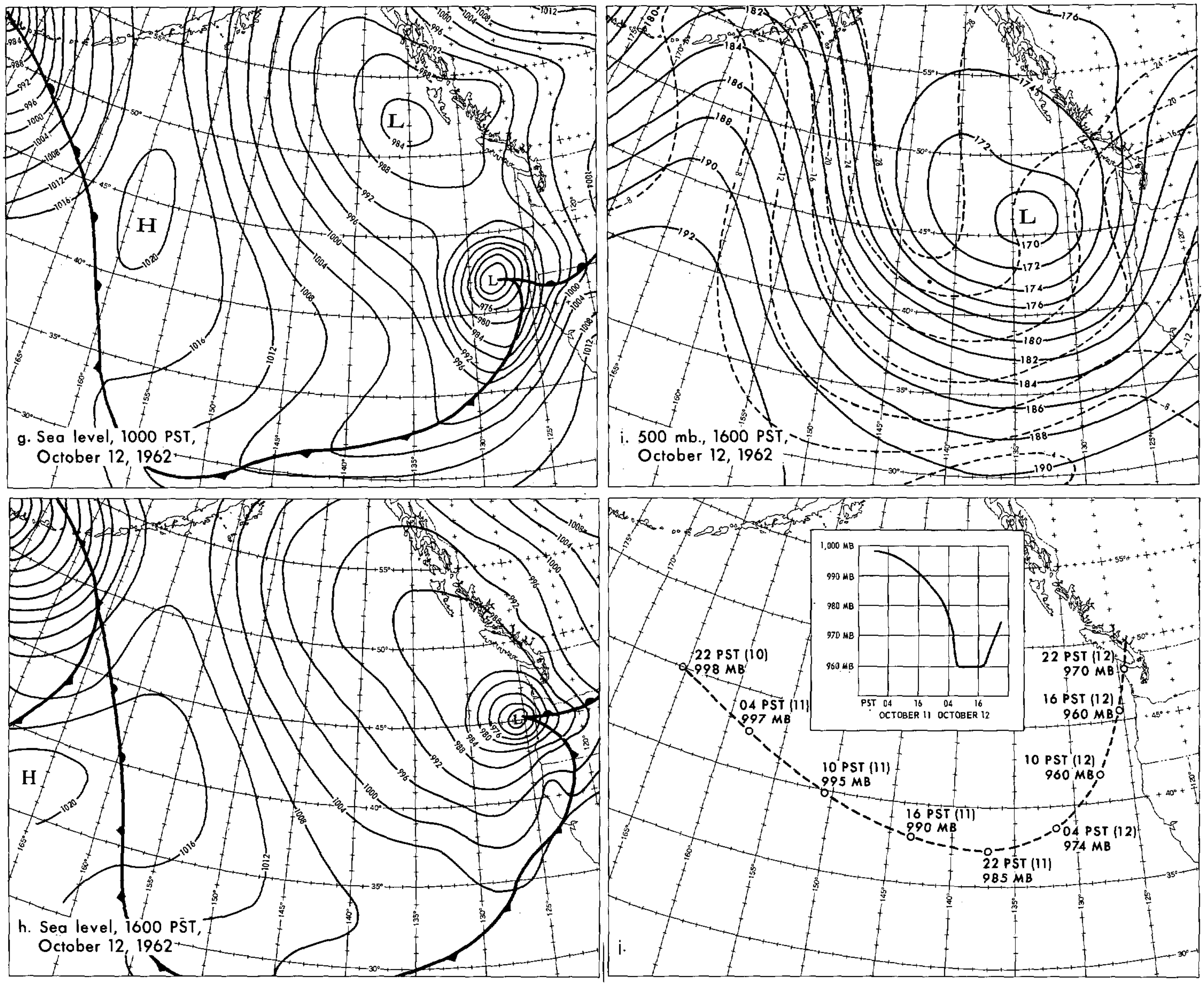
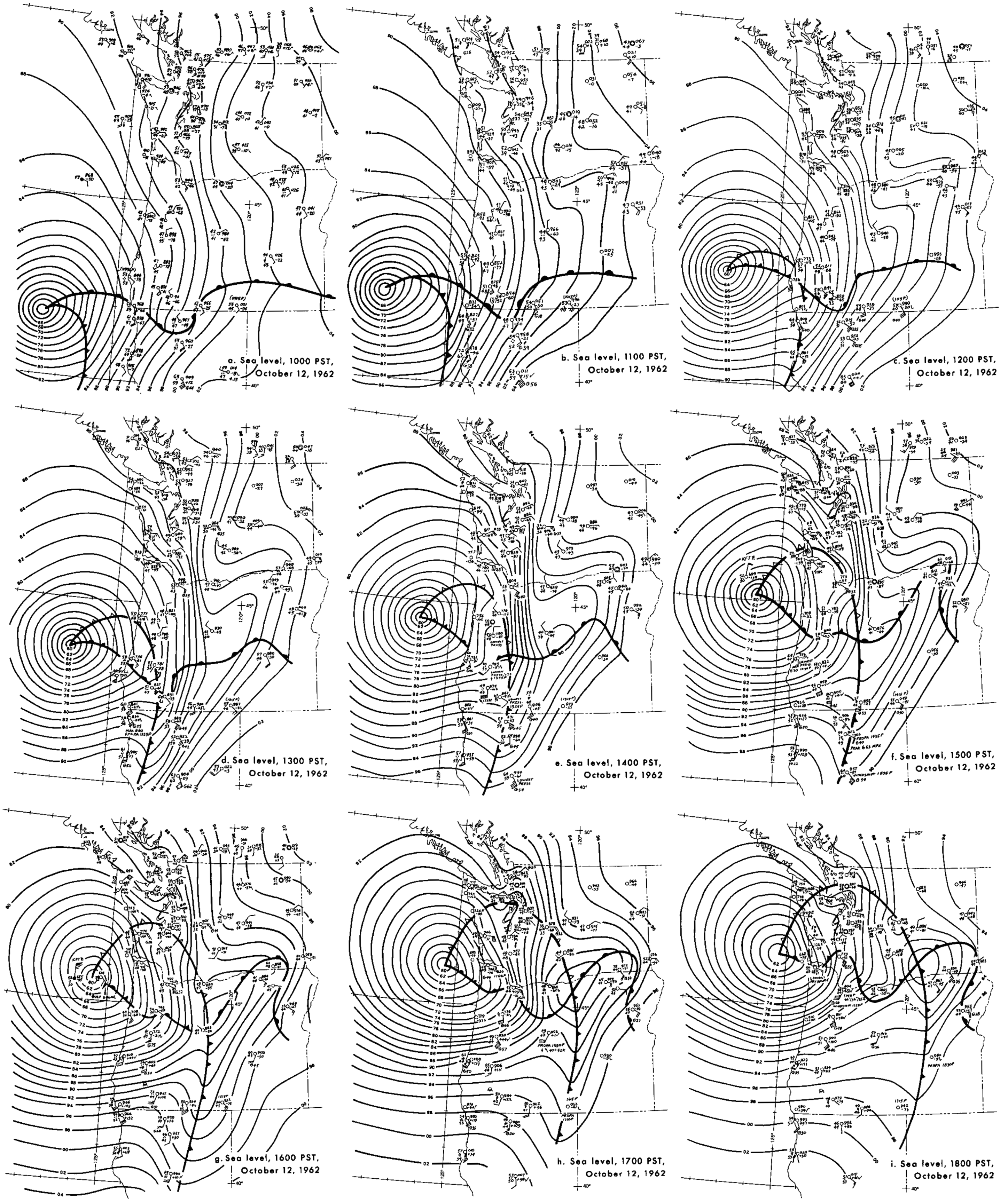


Figure 2.—Continued.

Why was the Columbus Day storm so violent? Was there some unusual characteristic that needs to be identified? Decker et al. [3] wrote: "Meteorologists will long study and puzzle over the storm's structure." They listed as unusual the double minimum of some barograph traces and the abrupt onset of high winds. They also mentioned the warming in eastern Oregon prior to the time of lowest pressure contrasted with the abrupt warming in western Oregon accompanying the pressure rise.

Immediately after the storm, forest agencies requested advice on the probable location of greatest blowdown. To locate the areas of strongest pressure gradient and to estimate the maximum wind, a series of sea level pressure maps was prepared for Oregon and Washington from airway teletypewriter data. The detailed structure of the storm was not clear from the preliminary analysis. Some teletypewriter reports were missing because of transmission difficulties during the storm, some data had poor fit, and the frontal positions seemed uncertain. A more detailed analysis was needed.

In addition to questions about this particular storm, there was another incentive for an intensive case study. Forest fire meteorologists have long been concerned with detailed weather conditions over rough terrain. The synoptic macroscale analysis is too coarse to meet many needs. A mesoscale network is not available. For investigative purposes, the intensive reanalysis of important cases is the best method to improve understanding of local weather structure. A reconstructed analysis can be refined by using all available data, including some not at hand for immediate analysis, such as micro-



a. Sea level, 1000 PST, October 12, 1962

b. Sea level, 1100 PST, October 12, 1962

c. Sea level, 1200 PST, October 12, 1962

d. Sea level, 1300 PST, October 12, 1962

e. Sea level, 1400 PST, October 12, 1962

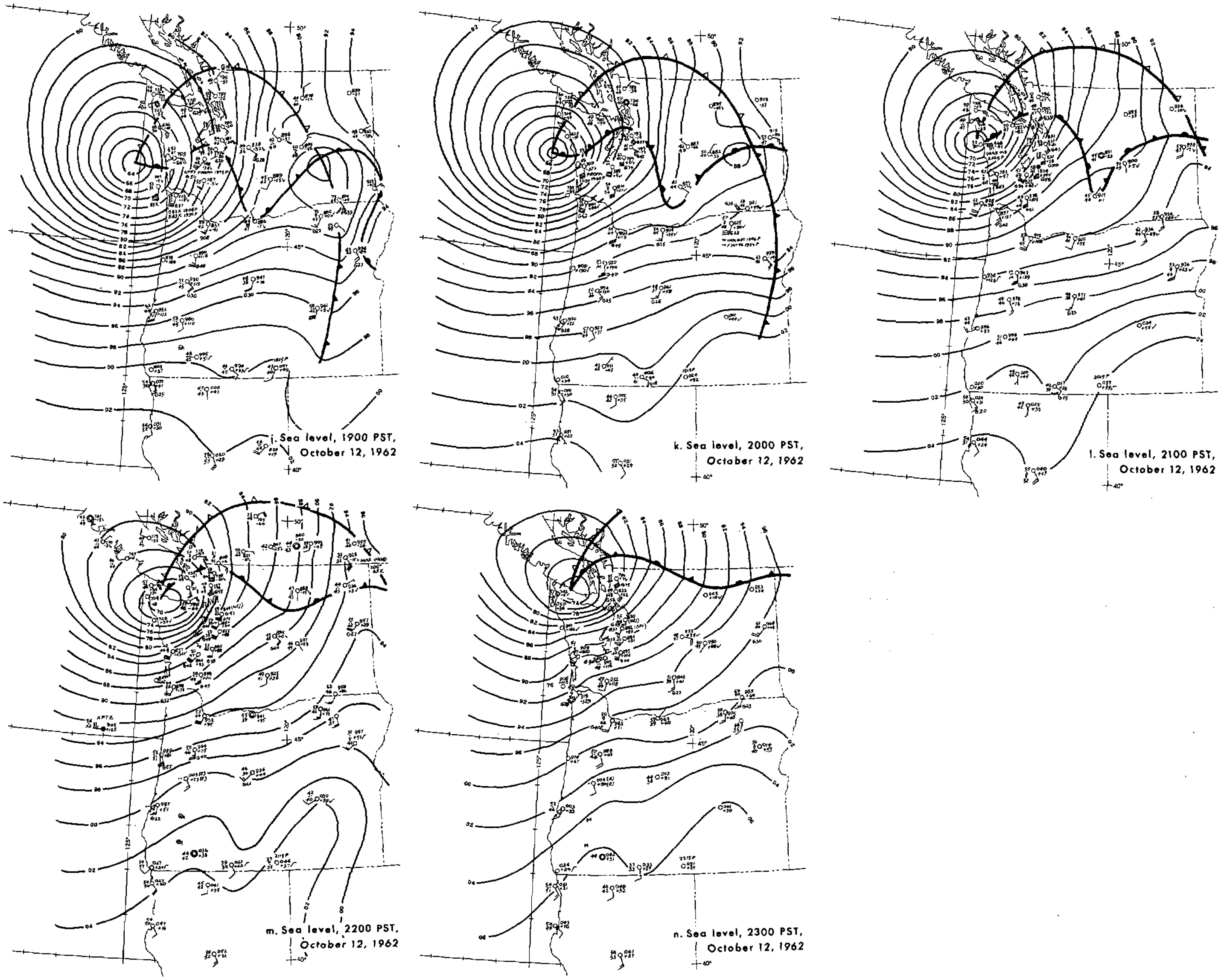
f. Sea level, 1500 PST, October 12, 1962

g. Sea level, 1600 PST, October 12, 1962

h. Sea level, 1700 PST, October 12, 1962

i. Sea level, 1800 PST, October 12, 1962

FIGURE 3.—Detailed hourly sea level maps for 1000–2300 PST, October 12, 1962.



j. Sea level, 1900 PST, October 12, 1962

k. Sea level, 2000 PST, October 12, 1962

l. Sea level, 2100 PST, October 12, 1962

m. Sea level, 2200 PST, October 12, 1962

n. Sea level, 2300 PST, October 12, 1962

FIGURE 3.—Continued.

barograph traces. Continuity can be improved by working backward as well as forward in time. Errors in observation can be corrected by systematic checking and comparing of data.

2. SOURCES OF DATA AND PROCEDURE

The National Weather Records Center provided photocopies of original surface and upper-air observations from both land stations and ships of the United States in the area shown in figure 1. Microbarograms from most of these stations were included. Unfortunately, original observations were not available from ships of foreign registry. The Weather Bureau Office at San Francisco provided a microfilm copy of manuscript sea level and upper-air charts [21].

Sea level maps of limited area were prepared for intervals of 1 hr. for a period of 14 hr., beginning at 1000 PST October 12, 1962. For these, pressure values were checked with microbarograph traces. Weather elements changed so rapidly that even a 10-min. error in observation time produced significant distortion of the pressure analysis. Records of observations were checked carefully, and a correction was made only if there was strong evidence that the reported value was incorrect.

A vertical cross section from north to south across the storm was made for 1500 PST. Fortunately, the fast-moving fronts were in a position that permitted sampling at mid-afternoon radiosonde observation time.

3. CHRONOLOGY AND STRUCTURE OF STORM

The Columbus Day storm was the second and the strongest of three storms which reached the Pacific Northwest on successive days. The first one, on October 11 (figs. 2a and 2c), caused damage to buildings and powerlines at Gold Beach, Oreg., estimated at $750,000. In some instances, damage from this storm may have been credited to the storm of October 12.

The relationship between the Columbus Day storm and earlier tropical storms has been reviewed by Green [6] and Namias [11]. First, typhoon Emma appeared in the western Pacific on October 3. Typhoon Freda developed about 1,000 mi. to the east of Emma on October 4. The huge cyclonic circulation, associated with these typhoons in the western Pacific during the period October 2–11, responded downstream in the next long wave, contributing to an abnormally strong upper trough near 135° W. during October 9–13.

After its formation near 23° N., 165° E., Freda moved northward for four days, then northeastward for two days. By 0400 PST October 10, Freda had weakened to less than typhoon intensity, and the remaining depression was at 45° N., 180° W. The depression moved eastward and southeastward as a moderate frontal wave at the surface and as a short-wave trough aloft (figs. 2a to 2i).

As the surface wave moved under the major trough near 135° W., it intensified rapidly as an extratropical storm and developed a central pressure of 960 mb. The storm followed a curved path (fig. 2j) quite similar to the mean wind flow aloft. The center passed very near picket ship PS 25 at 40° N., 130° W., at 0700 PST October 12. At that time, the pressure at the ship was 962.6 mb. and the 3-hr. pressure tendency was −22.5 mb. Hourly observations at the ship aided in the determination of the path and central pressure of the Low in that vicinity.

It is noteworthy that the maximum deepening of the storm had occurred by 0700 PST (inset, fig. 2j) near 40° N., 130° W. This location is nearly 300 n. mi. southwest of Brookings, Oreg. During the next 11 hr., until the center passed near Astoria, there was no evidence of any significant change in central pressure. After 1800 PST, the storm filled rapidly.

Detailed sea level patterns of the storm were prepared for each hour from 1000 to 2300 PST October 12 (figs. 3a-n). The warm front and cold front progressed into a warm-type occlusion. The cold front moved uniformly (fig. 4), whereas the warm front moved irregularly as local terrain aided or retarded the retreat of the shallow layer of cold air (fig. 5).

The low center on each map was located along a smoothed path between reasonably reliable fixes at 1000, 1600, and 2200 PST. The precise locations and central pressures cannot be determined, but any error depicted here is probably small. Reports from ship ZXJG, offshore from Brookings, were finally omitted because of several unresolved inconsistencies in five teletypewriter reports received over a 3-hr. period. Observations at ship KFTZ at 1500, 1600, and 2200 PST were assumed to have been taken somewhat early.

Notable conditions and events, with reference to the hourly sea level maps, are discussed below in chronological order:

1000 PST (*fig. 3a*).—The storm center, 160 n. mi. wes of Crescent City, was moving toward the north-northeast at approximately 42 kt. A shallow layer of cold air covered Washington and nearly all of Oregon. Isobars over the land were oriented north to south. Wind flow in the cold layer near the ground was from the east, hindered by the north-to-south Coast and Cascade Ranges. Winds aloft were strong from the southwest or south-southwest, a direction 90° to 135° different from that of surface winds.

1100 PST (*fig. 3b*).—A pilot reported southerly winds of 100 kt. at 9,000 ft. between North Bend and Crescent City.

1230 PST.—Seattle relayed a report from a U–2 pilot at 55,000 ft., position not reported, "Most severe turbulence ever experienced." Crescent City reported a frontal passage with pressure rising rapidly.

1300 PST (*fig. 3d*).—According to a letter from Marcus L. McGhee, in charge of the Cape Blanco Loran Station, the wind was estimated at 150 kt., gusting to 170 kt.; the anemometer had already been broken.

1400 PST (*fig. 3e*).—The pressure was rising rapidly at Roseburg and the temperature had suddenly risen 8° F. with the passage of the warm occluded front.

1440 PST.—A pilot reported downdrafts of 2,000 ft./min., 5 mi. west of Portland. The upper cold front had just passed.

1500 PST (*fig. 3f*).—Three-hour pressure tendencies showed remarkable contrasts—for example, −12.9 mb. at Hoquiam compared with +12.9 mb. at Brookings. Temperatures at Pendleton and Walla Walla rose 6° and 7° F. from the previous hour as wind moving downslope from the Blue Mountains scoured out the shallow, cool air. The wind at Eugene was from the east at only 8 kt.

1600 PST (*fig. 3g*).—As the warm occluded front passed Eugene, the wind shifted to south and increased to 55 kt., gusting to 75 kt., and the temperature rose from 50° to 61° F. The front had not reached Salem where the wind was only 15 kt. with gusts to 25 kt.

As the warm occluded front passed each location, extreme winds began abruptly. The lack of strong wind until this climactic moment was deceptive to anyone unaware of the frontal structure. In the area north of the warm occluded front, the isobars were still oriented north-south and surface winds were from the east. However, southward from the front, the isobars had rotated almost 90°. In the latter area, the surface wind was blowing from the south or south-southwest, from the same direction as the free-air wind. The two mountain ranges offered no important obstruction to wind from this direction. No longer was there any shallow layer of cold air shielding the earth's surface from free-air wind of 70 to 100 kt. Turbulent eddies could carry this wind downward to the surface for the first time.

1700 PST (*fig. 3h*).—Shallow, cold air in the Columbia Basin was pushed westward against the Cascade Range as water against a dam. An east wind over the Cascades produced a lee trough in the Puget Sound area (figs. 3 e–i).

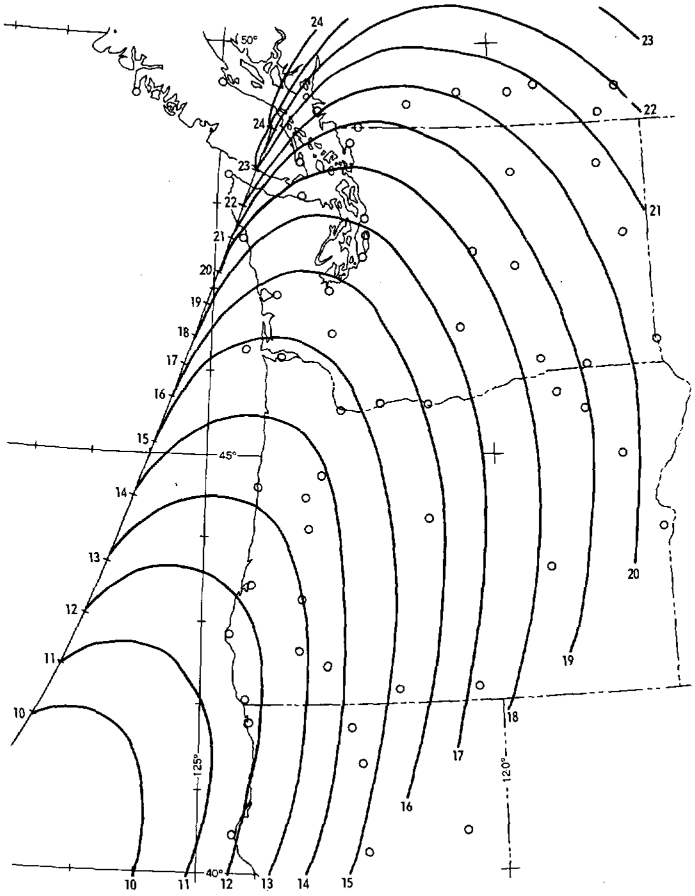


Figure 4.—Successive positions of cold front, October 12, 1962 (PST).

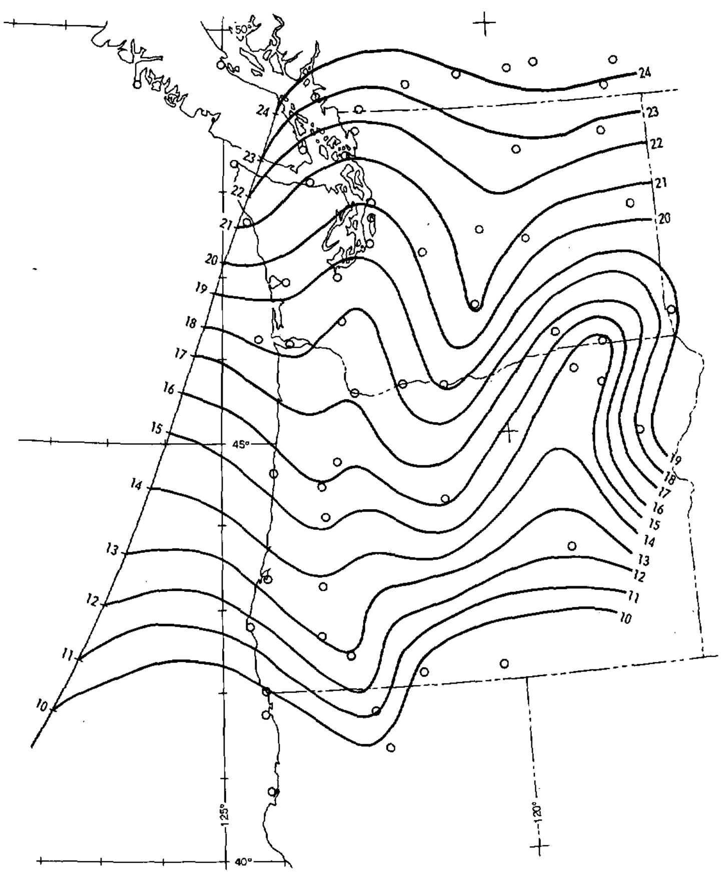


Figure 5.—Successive positions of warm front, October 12, 1962 (PST).

The secondary low center east of the Cascades had reached its maximum development. It was partly caused by the intersection of two fronts—a "point-of-occlusion Low"—and partly by the lee trough effect of southeast winds blowing down from the Blue Mountains. This secondary Low probably increased the wind in its own southeastern quadrant and probably decreased the wind in the Cascade Range in its northwestern quadrant.

1746 PST.—With the passage of the warm occluded front, the telepsychrometer at Portland recorded a temperature of 66° F., a rise of 10° F. in 10 min. During the same time, the relative humidity dropped from 72 percent to 33 percent. The warming and drying were only temporary, apparently caused by downdrafts. The temporary warming and drying observed with the frontal passage at Portland occurred at many other locations. Hygrothermograph traces at Illinois Valley in southwestern Oregon and Sisters Ranger Station in central Oregon (fig. 6) show abrupt warming accompanied by a change in relative humidity from saturation down to 50 or 60 percent.

2000 to 2300 PST (*figs. 3 k–n*).—Strong winds spread through the Puget Sound area. A "fastest mile" of 65 (56 kt.) was measured in downtown Seattle at 2057 PST.

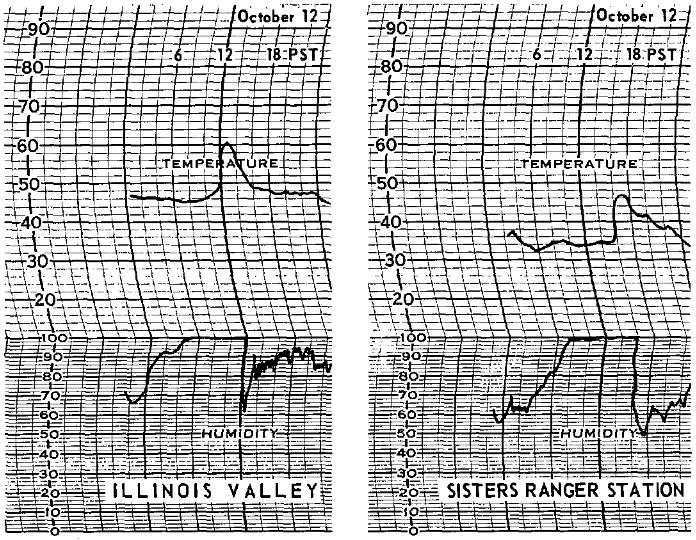


Figure 6.—Hygrothermograph traces for Illinois Valley and Sisters Ranger Station, October 12, 1962.

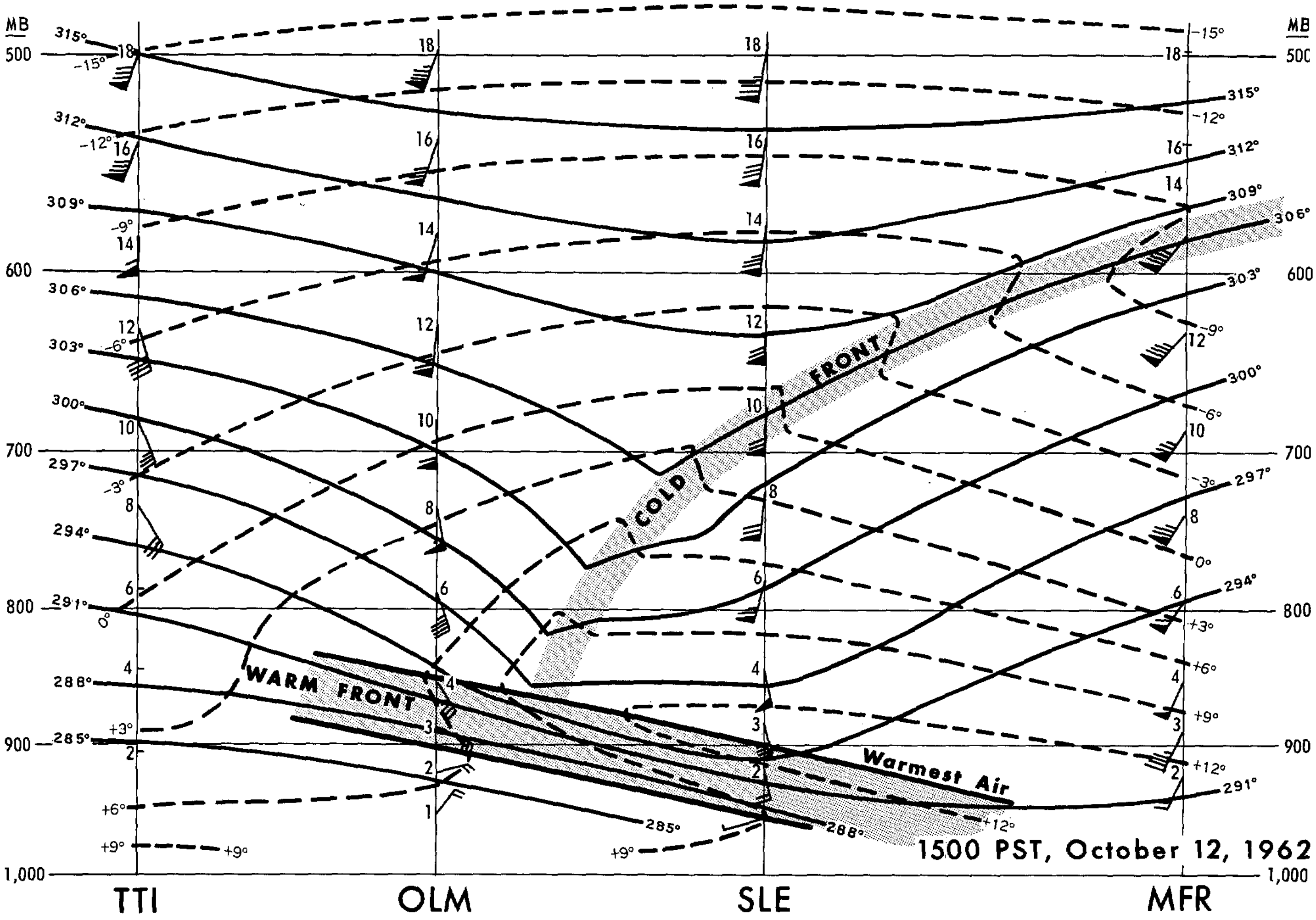


Figure 7.—Vertical cross section from Medford, Oreg. (MFR) to Tatoosh Island, Wash. (TTI). (SLE=Salem, Oreg.; OLM=Olympia Wash.) Solid lines are potential temperature in °A. Dashed lines are isotherms in °C.

Peak gusts were reported as follows: Renton tower, 87 kt. at 2000 PST; Whidbey Island, 78 kt. at 2142 PST; and Bellingham, 85 kt. at 2358 PST. The storm weakened rapidly as it moved into British Columbia, although additional destruction occurred there.

Additional types of analysis were used to show the structure and character of the Columbus Day storm. A vertical cross section (fig. 7) shows a north-south slice of the lower atmosphere across western Oregon and western Washington shortly before the extreme winds hit the Willamette Valley. The marked stability below the 900-mb. level which existed temporarily at Salem was due to the overlying warm front. Winds over Medford were blowing parallel to the cross section. The slope of the isentropes in this portion of the cold air mass indicated strong cold air advection. This slope and the increase in wind speed from 30 kt. at 2,000 ft. to 74 kt. at 8,000 ft. were conducive to strong downslope motion.

Neither the sounding for Salem nor for Medford (figs. 8 and 9) indicates at first sight the low relative humidity temporarily observed at Portland and elsewhere. However, if a point on the Medford sounding at 800 mb. is moved dry adiabatically down to 980 mb., it will show a temperature of 66° F. and a relative humidity of 32 percent, almost identical to values which occurred at Portland after the passage of the warm occluded front. Downdrafts of this magnitude probably were common.

Microbarograph traces during the period of lowest pressure are shown in their relative geographic positions in figure 10. The striking differences between stations suggest the complex details of the storm's structure. Frontal passages are quite evident at some stations (Salem, Portland) but are almost obscured at others (Baker, Stampede Pass). Times of frontal passages, as derived from the hourly maps (figs. 4 and 5), have been indicated on each trace. The nearby passage of the deep low center overshadows frontal passages at a few coastal stations (North Bend, Hoquiam). Early development of a lee trough in the Puget Sound area decreased the slope of the falling trace at Bellingham. A double minimum

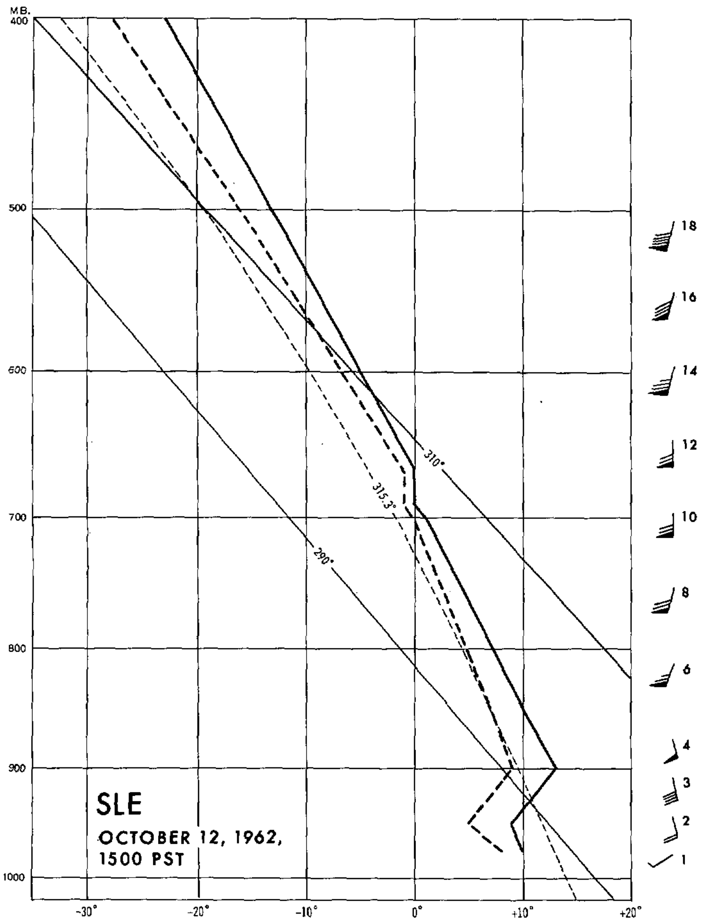


FIGURE 8.—Pseudoadiabatic diagram for Salem, Oreg., 1500 PST October 12, 1962. Temperature in °C.; dry and moist adiabats in °A. Wind: half-barb=5 kt.

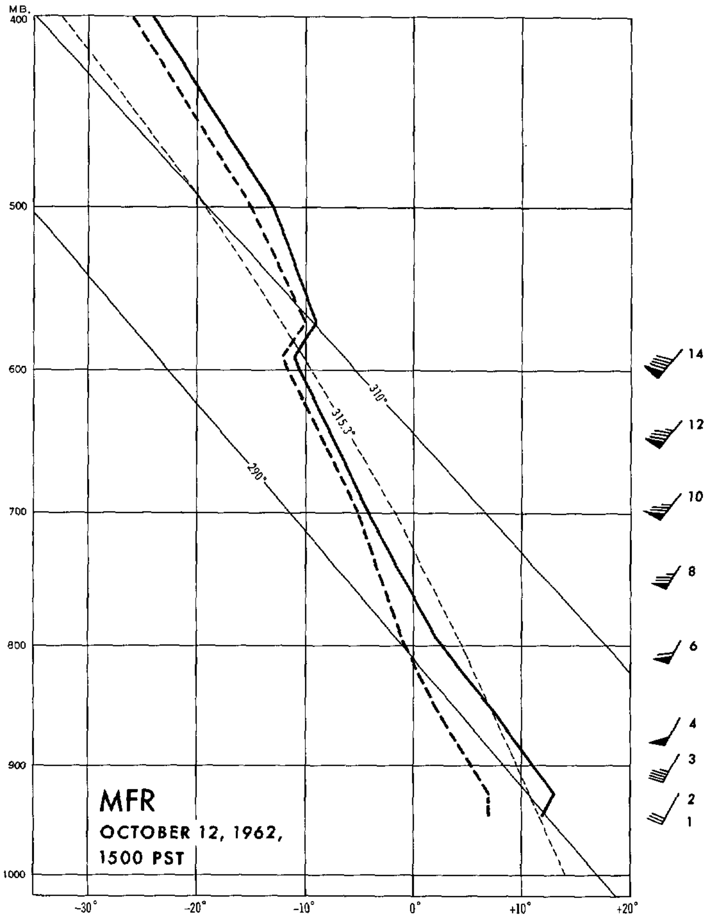


FIGURE 9.—Pseudoadiabatic diagram for Medford, Oreg., 1500 PST October 12, 1962. Temperature in °C. dry and moist adiabats in °A. Wind: half-barb=5 kt.

was pronounced at Eugene, Salem, Portland, and The Dalles. It was caused by the successive passages of the upper cold front and warm occluded front. The most rapid pressure rise observed anywhere during the storm was at Destruction Island where a 3-hr. tendency of +22.1 mb. was noted. Only a portion of that pressure trace is shown. Many trace variations remain unexplained; they were probably caused by structures too small or too transitory to be disclosed by the technique used here.

4. EVALUATION OF MAXIMUM WINDS

After the storm, there was an urgent need for accurate information on maximum winds for insurance companies, the legal profession, forest agencies, and even for the design of structures to replace those destroyed by the storm. Reports of highest winds on October 12 were compiled by Harper [7], Phillips [14], and Sternes [18].

It is improbable, however, that these reports represent the true maximum winds over the area. With respect to the Oregon reports, Sumner [19] remarked: "In practically every case there were periods of power failure. . . . It is quite likely much higher speeds occurred but for which no measurement was possible." Futhermore, very few anemometers are self-recording, and amid the confusion of the storm, observers could not devote constant attention to wind-speed indicators. Many of the published reports were only estimations and, for wind speeds exceeding previous experience, observer skill is questionable. In some cases, personnel safety took precedence over complete observations. Weather stations at Newport, Mount Hebo, and Corvallis were abandoned during the storm, possibly before the maximum wind occurred. The Troutdale tower was occupied only intermittently.

Under such circumstances, it is proposed that a careful analysis of sea level pressure gradients offers a conservative and sound basis for an approximation of true maximum winds. The locations and magnitudes indicated by pressure gradients supplement and revise the incomplete measurements and estimates which are available. Pressure gradients at 2-hr. intervals were measured from detailed sea level maps and drawn on a composite diagram (fig. 11). Measurements of isobar spacing were made across pressure differences of 10 mb. and applied to a

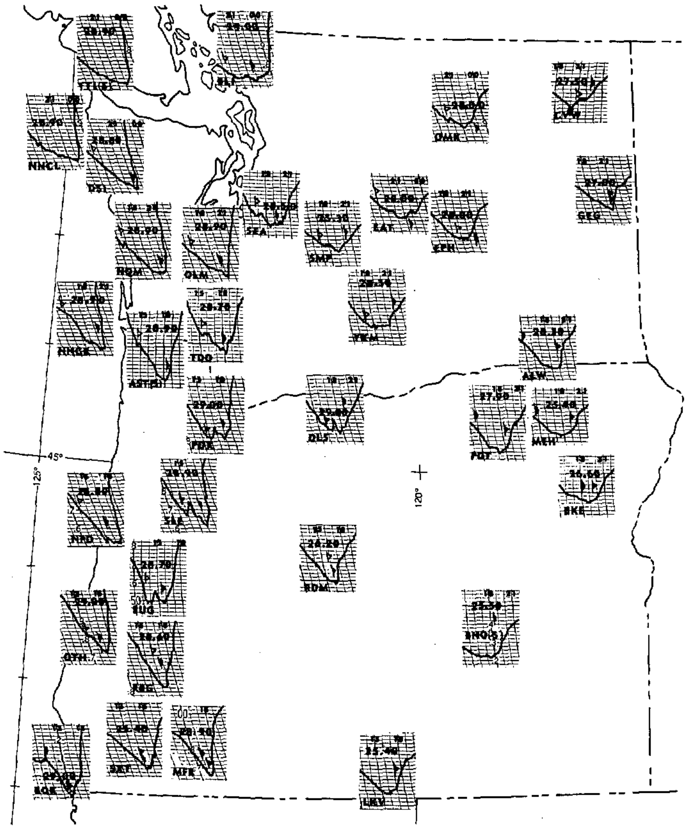


FIGURE 10.—Microbarograms for lowest station pressure on October 12, 1962. Horizontal lines for intervals of 0.02 in. Hg. Time is PST. Traces "shortened" from faster charts are labeled "S." Eugene trace partly estimated. Time of frontal passages indicated by symbols: |▶, cold front; |>, upper cold front; |◗, warm front or warm occluded front.

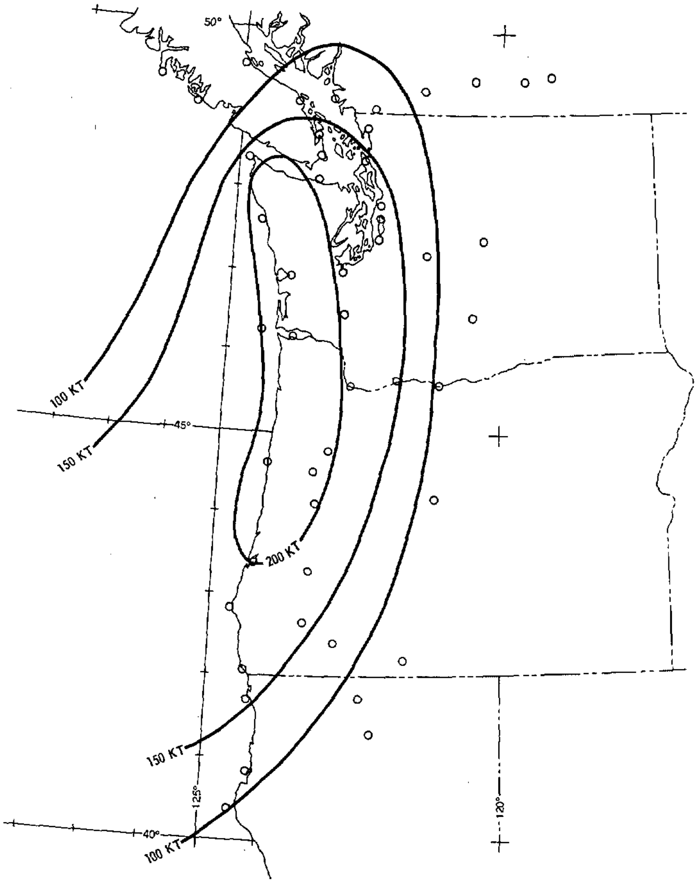


FIGURE 11.—Composite isotach chart of indicated geostrophic wind, derived from sea level isobars, between 1300 and 2300 PST October 12, 1962. (See text for restrictions imposed.)

simplified geostrophic wind scale (fig. 12). Not all the zones of maximum pressure gradient were included. For example, extreme pressure gradients appeared across the Cascade Range from east to west. Although easterly winds did blow across ridges and through passes in the Cascades, none was destructive because of blocking by the terrain and because this direction was dissimilar to that of the wind aloft. Also, areas covered with a layer of cold air, under the warm front surface, were protected from gusts and squalls in the faster wind above. Hence, measurements of isobar spacing were limited to areas south of the warm occluded front and to areas where the direction of the surface pressure gradient was within 40° of the direction of the upper wind, or approximately between 150° and 230° from the low center. The isotachs (fig. 11) show those areas where the strongest winds probably occurred.

The isotachs were labeled in units of indicated geostrophic wind. Adjustment from these values depends upon the particular need for maximum wind data, such as the highest 1-sec. gust, the highest 1-min. wind, or the wind at different elevations above the ground. Also, the individual exposure of any specific location will influence the maximum wind produced by any specific pressure gradient. For estimating the maximum wind at the standard elevation of 20 ft. at locations where no significant obstruction exists, the following ratios appear reasonable: The highest 1-min. wind will be 50 percent of the indicated geostrophic wind. The highest 1-sec. gust will be 70 percent of the indicated geostrophic wind. These ratios are in general agreement with the ratios described by Myers [10] and Sherlock [16].

5. SIGNIFICANT FEATURES AND COMPARISONS

The significant features of the Columbus Day storm are listed below:

(1) The broad pattern was unusually favorable for storm development. A strong upper trough covered the area off the west coast.

(2) A new storm appeared as an open wave under this upper trough. The central pressure decreased to about 960 mb. and the spacing of the isobars indicated geostrophic winds of at least 100 kt. The new storm was fully developed by the time it neared the coasts of Oregon

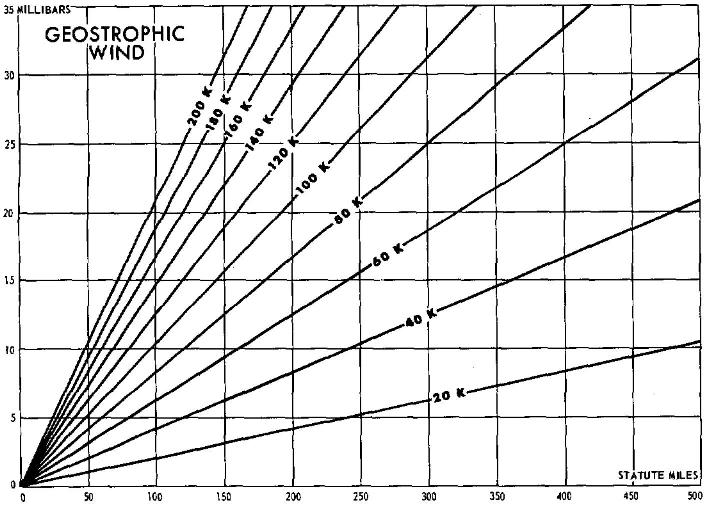


FIGURE 12.—Geostrophic wind scale for sea level isobars, for use near 45° N. latitude. Values from Smithsonian tables, multiplied by 0.816 to adjust to average density at sea level.

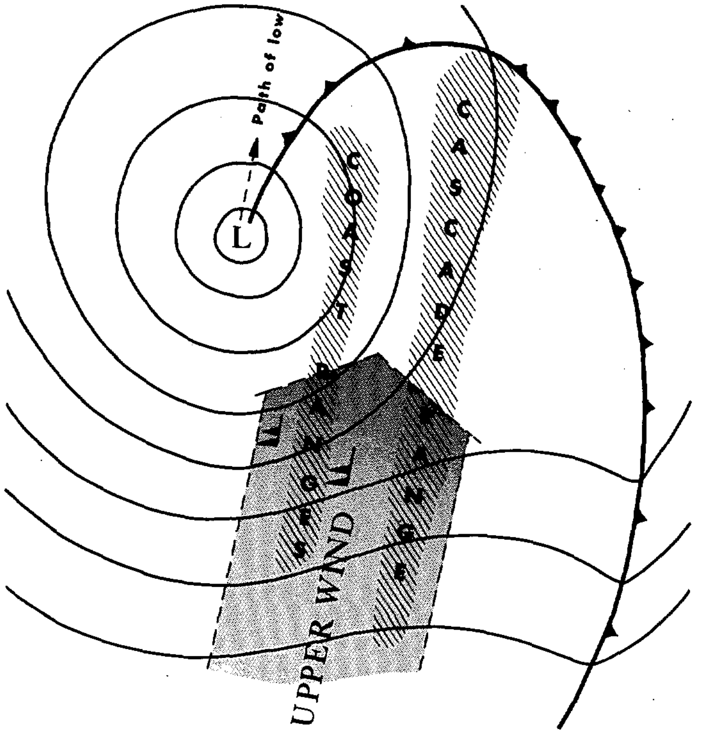


FIGURE 13.—Schematic diagram of a low center approaching from the south (Columbus Day storm).

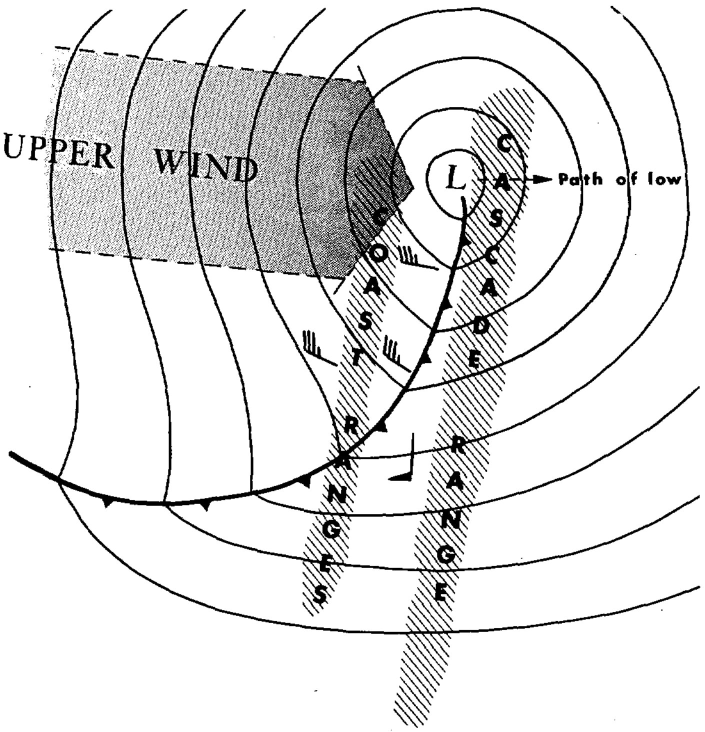


FIGURE 14.—Schematic diagram of a low center approaching from the west (windstorm not of Columbus Day type).

and Washington from the southwest. It remained at peak intensity as it moved north-northeastward along the coast.

(3) The upper wind at 700 mb. and 500 mb. was 100 kt. from about 230° over western Oregon and western Washington. As the storm approached, the wind direction backed slightly to about 190°. The surface storm center, steered by this upper wind, moved almost northward just off the coast, and reached the mainland near Tatoosh Island (fig. 13).

(4) The surface isobars across southwestern Oregon became oriented from west to east, or from southwest to northeast, creating a southerly wind. This wind blew between the north-south ranges of mountains with no significant blocking by terrain. The surface wind, from the same direction as the wind above, was reinforced by a transfer of momentum downward during squalls.

(5) Three-hour pressure tendencies of +12.0 mb. appeared in southwestern Oregon at the same time −12.0-mb. tendencies appeared in western Washington.

A *detailed* comparison of the Columbus Day storm with notable windstorms of earlier years was not undertaken. However, a limited search in files of Northern Hemisphere Historical Maps and printed *Daily Weather Maps* showed other windstorms of similar general type but of lesser intensity. Specific dates include November 14, 1953, April 14, 1957, February 24, 1958, and March 27, 1963. The sea level pattern of the famous Olympic Peninsula "hurricane" of January 29, 1921, was that of a storm moving northward just off the coast, but upper-air charts are not available for that date.

Some of the windstorms of the past, affecting western Oregon and western Washington, were significantly different from the Columbus Day storm. However, all storms not of the Columbus Day type appear to fall into a single category. This other type (fig. 14) approaches from the Gulf of Alaska and moves eastward across the area under the steering of a westerly wind aloft. Maximum surface wind also is from the south, but occurs ahead of the cold front, is of shorter duration, and is not reinforced by the upper wind. The cold front trails southwestward from the eastward-moving low center. Pressure rises behind the low center while pressure is still falling in southwestern Oregon ahead of the cold front. The south-to-north gradient between the mountain ranges immediately decreases as the low center reaches the Cascade Range. Surface wind in the wake of the storm is from the west or northwest and is hindered by the Coast and Cascade Ranges. Notably severe storms of this type occurred February 28, 1955, and December 16, 1961.

Even with limited investigation, it seems certain that no windstorm in the Pacific Northwest during the last 80 yr. equaled the Columbus Day storm in intensity and area of destruction. The storm of January 21, 1921, may have been nearly as strong; the 5-min. average wind at North Head, at the mouth of the Columbia River, was 110 kt. But the center of the storm was farther offshore and heavy timber blowdown was limited to the Olympic Peninsula.

The storm of January 9, 1880, probably was of comparable intensity. A newspaper of that date [12] reported widespread destruction in the vicinity of Portland, Oreg. The sea level pressure of 28.56 in. was the lowest ever observed at Portland, where the sequence of barometer readings showed a pressure rise of 22.8 mb. in 3 hr., equal to that observed at Destruction Island in 1962.

Two additional features about the Columbus Day storm should be remembered:

(1) It followed by only 30 hr. a destructive windstorm which also formed under the upper trough and moved northward along the Oregon-Washington coast.

(2) Its strongest wind occurred *after* the time of lowest pressure, after the frontal passage, and continued for 2 or 3 hr. Surface wind in advance of the storm center was generally from the east and deceptively weak, even along the immediate coast.

Because unusual 3-hr. pressure tendencies were observed during the storm, the concept of isallobaric contribution to wind was investigated. It was found that the existence of such an effect, or at least its relative importance, is subject to academic debate. Haurwitz [8] states: "The theoretical as well as the observational basis of the isallobaric wind is so unsatisfactory that this concept has to be abandoned." Isobaric gradients alone appeared adequate to explain the maximum winds of the Columbus Day storm.

After viewing each characteristic of the storm separate from the others, we found only one that was truly unusual—the appearance of a surface low center with a central pressure of 960 mb. in the vicinity of 40° N., 130° W. This location is far southeastward from the usual location of deep Lows. Other factors admittedly contributed to the violence of the storm, including the northward path close to the mainland and reinforcement of the surface wind by the upper wind. However, at least four other windstorms between 1953 and 1963 had similar characteristics, except that of such low central pressure.

6. CONCLUSIONS

In view of the economic havoc of severe windstorms in Oregon and Washington, it is regrettable that previous storms have not been more thoroughly analyzed and documented. The Columbus Day windstorm of 1962 was obviously worthy of the intensive analysis carried out in this study. The features of this storm should be compared with future storms.

The extreme intensity of the storm resulted from an unusual combination of circumstances. Primary among these was the formation of an abnormally strong upper trough near 135° W. This trough appeared to be linked dynamically with a huge typhoon circulation west of the dateline. The deepening of an open wave to a central pressure of 960 mb., off the coast of California, was a remarkable event. However, the subsequent path of the storm along the coast of Oregon and Washington was similar to several other notable windstorms in recent years.

This storm demonstrates that the occurrence of one intense storm beneath a persisting strong upper trough does not preclude the development of another intense storm in the same area within a short time interval. Hence, waves on trailing cold fronts, if beneath major upper troughs, should always be closely watched.

A detailed pattern of sea level isobars accurately indicated areas of maximum wind. During the Columbus Day storm, severe wind damage occurred in areas where four conditions were fulfilled:

(1) Major terrain features did not block surface wind flow.

(2) The indicated geostrophic wind was 150 kt. or more.

(3) Both surface winds and winds aloft were from similar directions.

(4) No inversion or stable layer existed between the strong winds aloft and the surface winds, permitting the strong winds aloft to reinforce the surface winds by turbulent eddies.

The described procedure for estimating both the location and magnitude of maximum wind is recommended for any future windstorm investigation, especially severe windstorms which render many anemometers inoperative by damage or power failure. However, the procedure cannot be applied to mesoscale windstorms such as tornadoes. The publication of isotach patterns for specific storms would be useful in the same way that isohyetal patterns of total storm rainfall are useful.

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