RADAR AND WEATHER

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ABSTRACT

In this paper a brief discussion of the use of radar in meteorology is presented. The appearance of various weather phenomena on radar scopes is described and a number of radar photographs of thunderstorms, cold fronts and typhoons is included.

[One of the most effective meteorological tools developed during the war was the application of radar to storm detection and tracking. No one knows who was the first to peer into the radar scope and decide that certain echoes were caused by reflection from precipitation occurring in storms. It is certain, however, that as early as 1942, personnel, both civilian and military, in all parts of the globe, in universities, in laboratories, and in combat units on the sea, in the air, and on the ground appreciated the tactical advantage to be gained by using radar in detecting storms as far away as 150 miles. Meteorologists quickly applied the results to forecasting, and by the end of the war radar storm detection was a vigorous new branch of the meteorological science. Therefore, in view of the enormous importance of radar as a tool in meteorological research and in the practice of professional meteorology, it is most appropriate to give credit to all the pioneers in this field who contributed to the vast amount of fundamental and operational knowledge of radar and weather. During World War II security considerations precluded widespread dissemination of the various applications of radar. The present paper describes radar techniques which have been gathered principally from operational reports from the U. S. Navy. It is expected that additional papers on this important subject will appear in subsequent issues of the *Journal.*—H. Wexler]

During World War II various members of the military services have had the opportunity to note the effects of weather phenomena on radar. Since such opportunities were not in general available to civilians, the brief discussion and the radar photographs of meteorological disturbances presented below may be of interest.

In connection with military operations the following three aspects of weather effects on radar were especially noted because of their practical importance: (a) weather as a *creator* of echoes on radar "scopes," (b) weather as a *modifier* of normal radar carrier paths with resultant anomalous propagation, (c) weather as an *obstacle* to perfect radar reception at a given instrument site because of precipitation static. In so far as was possible during war-time a considerable amount of fundamental research was done on these three aspects of the problem. However, time considerations were somewhat of a limiting factor on this research because of the ever present need for immediately usable results for war purposes. This paper deals primarily with the first aspect, namely, weather as a creator of echoes, but also touches briefly upon the use of radar in measuring two important meteorological elements affecting the movement of echoes on radar scopes, namely, wind force and wind direction. The phenomenon of radar echoes due to weather immediately suggests practical applications of radar in connection with storm detection and consequent improvements in short range weather forecasting.

The commonly accepted theory of the occurrence of radar echoes due to weather is that an echo is caused by reflection of the radar pulse from water drops or particles in the atmosphere. For given characteristics of the outgoing radar pulse the strength of the echo depends upon the mass of water encountered and upon the size of the individual water particles. In general, the more laden with water particles the air is, the stronger are the echoes, so that the severity of a storm may be judged approximately from the strength of the echo. However, it should be emphasized that the physical processes involved in meteorological radar echoes are not completely understood at the present time. Thus sometimes visual checks from aircraft or by other means fail to confirm the presence of weather phenomena indicated on radar scopes, and at other times known weather disturbances are not depicted on the scopes, although conditions seem otherwise favorable for their detection by radar.

The size of the individual water drops becomes increasingly important as the frequency of the radar is raised. As the frequency is increased the radar pulse is less able to penetrate a mass of water droplets but is capable of detecting weaker storms more easily. Thus for the general purpose of storm detection the so-called "S" band of radar frequencies appears to be better suited than the "X" band.*

Practically every known weather phenomenon which can appear on radar scopes has been well photographed and studied with the possible exception of the tornado. However, there are still many questions to be answered in connection with the theoretical interpretation of the photographs. As seen in the radar "PPI" scope† meteorological echoes differ from echoes caused by land features in that they continually change in shape, size and intensity. Groups of echoes may join and then break up again as they travel across the field of the scope. On the "A" scope‡ the echo is one of rapidly changing signal strength and resembles noise. Echoes can be obtained from clouds from which light, moderate or heavy rain, hail, sleet or snow is falling. Occasionally echoes may be produced by non-precipitating clouds such as heavy cumulus. Stratus clouds and fog usually cannot be detected on the S-band radar.

Storm types detectable by radar are showers, squall lines, thunderstorms, cold fronts, warm fronts, occluded fronts, typhoons or hurricanes and tornadoes. Ranges at which these storms can be detected depend on their vertical extent. Radar equipment located at the ground gives the following relation between vertical extent and range:

TABLE 1.

Vertical Extent of Storm in Feet	Range in Miles (Approximate)
5,000	8
10,000	120
20,000	175

With airborne radar greater ranges are possible. The following are the radar echo characteristics associated with various storm types:

Showers. On the PPI scope showers may be located at random, have poorly defined edges and show a hazy, indistinct character. They generally move with the direction and speed of the wind. At times it is possible to detect shower areas in which the precipitation does not reach the ground by scanning in the vertical.

Squall lines. Squall lines have an appearance similar to that of showers except that usually they are more distinct and show a band arrangement of echoes moving across the field of the PPI scope.

Thunderstorms. The echo from a thunderstorm is one of the most easily identified signals detected. When examined on the PPI scope it appears as a bright, dense central area with distinct boundaries. The center of the echo appears higher than the edges. The maximum angle of elevation at which the echo is received and the distance give a rough measure of the height and vertical structure of the thunderstorm. An example of thunderstorm echoes is given in Figure 1.

Cold fronts. A cold front usually appears as a zone or band of individual, well-defined echoes moving across the field of the PPI scope. The echoes may join, break up and join again during their travel across the field. The structure and activity of the cold front can be estimated qualitatively by considering the spacing between areas of brightness, the relative intensity of the echoes, the area covered by each echo and the vertical extent and velocity of the echoes. Weak cold fronts are often ill-defined and may be missed entirely. An example of cold front echoes is given in Figures 2–6.

Warm fronts. Warm front echoes are indistinct usually covering a wide irregular area on the radar scope. The echo shading varies continually. This is due to the changing character of precipitation associated with a warm front, i.e. light drizzle followed by light, then moderate, rain.

Occluded fronts. A warm occluded front produces an echo similar to a warm front. Cold occluded front echoes resemble those from a cold front although they generally cover a wider zone.

Typhoons or hurricanes. The echoes from this type of weather phenomena are very easily identified. The eye of the storm§ which appears as a dark area is surrounded by curved bands of echoes with feathered edges and trailing wisps. Even if the range is not great enough to encompass the eye of the storm, the definite whorls of the pattern are still unmistakable. From the shape of the bands the position of the center may be estimated. Examples of typhoon echoes are given in Figures 7–14.

From the material that has been presented it is clear that radar offers to the pilot and forecaster an actual "picture" of storms within the range of the set. With a little practice this picture can be analyzed in terms of length, depth, height, intensity, speed and direction of movement of any storm in the area covered. Use of radar storm detection techniques by pilots, forecasters and commanding officers will unquestionably result in greater safety to aircraft, more accurate and timely warnings, and be an aid in naval strategy. Another already existing use of radar is for obtaining measurement of wind speed and direction up to very high levels. This is accomplished by observing echoes reflected from specially equipped pilot balloons. Further research on this technique is under way.

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* The "S" band consists of radiation of 3 centimeters wave length, while the "X" radiation is of 10 centimeters wave length.

† The letters PPI are an abbreviation for "plan position indicator." The device gives the position of the source of an echo on a polar diagram.

‡ The "A" scope is essentially an oscilloscope which gives the range of the source of the echo and measures the echo strength.

§ The first known picture of a hurricane eye photographed on a radar scope was taken at the U. S. Naval Air Station, Lakehurst, New Jersey in September 1944.

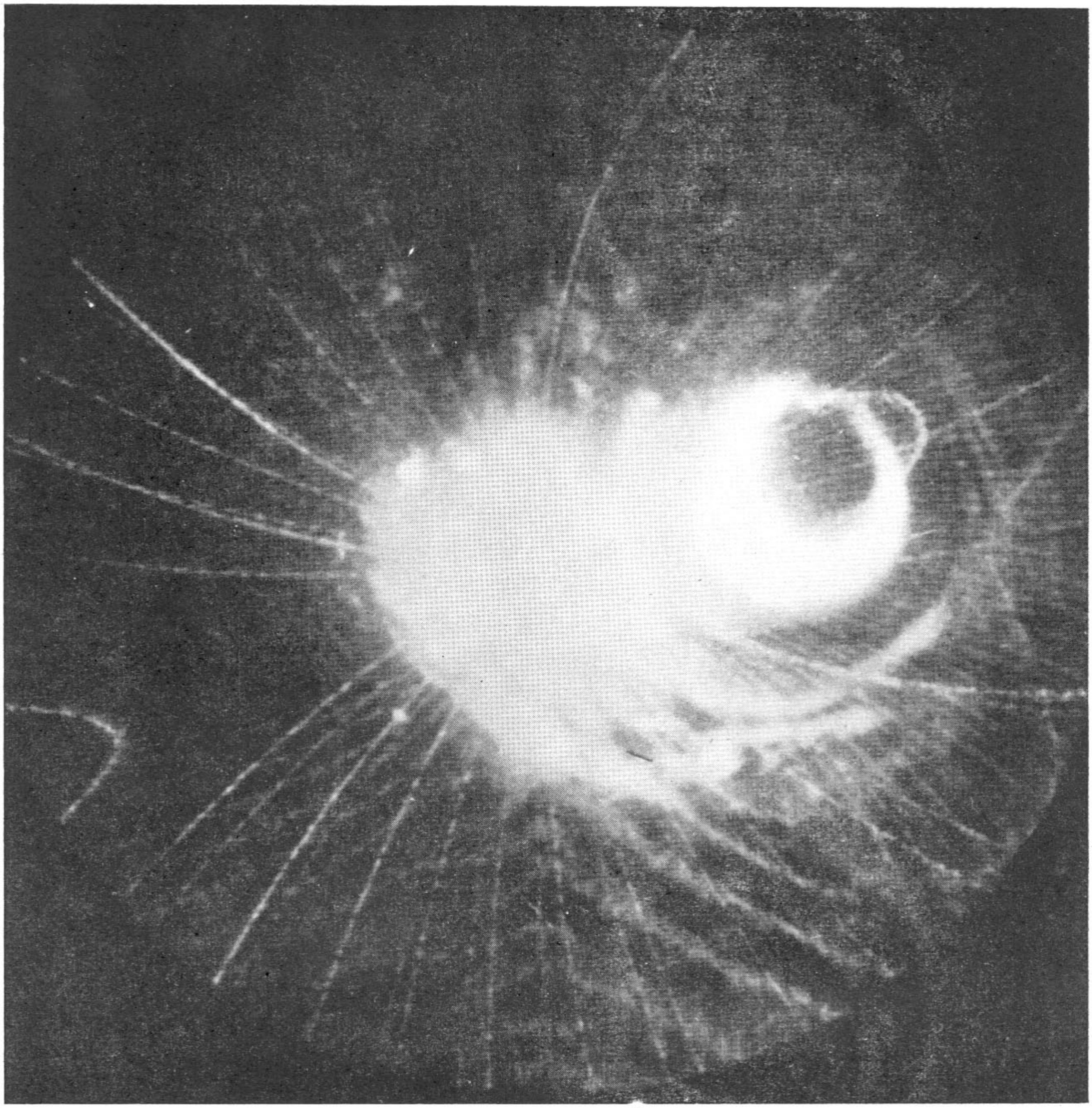

FIG. 7. Radar photograph of a typhoon in the Philippine Sea on December 18, 1944 at 11:00 a.m. The typhoon center was 39 miles distant, bearing 077 degrees from true north. The wind was 57 knots with gusts to 66 knots. The ceiling was less than 500 feet, the visibility ¼ to ½ mile. The seas were 20 to 40 feet high.

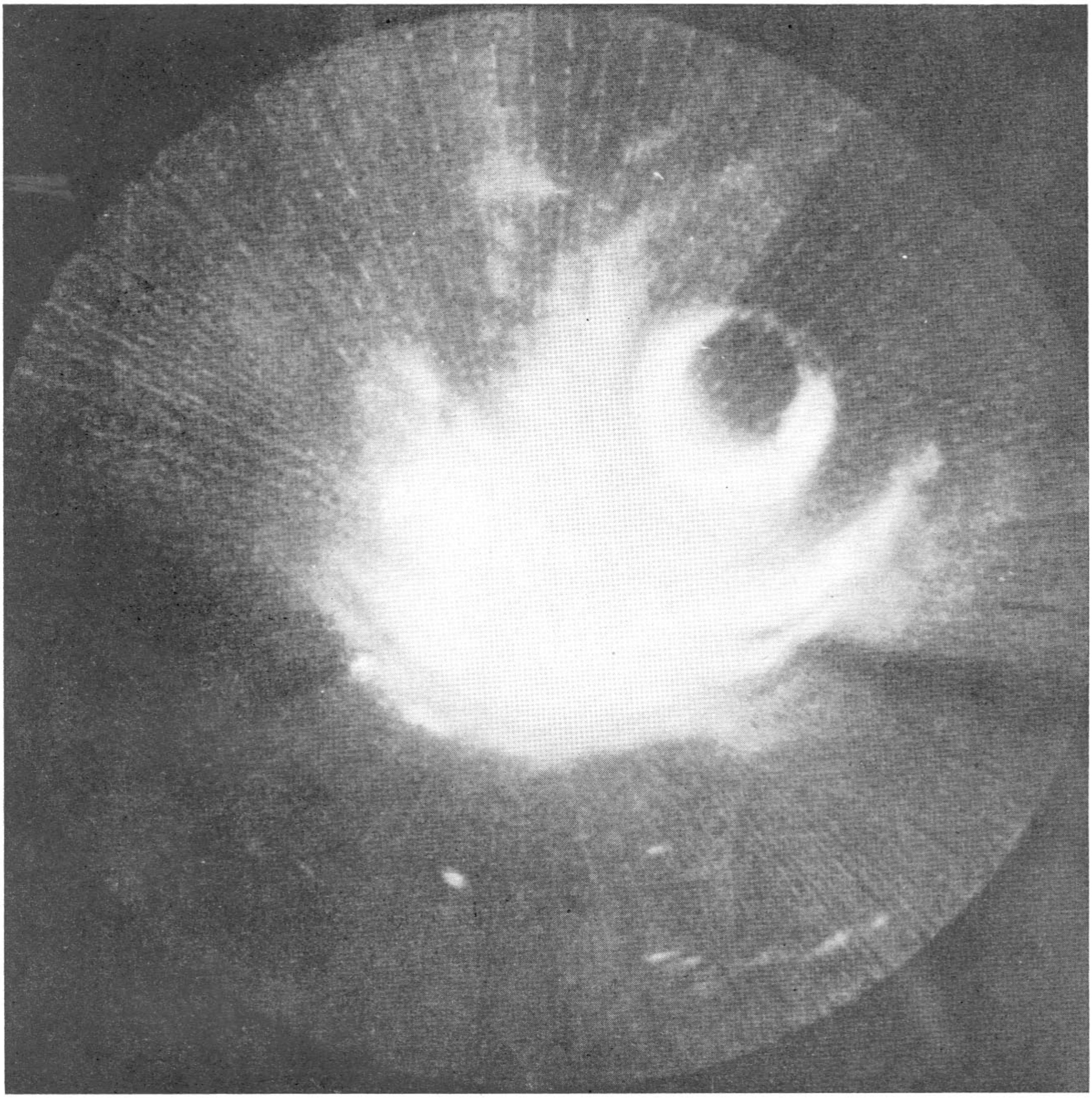

FIG. 8. Radar photograph of a typhoon in the Philippine Sea on December 18, 1944 at 12:00 noon. The typhoon was centered 40 miles distant, bearing 055 degrees from true north. Wind gusts from NW exceeded 75 knots, the ceiling was less than 500 feet, the visibility ¼ to ½ mile. Seas were 40 feet high. The whorls of clouds about the center are becoming discernible in this photograph.

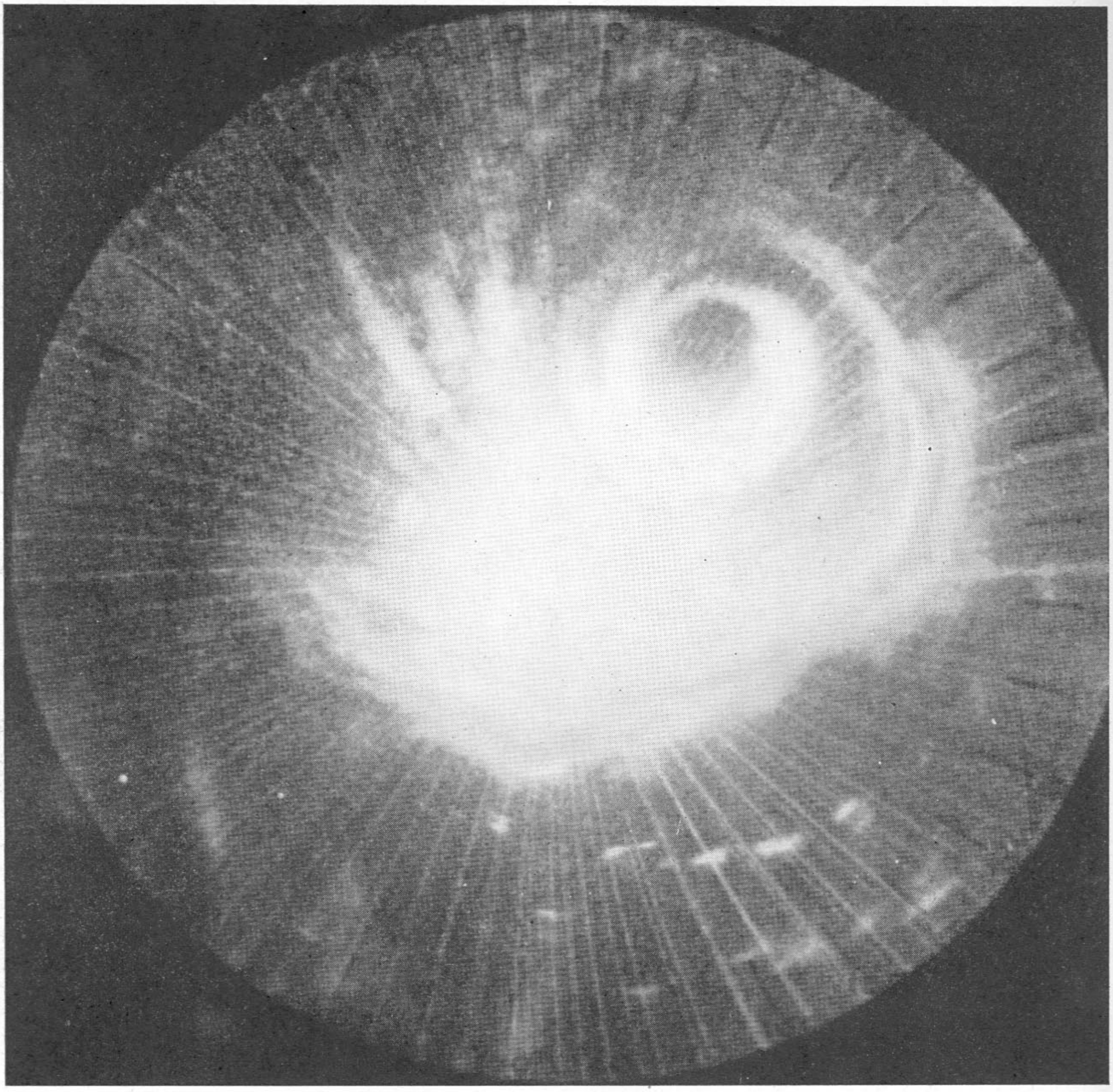

FIG. 9. Radar photograph of a typhoon in the Philippine Sea on December 18, 1944 at 12:30 p.m. The center was 37 miles distant, bearing 042 degrees from true north. The wind was 42 knots with gusts in excess of 75 knots. Precipitation was extremely heavy, producing a ceiling of less than 500 feet and visibility 1/8 of a mile. Seas were over 40 feet high. The structure of the typhoon is here clearly indicated—a spiraling cloud pattern, an extensive precipitation area and the "eye" of the storm enclosed by a closed circle of clouds.

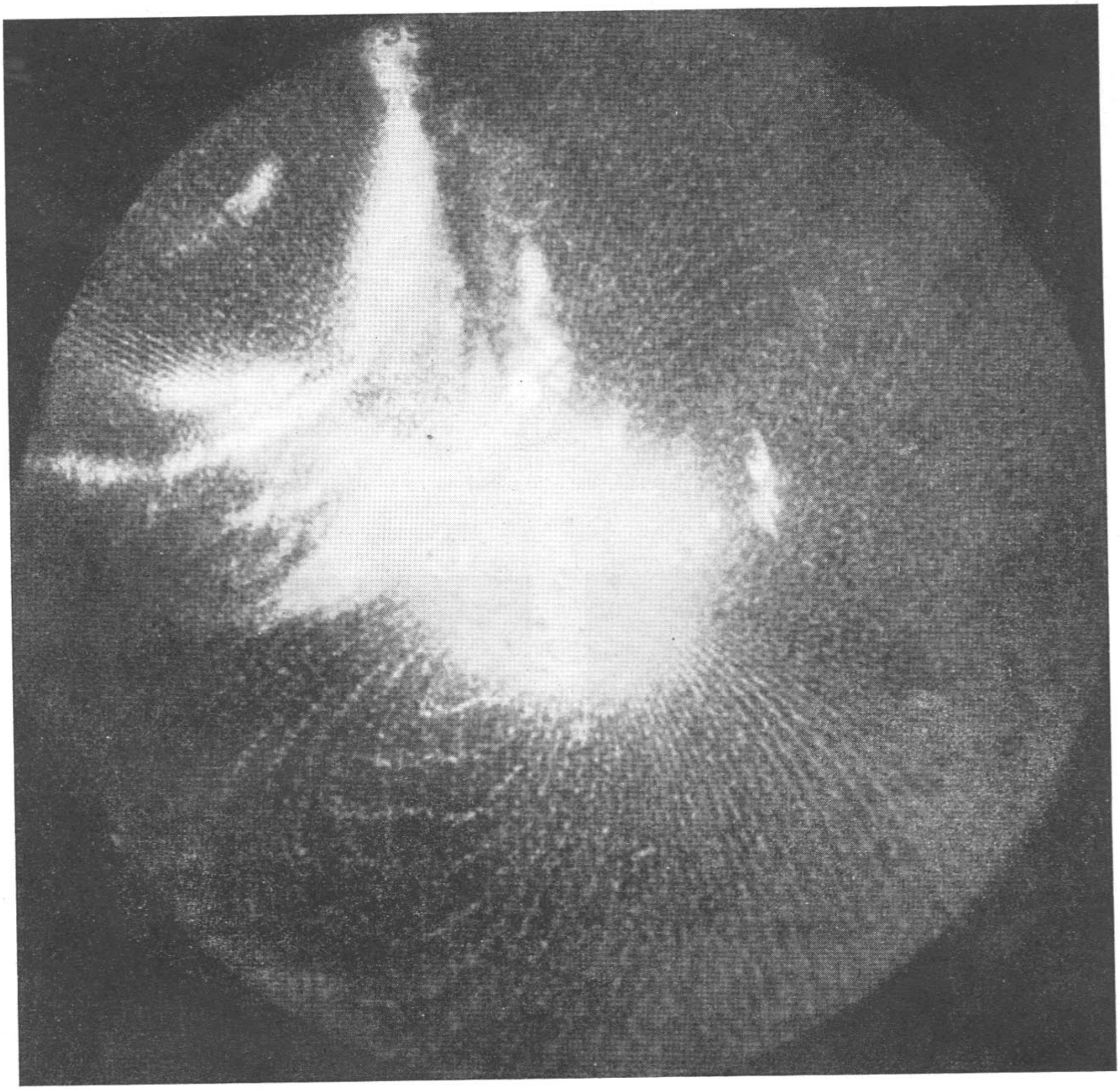

FIG. 10. Radar photograph of the peripheral region of a typhoon in the Philippine Sea on December 18, 1944 at 3:30 p.m. The center was beyond the range of the radar. However, its location can be computed from the geometry of the circular cloud and precipitation pattern in the northwest quadrant. Winds were 41 knots with gusts to 60 knots from WSW, the ceiling was 7,000 to 8,000 feet with isolated cloud patches at 1,000 feet, the visibility varied from 3 to ½ miles. Seas were 12 to 20 feet high.

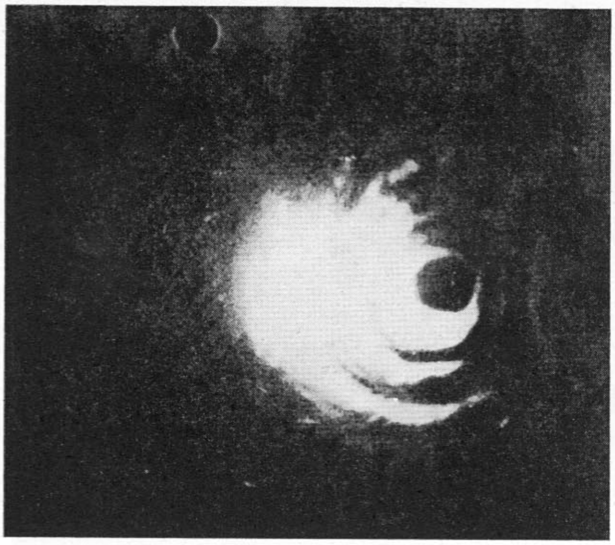

FIG. 11. Radar photograph of a typhoon taken 150 miles south of Kyushu on August 26, 1945 at 1:45 p.m. with a radar range of 80 miles and the radar antenna elevated, so that the beam was intersecting a vertical portion of the storm. The center was 42 miles distant, bearing 091 degrees from true north. The wind was 48 knots with gusts to 58 knots, the ceiling 700 feet, the visibility 800–1,200 yards in moderate rain and blowing spray. Seas were 25 to 35 feet high.

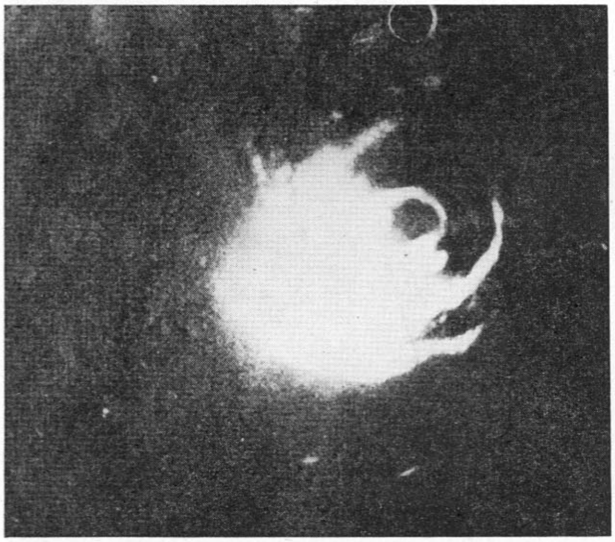

FIG. 12. Radar photograph of a typhoon taken 150 miles south of Kyushu on August 26, 1945 at 2:30 p.m. Radar range and antenna were the same as in Figure 10. The center was 39½ miles distant, bearing 061 degrees from true north. The wind was 45 knots with gusts to 60 knots, the ceiling 500 feet, the visibility 55–200 yards in moderate rain and blowing spray. Seas were 25 to 35 feet high.

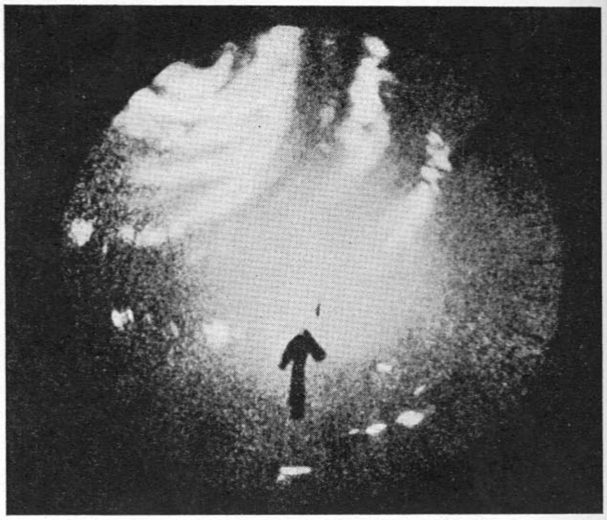

FIG. 13. Radar photograph of a typhoon taken 150 miles south of Kyushu on August 26, 1945 at 6:45 p.m. Radar range and antenna were the same as in Figure 10. The center was 82 miles distant, bearing 335 degrees from true north. The wind was 32 knots, the visibility 2 miles in haze with broken ceiling at 2,000 feet. Seas were 18 to 24 feet high. (The heavy arrow points toward the north.)

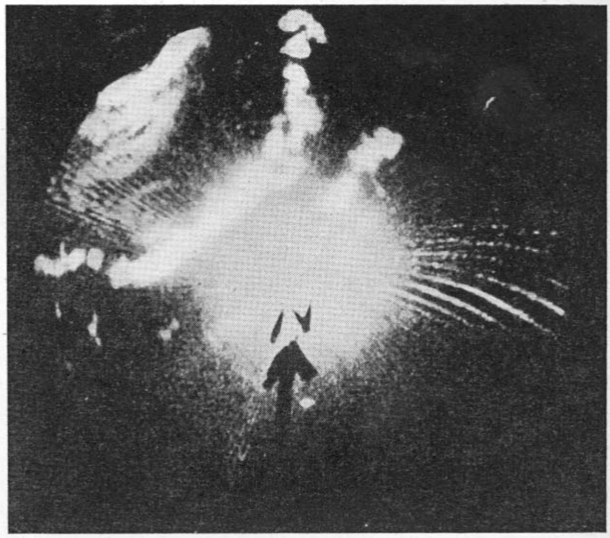

FIG. 14. Radar photograph of a typhoon taken 150 miles south of Kyushu on August 26, 1945 at 8:00 p.m. Radar range and antenna were the same as in Figure 10. The center was 92 miles distant, bearing 322 degrees from true north. The wind was 30 knots, the visibility 6 miles in haze with broken ceiling at 2,000 feet. Seas were 18 to 24 feet high. (The heavy arrow points toward the north.)

With the war at a close great strides are being made in reducing security restrictions on various applications of radar. It is thus becoming possible for various workers, not only those in meteorology but also those in related fields, to utilize and develop this valuable tool further. The possibility that institutions of learning and other organizations can now obtain certain types of radar sets at nominal costs offers great opportunities for expanding the use of radar as a method of weather study.