pole, consequently the anticyclone moves with the same speed as the cyclone families, but more slowly than the particular cyclones which during their existence move from the rear to the front of their family.

PERIODS OF METEOROLOGICAL ELEMENTS DUE TO CYCLONE FAMILIES AND MOVING ANTICYCLONES.

Disregarding the obstructions caused by the large continents, cyclone families and moving anticyclones may be imagined to travel continually around the pole.

This movement will produce a periodicity in the meteorological elements throughout the Temperate Zone. Places far north will, for instance, only receive precipitation from the first passing members and places far south only from the last passing members of a cyclone family. Places situated centrally in the cyclone belt, so that they receive precipitation from all the cyclones passing, will have a short spell of fair weather during the passage of the anticyclone which separates successive cyclone families. If the cyclone families perform perfect circuits around the pole,[11] the length of the periods should be equal in all parts of the cyclone belt. They may, however, be of different length in the two hemispheres, as the cyclone families north and south of the Tropics form two independent systems.

A count of the cyclone families passing over Europe in 1921 gives 66 as the total number. This would give a mean duration of 5.5 days, but the authors recognize an error of about 10 per cent.

Various investigators have found short period fluctuations in the climatic elements; probably the most thorough was that of Defant,[12] who found for a single year, 1909, a period of about 5.7 days in the Northern and 7.2 days in the Southern Hemisphere. The cyclone family period of 1921, 5.5 days, agrees so well with the precipitation period from 1909 Northern Hemisphere of 5.7 days that the two periods are considered as identical within the limits of errors.

DISCUSSION.

ALFRED J. HENRY.

The central idea in the foregoing is that cyclones are formed along lines of discontinuity which separate masses of dense polar air from lighter air of tropical origin. The underlying assumption is that the dense polar air is moving westward immediately adjacent to a current of warm air moving eastward. When for any reason the warm current bulges to the northward intruding into the westward moving polar air, the greater density of the latter will cause it to flow along the ground and to cause the warm air to ascend, thereby producing cloud and rain. The condensation of water vapor and the latent heat thus evolved will augment the ascensional movement thus mechanically originated which, together with the modification of the original motion of the air due to the earth's rotation, will create a cyclone. This, in brief, is the reviewer's understanding of the mode of origin of cyclones as advanced by the authors. The various changes which the cyclone undergoes in its brief course has been outlined in the pages preceding.

In view of the fact that the phenomena of cyclones and anticyclones are at best very imperfectly represented on weather maps by surface conditions it must be assumed that the specifications hereinbefore presented should be considered as applying to the conventional cyclone and anticyclone, or possibly to the average of conventional cyclones and anticyclones as they enter Norway.

Forecasters in the United States will be quick to recognize in the specifications hitherto mentioned many familiar phenomena in connection with the movement of cyclones and anticyclones. There are, however, some points of difference between the experience of the Norwegian forecasters and those of the United States; some of these have been mentioned in the series of footnotes appended to this article; others are not easily disposed of within the limits of a footnote. In what follows I shall refer to the most obvious differences between the larger features of the Bjerknes scheme as contrasted with the experience of forecasters in the United States.

Latitudinal differences.—Undoubtedly the origin and development of cyclones and anticyclones are more clearly defined in the latitude of Norway (north 58° to 77°) than in the United States. For the most part cyclones and anticyclones which traverse the latter arrive on its frontiers as fully developed systems of wind circulation. Secondary cyclones, however, frequently develop over the southern and middle portions of the Plateau region in barometric troughs which pass across those regions (from west to east). The development of a primary cyclone, using that term as synonymous with the A-cyclone of the Bjerknes terminology, in the United States is a very rare occurrence.

Cyclone families—The ability to foresee the occurrence of cyclones in families as contemplated in the Bjerknes scheme would be of very great significance in extending the forecasts beyond the conventional period. For reasons indicated in the preceding paragraph it is not only difficult to identify the *A* cyclone of each family on the charts of the United States Weather Bureau, but also, it seems highly improbable from the past experience of forecasters in this country that the occurrence of cyclones in families takes place in the latitudes of the United States with sufficient regularity to make the precept of definite value in long-range forecasting;[13] moreover cyclones at times move southeastward from the Pacific to the Gulf of Mexico and thence northeastward to the St. Lawrence Valley, or develop over the Gulf of Mexico and move similarly, apparently without regard to the development and movement of cyclones along the northern circuit. These cyclones sometimes occur in groups and apparently have no relation to those of the northern groups.

Precipitation.—The area of precipitation in the advance of cyclones in the United States is rarely symmetrically distributed around the front of the cyclone, but is irregularly distributed according to geographic position of the cyclone and the season.

On the Pacific coast and in the Plateau and Rocky Mountain region precipitation occurs as a rule in the rear of the cyclone center instead of the front. On the immediate coast the winds of winter, as is well known are relatively warm as compared with those of the land, and the precipitation that is associated with the movement of the cyclone is of the orographic rather than the cyclonic type. In the Bjerknes type of cyclone the cold air to the eastward of the cyclone is made to curve around the north side of the cyclone and swing in toward the center as a northwest wind. While this movement probably takes place in the conventional cyclone after

[11] The evidence of the Signal Service international series of observations seems to point to a gap in the path of cyclones around the pole as for example over northern Siberia.

[12] A. Defant: Die Veränderungen der allgemeinen Zirkulation der Atmosphäre in den gemässigten Breiten der Erde. *Wiener Sitzber*, 1912, p. 379.

[13] See footnote No. 8 on p. 470.

it advances far inland, the reviewer makes a mental reservation as to just how far this process is fulfilled in nature, especially on the Pacific coast.

In the theory of the formation of anticyclones no account is taken of the effect of radiation. The influence of radiation in the dry regions of the far West is believed to play a large part in the formation and maintenance of anticyclones in that region.

It is freely conceded that the researches of the meteorologists of the Bergen Institute represent a decided step in advance, yet it can not be said that the theory they advance is complete and satisfying. The reviewer's experience as a forecaster leads him to the opinion that for the United States, for example, the occurrence of precipitation in connection with cyclones and anticyclones is not fully explained by the Bjerknes theory; moreover, some doubt has been expressed in an unpublished manuscript by Mr. Herbert L. Choate, of the Drexel (Nebr.) kite station, as to the existence in the Plains States at least, of the cold front and the wind circulation on the front of the idealized cyclone of Bjerknes. In any event further study of the kite and pilot-balloon data now available will doubtless lead to a better understanding of the physical processes involved in the origin and maintenance of cyclones and anticyclones.

FOOT-LAYER DENSITIES OF SNOW.[1]

By H. F. ALPS, Meteorologist.

[Weather Bureau, Reno, Nev., September 19, 1922.]

This special investigation of snow densities was begun in the fall of 1916 and continued each season until its completion in the spring of 1921.

The measurements were made at Summit, Calif., about 40 miles west of Reno, at an elevation of 7,019 feet. Summit station is located near the easterly end of Summit Valley, which is about 3 miles long and 1 mile wide. This valley is fairly well timbered and the rim of the surrounding mountains is approximately 1,000 feet above the valley. This region is considered an ideal location for any kind of snow investigations, as the average annual snowfall is 442 inches, which is the greatest seasonal snowfall recorded in the United States. Moreover, the snowfall is comparatively free from drifting effects and therefore the snow cover is remarkably uniform in depth. The run-off from snow fields for irrigation and hydroelectric purposes is undoubtedly greater than from any other region in the United States. Fifteen miles to the southeast, and approximately 800 feet lower, lies Lake Tahoe, the largest body of fresh water at that elevation in the United States.

The work represents a total of 24 trips to Summit, during which 659 measurements were made. The first five trips were made by H. F. Alciatore and O. H. Hammonds, and beginning with April, 1917, the work was carried on by the author and O. H. Hammonds.

TABLE 1.—*Dates of trips and total depth of snow cover in inches.*

Season.	November.		December.		January.		February.		March.		April.		May.	
	Date.	Depth.	Date.	Depth.	Date.	Depth.	Date.	Depth.	Date.	Depth.	Date.	Depth.	Date.	Depth.
1916–17	29	8.8	30	59.0	30	87.8	27	154.8	15	168.0	30	107.0	29	37.0
1917–18	30	2.9	....	.....	2	5.8	26	82.5	....	.....	9	66.5	1	23.0
1918–19	....	.....	31	23.0	31	49.0	....	.....	5	122.0	8	88.0	7	33.2
1919–20	....	.....	31	39.0	....	.....	....	.....	5	68.0	13	66.0	13	36.0
1920–21	....	.....	....	.....	14	64.0	....	.....	17	97.0	29	63.0	....	.....

Note.—Measurements taken at Summit, Calif., elevation, 7,019 feet.

The primary object of the investigation was to test the accuracy of the Wengler formula [2] and ascertain whether the formula has any practical working value. This formula states in substance that the density of any given layer of snow bears a certain relation to the density of the top layer, depending upon the depth of the given layer below the surface. After starting the investigation, it was found that an excellent opportunity was given for the study of the snow cover throughout the entire season. Therefore, it resolved itself into the determination of the density of each 12-inch layer from the ground up.

For this work the following instruments were used: A Weather Bureau snow sampler 16 inches long and 4.002 inches in diameter, a Weather Bureau spring balance weighing in fiftieths of a pound, and a piece of apparatus called a "snow slicer" made of galvanized iron, about 14 by 14 inches, with a sharp semicircular edge on the side opposite two wooden handles. In order to make layer measurements, a smooth vertical section of the entire snow cover was obtained by digging a trench. The 12-inch layers were then marked on the face of this section, beginning at the ground. The snow slicer was inserted first beneath the top layer, and the density of this layer was determined with the sampler. The snow above the slicer was then removed and the density of all succeeding layers was determined in like manner. As the slicer formed the bottom of each layer while being sampled, accurate foot-layer measurements were obtained. Two or three samples of each layer were taken and the resulting average used in all cases.

During the season of 1916–17 seven trips were made to Summit beginning with November. This was the season when the snow cover reached its greatest depth, 168 inches on March 15. Table 1 shows the remarkable uniformity in the monthly increase of the snow cover from November to February, and decrease from March to May. This was an ideal season for snow work and it was fortunate that density measurements were started during this season. As the snowfall during this season was practically normal both as to time of occurrence and amount, the records are considered of greater value than those of any other season during which measurements were made.

Five trips were made to Summit during the season of 1917–18. This was an unusual year. The highway over the summit was open until January 12, when it was closed by 32 inches of snowfall. The snowfall for the season to January 12 was the least on record, and it was the only year in the memory of oldtimers when the highway was open on New Year's day. On November 3, 1917, the depth of snow was 2.9 inches, and on January 2, 1918, the depth was 5.8 inches. (Fig. 1.) February storms were moderately heavy, and on the 26th a depth of 82.5 inches of snow was measured. (Fig. 2.) The results of each trip are given in Table 2.

[1] Cf. H. F. Alciatore, Layer measurements of snow on ground near Summit, Calif. Mo. WEATHER REV. 48: 519–520.

[2] Wengler, Fritz: *Die Spezifische Dichte des Schnees.* Berlin, 1914.