The values 8° 12′ and 32°00′ were obtained with theodolites; 17°± and 19°± with an improvised plane-table device; and 23°20′ by measurements on the image of the halo in a basin of mercury. In this last case the reported value is 23°57′, but this reduces to 23°20′ on applying to it the same correction that must be applied to the simultaneously made measurements on the 22° halo.

In short, then, Besson computes the shape of the ice crystal from the radii of the halos; I take crystallographically possible crystals as determined from highly accurate X-ray measurements, and from among them find one that alone accounts, to well within errors of measurement, for seven, that is all, or, at least, all but one, of the recognized halos of unusual radii.

If that remaining unusual halo, of radius 28°, roughly, does exist, presumably it is formed in the manner suggested by Besson, but then it should be accompanied by a group of other halos, none of which, apparently, has ever been reported.

But whether this particular halo exists or not there is a great number of others that certainly do, and together they afford endless opportunities for observation and numerous interesting problems for the mathematical physicist, lines of work, both of them, in which Besson has long been a master.

WINDS AND WEATHER OF CENTRAL GREENLAND: METEOROLOGICAL RESULTS OF THE SWISS GREENLAND EXPEDITION.[1]

By CHARLES F. BROOKS.

[Clark University, Worcester, Mass., May 15, 1923.]

In the summer of 1912, Dr. Alfred de Quervain with three others crossed the south central part of Greenland from Jakobshavn to Angmagsalik, while another party headed by Dr. P. L. Mercanton made meteorological and glaciological observations along the west front of the inland ice near Jakobshavn. During the following winter, Dr. W. Jost and Dr. A. Stolberg made aerological observations at Godhavn, on the south coast of Disco Island. The meteorological results obtained by these three sections of the expedition will be discussed in succession.

I. SUMMER WEATHER ON THE ICE SHEET.

The ice sheet is a giant cooler projecting southward into the realm of a relatively warm ocean and spreading northward into the paleocrystic ice of the Arctic Ocean. Over such a cooler the air is continually shrinking, and, becoming heavier, it tends to slide off the ice. The prevalence of down-slope winds, even in midsummer, was strikingly in accordance with Hobbs' theory of the glacial anticyclone.[2] Under ordinary conditions, however, this would have been less marked, for there was a preponderance of general gradients westward across southern Greenland during the ascent, and eastward ones during the descent. No observations showed that a low-pressure area ever crossed the inland ice north of de Quervain's route. Some secondaries, however, passed across the southern tip. The cyclones on the west coast went north, just as those of the United States and Europe go east or northeast, and showed the characteristic barrier effect of the cold (NW.) wind in the left front quadrant, to the warm (SE.) wind (off the inland ice) in the right front quadrant. Strange though it may seem, the ice cap supplied the warm element of the cyclone under these conditions, when the air was drawn all the way across Greenland precipitating snow and liberating latent heat on the east slope and warming by compression on descending the west slope.

It was not to be expected that the temperatures over the inland ice would rise more than a degree or two above freezing, except under föhn conditions, when the wind is blowing right across Greenland. Nor was it thought that temperatures would fall much below freezing except over the surface where there was no wet snow or standing water to supply latent heat of fusion while the sun was lowest in the sky. Thus, it is not surprising to learn that the average temperature was 30.7° F. during the first 13 days the party was on the ice in the zone where melting was in progress, and that the departures of individual days amounted to only 2° to 4° F. notwithstanding a range of altitude from 550 to 1,900 meters above sea level. "On July 3 at 1,936 m., we suddenly entered a cold region," says de Quervain, to cross which required 13 days, as it extended 280 kilometers over the divide and down to an altitude of 2,250 m. on the east slope. The mean temperature of this zone was 14° F., and the means of the individual days were generally not more than 3° from this. The highest temperature was 25° and the lowest temperature, −7° F. For the last 5 days of the journey, in the eastern zone of melting, the mean was −0.02° C. (31.96° F.).

Since the sun remained above the horizon continuously during most of the crossing, the highest and lowest temperatures occurred just 12 hours apart, between 2 and 2½ hours after noon and midnight, respectively. The temperature of June 23–24 is described as characteristic of that of the border zone. The minimum, 23° F., came after 1:30 a. m. (the sun did not set) and the maximum, 35° F., between 2 and 3 p. m. Direct solar heating and perhaps also compression of descending air served to raise the air temperature above that of the ice. In the central zone, it seems likely that temperatures fall to −25° C. (−13° F.) in midsummer, and that the maximum daily range is 25° or 30° F. On cloudy days the mean range was 6.1°, on partly cloudy 9.5°, and on clear days 14.9° F. As the range in temperature is restricted where thawing and freezing alternate, it must be less in summer than at other seasons. Thus, in August and September, Nansen found daily ranges of temperature appreciably larger than those encountered by de Quervain. With continuous darkness in winter the range must be less than in autumn or spring. The rapidity with which the summer temperatures must plunge into the unknown cold of winter is shown by the contrast between the mean of all de Quervain's observations on the crossing, 23.9° F. (June–July), and Nansen's corresponding figure, 11.7° F. (August–September).

TEMPERATURES AND WINDS.

On the cold, sloping surface of the inland ice, which is smoother even than the waved surface of the ocean, it is not surprising that the air was usually smoothly flowing down the slope. Only at 6 of the 200 observations were there calms. At times the wind blew so hard that a man on skis, with two poles to push with, could not make

[1] Alfred de Quervain, P. L. Mercanton, and others: Ergebnisse der Schweizerischen Grönland expedition, 1912–1913. *Denkschr. der Schweizerischen Naturforschenden Gesellschaft.* Bd. 53. Zurich, 1920, 402 pp., maps, diagr.

[2] W. H. Hobbs: The rôle of the glacial anticyclone in the air circulation of the globe. *Proc. of the Am. Phil. Soc.*, Aug., 1915, 44: 185–225, 11 figs. Reviewed in *Bull. Am. Geog. Soc.*, Dec., 1915, 47: 963.

progress (maximum wind velocity about 20 m./s.). One day in five on the average was stormy (wind over 10 m./s.). It is well known that the speed at which cold air will descend to displace lighter, warm air depends largely on the difference in temperature. When the difference in about 100 meters of altitude exceeds 1° C. descending air will continue to be colder than the air it displaces, for on descent the adiabatic heating of air by compression is about 1° C. per 100 meters. At the edge of the ice sheet the temperature gradient always considerably exceeded the adiabatic, as it ranged from a minimum of 1.6 to a maximum of 5.5° C. per 100 meters in the course of the day. Therefore the wind off the ice continued throughout the 24 hours. The velocity, however, did go through a diurnal cycle corresponding to the changes in the temperature gradient, with a maximum averaging 5.3 m./s. at 5 a. m. and a minimum of 4.1 m./s. at 5 p. m. Upon the ice the times of maximum and minimum became later and the extremes greater, becoming 7.6 m./s. at 9 a. m. and 1 m. s. at 9 p. m. in the inner zone. Evidently the greater speed to be expected where the air is thinner is just balanced by the tendency to lesser speed in the interior, owing to smaller slope and greater distance from the marginal heated area. The broad, central zone in which melting never takes place supplies the flow of cold air down both slopes. This is continuous to the margins, but it does not reach across the bare strip on the west to Jakobshavn. The expansion of the air over the heated, rocky foreland is insufficient to do more than stop the outflow of cold air.

In clear, quiet weather wind direction is as steady as the velocity, hour after hour and day after day. On the west border of the ice the wind was SE. at 51 per cent of the observations and on the west slope from that direction 34 per cent of the times. On the southeast slope the wind direction was directly down grade, but on the west it averaged 55° to the right of the direction of the slope. Part of this difference was owing to the deflective effect of the earth's rotation over the long, westward slope, and partly owing to the position of the Baffin Bay low-pressure area. There was no evidence of a diurnal period of wind direction, except on the 5th and 6th of July, when the wind shifted at noon to S. and SW. from SE. On these days there must have been an unusual amount of expansion over the heated zone, the overflow from which impinged on the upper part of the ice slope. The wind at the edge of the ice sheet, however, remained SE. at noon on these days. A most interesting vegetational effect of the constancy of the direction from which strong, though exceedingly dry, föhn-storm winds came was seen on a delta at the northern end of the Hundebucht (E. Greenland). Stretching like a snowdrift in the shelter of each of a number of stones was a line of vegetation many meters long.

On account of the constantly windy conditions, the air temperature follows closely that of the snow surface. The snow rises to the air temperature at about 4 a. m. and gets 4° or 5° F. above it by noon (one case), then sinks very rapidly, going below the air temperature at 3 or 4 p. m. At 6 the snow is already nearly 2° colder than the air, but the depression becomes no greater. The average difference of but 2° F. is to be compared with an average difference of 9° to 10° on clear summer nights at corresponding heights in the Alps.

THE FÖHN, OR WARM WIND, OFF THE ICE SHEET.

While usually the descending air lost an appreciable degree of its compressional rise in temperature to the cold snow surface, on occasions when a general wind blew right across the ice cap (total föhn) the volumes of air and the velocities involved prevented the local cooling from becoming appreciable. Then the slope up which the wind was blowing became cloudy, and snow was precipitated as expansion cooled the rising air. The latent heat from such precipitation preventing the attainment of the adiabatic rate of cooling, the air reached the crest at a moderate temperature and on descending warmed rapidly to a high degree. Such was the case when with a gale off the inland ice the air temperature rose to 61° F. at sea level on the east coast, July 23. The air as it comes over the crest has left in it the maximum amount of water vapor possible at the temperature and pressure. If, then, the absolute humidity and temperature of the warm wind are determined as it reaches the coast, it becomes possible to find from what altitude the wind descended. On three occasions at Jakobshavn the heights indicated were 2,250, 2,400, and 2,350 meters in directions to the south of de Quervain's route, where de Quervain's observations of slope indicate a probable height of 2,400 meters on the crest over which the winds came. De Quervain says: "Whoever wishes to know the height of the middle Greenland inland ice, needs only to read the psychrometer on a true föhn day * * * and compute the rest."

HUMIDITY AND EVAPORATION.

With air temperature and snow temperature about the same and with the snow constantly evaporating the relative humidity was necessarily high, averaging 82 per cent, and, in general, varied but little. On comparing the snow-surface vapor pressures with those of the overlying air it was found that only in the central, cold zone, and there only at midnight could evaporation have ceased. Condensation on the snow surface at other seasons, however, seems to prevail, according, at least, to Wegener's conclusions on the central crossing in the spring of 1913. The summer evaporation from the inland ice must limit appreciably the amount of ice the snowfall can make. Computing the evaporation at 0.3 mm. per day, de Quervain concludes that the annual evaporation if the loss in winter is negligible should be about 55 mm. As this is equivalent to about 15,000 cubic meters of ice, it appears that were it not for evaporation the ice front would stand 7 or 8 km. farther west.

Cloudiness was not great. On the average the sky was less than half cloudy (46 per cent), and clear days were twice as numerous as cloudy (one-third versus one-sixth). The sky was much less cloudy than at the edge of the ice, and markedly clearer than on Nansen's more southern, autumn crossing, when the sky was more than six tenths covered on half the days. While practically all the internationally recognized cloud forms were observed, the large cumuli over the bare coastal strip, and occasional cumuli over the inland ice were the most striking. The The formation of cumulus clouds over the ice sheet had not been expected. It showed that the midday warming there induced a circulation reaching a height of a few hundred meters above the ice. On July 5, cumulus clouds at 500 meters were practically stationary, indicating a restricted vertical extent of the surface wind. Cirrus and cirro-stratus, and alto-cumulus clouds were the most common, each being noted at more than one-third of the observations. Much of what was noted as cirro-stratus after June 19 was the volcanic dust cloud from Katmai. Halos were observed but four times. The dust veil led the eastern Eskimos to fear that next year there would be no summer. With but one exception the upper clouds moved from some easterly direction, as would be expected, owing to the deep low pressure centers of action to the southwest and southeast. The intermediate clouds, however, averaged from a little west of south, or slightly upslope, representing, probably, the inpouring of air at a moderate height compensating for the outward flow over the ice surface. But little diversion of this wind to the right would be necessary to make it to blow directly upslope and thus yield precipitation.

PRECIPITATION ON THE ICE SHEET.

Though rain is a common phenomenon on the bare land west of the ice sheet, it was observed only once while the party was crossing the inland. Snowfall occurred six times, and in the 5 weeks totaled not more than 17 cm., with a water content of 2 to 2.5 cm. On stormy days, it was difficult to tell whether or not the snow in the air was all wind driven from the surface. On days when snow surely fell, the wind had shifted to upslope directions.

Only in the interior zones, from about 1,800 to 2,400 m. altitude on the west slope and from about 1,200 to 2,300 m. on the east slope, where the snow melted a little in summer, was it possible to determine the approximate amount of annual precipitation. The water content of the annual accumulation here appeared to be about 35 cm., which with 5.5 cm. evaporation makes the probable annual precipitation about 40 cm. In the far interior zone, the precipitation is less, perhaps 30–35 cm. if the trends indicated by the successive determinations on each side may be used as a guide. The average annual precipitation at Jakobshavn is 25 cm., and at Angmagsalik, 100cm.[3] The height of the snow line on the west slope, about 1,450 to 1,500 m., is greater than that on either coast, 1,100 m. at Disco and not more than 1,000 to 1,100 m. at Angmagsalik. The decreasing precipitation toward the interior, the greater brightness of the sun on föhn days, and the general anticyclonic weather, are the important factors in the high snow line of inner Greenland. There is little, if any, effect from rising summer temperature toward the interior, as in the Alps.

An interesting application of barometry was made in determining altitudes while the party was crossing the inland ice. As the ice is devoid of landmarks for triangulation barometric determinations of altitude alone are available. A hypsometer was the standard used, and three "compensated" aneroids were set by it daily. For comparison, barographs were in operation at both ends of the crossing route, and simultaneous observations of pressure and temperature were made at stated hours. On account of the considerable horizontal distances involved it was necessary to consider the weather and wind direction and velocity to make allowance for the horizontal gradient in pressure, before the vertical difference and altitude could be obtained. On the march the aneroids, including a pocket barograph, were used. It was found that a slope of as much as 5 per cent up may be mistaken for a slight down grade. At each camp a theodolite was used to get the depression (zenith distance) of the horizon in 8 directions.

II. SUMMER WEATHER ALONG THE WEST COAST AND ICE FRONT.

The weather of the bare coastal zone on the west is closely related to that of the inland ice, and its effectiveness in melting the ice front is coordinate in importance with the accumulation of snow in the interior. The general meteorological situation over the bare zone is about the reverse of that over the ice cap in summer. The bare zone is much heated by the sun and, thus, is a warm belt between the cold of the inland ice on the one side and the cold of the iceberg-dotted water (Davis Strait) on the other. On account of the expansion and lateral overflow of the heated air, pressure gradients are established toward the warm zone, resulting in a daily sea breeze on the western portion and a daytime intensification of the fall wind off the ice with rising air between. This circulation gives the coasts chilly weather, and causes some daytime cloudiness over the bare zone. (See fig. 1.) The heat of the bare zone is more than sufficient to offset the expansional cooling of sea air as it moves up the slope. Also, the heat hinders the cooling during the hours of low sun to such an extent that the fall wind from the ice can at no time of day continue down to the coast.

Some numerical details from the observations made by the Swiss expedition may be of interest. During the first half of May the temperatures at a fiord head 65 km. from the coast were almost constantly 2° to 4° and once apparently 10° (F.) higher than those at Holstensborg on the coast (lat. 65). Only after very clear nights was the fiord head somewhat colder than the coast, but

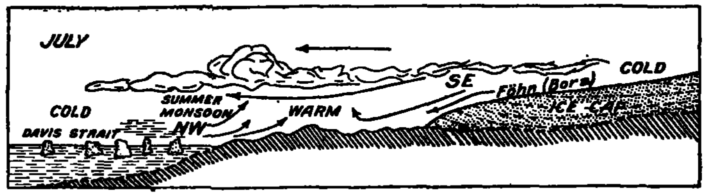

FIG. 1.—Diagram of the summer air circulation between the sea and the inland ice of West Greenland about latitude 68–70°, based on various observations by the Swiss expedition. (After de Quervain, op. cit., p. 212.)

then not as much as 1° (F.). On the inland (glacial) edge of the bare area, about 65 km. back of Jakobshavn, the air temperature at midday in summer was as high as that on the coast, nothwithstanding an altitude 500 m. greater and the practically continuous flow of air off the ice sheet only 600 m. away. In the early morning the temperature there was only 5° (F.) lower than that at Jakobshavn. In the center of the bare zone here the temperatures must have been higher than those so near the ice front and, therefore, higher than on the coast. The effectiveness of the bare zone as a heater may explain in part the average difference of 8° (F.) between a station on the ice and that on the bare land 1 km. away and 50 m. lower. It is a mystery how a wind 12 to 14 miles an hour could be so much warmed in crossing a strip of rocks only 500 to 1,000 m. wide. When a föhn was blowing, the wind went all the way to the coast, where the temperature rose to 15° (F.) above that on the edge of the ice. Normally the difference was 11°.

While there were frequent calms at Jakobshavn, only once was the air still at the ice edge. Southeast winds showed a marked preponderance at both places, though at Jakobshavn, so close to the cold water, the west winds in July were more frequent than the southeast ones. Although there were no fogs on the coast, the sky was more cloudy than at the ice edge, where the descending air was generally unfavorable for cloudiness. The averages in July were 7.1, 6.7, and 6.9 tenths, morning, afternoon, and night, at Jakobshavn, and 5, 5.8, and 6.5 at the ice edge.

The intensity of solar radiation at Holstensborg, altitude 40 m., latitude 66° 56′, was about the same as

[3] A detailed discussion of the relation of this precipitation to the maintenance of the ice sheet, is published in the *Geogr. Rev.*, July, 1923.

that of Montpelier, altitude 44 m., in southern France. On clear days between May 15 and 26 at Holstensborg the average was 1.18, and extremes 1.11 and 1.24 gm. cal. per minute per square centimeter normal to the sun's rays. In the brightest month, April, the average for clear days was 1.16. An observation made August 18 at 2 p.m., in latitude 69° 45′ and 5 m. altitude, gave 0.73. Reduced to the same solar altitude as the May observations, the value would be 0.80, or more than 30 per cent under the intensity in May. This great reduction was owing to the volcanic dust veil. The sun set July 15, for the first time after midsummer, a full week too early. The volcanic dust veil looked like banks of cirro-stratus clouds, flocculent, often undulated, and at times in NW.–SE. bands. Few halos were seen after the advent of the dust. Abnormal atmospheric refractions were observed. The setting sun was much distorted. Mirages were seen strongly developed over the water, where the surface layer of air was notably colder than that above. The green ray, occasionally observed at sunset, was evidently a phenomenon of mirage.

III. WINTER WEATHER AT GODHAVN.

An important phase of the expedition's work was the maintenance of an aerological station at Godhavn, on the south shore of Disco, from October, 1912, to June, 1913. Godhavn and Jakobshavn are under the same general meteorological conditions; near the open ocean on the west, and within reach of the SE. föhn off the inland ice. On account of the marine influence the early winter is wettest and stormiest, while March is the coldest, most quiet, and foggiest month. Godhavn being nearer the open ocean than Jakobshavn it is not surprising that the climate of Godhavn is more marine than that of Jakobshavn. From October to April the monthly temperatures were 2 to 5° F. higher and the cloudiness 1 to 2.5 tenths greater at Godhavn than at Jakobshavn, and the precipitation about twice as great at the former as at the latter. In May and June Godhavn, naturally, had a more prevalent sea breeze blowing daily toward the heated bare zone, and, therefore, was about 2° (F). colder than Jakobshavn in these months. In June there was an east wind of mornings as regularly as a west wind of evenings.

The position of Godhavn on the coast, at the foot of the steep, south wall of Disco 1,000 meters high, and not far from the 1,400–1,500 meter heights of the interior has a considerable effect on the winds. The general easterly and southeasterly wind is deflected into a northeasterly one and reduced in velocity to such an extent that the average at Godhavn is 25 to 30 per cent less than at Jakobshavn. Warm, dry fall winds from the interior of Disco occurred 10 times from October to February, when the open ocean was warmest in contrast to the snow-bound interior. These winds did not extend far out to sea. They caused some local precipitation over the water. Very sudden changes in temperature, upward with the arrival of a fall wind, and downward at its cessation were common. Their relative humidity averaged 20 to 30 per cent. The wind was extremely gusty and turbulent, so much so that kite flying was impracticable. Pilot balloons, showed, however, a south wind usually prevailing above the fall wind from the north. The precipitation at Godhavn in the winter of 1912–13, which was a mild, stormy one, was 201 mm. from October to June, inclusive, of which 80 mm. came in November, and 50 in December. The temperatures did not go extremely low, −13° F. at Godhavn and −17° F. at Jakobshavn, being the lowest for the winter. In all months but March, föhns from the inland ice raised the temperature to above freezing, sometimes even melting the sea ice and driving it away. These föhns made the monthly range more than 45° (F.) in November, January, and February, while in March, when there was no föhn, the range was only 28° (F.) In June the range was greater, 34°, from 30° to 66° F. Fifty-four auroras were observed, mostly as moving draperies in the south.

GENERAL CIRCULATION OF THE ATMOSPHERE ABOUT GREENLAND IN WINTER.

The aerological observations by the expedition in connection with those made at the same time in northeast Greenland, Iceland, and Spitzbergen much needed information concerning the general circulation of the atmosphere in the north polar regions. The pilot balloon work was carried on in May, 1912, and throughout the following winter. Preliminary work had been done in 1909, when 60 ascents had proved so interesting that a complete winter series was planned. Balloons with a computed ascensional rate of 200 meters per minutes, and the de Quervain theodolite were employed. The ascensional rate was found too small for strong turbulent winds, but it is not thought that the results were badly vitiated by this. Observing through the theodolite is not necessarily easy in view of the cold and the wind. Spectacles were sometimes blown off the observer. One third of the balloons were followed to a distance of 24 to 29 km. Smaller distances has to suffice when there was a general, light cirrus sheet. Some of the observation series were very long and trying. The mean height reached was 6 km., while for the ascents where the balloon did not go into clouds the average height was 8 km. The greatest duration of an ascent was 3 hours and 15 minutes, that in which the balloon was thought to have reached a height of 39 km. The greatest distances of disappearance were 132 (?), 42, and 37 km. The results were tabulated by height intervals of 100 to 500 meters. To provide meterologists with an opportunity to study the results in detail a brief account of the weather map and results of each flight is given for the 22 ascents from Holstensborg, April 30–May 29, 13 ascents from Quervainshavn and Jakobshavn, August 3 to September 5, and 82 ascents from Godhavn, September 21, 1912, to May 31, 1913. A special treatment is accorded the longest flight, and some reasons advanced for believing a height of 39 km. was reached.[4]

The significance of the results for the general circulation of the atmosphere is full of some surprises. In the first place, assuming reasonable vertical temperature gradients which would bring the temperature down to −55° C. at 9 km. a northward pressure gradient should obtain over Greenland from as few as 4 km. upward. But there was none such. The upper winds over west Greenland were generally S., indicating gradients toward the west. This could only mean that the cold air overlying Greenland is in but a thin layer, above which the temperatures are surely no lower than those of neighboring low-pressure areas. It is evident that the anticyclone over Greenland is of great vertical extent and that it is probably maintained dynamically. Certain it is that there is no northern circumpolar whirl in these latitudes, according to current theory of the general circulation of the atmosphere, though in the practically

[4] American aerologists are skeptical, however, and believe the balloon must have sprung a leak, thereby reducing its ascensional rate, or even allowing it to descend.

unobstructed Southern hemisphere there may be such a true, circumpolar whirl.[5] The low pressures of Davis Strait and Baffins Bay appear to extend all over the American Arctic Archipelago. The problem of the north polar circulation is still left open, though there is a fair hope of its solution during Amundsen's expedition, in conjunction with which aerological observations are being conducted in the polar regions. There should be a permanent meteorological station in northeast Greenland, which is apparently the north polar, high-pressure center of action.

Occasional captive balloon and kite flights were made at Holstensborg and Godhavn. The weather of May 22–24 was fairly typical of spring conditions at Holstensborg; clear weather began with slowly falling barometer and continued so long as the barometer fell. The wind, at least in the free air, was SE. to S. With rising pressure come W. and NW. winds, with the sky covered with low clouds, stratus and nimbus, and with precipitation. This northwest streaming seems usually to be very thin. There appears to be a direct connection between the inflowing cold, heavy air from the northwest (Davis Strait) and rising barometer. With a layer 1,000 m. thick the rise was 4 mm. but with lesser thicknesses 2 or 3 mm. The wind aloft was föhnlike, from the SE.

The captive balloon was used in midwinter and later, when it was certain there would be enough hydrogen for the pilot balloons. On February 24, a warm winter day, there was an inversion of 4° C., with the maximum temperature at 250 to 400 m. At the time of minimum temperature that day the inversion must have been 8° or 9° C. On the coldest day, March 10, with the minimum −24.7° C., there was no inversion at noon, and practically no wind.

On the 28th to 29th of May eight ascents were made to get the diurnal sequence of temperature. The greatest inversion occurred at 23 h., and thereafter the ground temperature rose, while that aloft sank; the altitude of the maximum temperature usually varied from 150 to 260 m., but at 4 a. m. it was at 400 m. With a sea fog at 6 a. m. the fall in temperature began first at 100 to 300 m. and later at the ground. This made a strong, vertical temperature gradient.

The general results of 83 pilot balloon ascents in Iceland by Thorkelsson were not so great as those in Greenland, for the weather was generally adverse and only when low clouds would not interfere was it practicable to attempt flights. Lack of balloon materials prevented the making of any flights in January before the 29th. South was the most frequent direction of the wind, then W., and NW. NE. and E. winds were absent, partly because flights could not be attempted when such winds occurred, the clouds being too low. It was found that the wind in the lowest 100 m. was governed by the direction of the deep fiord in which the station lay. Winds aloft often did not show any connection immediately with the surface pressure distribution. This may be accounted for by the fact that under some conditions the temperatures make the pressure distribution at even moderate heights differ markedly from those at the surface.

The most pronounced facts from these 83 flights are: On the E. or NE. side of a depression the turn of the wind outwards 50 to 70° was striking. It began to occur at only 2 to 3 km. In a saddle the wind aloft was prevailing west. On the back side of an eastern depression the NW. wind goes to great heights. With the distant approach of a low on the SW., however, the wind may go suddenly to S., or a SE. wind may come in at a different level. The center of a depression leans N. or NW. In many cases, particularly in winter, when there is high pressure to the north the wind aloft is SW. to W., indicating that the cold air which makes the high pressure under such conditions can not be in a very thick layer. Only in October (once) and several times in March and April did the characteristic easterly winds aloft occur with high pressure to the north. This is explained as a result of the anticyclones of winter in this region being a relatively thin layer of cold air, while by spring the overflow from warmer latitudes has so built up the air column that the anticyclone is dynamic. Even in west Greenland there are indications of a more pronounced development of the E. and SE. winds aloft in spring than in winter (partly in fall).

The results of the Spitzbergen flights by K. Wegener and H. Robitsch show characteristic S. to SE. winds with depressions in the SW. and NW. winds with depressions in the SE. No depressions seem to have passed on the north. There are, however, a number of instances, more numerous than the case with E. to NE. winds to heights of 6 km. or more, in which westerly winds prevail aloft (in fall and spring). Especially interesting are the westerly winds above high pressure areas lying north of lows. It seems as if there were here the edge of a true circumpolar whirl, north of the high pressure belt between 70° and 80°N. which bounds the subpolar low-pressure belt.[6] Yet this high pressure "belt" may be merely a wind divide between the Atlantic low and one on the other side of the pole. Whether or not it is such must be determined from more extended observations, such as those Amundsen is making.[7]

[5] Cf. W. H. Hobbs, loc. cit.

[6] V. Bjerknes seems to have used these observations as the basis for a new detail in his general circulation of the atmosphere. See Fig. 31 in *Geofysiske Publ.* No. 5, Kristiania, 1922.

[7] A general review of the work of the Swiss Greenland expedition is published in the *Geogr. Rev.*, July, 1923.

SNOWSTORM OF MAY 8-9, 1923, IN MICHIGAN.

By B. B. WHITTIER, Meteorologist.

[Weather Bureau Office, Lansing, Mich., June 20, 1923.]

The months of March and April and the first half of May, 1923, were marked by unusually capricious weather in Michigan, with frequent cold waves, which in many localities broke all previous records for low temperature in the months in question. Killing frosts on the 10th and 13th of May were unusually late in the season, but as the cold spring had held vegetation back, and fruit buds were snow covered, the frost caused but little loss. The most unusual feature of the late spring was the snowstorm of May 8–9, which was the heaviest on record for the month of May in the State by a full inch, averaging 3.3 inches for the State, against 2.3 inches for May, 1917, the previous record. What threatened to be a very damaging frost to fruit, much of which was in full bloom, on the morning of the 10th, was minimized by the melting snow on the branches.

The weather map on the morning of May 8 showed a low-pressure area over the Great Lakes, with the main center over northern Lake Huron, and a secondary center over northern Lake Michigan, with high pressure and