EFFECT OF UNUSUALLY DEEP LOWS UPON PRESSURE FIELD OF THE NORTHERN HEMISPHERE IN WINTER MONTHS

Thesis by

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INTRODUCTION

The aim of this project was to select from Northern Hemisphere charts all cases of deep winter lows during the past 40 years, and then study the effect of such deep lows upon normal pressure patterns of the Northern Hemisphere. It was intended that this project be part of a larger study of Northern Hemisphere weather and synoptic patterns. Wave lengths of unusual length, intensity, and symmetry accompanying the abnormally deep lows were to be studied also.

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PROCEDURE

After a preliminary examination of approximately 10% of the total number of deep lows, the following rather arbitrary limits were set up, in order to govern selection of cases:

1. Scandanavian lows: 5 deg. W. to 55 deg. E.

2. Greenland-Iceland lows: 5 deg. W. to 65 deg. W.

3. Gulf of Alaska lows: 115 deg. W. to 175 deg. W.

4. Kamchatka lows: 175 deg. W. to 125 deg. E.

On enclosed sheets are tabulated all observed deep lows for January, February, and March from 1899 to 1939. Unless the pressure of the low was 960 or less, in January or February, and 965 or less in March, it was not tabulated. Latitude and longitude and number of days the pressure of the low stayed below 960 or 965 mb. resp. are also given in the accompanying tables.

In certain mid-winter months, there were many more cases of deep lows within these limits, in one or more of the four classes above, than could be studied in this preliminary investigation. Therefore in certain cases, as with the Greenland-Iceland low in January and February, only those examples where the pressure fell to 950 mb. or less, were used for further study. In March, there were generally higher pressures than in January and February, so lows as shallow as 965 mb. in the Gulf of Alaska and Kamchatka sectors were used.

Normal sea level pressure charts for the Northern Hemisphere (after Shaw) were obtained for each month of the year. Then for January, the normal pressure and position of each center of action (high or low cell) was noted on separate small blank hemisphere charts. Upon one of these, the pressure and position of each high and low from an old synoptic hemisphere chart containing an unusually deep (960 mb. or less) low cell was noted. If the highs and lows that actually occured were in positions near "normal chart" highs and lows previously recorded on the same chart, then the intensity of the actual highs and lows was recorded by a plus or minus deviation. Thus Plus 10 at

40 degrees N., 30 degrees W., indicates a high cell 10 mb. stronger than the normal for that month occured at that spot. Approximately a dozen cases were plotted on this Greenland-Iceland January chart, and roughly equal numbers down to as few as half a dozen cases, were plotted on corresponding charts for February and March, and for Kamchatka and Gulf of Alaska deep lows. The Scandanavian cases were fewer in number and have not been plotted yet.

After the highs and lows had been spotted upon small hemisphere charts, those highs and lows that were bunched closely together were circled to give greater emphasis, and to show which areas showed greatest pressure rise or fall, (due to an adjacent abnormally deep low.) Because such areas of maximum and minimum pressure lay at different latitudes, it was deemed advisable to separate them into high latitude, middle latitude, and low latitude groups. Also since such areas of max and min lay at different longitudes, subdivisions were arbitrarily made at 15 degree intervals, giving 24 longitudinal zones. At high latitudes this was too narrow an interval and caused some difficulty, but otherwise it was convenient and gave a polar hemisphere chart subdivided in a fashion similar to the face of a 24 hour clock, such as the military forces use. Furthermore the width of each such division, at middle latitudes, is about equal to the average 24 hour cyclonic displacement in winter time, and about equal to one third of the distance between mean pressure troughs (on 3 day or 5 day mean pressure charts).

Each chart was numbered off into longitudinal zones in a counter clockwise fashion, starting with the center line of the zero zone bisecting the center of the group of abnormally deep lows. Then each chart was checked to see in what zones and what latitudinal bands the pressures seemed to be particularly and consistantly high or low. It was quickly observed that a few cases repeated themselves in a similar if not almost identical fashion, even when the position of the abnormally deep low lay in a different sector. This indicated that the effect of the low upon the pressure pattern of the adjacent portions of the hemisphere was so great as to superimpose added increments of pressure of rather large magnitude upon adjacent areas, and even affect more distant areas at least slightly in some cases. Particular note was made of cases in which pressures rose or fell abnormally on each side of unusually deep lows, and note of the distance away of such rises or falls, was made also. Observations that were made for the three main deep low positions showed much in parallel, and are summerized in Appendix C, with distinction being made between those cases where pressure systems were over land, and other cases when they were over water.

Results

In nearly all cases during January, February, and March, the Gulf of Alaska, Kamchatka, and Icelandic unusually deep lows occured at the same time that higher than normal and often much higher than normal pressures occured over land areas to the East a distance of 4 to 4½ zones (60 to 68 degrees longitude), East of the unusually deep low, this area of strong high lay at middle latitude. In the cases of the Kamchatka deep lows there was usually an additional very intense high cell that appeared at high latitude about 3½ to 4 zones East, over land. Subtropical highs over water areas at low latitudes were observed in some cases, but were deemed much less significant, even when moderately intense. At 8½ to 9½ zones East of the unusually deep low, and at high latitude over water areas, a secondary low area was observed. Sometimes this feature appeared at middle latitude or at both middle and high latitude. If it appeared over land instead of water, continental effects seemed to dominate and obscure it. Approximately 10 zones East of the deep low, a low latitude or occasionally middle latitude high cell of only slightly greater than normal intensity usually developed. Approximately two to three zones West of the deep low, a shallow low trough was present in many cases. Approximately 5 to 5½ zones West of the unusually deep low a continental high usually in middle but occasionally in low or high latitude appeared. In winter, because of the Continental effect, deep lows are less deep over land than over water, so none of the cases considered in this report occured over land. However relatively speaking, a 975 mb. low over the center of a continent is very deep, and when one such case occured near Chicago in the winter of 1940, there was a strong middle latitude high 3 zones to the west centered just off the Pacific NW coast, and a very strong high latitude high cell 5 zones to the West in Alaska with a strong wedge to the SE into Canada. There was no shallow trough apparent, 2 to 3 zones West of the primary low located near Chicago. A few cases in this report, especially in the Scandanavian area, did occur very near land, or over relatively small penninsular land areas largely surrounded by water. In the cases studied in this paper, 11 zones West of the unusually deep low, a continental low at high latitude or a maritime low at middle latitude appeared.

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CONCLUSIONS

Assuming the most simple case (a water covered hemisphere with uniform heating and friction along latitude lines) every 3rd longitudinal zone (each zone 15 degrees in width at middle latitudes) would be a zone of lowering pressure with increasing pressure midway inbetween. When however continental effects are included, the simple case begins to break down to a more complex series of ridges and troughs (aloft) or highs and lows (surface). When further, the pressure falls abnormally low in some zone (usually over water in winter) due to an exceptionally deep low, then air removed from the low is piled up on both sides of the low. A detailed explaination of the deepening of extra-tropical cyclones is beyond the scope of this paper, but is treated in considerable detail by J. Bjerkness in the 1940 supplement of the quarterly Journal of the Royal Meteorological Society. He says, "The upward motion over the warm front of the cyclonic wave or waves of the deep low builds up the upper air wedge of high pressure to the East, so therefore the upper perturbations are rather rigidly connected with the polar front wave of the low, and invariably cause a field of divergent flow over the deepening cyclonic center or centers of the deep low at the ground. In an old deep low, the vertical axis loses its Westward tilt and becomes nearly vertical (after the warm air is all lifted aloft and deepening has stopped). The narrowing of the warm sector is connected with the horizontal spreading and descent of the polar air in the rear of the cyclone, and the tropical air above the subsiding cold front wedge also has to descend. At high altitude downward motion of air West of the cyclone center is indicated by lowering of the tropopause, warming of the stratosphere to maximum heights balloons can reach, and by Ozone maximum." Ahead of the deep lows (on their East side) that were examined on this project, it was observed that the accumulation of air advected from the low caused the third zonal trough to be greatly weakened and minimized, shifted far northward, or obscured almost completely. In its stead, it was replaced largely, by high pressure often much above normal, centering at 4 to $4\frac{1}{2}$ zones East. Behind (West of) the unusually deep low, the pressure increases were again evident. However the nearest theoretical three day trough (of the 21st zone) was not minimized in most cases, but remained quite apparent. Instead the 2nd trough West in the 18th zone was greatly weakened and minimized, shifted far Northward, or obscured almost completely by the large high which centered as a rule at about the 19th zone (5 zones West or 75 degrees Longitude West) of the deep low. At first sight, this would seem to indicate that this high to the West was both larger than the one to the East of the deep low, and that the slope of the pressure cells was more gentle than that to the East. This in turn would contradict the normal pressure pattern of the earth since it would necessitate a warm type high behind rather than ahead of the deep low. However it is the present opinion of the writers that this apparent inconsistancy can be avoided if the trough in the 21st zone, approximately 45 degrees West of the deep low, is considered a part of the huge low center or system. If it is located over land, it may be weakened by the presence of strong continental highs, ie, continental effects (especially strong in winter months), and appear more as an upper cold front trough than as a deep surface development, although 45 degrees further East the primary low may be very deep. Deepening of a cyclone is dependent on the upper air trough being behind the center at the ground. Often two or more cyclonic centers are present, forming a cyclone family, but generally if one low becomes abnormally deep, other adjacent closed centers tend to be absorbed into the primary circulation, lose their individual identity, and remain as weaker troughs superimposed upon the larger cyclonic circulation. In very old deep lows, fronts often tend to weaken or disappear toward the center of the low, and then weak fronts may be observed traveling about the outer periphery of the low. Such cases are most common in the NE Atlantic and NW Europe, but also occur in the NE Pacific and elsewhere. Sometimes the weak fronts in the outer periphery of the old low seem to be stable open waves traveling at high velocity. Such cases sometimes occur near the British Isles. Sometimes large and deep low pressure centers have secondary cold fronts and associated troughs well to the West or South West of the main center. Such is often the case in the West Atlantic, and likely also in the West Pacific. Over continents in winter, secondary cold front troughs seem to trail less far to the West and South West in the wake of deep lows (which rarely become as deep as 965 mb. because of higher normal pressures over land in winter). Such factors as these, especially the case of maritime secondary cold front troughs, should account for the fact that the trough in the 21st zone is not obliterated from the average picture for the very deep lows. Sometimes relatively deep polar lows with weak frontal troughs and sometimes no fronts toward their centers, move unusually far Southward or South East, in over the land masses of central France or Germany as there are no mountains to hinder. Then the weather in such areas becomes bitterly cold and windy, and scattered snow flurries prevail. In the very extreme case of so called "Negative Index" (Rossby), the strong continental high to the NE over West Russia may push the deep low (relatively deep considering the latitude and the normal pressures) South into the Mediterranian and then icy Easterly gales sweep all central and South Europe West to the Atlantic, bringing snow far South of Normal. A good case occured the last ten days of February, 1944, and when the strong high centered near Leningrad finally split, half of it moved West and built up to over 1055 mb. centering near Iceland. In that case, the secondary band of Westerlies with associated weak frontal troughs was displaced far South, actually into North Africa, while the primary Atlantic storm track remained far North on a line from South Greenland to Spitzburgen. With Negative Index in ultra extreme cases, the deep Mediterranian low may move West, and fronts may move from East to West about its North side. Or if in Germany, it may move West into France. Although such lows are relatively deep compared to normal pressures, they are not deep enough to show up in the tables of this report, and haven't been studied in detail by the writers. They are considered important enough however to warrent mention in passing, and perhaps further study at a later date. Type D lows off Vancouver Island are of slightly similar nature, they also are relatively deep and presistant, in place.

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Moderately strong lows appeared with a fairly high degree of constancy nine zones East of and 11 zones West of the abnormally deep low in or near three day trough positions. This regularity of appearence of two deep lows at spots less than 180 degrees from the primary one immediately breaks down any hope of the existance of any simple wave pattern such as might produce a 180 degree wave and another unusually deep low at the opposite side of the earth simultaneously. The writers saw no case of two unusually deep lows occuring simultaneously 180 degrees apart, or even approximately 180 degrees apart. In fact the picture is further complicated since the wave length to the West of the reference cell low is, ignoring the weak trough three zones West, longer than that to the East, being approximately 5½ zones as compared to 4 zones. However this does explain the consistant appearance of the weaker high pressure cell at zone 10 East, for taking half of each wave length (for this can be assumed to be the meeting place of the two waves) and adding this to the position of the secondary lows at zones 8 and 13, the result is a position very near zone 10 and this would be an area of air accumulation. As a result, although the simple three day trough positions are outwardly completely overshadowed by these stronger, more dominant wave lengths coincident with the existance of a very abnormally deep low somewhere in the Northern Hemisphere, it still would seem as though they exerted a definite influence on the establishment of high and low pressure cells around the Earth, for in studying the chart of wave lengths included in Appendix C, we notice that in most cases of the existance of the high and low cells noted above, these cells seemed to fall in the immediate area of one of the three day troughs or wedges. The one exception that occured repeatedly is that of the low cell located near zone 13 which nearly coincides with a three day wedge. Assuming then that the "abnormal" and three day troughs and wedges must ordinarily line up and coincide, in order to form regularly recurring highs or lows, we have an explanation as to why few or no other persistant features carried through for all three of the sectors studied. Thus, the troughs and wedges (in the instantaneous one day picture) simply didn't coincide at any other places than those listed in appendix C with the result that other factors such as continentality determined whether high or low pressure existed. In other words, if certain zones were over land, continental effects tended to produce high pressure, but if those same zones were over the sea, lower normal pressures tended to cause lower actual pressures and perhaps cyclonic disturbances to occur in such zones. From the standpoint of the chemist, these zones were not "Buffered" in advance by the nearly Hemisphere wide influence of an abnormally deep low upon Northern Hemispher pressures. From the standpoint of the physicist, these zones fell at nodal points and thus were affected by smaller external forces more strongly (ie, forces such as Continentality).

Looking at the picture as a whole, a certain rough almost tri-clinic sort of symmetry may be observed. Air accumulates more compactly, ahead of the deep low than behind it (some depletion occurs immediately to the West of the low) where it forms another strong high cell further to the West. About 2/3 of the atmosphere by weight, has horizontal divergence ahead of, and convergence behind, the upper trough, with deepening cyclones moving Eastward according to J. Bjerkness. A removal of air will take place from the region behind the trough and the preceeding wedge, and an accumulation of air will take place into the region between the trough and the following wedge* A line drawn like a chord across the hemisphere chart, intersecting the very deep low and the midpoint between the two roughly opposite lows, divides the Northern Hemisphere pressure pattern into two similar but not identical halves. The halves would be almost mirror images if there was no difference in the spreading out of accumulated air and position of moderately intense resultant middle or high latitude highs, and in the position of two additional middle or high latitude lows twice as far away from the deepest low.

In triclinic symmetry in Crystallography, the crystal has no symmetry axes about which mirror images or stereoscopic images can be resolved were the crystal to be divided into two halves. The same seems to be true of the Gneumonic or polar projection of the Northern Hemisphere weather pressure patterns containing unusually deep lows. They are not completely symmetrical with each other, and although the

*Meteorologische Zeitschrift Dec., 1937, P.426

pressure phenomena East of a very deep low correspond to the pressure phenomena West of a deep low, there is rarely if ever an identity. One possible reason for the longer distance between the deep low and the strong high to the West as compared to the shorter distance between the deep low and the strong high to the East, is that the deep low is in many cases moving East and is catching up with the air piling up ahead of it, and is leaving a partial vacumm behind itself. It is sort of like Sound waves. Thus when a Railroad train goes by, the sound of its whistle drops in pitch, as the sound waves are shorter in wave length as the train is approaching, and longer with lower pitch (being more spread out) as the train is receeding. A somewhat similar principle applies to the light of stars. Thus we have the Red shift for distant Nebulae or star cities, and this indicates that the universe is probably expanding, and the further away a star is from us, the faster it is receeding from us.

Such abnormally deep lows with wavelengths of pressure approximately twice normal length are rather stable and slow moving centers of action on mean pressure charts, ie, in most cases, although it was observed that individual cyclonic disturbances of great depth sometimes moved long distances across the Northern Hemisphere without losing their great depth or intensity, and in some cases moved at quite high velocity, as for instance along the storm track from Iceland past or through North Scandanavia to the White Sea. Usually however the very deep lows were transitory and filled quickly to more normal levels, once East of the very deep but more slow moving 3 or 5 day mean low trough (as drawn on 3 or 5 day mean pressure charts). Then frequently a new low from the West would become as deep or even more deep than the original when it reached the same area. In such cases the deep mean low (as drawn on a mean pressure chart) is of far greater amplitude, wave length, and importance, than the much shallower, fast moving rough three day pressure waves, which may be outwardly largely obscured in the stronger circulation about the very deep low and adjoining strong highs or areas of strongly built up pressures. Such 3 day pressure waves usually don't show up at all in the deep low circulation as shown on a 3 or 5 day mean chart where there is strong Westerly, WSW, or zonal flow about the south side of an East and West, or ENE-WSW enlongated deep mean low cell. The latter type tilt is particularly common in the North Atlantic and parallels the tilt of the mean low on the Normal pressure charts of Shaw.

Since most centers of action, highs, lows, etc. seem to bunch into patterns that tilt toward the North East with higher latitude, those pressure cells in the high latitude band are East of a probable ideal position with respect to wave length, from the primary deep low, and those pressure cells in low latitude are displaced perhaps a zone to the West, or a half zone at the least.

From the foregoing we can draw some rough conclusions although considerable further study and investigation remains to be carried out in order to produce a well ballanced study of World weather. One thing that is important is that by looking at the weather of a hemisphere as a whole, and considering the effects of an abnormally deep low (or strong high) on the rest of the hemisphere, one can size up a situation more completely and make a more tempered statement concerning probable future developments. It should be noticed that an abnormally deep low can influence pressure patterns even on the opposite side of the world. The writers have found that when pressures drop down to very low levels, they tend to bounce up to very high levels on both sides in most cases, if not at the same time, then at least shortly afterwards. In the case of a deep Kamchatka low, there is usually a very intense high cell far north in Alaska for instance. The latter in turn affects all North American weather, at least indirectly. A fairly definite pattern of secondary lows and highs was found to accompany an abnormally deep low, and this pattern was found to coincide fairly well with the troughs and crests of the three day wave pattern in the one day instantaneous picture. Further, it seemed almost as if the very deep low and associated secondary pressure phenomena became pronounced only when they came into phase with the three day troughs and wedges. Further work is necessary to confirm this theory, that coincidence of a three day trough with an already deep low is necessary to produce an abnormally deep low, and the same for highs.

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One point should be noted in passing however. Very few abnormally deep lows lasted more than two days, and most lasted only one. Those that did last longer, in many cases were fast moving lows, traveling at the same approximate speed as the three day troughs and wedges of the theoretical picture, or at least at a speed that kept them more closely in phase than if they had remained nearly stationary. Other traveling lows however did not remain deep, but in such cases there was a more persistant stationary deep mean low.

SUGGESTIONS FOR FURTHER RESEARCH

Only the features applicable to the case of the existance of an extremely abnormal pressure phenomenon have been studied in this paper, and a few theories have been formulated to cover the observations made. The next step would be to take another type of abnormal feature, such as very intense high pressure, and then investigate in a roughly similar fashion a representative sample of cases of hemisphere charts containing at least one very intense high pressure cell. Allowence might have to be made for the fact that in Siberia there is a very intense high cell on the normal chart already.

Middle latitude blocked lows and so called polar lows that tend to move Southward or in other uncommon or erratic ways with no consistant frontal structure apparent in some cases, offer another line of study. Generally there is an abnormally ~~amount of extreme~~ high pressure at very high latitude accompanying such blocked and polar lows that lie in middle latitude.

Situations that are marked by strong polar outbreaks offer another very large and comprehensive line of study. The Russian meteorologists have based one line of long range forecasting upon the action of polar outbreaks and strong high pressure cells, but dispute among themselves as to whether the method works. Even if it does not, it offers new methods of organizing data for comparison and study, ie, offers a new way of classifying synoptic situations. All classification schemes that are based upon hemispheric weather patterns are potentially valuble for a study of this type, ie, a study of world weather.

The ultimate aim of all meteorologists that take a keen interest in forecasting, is to forecast accurately for longer periods in the future. If exhaustive study of World weather, first of abnormal situations, and then secondly of more normal situations, will extend the period of accurate forecasts, and extend the area for which such forecasts can be made, so as to meet the new demands of globe circling airlines, then more meteorologists should undertake such studies, and publish their findings.

Appendix A Icelandic Reference Low

Date		Pressure	Lat.	Long.	Persistance		Remarks
Jan	19, 1900	960	65N	17W	1	day	
"	1, 1899	955	65N	30W	3	"	
"	14, 1900	950	65N	28W	2	"	
"	19, 1901	950	60N	49W	4	"	940 on 21st to 22nd
"	2, 1902	960	55N	40W	1	"	
"	14, 1903	950	60N	47W	1	"	
"	27, 1904	960	63N	17W	4	"	
"	16, 1905	960	61N	27W	1	"	
"	11, 1906	950	64N	22W	4	"	
"	24, 1906	960	65N	15W	1	"	
"	15, 1909	955	63N	15W	3	"	
"	5, 1911	960	62N	35&55W	1	"	two centers
"	14, 1912	960	51N	37W	2	"	955 on 15th
"	29, 1913	950	63N	42W	3	"	2nd center of 955 at 66N 55W
"	12, 1914	960	54N	45W	1	"	
"	20, 1914	960	56N	42W	1	"	
"	1, 1915	955	54N	10W	2	"	
"	19, 1916	950	65N	20W	2	"	
"	23, 1916	940	64N	22W	2	"	
"	30, 1916	950	64N	35W	1	"	
"	25, 1917	960	61N	50W	1	"	
"	6, 1919	960	55N	18W	2	"	
"	13, 1919	955	62N	37W	1	"	
"	11, 1920	955	60N	10W	1	"	
"	23, 1920	960	64N	28W	1	"	
"	28, 1920	960	64N	15W	1	"	
"	15, 1921	960	61N	33W	1	"	
"	7, 1922	960	61N	28W	2	"	
"	14, 1922	960	65N	40W	1	"	
"	21, 1922	950	50N	35W	2	"	
"	24, 1922	955	50N	35W	2	"	
"	23, 1924	960	65N	42W	2	"	
"	23, 1926	945	55N	50W	4	"	
"	30, 1926	960	55N	35W	4	"	
"	24, 1927	960	60N	35N	2	"	955 on 28th
"	17, 1928	955	61N	45W	1	"	
"	20, 1928	940	64N	23W	1	"	
"	22, 1928	960	67N	55W	4	"	955 on 23rd
"	4, 1929	955	66N	37W	1	"	
"	7, 1929	960	57N	63W	1	"	
"	20, 1929	960	52N	46W	3	"	950 on 21st
"	30, 1930	955	53N	17W	2	"	955 on 31st
"	12, 1932	955	58N	25W	3	"	
"	17, 1932	950	60N	25W	2	"	
"	1, 1933	945	55N	40W	4	"	925 on 2nd
		950	66N	25W			
"	7, 1933	960	65N	28W	1	"	
"	11, 1933	955	61N	39W	2	"	
		940	59N	25W			
"	14, 1933	945	70N	12W	2	"	
"	11, 1937	960	62N	30W	2	"	
"	20, 1937	955	57N	25W	4	"	2nd center formed on 23rd and deepened to 945 on 24th
"	24, 1937	945	52N	18W	2	"	
"	13, 1938	955	64N	11W	1	"	
"	15, 1939	955	54N	17W	2	"	

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Feb	2, 1899	960	46N	37W	9 days	950 on 3rd
"	16, 1900	960	58N	6W	1 "	
"	18, 1903	960	53N	43W	4 "	935 on 19th
"	24, 1903	940	62N	21W	2 "	
"	12, 1904	960	56N	24W	1 "	double center
			52N	20W		
"	15, 1905	955	67N	45W	2 "	
"	9, 1907	960	64N	20W	1 "	
"	21, 1908	960	63N	18W	2 "	955 on 22nd
"	17, 1910	960	60N	10W	1 "	
"	20, 1910	960	58N	13W	1 "	
"	4, 1915	960	64N	20W	1 "	
"	3, 1916	960	62N	21W	4 "	950 on 7th
"	8, 1918	960	62N	22W	2 "	
"	17, 1918	950	64N	25W	1 "	
"	19, 1918	960	63N	25W	1 "	
"	9, 1920	960	64W	23N	3 "	950 on 10th
"	26, 1920	960	50N	61W	4 "	955 on 28th and 29th
"	23, 1921	960	64N	39W	1 "	
"	19, 1922	950	64N	21W	1 "	
"	6, 1923	960	60N	22W	4 "	945 on 9th
"	26, 1923	960	53N	8W	1 "	
"	8, 1925	960	66N	9W	2 "	945 on 9th
"	1, 1926	960	52N	23W	2 "	carry over from January
"	13, 1926	960	57N	34W	1 "	
"	20, 1926	960	51N	57W	2 "	955 on 21st
"	4, 1927	955	56N	39W	1 "	
"	1, 1928	960	63N	8W	1 "	
"	20, 1928	950	62N	39W	1 "	
"	25, 1929	960	50N	30W	1 "	
"	28, 1930	960	61N	40W	1 "	
"	9, 1931	960	66N	19W	3 "	
"	1, 1932	960	63N	65W	1 "	
"	9, 1933	960	50N	61W	2 "	955 on 10th
"	17, 1933	950	63N	62W	1 "	
"	20, 1935	960	61N	12W	2 "	955 on 21st
"	13, 1937	960	63N	25W	2 "	955 on 14th
"	9, 1939	960	48N	37W	1 "	
"	20, 1939	960	64N	30W	1 "	
Mar	2, 1901	960	60N	19W	1 "	
"	6, 1901	960	61N	6W	1 "	
"	20, 1902	965	61N	5W	1 "	
"	17, 1903	965	62N	15W	2 "	
"	25, 1903	955	58N	18W	1 "	
"	31, 1903	960	61N	50W	1 "	
"	11, 1905	965	56N	10W	1 "	
"	14, 1905	960	54N	23W	3 "	
"	21, 1908	965	55N	30W	1 "	
"	27, 1908	955	60N	17W	1 "	
"	24, 1915	965	47N	40W	1 "	
"	1, 1917	965	67N	35W	1 "	
"	17, 1918	965	53N	50W	1 "	
"	2, 1920	960	67N	55W	3 "	
"	8, 1920	965	63N	52W	2 "	
"	23, 1920	960	64N	32W	2 "	
"	8, 1921	965	63N	25W	1 "	
"	11, 1921	965	62N	47W	1 "	
"	13, 1921	965	62N	25W	1 "	
"	23, 1921	960	65N	20W	1 "	

Mar	20, 1923	965	50N	57W	2	day	960 on 21st
"	25, 1927	965	57N	22W	1	"	
			54N	7W			
"	7, 1929	955	51N	55W	1	"	
"	3, 1930	960	52N	65W	1	"	
"	29, 1930	960	67N	10W	1	"	
"	8, 1939	960	58N	52W	1	"	

Kamchatka Reference Low

Jan	16, 1904	960	47N	169E	1	day	
"	28, 1905	960	63N	172E	1	"	
"	13, 1924	960	53N	178W	1	"	
"	20, 1926	955	48N	150E	2	"	
"	21, 1928	960	51N	172E	1	"	
"	3, 1929	960	46N	162E	1	"	
"	9, 1929	960	53N	176E	1	"	
"	15, 1929	960	53N	179W	1	"	
"	28, 1929	955	48N	176E	1	"	
"	4, 1930	955	55N	170E	1	"	
"	11, 1930	960	51N	179E	1	"	
"	28, 1931	955	48N	180W	2	"	
"	3, 1935	955	50N	173E	1	"	
"	13, 1935	960	47N	167E	1	"	
"	4, 1939	955	43N	175E	4	"	
Feb	17, 1901	960	51N	174E	1	"	
"	11, 1910	955	48N	157E	1	"	
"	21, 1916	960	43N	179E	1	"	
"	14, 1917	950	50N	165E	1	"	
"	9, 1928	950	55N	161E	1	"	
"	3, 1929	945	47N	172E	2	"	940 on 4th
"	10, 1929	945	54N	177W	1	"	
"	26, 1930	960	51N	177E	1	"	
"	21, 1934	960	49N	175E	2	"	
"	9, 1939	960	49N	175E	1	"	
Mar.	4, 1901	955	44N	162E	1	"	
"	20, 1919	960	46N	158E	1	"	
"	4, 1922	965	50N	177E	1	"	
"	25, 1922	960	47N	170E	3	"	
"	30, 1922	955	46N	179W	2	"	
"	31, 1923	965	46N	168E	1	"	
"	6, 1931	960	50N	174E	2	"	
"	10, 1933	965	53N	165E	1	"	
"	23, 1933	965	48N	175E	1	"	
"	30, 1934	960	45N	160E	2	"	
"	14, 1935	960	57N	177W	1	"	
"	25, 1935	965	39N	147E	1	"	
"	23, 1937	965	47N	165E	1	"	

Gulf of Alaska Reference Low

Jan	2, 1914	960	49N	160W	1	day	
"	6, 1920	960	54N	167W	1	day	
"	10, 1922	960	52N	150W	1	"	
"	26, 1926	960	49N	163W	3	"	955 on 28th
"	1, 1927	960	48N	145W	1	"	
"	6, 1928	960	49&50N	168&155W	1	"	double center
"	5, 1931	955	51N	172W	3	"	
"	16, 1931	955	51N	161W	2	"	
"	26, 1933	960	57N	140W	1	"	

Jan 27, 1935	960	49N	150W	1	day	
" 20, 1936	960	54N	165W	1	"	
Feb 17, 1919	960	51N	167W	1	"	
" 26, 1921	950	49N	158W	1	"	
" 25, 1924	955	53N	166W	2	"	950 on 26th
" 25, 1925	955	48N	166W	1	"	
" 3, 1926	960	52N	144W	1	"	
" 4, 1928	955	51N	163W	2	"	
" 18, 1934	960	47N	170W	1	"	
" 14, 1937	955	59N	147W	1	"	
" 12, 1939	960	52N	174W	2	"	955 on 13th
Mar 12, 1905	965	34N	131W	1	"	
" 30, 1925	965	57N	169W	1	"	
" 21, 1926	965	57N	147W	1	"	
" 26, 1926	960	52N	167W	1	"	
" 29, 1933	965	54N	145W	1	"	

Scandinavian Reference Low

Jan 22, 1901	950	70N	15E	1	day	
" 22, 1904	960	81N	45E	1	"	
" 4, 1905	960	69N	45E	1	"	
" 9, 1905	960	66N	18E	1	"	
" 28, 1905	955	74N	23E	1	"	
" 27, 1906	955	68N	20E	2	"	
" 11, 1910	960	72N	15E	1	"	
" 8, 1920	950	62N	10E	3	"	
" 2, 1922	960	63N	20E	2	"	
" 12, 1925	955	78N	5E	1	"	
" 15, 1925	950	75N	20E	1	"	Moved in from Ireland
" 18, 1925	955	76N	17E	1	"	
" 11, 1930	955	64N	4W	2	"	
" 7, 1932	960	62N	20E	1	"	
" 29, 1932	955	69N	35E	1	"	
" 23, 1935	960	70N	20E	1	"	
" 6, 1937	960	73N	30E	1	"	
" 21, 1938	960	76N	5W	1	"	
" 26, 1938	960	80N	5E	1	"	
Feb 9, 1903	960	62N	44E	1	"	
" 11, 1903	960	72&67N	27&22E	1	"	double center
" 20, 1903	960	72N	15E	2	"	
" 20, 1907	950	59N	7E	2	"	
" 16, 1916	960	59N	3E	1	"	
" 10, 1928	960	63N	35E	1	"	
" 2, 1933	960	67N	10E	1	"	
" 9, 1933	960	70N	10E	1	"	
" 1, 1934	960	78N	32E	2	"	955 on 2nd
" 14, 1934	960	82N	45E	1	"	
" 18, 1934	960	72N	69E	1	"	
" 2, 1935	950	65N	15E	1	"	
" 1, 1938	960	62N	0E	1	"	
" 16, 1939	960	77N	50E	1	"	
Mar. 8, 1906	955	67N	5E	1	"	
" 12, 1906	960	58N	12E	1	"	
" 19, 1908	965	80N	45E	2	"	
" 4, 1920	960	70N	28E	1	"	
" 7, 1920	960	68N	10E	2	"	950 on 8th
" 2, 1926	950	72N	20E	3	"	

Appendix B Table of Recurring Features

The following table shows the average distances to the East of the three reference lows of regularly recurring increasing or decreasing pressure centers. The displacement figures represent 15 degree latitudinal displacement. Values are given with reference to a control cell, month of occurance, low, middle or high placement and whether located over land or water.

	Gulf of Alaska			Kamchatka			Iceland			
Periods (east)	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar	
4 (Increase)	2½-3L	4L	4½L	5L	4L	4L	4L	3L	4L	(Middle Lat)
9 (Decrease)	7½LW	8½LW		9W	9½W	10W	6L	4L	6L	(High Lat)
			7W							(Middle Lat)
10 (Increase)					12WL			8½L	9L	(Middle Lat)
	9W	10W	8W	10½W		10W	10L			(Low Lat)
13 (Decrease)	12LW	14LW	12LW	13LW	14½LW	14½LW				(High Lat)
							13W	13W	13W	(Middle Lat)
19 (Increase)	18L	18½L		19L	19L	19L		18L		(Middle Lat)
			18½L				19L		16½W	(Low Lat)

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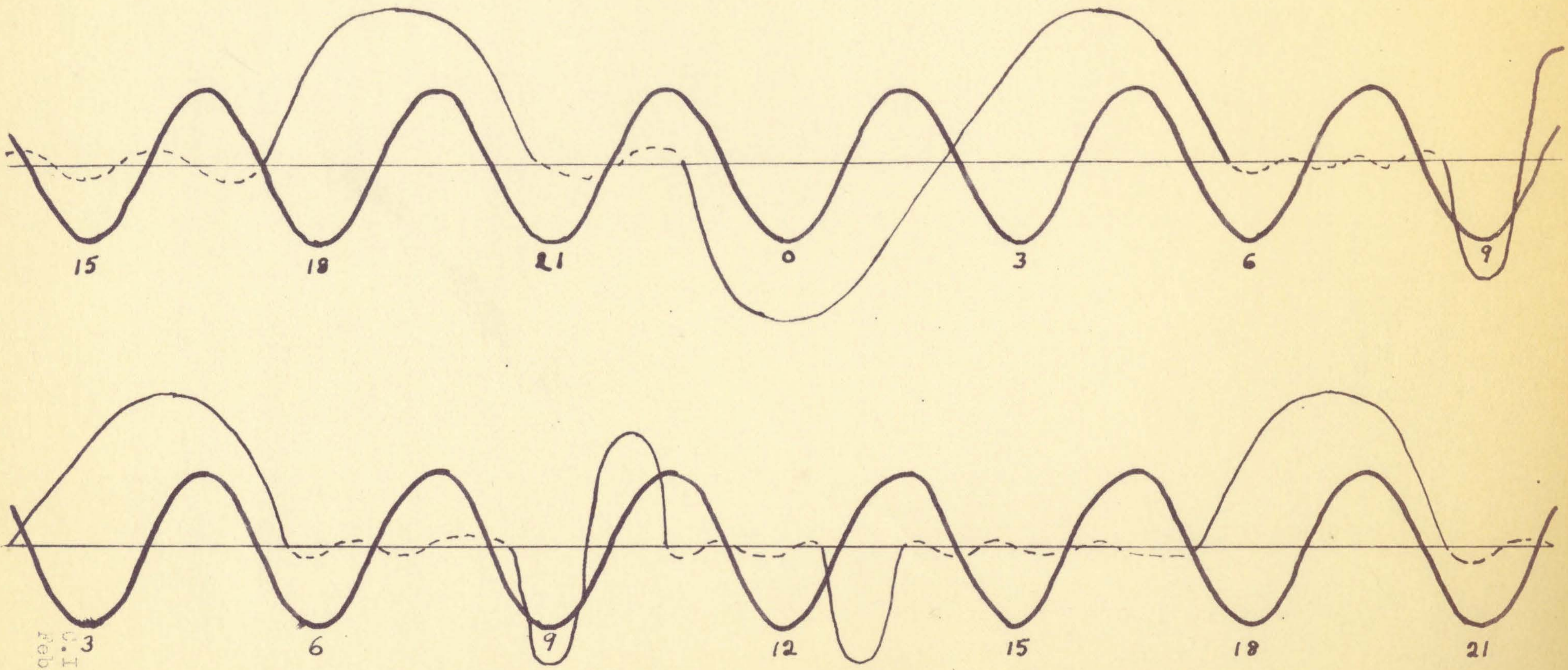
Appendix C   Pressure Distribution in Terms of Wave Lengths



Heavy lines with zone numbers below troughs represent theoretically normal pressure distribution.
Lighter lines represent recurring pressure patterns when a very deep low exists.

Dashed lines represent areas where no definite recurring pressure patterns existed.

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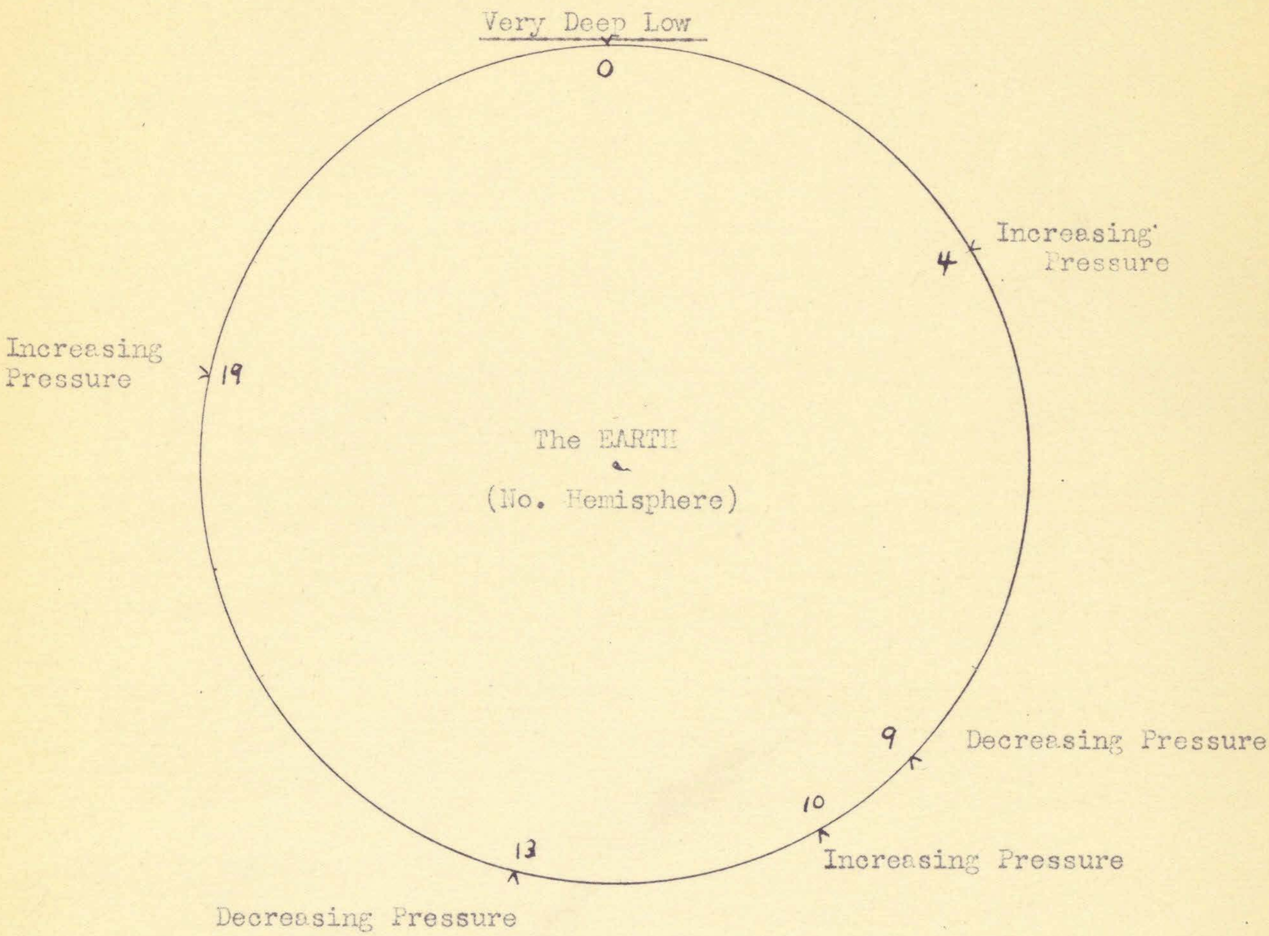
Appendix D . Diagram of Pressure Cells Around the Earth when a Very Deep Low (960 mb. or less) exists.



Note: Numbers represent 15 degree zones to the east of the Very Deep Low .

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APPENDIX E CORRELATION IN THE PERIOD OF DEVELOPMENT OF DEEP LOWS

The following material was gathered in an effort to determine whether or not any fixed period between the development of deep lows in one reference area as compared to another reference area existed. For this purpose the January cases of the Gulf of Alaska Lows were taken as the primary reference lows. Then all of the maps within twelve days, plus or minus, of the development of the Gulf of Alaska Low to 960 mb or less were studied and the dates of development of the deepest lows in the Icelandic and Scandinavian areas were tabulated. Similarly the dates of the development of the second deepest lows were tabulated. NO FIXED PERIOD OR EVEN SIMILARITY THERETO SEEMED TO EXIST.

ALASKAN LOW	SCANDINAVIAN LOW				ICELANDIC LOW			
Date	Deepest Low		2nd Deepest Low		Deepest Low		2nd Deepest Low	
Jan. 2, 1914 (960 mb)	(975 mb)	-5 da 0 +3	(980 mb)	-12 da -6	(960 mb)	+10 da	(975 mb)	-8 da +2 +6
Jan. 6, 1920 (960 mb)	(950 mb)	+2	(970 mb)	+7	(955 mb)	+5	(960 mb)	-7
Jan. 10, 1922 (960 mb)	(960 mb)	-8 -7	(970 mb)	-11	(950 mb)	+11	(960 mb)	-3 +4
Jan. 26, 1926 (960 mb)	(975 mb)	-9	(980 mb)	+4	(945 mb)	-3	(960 mb)	+4
Jan. 1, 1927 (960 mb)	(970 mb)	-3	(975 mb)	-6 +12	(970 mb)	+5	(975 mb)	-1
Jan. 6, 1928 (960 mb)	(965 mb)	+2	(970 mb)	+5	(955 mb)	+11	(960 mb)	+4
Jan. 16, 1931 (955 mb)	(955 mb)	+1	(980 mb)	-7	(965 mb)	+7	(970 mb)	-12
Jan. 26, 1933 (960 mb)	(960 mb)	+7	(980 mb)	+2	(945 mb)	-12	(965 mb)	-5 +3 +6
Jan. 27, 1935 (960 mb)	(950 mb)	+6	(960 mb)	-4 -2	(965 mb)	+11 -12	(970 mb)	-3
Jan. 20, 1936 (960 mb)	(965 mb)	-10	(970 mb)	0	(970 mb)	+1 +7	(980 mb)	+8

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APPENDIX F DISPLACEMENT OF PROMINENT PRESSURE CELLS

During the process of checking the maps shown in Appendix B, it was noted that for example, the distance between the Gulf of Alaska low and the Polar Basin High increased in February, as compared to January. As a result it was decided to note the average positions of all the more or less permanent high and low pressure centers for the months under study as they appeared on the reference low charts plotted for Iceland, Kamchatkam and Gulf of Alaska. This was done in an effort to determine whether or not any consistant movement to West or East of the average position for the various features would bear out in all cases for the different months corresponding to the movement of the reference cell to East or West. The results are tabulated below. No definite movement of a general nature bears out. It will even be noted that the closest feature, such as the Polar Basin High related to the Gulf of Alaska low, did not move consistantly with the reference cell.

	Gulf of Alaska			Kamchatka			Iceland			
Feature.	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar	Average
Kamch. Low	155E +	---	155E +	175E -	175E-	170E -	165E +	170-175E-	155E +	167½E
G.ofA.High	155W o	165W +	155W o	145W -	145W-	155E o	150W -	---	155W o	155W
Pac. High	130W-	---	135W?-	135-140W-	145W +	140-145E o	140W -	150W +	145-150W +	142½W
Polar High	115W-	105W-	?	130&110W o	130W +	140W +	110-115W-	110W -	---	120W
G.Lakes Tr.	95W o	85W?-	?	85-90W-	100W +	105W +	95W o	90W -	105W +	95W
SE US High	90W +	80-85W-	?	80W -	85W o	90-95W +	85W o	---	85W o	85W
Iceland Low	45W +	40W o	45-50W +	50W +	45W +	45W +	35W -	25W -	35W -	40W
Azores High	20W +	15W -	35W? +	25W -	20W -	35-40W +	30W o	35W +	35-40W +	30W
Scand. Low	20E +	50E -	15E? +	15E +	40E -	30E +	35E -	35E -	50E -	32½W
Russian Hi.	---	50-55E-	80E?-	40E -	15E +	20-25E +	25E +	15-20E +	20E +	30E
Siberian H.	110E-	110-115E-	125E-	105-110E o	105E +	95E +	110E -	105E +	95E +	107½E
	o	-	-	-	+	+	-	-	+	

The figures above indicate the pressure system under consideration or rather they indicate series of similarly placed pressure systems for various months, and for various positions (near to one of three reference cells). The figures indicate the average position for all three months also, and a Plus or Minus figure is added to indicate Westward or Eastward displacement respectfully. Average displacement East or West is noted at the bottom, qualitatively. It is to be expected that in different months, highs and lows lie in different spots, with maximum high over land and strongest low over water in mid-winter, normally.

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