THE VERTICAL PROFILE OF WIND AT LAKE HAZEN, N.W.T.

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DURING the International Geophysical Year 1957-58 (IGY) a record of surface weather was obtained from Lake Hazen in northern Ellesmere Island (Fig. 1). The data collected in that period (20 August 1957 to 10 August 1958) have been analysed by the present author and published in various forms (see especially Jackson 1959a, 1959b, 1960). A microfilm copy of the records is deposited with the Meteorological Branch in Toronto.

Upper air measurements were not made at Lake Hazen during the IGY, partly because it was expected that conditions aloft would be similar to those at the permanent weather stations of Alert and Eureka. These stations are respectively about 100 miles northeast and 220 miles southwest of the Lake Hazen site. The record of surface observations, however, showed substantial differences from Alert and Eureka, suggesting that conditions in the lower troposphere in the vicinity of Lake Hazen might be very unlike those over the coastal stations. In particular, the Lake Hazen site experienced much colder surface temperatures and much less surface air movement than either Alert or Eureka. Air temperatures below —40°F. were recorded in 1957 and 1958 on 121 days at Lake Hazen, compared to 83 days in the same period at Eureka and only 29 at Alert. Surface winds of 20 mph or more occurred at 243 synoptic observations at Alert and 309 at Eureka, but at only 29 at Lake Hazen. More than half the 2,800 regular observations at Lake Hazen recorded calms or virtual calm at the surface. The frequency of cold temperatures appeared to be linked to the absence of appreciable surface wind, and an investigation of the wind profile at Lake Hazen was required for the explanation of both phenomena. A series of pilot balloon measurements was therefore made at Lake Hazen during the summer of 1961 to provide a comparison with conditions at Alert and Eureka, and these data are discussed in the present paper. The usual surface observations were also made in 1961 and these have been analysed elsewhere (Jackson 1963). Light surface winds were again a feature of the records. The run of wind at 40 ft. throughout the period from 20 May to 17 August was equivalent to a mean wind speed of only 2.2 mph.

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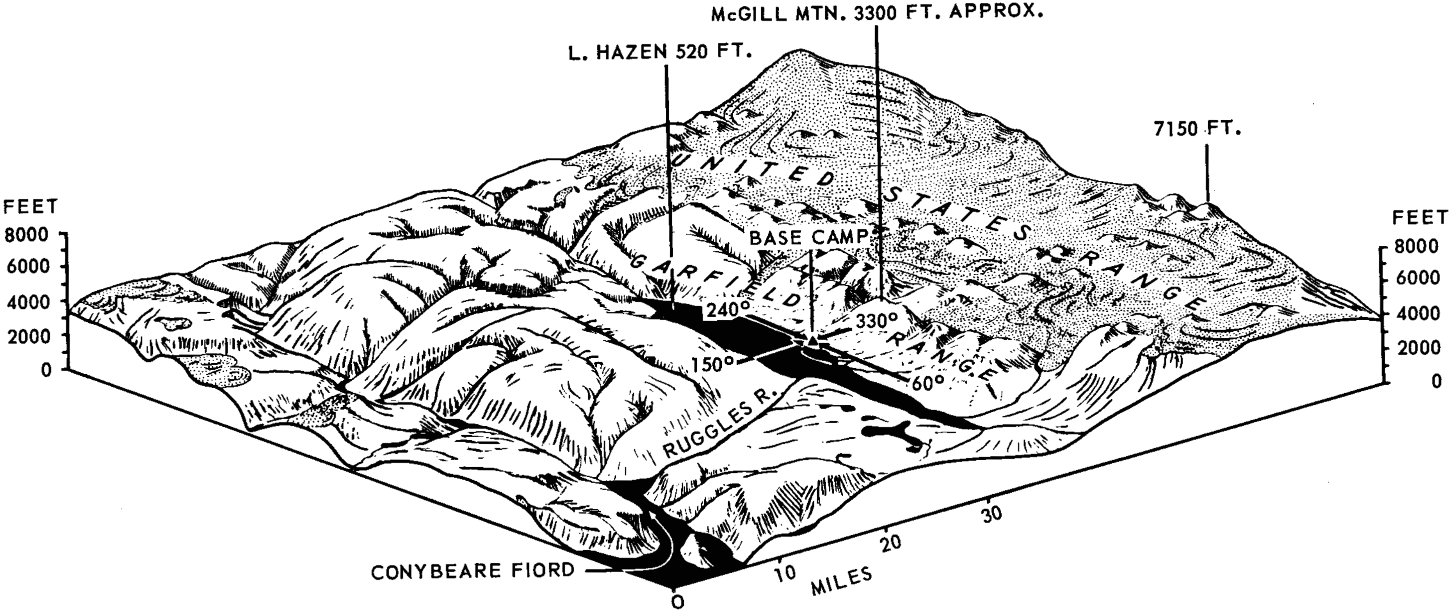

Fig. 1. Isometric block diagram of the Lake Hazen area. The stippled area represents permanent icefields and glaciers. Water bodies are shown in black. The approximate orientation of the wind components is shown with respect to the Lake Hazen station. Based on the 1:1 Million World Aeronautical Chart, sheets 2007 and 2008, Department of Mines and Technical Surveys, Ottawa, 1961-63, and on ground and air photographs.

The field programme

The author, with David Feather as field assistant, took part in the 1961 phase of "Operation Hazen." The party arrived at the base camp on 11 May and meteorological observations began on 16 May. These were maintained regularly until 18 August and evacuation was completed on 20 August.

Although a rawinsonde record would have provided the most satisfactory data, the ground installation which rawinsondes require was not feasible for the short period of observations in expedition conditions, and therefore only pilot balloon ("pibal") observations were made. Helium-filled balloons were tracked by the single-theodolite method which assumes a constant rate of ascent (180 metres per minute). Balloons were released at six-hourly intervals, to coincide with upper wind measurements at Alert and Eureka (where rawinsondes are released at 00 and 12 GMT; at 06 and 18 GMT pilot balloons are used). When possible, balloons released at Lake Hazen were tracked to 25,000 ft. before being abandoned. Between 1 August and 15 August, the frequency of releases was increased to 10 per day, with soundings every two hours between 12 and 06 GMT. In subsequent discussion, however, the data analysed are only those collected at the usual synoptic hours.

Table 1. Upper wind measurements in northern Ellesmere Island. 14 May — 19 August 1961.

	Rawinsondes		*Pilot Balloons*		*Total*	
Station	*Possible*	*Released*	*Possible*	*Released*	*Possible*	*Released*
Lake Hazen	—	—	375	356	375	356 (94.9%)
Alert	190	185	192	73	382	258 (67.5%)
Eureka	194	194	192	117	386	311 (80.6%)

Because pilot balloons are tracked visually, the method gives poor results when cloud base is low, when precipitation (especially snow) is falling, or when winds are strong at the surface. The evidence of the IGY period suggested that these problems would not prevent the collection of adequate data, particularly in the lower troposphere. Tables 1 and 2 show that this assumption was justified. From Table 2 it can be seen that there is a progressive and substantial decline in the proportion of ascents which provided data for successive levels above 5000 ft. This is a direct result of the distribution of cloud, which did not affect the rawinsonde data at Alert and Eureka. Nevertheless one-third of all the Lake Hazen soundings reached 20,000 ft. and the critical area of the lower troposphere is well-documented. Also of interest is the relatively low proportion of releases at Alert shown in Table 1. A few of the missing observations were caused by technical or similar difficulties with the rawinsondes, but at both Alert and Eureka the vast majority of the missing observations was due to the frequency of adverse weather for pilot balloons. At Alert 119 out of a possible 192 pibals could not be released.

Table 2. Availability of data at different altitudes.
14 May — 19 August 1961.

Altitude (000 ft.)	*Lake Hazen No. of soundings*	%	*Alert No. of soundings*	%	*Eureka No. of soundings*	%
(Releases)	(356)	—	(258)	—	(311)	—
1	311	87.4	218	84.5	311	100
2	334	93.8	217	84.1	311	100
3	341	95.8	219	84.9	309	99.4
4	315	88.5	220	85.3	305	98.1
5	316	88.8	227	88.0	302	97.1
6	292	82.0	230	89.1	294	94.5
7	244	68.5	230	89.1	286	92.0
8	229	64.3	227	88.0	280	90.0
9	203	57.0	228	88.4	278	89.4
10	191	53.7	227	88.0	274	88.1
12	176	49.4	221	85.7	260	83.6
14	163	45.8	214	82.9	258	83.0
16	149	41.9	210	81.4	243	78.1
18	139	39.0	209	81.0	238	76.5
20	123	34.6	209	81.0	230	74.0
23	104	29.2	192	74.4	207	66.6

Analysis

To provide comparisons with the Lake Hazen data, the contemporaneous measurements at Alert and Eureka must be considered. Through the courtesy of the Meteorological Branch, microfilm copies of the actual records of ascents were made available. These provide more detail than the data published in the Branch publication *Arctic Summary.*

The data at all 3 weather stations were transferred to standard punched cards for analysis by computer. The 80 columns of each card provide space for one ascent, and contain a station identifier, the date and time of the ascent, and the wind direction and speed for 18 levels from the surface to 25,000 ft. The reason for the termination of the ascent was also punched. A copy of the card deck for Lake Hazen (including the extra ascents in August) has been deposited with the Meteorological Branch in Toronto.

The vertical profile of mean wind speed

The simplest comparison which can be made between the stations is of the vertical profiles of mean scalar wind speed throughout the period of observations. These profiles are shown in Fig. 2. The contrast at low levels between Lake Hazen and the other stations is apparent. Whereas the surface wind averaged about 8 knots at Alert and Eureka during the 1961 summer, it was less than half as strong at the inland site. The difference may appear small in absolute terms, but since it is based on several hundred observations, it is a real one.

Above the surface, the contrast between Lake Hazen and the other stations gradually decreased, until at 7,000 ft. the mean speeds at Alert and Lake Hazen were virtually identical. This suggests that above this altitude the local effects peculiar to the Lake Hazen site are eliminated and any differences between the stations are due to other factors. The explanation of these latter differences is beyond the scope of the present paper, but they are more likely to be due to synoptic than to topographic factors. The lower speeds aloft at Lake Hazen are in part a reflection of the dependence on pilot balloon observations. Significant upper winds are usually associated with the invasion of the area by synoptic disturbances (Jackson 1961) and the associated cloud systems often prevent pilot balloon observations. The difference between Alert and Eureka may be due partly to the greater frequency with which such disturbances affect the more southerly station.

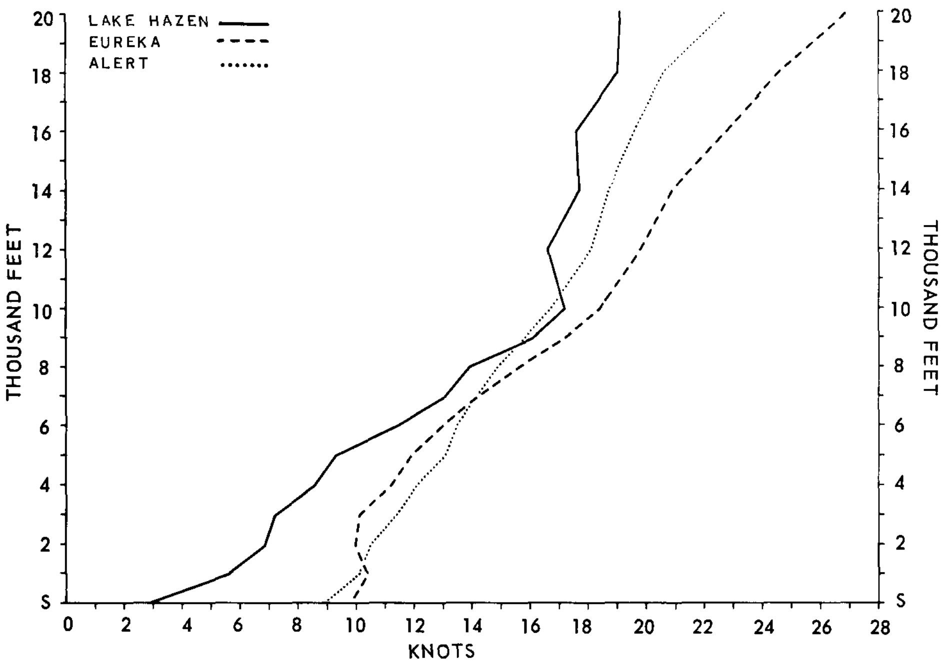

Fig. 2. Profiles of mean scalar wind speed, summer 1961.

Examples of scalar means of individual weeks during the 1961 summer appear in Figs. 3 and 4. On this time-scale there are often problems of missing observations, but in the weeks chosen the curves are all based on at least 15 (i.e. more than half the possible) observations at each level, except for Week 10 (16 July to 22 July) when data were available for Alert at some levels on only eleven occasions. Week 10 is an example of a period when winds were much stronger than usual. Two characteristics are noteworthy. Eureka, like Lake Hazen, had a mean surface wind much lighter than the layer immediately above, whereas Alert's profile for the first five thousand feet was fairly homogeneous. Yet the surface wind at Lake Hazen was still substantially less than at Eureka. More important, despite the increase in speed with height at Lake Hazen, the wind at all levels below six to seven thousand feet remained substantially below that at the other stations, even though the speed at Lake Hazen itself was greater than usual.

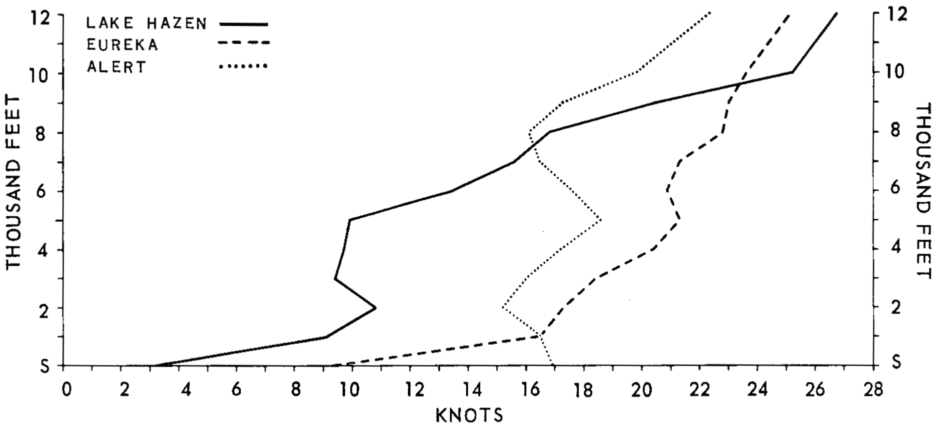

Fig. 3. Profiles of mean scalar wind speed, week 10 (16-22 July 1961).

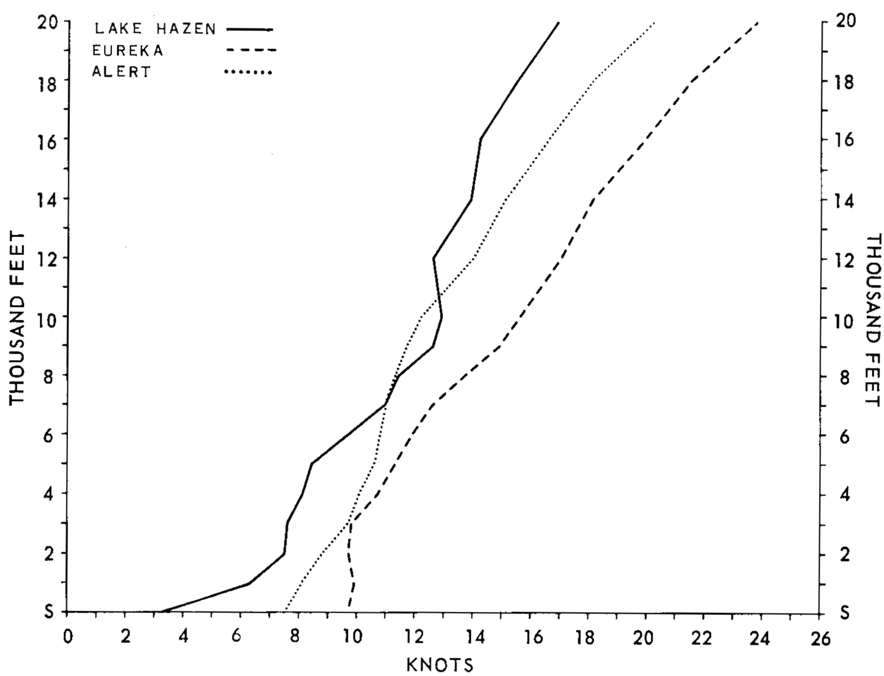

Fig. 4. Profiles of mean scalar wind speed, week 12 (30 July — 5 August 1961).

Although significant winds occasionally extend right down to the surface during the Lake Hazen summer, the more usual pattern is for the speed in the lowest mile or so to be reduced considerably by comparison with values at Alert and Eureka, and for the quasi-calm area very close to the surface to remain intact.

The wind profile during Week 12 (30 July to 5 August) was very different. Throughout the lower troposphere the mean scalar wind speed at Alert scarcely exceeded 10 knots and the same is approximately true of the other two stations. The quasi-calm surface layer at Lake Hazen and its generally lower wind speeds below 7,000 ft. are still apparent, but the general lack of wind at all three stations makes Lake Hazen seem much less anomalous than during Week 10. The values during Week 12 are more typical of the summer as a whole, as a comparison between Figs. 2 and 4 indicates, and this illustrates one of the main difficulties in the investigation of the Lake Hazen anomaly. For much of the time the anomaly is masked, or appears scarcely significant, because winds in the lower troposphere of this area of the Arctic are usually light. The arctic circulation is not a high-energy one, even in summer (Hare and Orvig 1958). Over a 4-year period at Alert, the surface wind was below 6 knots on 74 per cent of all occasions and on 57 per cent during a 6-year period at Eureka (Wilson and Markham 1957). It is on the comparatively infrequent occasions when the winds are relatively strong that the anomaly is most pronounced and most easy to study. It is therefore necessary to isolate these occasions and consider them separately.

Profiles of strong winds

From the preceding discussion, it seems probable that the Lake Hazen anomaly, whatever its cause, disappears above approximately 7,000 ft. The level of 10,000 ft. seems a suitable altitude to use in the selection of soundings characterised by significant air movement aloft. Fig. 5 shows mean profiles of those soundings when the wind at 10,000 ft. was 10 knots or more. A wind of 10 knots at this altitude is relatively light by mid-latitude standards, but at 80°N. the scalar mean wind speed at that level is only about 14 knots (U.S. Weather Bureau 1961). Some 40 per cent of the soundings at Lake Hazen and Alert are eliminated by this filter, though only some 24 per cent at Eureka.

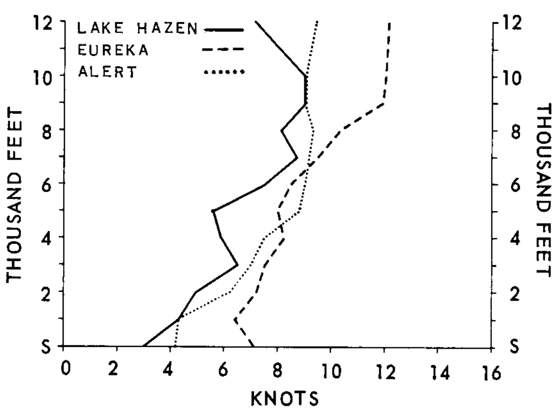

Fig. 5. Profiles of mean scalar wind speed, summer 1961, excluding all ascents when the wind at 10,000 ft. was below 10 knots. The profiles are based on 118 ascents at Lake Hazen, 133 at Alert and 208 at Eureka.

Figure 5 illustrates the similarity between the speeds at Alert and Eureka under such conditions, and the contrast with Lake Hazen. This anomaly is again at a maximum at the surface and is not finally eliminated below 8,000 ft. The anomaly is emphasised by the fact that the mean wind speed at Lake Hazen between the surface and three thousand feet is *less* under strong wind conditions than for all observations, suggesting that for the majority of the time, the regional wind field has little relevance to conditions in the lowest few thousand feet at Lake Hazen. On many occasions, in fact, there is a well-organised, if light, flow in the lowest few thousand feet at Lake Hazen which is in the reverse direction to that aloft. A typical example is shown in Fig. 6.

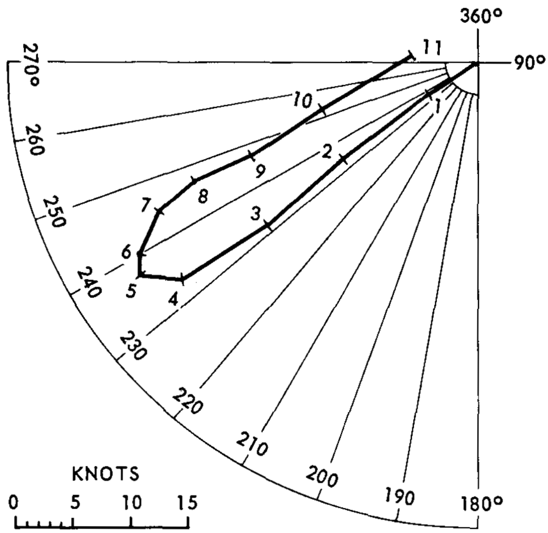

Fig. 6. Plot of pilot balloon ascent at Lake Hazen, 0600 GMT, 3 June 1961. The points numbered 1-11 represent the plan positions of the balloon at intervals of one minute between ½ and 10½ minutes after release. The rate of ascent is assumed to be 180 metres per minute and so the altitude at which the wind direction is reversed (point 5) is approximately 3,500 ft.

Orographical influence on the wind field

One of the most straightforward explanations which might account for the Lake Hazen anomaly is that the site is protected by the high land of the Garfield and United States ranges to the northwest (Fig. 1). This hypothesis is *prima facie* unlikely to be the complete answer to the problem, because calm conditions, during the winter at any rate, are almost constantly observed, although there must be a number of occasions when the synoptic flow is parallel to the structure and therefore less likely to be reduced in speed. Nevertheless the wind direction, as well as the wind speed, must be considered.

In order to make comparisons between different stations and levels, the observed instantaneous vectors were resolved into components. Instead of the usual u and v components of motion, positive eastward and northward respectively, the positive axes at all three stations were aligned at 60 and

330 degrees from true north, directions which are respectively parallel and normal to the general structural trends in the Lake Hazen area and particularly to the Garfield Range (Fig. 1). If shelter were a significant cause of the reduction in wind speed, it might be expected that this would be demonstrated at Lake Hazen by a marked reduction in the component normal to the mountains (here designated v*) as compared to the component parallel to the structure (u*). By taking separate means of the positive and negative values of each component, the profiles of the mean components of motion in four directions were computed: u* positive (i.e. the component of wind blowing from 240° or approximately SW); u* negative (60° or NE); v* positive (150° or SE) and v* negative (330° or NW).

This resolution into components brings with it problems of sample size. It is difficult, for instance, to compare the different components on the basis of weekly means at a station. Although in any individual week perhaps 20 out of the 28 possible soundings provided data at a particular level, only 2 or 3 of these may have given a value for an individual component at that level. This might be caused by the damping-out of the component by relief, but it might equally be due to a predominance of synoptic flow from the opposite direction. For means taken over the whole summer, whether for all observations or for high winds only, the problem is less but is not eliminated. At some levels the mean speed along a particular component is based on no more than thirty individual values.

The mean components throughout the summer, using only the soundings with a 10,000 ft. wind of 10 knots or more, are shown in Fig. 7 A-D. The contrast between Lake Hazen and the other stations, so apparent in the scalar means, is here much less distinct. The main contrast is now in the Lake Hazen values themselves, between the u* components on the one hand and the v* components on the other, i.e. between the components parallel and normal to the structure. This is masked somewhat at the surface, but between 1,000 and 5,000 ft. the u* components are comparable and occasionally stronger than those at Alert and Eureka. The other components are markedly smaller and below 4,000 ft. may be termed insignificant.

The persistence of this contrast at Lake Hazen is shown in Table 3, for conditions at the three thousand foot level in each of the 14 weeks of the 1961 observations. Values for the u* components fluctuated considerably, but only rarely fell low enough to be comparable to the v* components, neither of which achieved a mean value greater than 3.5 knots in any of the 14 weeks.

From this it seems reasonable to conclude that the light winds in the lower troposphere can be explained to a considerable extent in terms of the damping-out of the components of motion which cross the structure. The mountains to the northwest of the Lake Hazen site provide a barrier to the circulation which is of very great importance to weather conditions at the surface. The effect on winds approaching from the southeast is as great as that on those from the northwest, presumably due to the creation of a 'bolster' of the type described by Scorer (1955).

The explanation of the light winds close to the surface at Lake Hazen

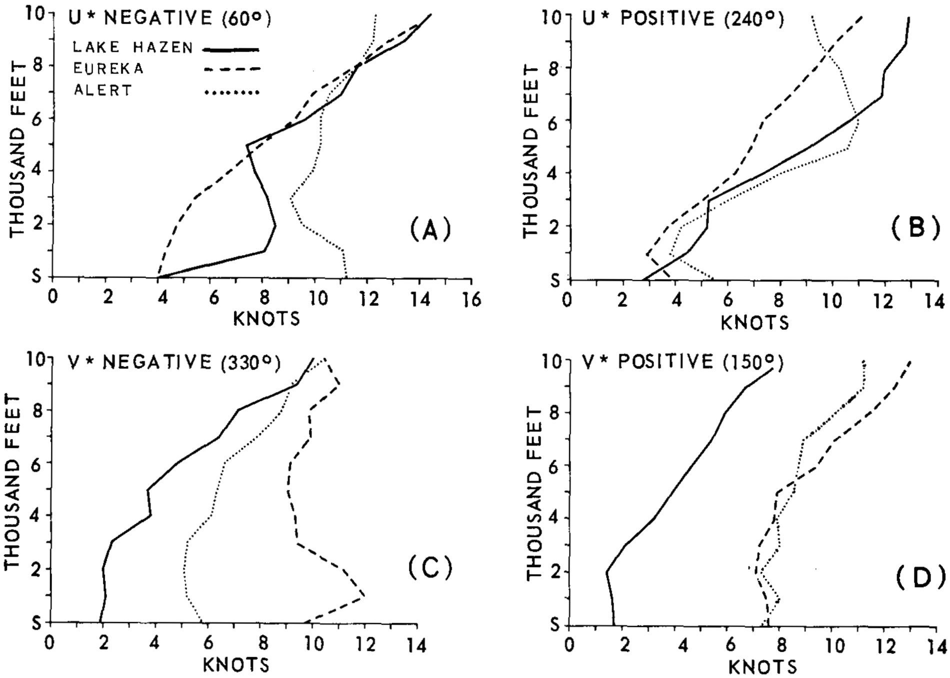

Fig. 7. Profiles of mean components of wind from four directions, summer 1961. Ascents with wind speeds at 10,000 ft. below 10 knots have not been included.

is still incomplete. It has already been pointed out that in the very lowest layers there is a marked reduction in speed which apparently affects the components along the structure as much as those normal to it. If it is accepted that the mountains are a barrier to the winds crossing them, it is equally to be expected that the Lake Hazen station would be open to the full force of winds travelling parallel to the structure. The meteorological site was situated close to the shores of the lake and for more than a dozen miles in each direction such winds would blow across low relief, mainly the smooth surface of lake ice with a minimum of surface friction. The relief in the immediate vicinity of the station is also low and unlikely to cause the anemometer or balloon readings to be unrepresentative. That they are in fact typical of the general vicinity of the station is best demonstrated by the snow profiles developed on Lake Hazen during the winter of 1957-58, which have been studied by Hattersley-Smith (1960) and in more detail by Harington (1960). These profiles showed that there was little or no compaction which could be attributed to wind, except during the midwinter gale of January 1958. It was the absence of wind from any direction, whether along the structure or across it, which led to the present investigation. Even though so much of this reduction can be explained in terms of relief, the residual problem is of equal interest.

Table 3. Weekly means of components of wind at 3,000 ft., Lake Hazen, May-August 1961. (knots)

Week	*Mean Wind*	*Components* $u^* + (240°)$	$u^* - (60°)$	$v^* + (150°)$	$v^* - (330°)$
1	6.9	8.7	6.2	1.3	1.4
2	8.7	6.9	9.5	1.9	1.9
3	5.1	3.1	6.7	1.0	1.3
4	6.9	7.1	5.9	1.5	1.2
5	8.5	11.0	6.5	2.0	1.9
6	7.2	3.2	7.2	3.1	2.8
7	7.0	7.5	4.9	2.8	2.5
8	9.2	5.1	9.3	2.3	2.7
9	8.9	6.7	8.8	2.6	3.2
10	9.3	2.2	10.1	1.4	3.4
11	12.2	6.0	13.8	3.5	2.9
12	6.5	6.5	4.9	1.6	2.2
13	5.7	5.8	3.3	1.2	1.6
14	4.8	2.6	5.5	1.2	2.3
Mean	7.7	6.1	8.1	2.0	2.4

The influence of the Lake Hazen inversion

It seems likely that the calm conditions in the lowest few thousand feet may be explained by the persistent stability of the air near the surface, together with some reduction in speed due to surface friction. Although no vertical temperature profiles exist for the Lake Hazen area, a comparison of *surface* temperatures there with the vertical profiles at Alert and Eureka has shown that there must exist throughout virtually the whole winter a strong temperature inversion, with surface air temperatures frequently below —40°C., while those in the troposphere a few thousand feet above are often 20°C. or so warmer (see, for example, Jackson 1959a, Fig. 3). In such conditions the vertical shear probably becomes considerable, since mechanical turbulence is damped-out by the stability and the inversion is not dissipated by mixing. The relatively calm conditions at the surface assist the development of a still more intense inversion and a self-sustaining system is established which is eventually broken down either by the warming of the lower troposphere by long-wave radiation from clouds or precipitation, or more rarely by the occurrence of a wind aloft, strong enough to produce eddies which can "roll-up" the inversion. In midwinter, however, the latter phenomenon seems to be extremely rare, since the wind speed required is very high and, in this area of low kinetic energy, rarely occurs. An example of such an exceptional wind is discussed later.

This hypothesis, while attractive for the winter months, appears at first sight to be a much less likely explanation for the light winds of the summer months, when the snow has gone and with it the main cause of the thermal inversion. It seems, however, that the continued presence of an ice cover on the lake, long after the snow disappears in June, may be sufficient to maintain a shallow inversion of sufficient strength. The winds above, as has been seen, have usually been reduced in speed by the orographic factor, and are hence less likely to be able to dissipate the shallow inversion by mixing.

The existence of this summer inversion could be proved only by a series of temperature soundings, but there is a certain amount of circumstantial evidence which may be put forward to support this hypothesis. On only 30 occasions out of a total of 356 during the summer of 1961 (including the extra observations in August) was the surface wind at Lake Hazen 10 mph or more and only twice was it over 20 mph. Twenty of these occasions were in the last 10 days of July, when surface heating, over the surrounding land at any rate, was near its summer maximum. Similarly, 17 of the 29 observations of winds of 20 mph or more recorded during the 12 month IGY period occurred in late August 1957 at a time when the ground was clear of snow and the lake ice had completely melted. On such occasions the inversion can probably be dissipated readily.

The argument that the lake is sufficiently extensive to affect the lower troposphere in this way in summer gains some support from the clear evidence of the effect which it has when free of ice at the beginning of winter. During the IGY a *ceiling* (i.e. the level at which opaque cloud covers six-tenths or more of the sky) below 2,500 ft. was usually recorded at no more than a few per cent of all observations. In the month of September the proportion rose to about 37 per cent. This cloud was associated with relatively warm air temperatures and both appeared to be due to the existence of the lake as a relatively warm body of open water for approximately a month after the appearance of a continuous snow cover on land. Occasionally a very low layer of stratus followed the perimeter of the lake remarkably faithfully; more normally the cloud extended over the whole of the Lake Hazen trough, although its local control was indicated by sun shining on the ground in the distance in various directions. Once the lake became completely ice-covered the air temperature fell rapidly and the cloud cover disappeared. The phenomenon had been discussed more extensively elsewhere (Jackson 1959b, 1960).

It should be noted that the existence of the inversion is insufficient as a complete explanation of the Lake Hazen anomaly, since the permanent weather stations, not only at Alert and Eureka but throughout the Queen Elizabeth Islands, are situated at coastal sites, close to larger ice bodies than Lake Hazen. Yet they do not share the marked prevalence of calms. It is therefore concluded that the Lake Hazen anomaly is a result of the interaction of two factors: the shelter afforded by the surrounding topography and the great stability of the lower troposphere in the area.

Although much of the evidence in the Lake Hazen area appears to accord with this explanation, it does nevertheless seem surprising that the calm conditions should so rarely be disturbed. An interesting comparison may be made between the Lake Hazen area and Tanquary Fiord, about fifty miles to the southwest. Superficially the sites are remarkably similar: the fiord and the lake are of the same order of size, aligned in similar directions, each surrounded by considerable relief. Tanquary Fiord is in fact much more enclosed than Lake Hazen, although it is of course open to sea-level in a narrow mouth at the southwest end. Despite this similarity of physique, Tanquary Fiord appears to be characterised both in spring (Hattersley-Smith 1963) and summer (Barry 1964) by significant surface winds, mainly from a southwesterly direction and apparently funnelled along the axis of the trough. It was seen from Figs. 7, A and B that the relief in the vicinity of the Lake Hazen station has little effect on components along the structural axis and funnelling might reasonably be expected here. If it is the strength of the thermal inversion which acts as a barrier to this, it is difficult to see why an inversion of similar depth and intensity should not be developed in Tanquary Fiord. Possibly the existence of a gap at sea-level, although very narrow, is critical.

Individual examples

The summer of 1961 provided a number of synoptic situations from which the strength of the anomaly, and the conditions necessary to overcome it, could be estimated. An example of an occasion when the regional wind field was apparently sufficiently strong to overcome the surface inversion is 26-27 July 1961. The seven synoptic observations at Alert from 15 GMT on 26 July to 09 on 27 July all recorded a west wind, varying in speed between 35 and 50 mph. At Lake Hazen the direction was SW or WSW — along the line of the trough— and speeds varied between 5 and 25 mph. A totalising anemometer 20 ft. above the surface at Lake Hazen recorded a run of wind of approximately 224 miles between 00 and 12 GMT on the 27th, an average wind speed during the twelve hours of almost 19 mph. The pibal record at Lake Hazen was limited by cloud to the layer below about 6,000 to 8,000 ft. for most of the period. The general pattern was one of a rapid increase in wind speed in the lowest few thousand feet, with rather more variation in speed above this. There was however little change in wind direction from the surface to the top of the sounding. No pibals were released at Alert during this period and the rawinsonde record is incomplete, but it suggests that the wind at 10,000 ft. was blowing at over 30 knots from the west or southwest for most of the period. These conditions occurred at the end of a warm and sunny period when screen temperatures at Lake Hazen had exceeded 50°F. almost every day for the preceding 10 days and when the lake ice was beginning to break up. The main factors responsible for the disruption of the quasi-calm conditions at the surface were however the strength of the upper wind and its alignment with the Lake Hazen trough.

An example of an occasion when upper winds were not sufficient to roll up the inversion is probably 2 June 1961. Between 03 and 21 GMT surface winds at Alert varied between W and SW in direction and between 20 and 32 mph. The wind at 10,000 ft. was blowing from approximately SW at about 25-30 knots. Eureka recorded surface wind speeds up to 30 mph from the S or SE. Yet calm or virtually calm conditions persisted at Lake Hazen throughout the period. The soundings indicated that winds of 15 mph or more were present above about 3,000 ft. but they never reached the surface. Their direction was favourable, but it seems that when the snow cover is still continuous and the inversion well-developed, a gradient wind of something over 30 knots is required to dispel the surface calm.

In winter, when the inversion is at its most intense development, the conditions necessary to dispel it appear to be realised only about once or twice each year. In 1958 unusually strong pressure gradients over northern Ellesmere Island maintained surface wind speeds over 40 mph at each three-hourly observation at Alert between 06 GMT on 16 January and 15 GMT on 18 January. Throughout the greater part of this period, however, there was little or no surface wind at Lake Hazen: the run of wind at 40 ft. between 12 GMT on 16 January and 12 GMT on 17 January averaged only 2.1 mph. Only when surface winds reached 90 mph at Alert was the upper flow at Lake Hazen strong enough to overcome the combined effects of topography and thermal stability. Once the inversion had been dissipated, however, surface winds at Lake Hazen increased steadily to about 40 mph.

Conclusion

The explanation of the light surface winds characteristic of the Lake Hazen area is probably to be sought in the sheltering effect of the mountains to the northwest and in the thermal stability of the air in the Lake Hazen trough, both winter and summer. Each of these is necessary for the observed pattern of wind distribution and neither is sufficient alone. The topography has little effect on winds blowing parallel to its principal axis; the thermal stability, while still apparent in summer, would be insufficient to maintain calms so constantly were it not that speeds have usually been reduced by the topographic effect. The stability can be overcome by a sufficiently strong wind, but the latter is unusual in summer and, because of the much greater strength of the inversion and the seasonal rarity of synoptic systems, exceptional in winter.

Some general rules can be suggested as a guide to the forecasting of wind in the Lake Hazen area, a task which was found impossible in the local forecast study attempted earlier (Jackson 1960, 1963).

1. Gradient wind forecasts are likely to be valid above an altitude of 7,000 ft.

2. Below this altitude in the Lake Hazen area, components of motion across the topography are subject to a progressive and substantial reduction.

3. In the surface layers, the characteristic inversion in the Lake Hazen trough damps out forced convection and so reduces air motion even more. The altitude to which this factor is effective varies according to season: less than a thousand feet in summer, but several thousand feet in the snow period.

4. Strong winds at the surface are possible if upper winds are strong enough to provide eddies which can "roll-up" this inversion. The upper wind speed necessary to achieve this will vary greatly according to season and wind direction, but minimum values are probably of the order of 25 mph in high summer and as much as 70 mph in midwinter.

Acknowledgments

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