METEOROLOGICAL ACTIVITIES IN THE CANADIAN ARCTIC

R. W. Rae*

THE establishment of a joint weather station by Canada and the United States on Cape Belknap, on the north coast of Ellesmere Island, in April 1950, marked an important milestone in the progress which is being made in our meteorological knowledge of the arctic regions of North America. This station was named Alert after one of the ships of the Nares expedition of 1875-6, which carried out the earliest exploratory work in this area.

Instrumental meteorological observations had been taken at a few isolated locations in northern Canada over one hundred years ago, for example, at the Hudson's Bay Company's Post at York Factory in 1772 and 1773. Numerous arctic expeditions also provided data, but these were only of limited use in meteorological research because they rarely extended over a period longer than a year for any one location. Moreover, observations at different locations were seldom taken during the same years, so that comparisons were difficult.

The need for permanent weather reporting stations in the Arctic was recognized in the earliest days of the Canadian Meteorological Service, but their establishment was a slow process owing to lack of funds, lack of communications, and the inaccessibility of these regions. Stations were established between 1900 and 1910 along the Mackenzie Valley as far north as Herschel Island. In the late 1920's government radio stations were opened at Aklavik, Coppermine, and other parts of the Northwest Territories, enabling northern observations to be transmitted rapidly to forecast centres in the south. During this period stations were also established by the Marine Radio Section in Hudson Bay and Hudson Strait to provide navigational aids to shipping and to take meteorological observations.

The most important and dramatic expansion of the weather station network in the Canadian Arctic has taken place since 1946. Five permanent weather stations, manned jointly by Canada and the United States, have been established on the Queen Elizabeth Islands, in the extreme north of the Canadian Arctic. In March 1952 a station was set up by the United States Air Force still farther north on the Ice Island T3,[1] and observations were transmitted regularly until May 1954. At that date the ice island, which appeared to be drifting along the same path it had travelled previously—

*Canadian Army Operational Research Establishment, Defence Research Board of Canada (formerly Head of Arctic Section, Meteorological Division).

[1]For an account of our present knowledge of the origin and paths of travel of ice islands, *see* Koenig *et al.* (1952).

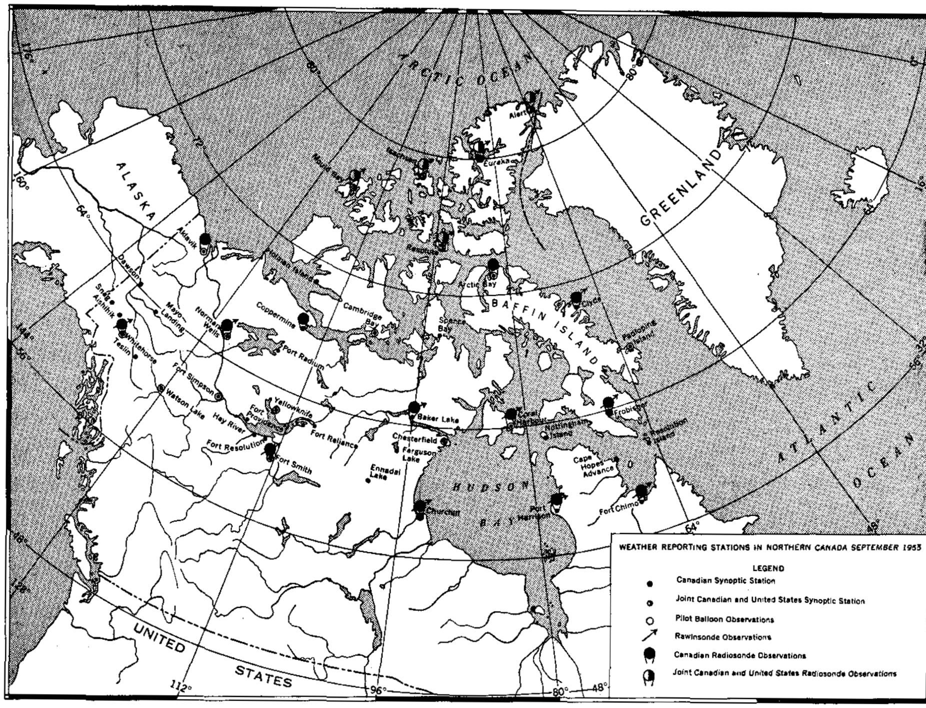

Fig. 1. Weather reporting stations in northern Canada.

clockwise towards the 180th Meridian and then northwards over the pole towards Ellesmere Island—was lying near Alert and was therefore abandoned.[1] It is hoped that these ice islands, which are believed to originate from the Ellesmere Ice Shelf, will make it possible to maintain semi-permanent weather stations in the Polar Basin and to fill a considerable gap in our knowledge.

By September 1955 there were as many as forty-one weather stations operating in the Canadian Arctic and Subarctic between 58°N. and 82°30N. (*see* Table 1 and Fig. 1).

Use of meteorological observations

Meteorological observations are used mainly for three purposes: the preparation of synoptic charts, the compilation of climatological summaries, and physical research. As soon as an arctic station is established, and has made radio contact with a main collecting station such as Resolute, its observations are immediately used in the preparation of synoptic charts at forecast centres throughout the northern hemisphere. Arctic observations have been found to be especially useful in the construction of work charts for long-range forecasting, such as the five-day and thirty-day forecasts that are issued regularly by the U.S. Weather Bureau.

[1] A small United States party reoccupied the ice island in April 1955 on a temporary basis, but meteorological reports were not transmitted. *Ed.*

Table 1. Weather reporting stations in northern Canada, September 1955

Station	*Latitude*		*Longitude*		*Altitude in ft.*	*Types of observations*	*Year first surface obs. made*
Aishihik, Y.T.	61°	39N.	137°	28W.	3170	SH	1943
Aklavik, N.W.T.	68	14	135	00	30	SIPR	1926
Alert, N.W.T.	82	30	62	20	205	SIPR	1950
Arctic Bay, N.W.T.	73	00	85	18	36	SPR	1937
Baker Lake, N.W.T.	64	18	96	05	30	(S)(I)PR	1946
Cambridge Bay, N.W.T.	69	07	105	01	47	S(H)P b)	1928
Cape Hopes Advance, P.Q.	61	05	69	33	240	SI b)	1928
Chesterfield, N.W.T.	63	20	90	43	13	SIP	1921
Churchill, Man.	58	45	94	05	115	SHPR b)	1884
Clyde, N.W.T.	70	27	68	33	26	SPR b)	1942
Coppermine, N.W.T.	67	47	115	15	13	SR	1930
Coral Harbour, N.W.T.	64	11	83	17	193	S(H)PR	1933
Dawson, Y.T.	64	04	139	29	1062	S(H)	1898
Ennadai Lake, N.W.T.	61	08	100	55	1065	SI	1949
Eureka, N.W.T.	80	00	85	56	8	SIPR	1947
Ferguson Lake, N.W.T.	62	52	96	49	400	(H)	1953
Fort Chimo, P.Q.	58	05	68	25	117	SHPR b)	1921
Fort Providence, N.W.T.	61	20	117	40	547	S	1942
Fort Reliance, N.W.T.	62	43	109	06	539	SH	1948
Fort Resolution, N.W.T.	61	10	113	41	549	S(H)b)	1914
Fort Simpson, N.W.T.	61	52	121	21	415	SIP	1897
Fort Smith, N.W.T.	60	01	111	58	665	SHPR	1913
Frobisher, N.W.T.	63	45	68	33	68	SHPR	1942
Hay River, N.W.T.	60	51	115	46	529	SH	1893
Holman Island, N.W.T.	70	30	117	38	30	(S)	1940
Isachsen, N.W.T.	78	47	103	32	83	SIPR	1948
Mayo Landing, Y.T.	63	35	135	51	1625	S(H) b)	1927
Mould Bay, N.W.T.	76	17	119	28	50	SIPR	1948
Norman Wells, N.W.T.	65	18	126	51	240	S(H)PR	1944
Nottingham Island, N.W.T.	63	07	77	56	54	SI	1928
Padloping Island, N.W.T.	67	06	62	21	130	SIP	1941
Port Harrison, P.Q.	58	27	78	08	66	SIPR	1921
Port Radium, N.W.T.	66	05	118	02	600	S(H)	1942
Resolute, N.W.T.	74	43	94	59	209	SIPR	1947
Resolution Island, N.W.T.	61	18	64	53	127	SI	1928
Snag, Y.T.	62	22	140	24	1925	SH	1943
Spence Bay, N.W.T.	69	31	93	27	55	(S)	1951
Teslin, Y.T.	60	10	132	44	2300	SH	1943
Watson Lake, Y.T.	60	07	128	48	2248	SHP	1937
Whitehorse, Y.T.	60	43	135	05	2289	SHPR b)	1904
Yellowknife, N.W.T.	62	28	114	27	682	SHP	1942

Symbols:
- b) Broken record.
- P Pilot balloon or rawinsonde observations.
- R Radiosonde observations.

Surface observations are made and transmitted as follows:
- S At the principal synoptic hours (0030, 0630, 1230, 1830 GMT).
- (S) At some but not all of the principal synoptic hours.
- I At the intermediate synoptic hours (0330, 0930, 1530, 2130 GMT).
- (I) At some but not all of the intermediate synoptic hours.
- H Hourly throughout the 24 hours.
- (H) Hourly during part of the 24 hours, or on request.

Although the density of weather stations in the Arctic has steadily increased in recent years, there are still many gaps at strategic points where the establishment of a weather station would aid materially in the preparation of synoptic charts for the far north. For instance, a station on Melville Island, which has no observation stations within a radius of 250 miles, would help explain such problems as the westward penetration of the moist polar–Atlantic air masses. These air masses, which are much milder than the adjacent arctic air, are sometimes pumped over the Eastern Arctic islands as far west as Resolute by winter storms in the Davis Strait area.

A station on the south coast of Melville Island, in the vicinity of Winter Harbour, was included in the original plans for the network of joint Canadian/United States arctic weather stations, and a cache of prefabricated building components and fuel was made near Bridport Inlet in the summer of 1951. However, because the U.S. Weather Bureau was unable to obtain funds for participating in this project, and because there was insufficient demand for the station to warrant its installation by Canada alone, it was decided in January 1954 to abandon the plan. Nevertheless, a weather station is being established by Canadian agencies on the west coast of Banks Island in the near future.

Climatological records

A minimum of ten to fifteen years of records is necessary for the determination of representative climatic means. Observations from many stations in the Canadian Arctic are clearly inadequate in this respect. Nevertheless, their records have already made it possible to correct climatic charts for this area. For example, temperature observations from Eureka station indicate that the "cold pole" for North America lies in northern Ellesmere Island rather than on the mainland west of Hudson Bay, as previously supposed (Rae, 1951).

The network of stations in the Arctic is too sparse to permit filling in the variations caused by local factors. Some of these variations may be of considerable magnitude, especially in the vicinity of areas like the North Water in Smith Sound, where open water persists throughout the winter. A useful general study of the effect of ice and open water distribution on the winter climate of the Eastern Arctic has been completed by Hare and Montgomery (1949), but the effect of the North Water on the winter temperatures of adjacent land areas requires further investigation.

All the weather stations in the arctic islands are located on the coasts and therefore additional temperature records are needed farther inland. It is likely that temperatures in the interior of the larger islands are somewhat higher in mid-summer, and lower in mid-winter than temperatures near the coast. Some idea of the possible extent of this effect is provided by the records from Pond Inlet, which lies in a sheltered valley, where the average monthly temperatures in winter are about 10 degrees lower than those at Clyde, on the open coast. The occurrence of extremely low winter temperatures in sheltered valleys is especially marked in the Mackenzie basin and the Yukon. For example, the lowest temperature that has been recorded officially in Canada, -81.4°F, occurred at Snag Airport in the Yukon in February 1947.

Upper air observations

In recent years the emphasis in meteorology has been shifting from surface observations to a study of the atmospheric processes at higher levels. A thorough knowledge of upper air conditions in polar regions is essential in order to complete the three-dimensional picture of atmospheric motions over the earth as a whole. Upper air soundings are taken regularly at almost all weather stations in the Canadian Arctic.

An excellent summary of northern Canadian aerological data was prepared by Henry and Armstrong (1949), and now needs to be supplemented with more recent observations from the joint arctic weather stations. Some progress is being made in this regard by the Canadian Meteorological Service with a summary of radiosonde data for all Canadian upper air stations, which will be published shortly.

Observations for air operations

The shortest air routes between North America and many parts of Europe lie across the Canadian Arctic, and several such routes were used to ferry aircraft during the Second World War. Commercial aviation companies are also beginning to take an active interest in the development of transpolar air routes, and both the Scandinavian Airlines System and Canadian Pacific Airlines have commercial flights across the Canadian Arctic on a routine basis. Observations from the arctic weather stations are essential for these operations. The Research Section of the Canadian Meteorological Service is at present analysing and summarizing upper wind data so that frequency distributions of flight times can be obtained for a given route and a given aircraft. The extension of the method to transpolar routes will be possible as soon as sufficient upper wind data are available from the Canadian arctic stations.

Extensive air operations over the Arctic will entail the use of many arctic stations as staging points or alternate landing fields, and will thereby create a demand for terminal forecasts for these stations. Arctic weather forecasting during the summer months does not present insuperable problems to a meteorologist trained in temperate latitudes. In winter, however, when frontal activity in the Arctic is very slight, and the weather is greatly influenced by local factors, an intimate knowledge of the topography and local wind regime is essential in order to determine the frequency of ice fog and blowing snow, which are the two main causes of reduced visibility.

Ice fog studies

Extensive analyses have been made by the Canadian Meteorological Service of the occurrence of low temperature fog at Canadian stations, including those in the Arctic. These analyses have been chiefly climatological in order to determine the physical principles involved.

In general terms, the results obtained so far indicate that the probability of fog decreases as the temperature drops from 32°F to about –20°F. Below –20°F there is a gradual increase in probability, which becomes more rapid as the temperature drops below –30°F. For temperatures below –40°F, ice crystal fog is almost certain to occur, although it may not be of sufficient density to affect air operations. Visibility at the ground is usually greater than one mile in ice crystal fog, but visibility from the air may be limited to the vertical.

Blowing snow

Blowing snow is almost inevitable during arctic winters whenever the surface wind speed is greater than 15 m.p.h. Empirical methods have been used at many forecast stations to relate visibility in blowing snow to the speed of surface wind. In 1947–9 at Resolute it was noted that for winds below 15 m.p.h. blowing snow was limited to ground drift, and visibility was generally over 6 miles. As the wind increased above 15 m.p.h., more and more snow particles were whirled aloft with a corresponding reduction in visibility, until at speeds over 30 m.p.h. the visibility was less than one-half mile. At moderate wind speeds, the severity of blowing snow for a given wind speed was not constant from day to day. This variation might be explained by the difference in the degree of binding among the crystals forming the snow surface. Further observational data concerning snow surface conditions are required to evaluate the magnitude of this effect.

Research in arctic meteorology

Observations of the various meteorological elements both at the surface and in the upper air are being steadily accumulated from the arctic stations to provide data for research. It is self-evident that before research can be carried out on any problem it is necessary to begin with accurate observations, as any inaccuracies in the basic data will tend to invalidate the results obtained. For this reason a large proportion of arctic meteorological data must be treated with caution, for some meteorological elements cannot be measured accurately in the Arctic. The elements which present the greatest problem are humidity, snowfall, and, in winter, the amount and type of clouds.

There are many organizations in North America carrying out research in arctic meteorology. One such group is the Arctic Forecast Team, Meteorological Division, Department of Transport, at Edmonton, which is working mainly in the synoptic field. Dewar, Thompson, and Wilson, who are members of the team, and Markham, a former member, have published their results in a number of Meteorological Division circulars.[1]

Humidity

The ordinary hair hygrometer becomes inoperative at temperatures lower than about –20°F, and is therefore useless throughout most of the arctic winter. Moreover, the difference between readings taken with wet- and dry-bulb thermometers at low temperatures is generally so small that the observer cannot detect it, and often arbitrarily manipulates the readings to give a difference of 1/10 of a degree. There is no need to elaborate on the worthlessness of such observations, and yet winter humidity observations are published for many arctic stations that are not equipped with any other humidity measuring devices than a hair hygrometer and wet- and dry-bulb thermometers.

A frost-point hygrometer has been developed, which can measure the absolute humidity of very dry air at temperatures as low as –90°C (Brewer *et al.*, 1948), but it is too complicated for routine use at weather stations, and none of the Canadian arctic stations are equipped with it. The Instrument

[1]See references.

Section of the Canadian Meteorological Service is working on the development of a visual type of dew-point apparatus which may also be used at low temperatures. A small thermistor is inserted into the surface of the instrument just below the dew observation button. The deposit on the button is observed through a fixed magnifying glass, and the sampled air is pumped on to the surface through a jet, and cooled by expanding CO_2 from a bottle through another jet just below the button. Rate of cooling may be adjusted by a needle valve which regulates the escape pressure. Extensive tests indicate that the instrument is satisfactory for routine use, and although it is expensive to manufacture, it is hoped that some of the Canadian arctic stations can be supplied with one in the near future.

Snowfall

Measurements of snowfall at arctic stations are often rendered inaccurate by drifting. Other inaccuracies are likely to occur in published figures of arctic precipitation when conversion is made from snow to an equivalent amount of rain. The most widely used conversion factor is ten inches of snow to one inch of rain. This ratio is approximately correct for newly fallen snow in temperate latitudes, but for arctic regions, five inches of snow to one inch of rain would be a closer approximation.

Cloud type and amount

Cloud observations must be made indirectly during the winter dark period when the moon is not up. The presence of clouds is assumed when stars are not visible in any section of the sky, and the height and type can usually only be guessed. Nevertheless, the low-powered ceiling projectors recently installed in some of the arctic stations are proving helpful in increasing the accuracy of observations.

Permafrost studies

Perennially frozen ground underlies the greater part of the Canadian Arctic, and undoubtedly exercises considerable influence on the climate of the region. The Arctic Forecast Team is already carrying out a study of the meteorological aspects of permafrost, but further investigations are needed.

Jet streams

One of the most striking advances to be made in meteorological research in recent years was the discovery of a narrow zone of extremely strong winds in the upper troposphere. This belt of high winds, which has been given the descriptive name of "jet stream", is usually associated with the polar front, but there is evidence to indicate that a jet stream may also be associated with the arctic front at times. For example, Greenaway (1950, p. 3) has made the following observation: "The strongest wind encountered was in February, and had a speed of 118 kts. blowing from the NNE at 12,000 feet about 40 miles off the north coast of Borden Island. At the time light to moderate turbulence was encountered and a layer of cloud extended up to flight level. Wind velocities measured at half-hour intervals on either side of this wind were not greater than 45 kts. This exceptionally strong wind has many of the characteristics of a jet stream and may be due to similar causes. At the time there was an extensive low over the eastern part of the archipelago, and as far as I can judge from the available data, the arctic front was probably fairly far north. We may have here an indication of a jet stream associated with the arctic front and the absence of previous evidence of this phenomenon may be simply due to the meagre upper air records in high latitudes".

Studies of the structure and behaviour of jet streams at high latitudes are being pursued by the Research Section, Canadian Meteorological Service, by means of cross-sectional analyses of selected situations. In particular, an attempt is being made to determine the relationship, if any, between such jet streams and fronts in the Arctic (McIntyre and Lee, 1954).

Ozone

The basic meteorological observations consist of temperature, pressure, humidity, and wind. The radiosonde and rawinsonde are the main tools of synoptic meteorologists for determining these properties from the surface to high levels. However, more and more attention is being focused by research meteorologists on other types of observations, which may throw additional light on meteorological problems.

Ultraviolet radiation from the sun in the wave length band 2,200 to 2,900 A is absorbed in the upper stratosphere. It has been demonstrated that the absorbing agent is ozone, and its total amount above a station may be measured by means of an instrument known as a Dobson spectro-photometer. Changes which occur in the ozone spectrum provide information about the height of the centre of gravity of the ozone layer and also the nature of the vertical distribution curve.

Although there are day to day variations in the amount of ozone above any station, the average amount has been observed to increase with latitude from a minimum at the equator to a maximum at high latitudes. According to Craig (1950, p. 10), the ozone maximum occurs at a latitude between 45° and 60°N., with a gradual decrease farther poleward, except perhaps in the spring. However, very few observations have been made north of latitude 70°, and observations from a place such as Alert, near latitude 82°30N., would provide valuable material for further study.

The importance to meteorology of research on atmospheric ozone results from the fact that the ozone content of the air appears to be relatively stable, and that day to day variations in the amount of ozone in any one place are caused largely by advection or turbulence. For this reason, ozone observations may provide a means of studying air circulation at high levels, and aid in completing the picture of the general circulation of the atmosphere.

At present there is only one Dobson spectro-photometer in Canada, and it is located at Edmonton. An instrument at one of the weather stations in the Archipelago would assist materially in exploring the potentialities of routine ozone observations in weather forecasting, and be of great value in high latitude observations.

Radiation measurements

In arctic regions the annual outgoing radiation is greater than the incoming radiation, whereas in tropical regions the reverse is true. Since there is no evidence to indicate that the Arctic is getting progressively colder and the Tropics progressively warmer, there must be some mechanism which provides for the exchange of heat between the Arctic and the Tropics. If the net radiation loss in the Arctic and the net gain in the Tropics were accurately known, a computation could be made of the magnitude of air transport required between the Arctic and the Tropics to maintain equilibrium conditions.

Very few radiation observations have been made in the Canadian arctic islands, though some solar radiation measurements are being made at Resolute. Moreover, measurements of the temperature profile in the lower layers of the air at Alert, and soil temperatures at Resolute, provide additional material for radiation studies. It is hoped to extend the scope of the present radiation measurements by installing a long-wave radiometer at Resolute in the near future.

Studies on the relationship of solar radiation, visibility, sunshine duration, and vertical distribution of humidity are being made by the Canadian Meteorological Service in order to be able to predict the daily amount of insolation at any specific location, and to prepare charts of monthly mean solar radiation, as well as mean clear-day radiation amounts, for all Canada. Theoretical studies of long-wave radiation are also being carried out, which will eventually be applied to determine fluxes and cooling rates, and to interpret radiation measurements in the Arctic.

Night sky radiation and aurorae

The general structure of the upper regions of the atmosphere has been surmised from many different types of observations such as meteors, night sky radiation, and aurorae. Experiments have been carried out in several countries on the measurement of night sky radiation (Hulburt, 1951). Observations have been taken as far north as 63°, and from the data, it was concluded that on nights when aurorae were not present, the brightness of the sky did not vary because of changes in latitude. It would be of interest to carry out a series of observations during the polar night at a station as far north as Alert, to determine whether these results apply to the arctic regions as well.

Detailed auroral investigations have been made in Norway, but such investigations in the Canadian Arctic would be of special interest owing to the proximity of the north magnetic pole. A limited series of auroral observations was begun for the Radio Physics Laboratory of the Defence Research Board at Alert, Eureka, Isachsen, and Mould Bay, in the fall of 1952.

Canadian responsibility in arctic meteorology

In view of the extent of the Canadian sector of the Arctic, Canada shoulders a heavy burden of responsibility for the maintenance of weather stations in the Arctic. This responsibility has been accepted, although the expense of establishing and maintaining stations in isolated arctic locations is vastly greater than in more settled areas. The joint program being carried out by Canada and the United States in the arctic islands is a splendid example of international cooperation. It is providing a means for obtaining extensive meteorological and other scientific data, which will be available for research at centres throughout the world.

References

Brewer, A. W., B. Cwilong, and G. M. B. Dobson. 1948. "Measurements of absolute humidity in extremely dry air". *Proc. Phys. Soc. Lond.* Vol. 60, pp. 52–70.

Craig, R. A. 1950. 'The observations and photochemistry of atmospheric ozone and their meteorological significance'. *Met. Monogr.* (Amer. Met. Soc.) Vol. 1, No. 2, 50 pp.

Dewar, S. W. 1952. "Notes on arctic weather phenomena". CIR 2198, TEC 132, Met. Div. Dept. of Transport, 13 pp.

Greenaway, K. R. 1950. "My experiences with arctic flying weather". *Publ. Roy. Met. Soc.* Can. Branch, Vol. 1, No. 9, 12 pp.

Hare, F. K. and M. R. Montgomery. 1949. "Ice, open water, and winter climate in the Eastern Arctic of North America". *Arctic*, Vol. 2, pp. 79–89, and 149–64.

Henry, T. J. G. and G. R. Armstrong. 1949. 'Aerological data for northern Canada'. Toronto: Met. Div. Dept. of Transport, 271 pp.

Hulburt, E. O. 1951. "Night-sky radiations from the upper atmosphere". *Compendium of Met.* (Amer. Met. Soc.) pp. 341–6.

Koenig, L. S., K. R. Greenaway, Moira Dunbar, and G. Hattersley-Smith. 1952. "Arctic ice islands". *Arctic*, Vol. 5, pp. 67–103.

Markham, W. E. 1953. "Aviation weather summaries for selected Canadian arctic stations". CIR 2366, TEC 165, Met. Div. Dept. of Transport, 7 pp.

McIntyre, D. P. and R. Lee. 1954. "Jet streams in middle and high latitudes". *Proc. Toronto Met. Conf. 1953*, pp. 172–8.

Rae, R. W. 1951. 'Climate of the Canadian Arctic Archipelago'. Toronto: Met. Div. Dept. of Transport, 90 pp.

Wilson, H. P. and W. E. Markham. 1951. "A study of monthly mean pressures for selected stations in northern Canada". CIR 1955, TEC 91, Met. Div. Dept. of Transport, 82 pp.

——— 1952. "1951 aviation weather summaries for selected Canadian arctic stations". CIR 2094, TEC 112, Met. Div. Dept. of Transport, 5 pp.

——— 1951. "Terminal weather conditions at Eureka, Isachsen, Mould Bay, and Resolute". CIR 1954, TEC 90, Met. Div. Dept. of Transport, 23 pp.

Wilson, H. P., W. E. Markham, S. W. Dewar, and H. A. Thompson. 1953. "Weather in the Canadian Arctic". CIR 2387, TEC 170, Met. Div. Dept. of Transport, 30 pp.