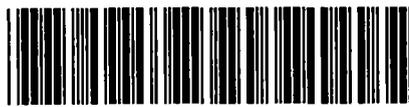


Environment Canada Imaging Cover Page

Report N.:



\* C D S - 1 5 - 6 5 \*

SKP Box Number: 672572447

SOME FEATURES OF THE  
UPPER AIR CLIMATE OF CANADA

R.L. Titus

1.           INTRODUCTION

1.1.           Our understanding of climatology as related to the upper air is continually being revised as methods are developed to provide more abundant, complete and reliable data measurements, and these data become available and are analyzed. Until the early 1940's it was believed that temperatures over all the earth's surface decreased to the tropopause level and that isothermal conditions prevailed in the stratosphere at all levels above the tropopause. As radiosonde data became more abundant with more and more probes into the stratosphere up to about 100,000 feet this simple concept of stratospheric conditions had to be revised. More recently the relatively limited number of rocket probes in the layer from 30 to above 180 kilometers has brought to light more complex relationships.

1.2.           Tentatively the atmosphere is now divided into the following zones: troposphere, stratosphere, mesosphere and thermosphere. Between the troposphere and the stratosphere is the tropopause at approximately 10 kilometers, between the stratosphere and the mesosphere is the stratopause at approximately 50 kilometers, and between the mesosphere and the thermosphere is the mesopause in the vicinity of 80 kilometers. The troposphere is characterized by falling temperatures to about 200 to 230°K. at the tropopause, the stratosphere with approximately isothermal conditions in the lower portion then rising temperatures to the vicinity of 270°K. at the stratopause, the mesosphere by falling temperatures to sometimes less than 200°K. at the mesopause, then rising temperatures in the thermosphere.

1.3.           Our present knowledge of the troposphere is reasonably satisfactory, data for the lower and middle stratosphere are now being gathered and will lead to a fuller understanding of conditions there. Above 30 kilometers, the sparsity of reports makes our present understanding of the high atmosphere sketchy. An expanded rocket program will eventually add considerably to our present knowledge of conditions above that level.

2.           GENERAL FEATURES OF THE EARTH'S TROPOSPHERIC CIRCULATION

2.1.           In general the greater radiation received and retained in the atmosphere at low latitudes compared to high latitudes creates a mean latitudinal thermal gradient in the troposphere extending from the sub-tropics to the polar regions. There is, therefore, a mean westerly component continually being added at successively higher levels from the surface to the tropopause. This manifests itself aloft over the earth's surface as a large west to east circumpolar whirl extending from the sub-tropics to the polar regions. In locations where thermal gradients are strongest, that is frontal zones, the winds are strongest. It is therefore at a level near the tropopause in these frontal zones that the level of maximum wind is generally found and jet streams are located. Each frontal system has its associated jet, but the predominant jet in the northern hemisphere has a mean position in winter near 35 degrees north, while in summer it has moved northward to about 45 degrees and is weaker.

2.2. Because of uneven heating over the land masses of the earth's surface, because of differences in the heating over land and ocean areas, and because of obstructions such as mountain barriers, this mean circumpolar whirl and its associated jet streams is not a straight westerly flow but rather a series of ridges and troughs around the hemisphere with preferred locations where the mean flow is relatively weak or strong. In the northern hemisphere the two main troughs are located some distance east of mountain barriers - that is over eastern North America and near the Pacific coast of Asia. Another minor trough is located in Europe between these two major troughs. Because of lack of mountain barriers and land masses south of 40 degrees in the southern hemisphere, the mean flow aloft in that hemisphere is more zonal and somewhat stronger than is found in the northern hemisphere.

### 3. VERTICAL TEMPERATURE DISTRIBUTION IN THE TROPOSPHERE OVER CANADA

3.1. The temperature regime in the lower troposphere over most of Canada exhibits much more marked seasonal changes than are observed at the higher levels up to the tropopause.

3.2. At the lower levels during the winter, radiative cooling over the snow-covered land and Arctic ice produces an extremely stable stratification. A temperature inversion near the surface with a more or less isothermal layer up to the vicinity of the 700 mb. level is clearly shown on the mean monthly temperature profiles for all northern stations and for inland locations in southern Canada. At southern stations where there is a maritime influence, the mean winter profiles in the lower levels are either isothermal or show a slight decrease of temperature with height. In the summer months at continental locations in southern Canada, the mean monthly profiles in the lower levels show lapse rates lying between the dry and moist adiabatic, while stations with a maritime influence and most locations in northern Canada exhibit mean lapse rates somewhat less than the moist adiabatic.

3.3. In the middle and upper troposphere there are only minor changes from season to season in the average vertical temperature gradient throughout Canada. In the summer months the mean monthly lapse rate is slightly less than the moist adiabatic at those levels, while in the winter season the fall-off of temperature with height is a little less rapid.

3.4. Southern Canadian stations having a maritime influence show the least seasonal change in the vertical temperature distribution in the troposphere. The maritime influence stops the development of inversions in the lower levels in the winter months and inhibits the development of strong lapse rates near the surface during the summer season. At such maritime locations such as Sable Island the steepest lapse rates in the lower levels occur in the late autumn when air that has been cooled to well below freezing passes over the unfrozen and therefore relatively warm water surface.

### 4. GEOGRAPHICAL TEMPERATURE DISTRIBUTION IN THE TROPOSPHERE OVER CANADA

4.1. Geographically over Canada, at any standard pressure level in the troposphere, the mean temperature decreases poleward. The north-south temperature gradient is strongest in the southern part of the country and decreases northward.

At any given latitude western Canada is for the most part warmer than the east. The isotherm pattern at all levels in the winter months shows a general troughing of the isotherms in the vicinity of Hudson Bay and northward to the eastern part of the Arctic Archipelago. During the summer season a ridging effect is evident in the lower levels in the vicinity of the Rockies and the western prairies, while in the middle and upper troposphere the isotherms are orientated in a more or less west-east direction.

## 5. MEAN CONTOUR AND WIND PATTERN OVER CANADA

5.1. The mean contour pattern for any standard pressure level of the Canadian troposphere is characterized by the same general features throughout all four seasons. In general, there is, in the vicinity of Ellesmere or northern part of Baffin Island, a closed low with a shallow trough extending south-southeastward to Hudson Bay and western Quebec. In the summer months the closed low becomes an open trough north-northwestward to the Arctic ocean. These features give rise to a cyclonic flow over most of the country, while a ridging effect, particularly in the winter months, is evident from the mountains over British Columbia to west of the Mackenzie delta. This results in a southwest to a westerly flow off the Pacific becoming more northwesterly over the prairies, then westerly in the vicinity of the Great Lakes and somewhat south of west at the east coast.

5.2. Because of the added westerly thermal component at successively higher levels in the troposphere, the average wind speed increases with increasing altitude up to the tropopause. Also because of the generally stronger thermal gradients over southern Canada, the mean wind speed at any level in the troposphere is strongest in the southern part of the country and decreases northward.

5.3. Table I gives the vector mean wind and constancy values at selected standard pressure levels up to 200 mb. for three localities in Canada - Port Hardy on the west coast, Goose Airport near the east coast and Mould Bay in the Northwest Territories. The constancy value expressed as a percentage, determined by dividing the vector mean wind speed by the scalar mean wind speed and multiplying by 100, is a measure of the variability in the wind direction.

5.4. Values in Table I reveal that the mean wind speeds at Mould Bay are generally weaker at all levels than at the two more southern locations. Also at all three stations there is an increase in wind speed values at successively higher levels up to the 300 mb. surface, this being the level near which the tropopause is most often located. Constancy values are generally lowest near the surface and increase with increasing altitude in the troposphere. Wind directions in the low levels appear the most variable near the east coast in the winter and spring, on the west coast in the summer, and in the north in spring and autumn.

TABLE IVECTOR MEAN WIND AND CONSTANCY (5 YR. PERIOD)

	<u>JANUARY</u>		<u>APRIL</u>		<u>JULY</u>		<u>OCTOBER</u>	
	Wind (Deg/Mps)	Constancy (%)	Wind (Deg/Mps)	Constancy (%)	Wind (Deg/Mps)	Constancy (%)	Wind (Deg/Mps)	Constancy (%)
<b>Goose, Nfld.</b>								
200 mb.	245/16	64	270/12	69	256/16	71	270/24	73
300 mb.	245/16	58	280/11	44	260/14	59	270/24	76
500 mb.	245/09	44	295/05	29	270/10	63	275/16	70
700 mb.	265/04	27	345/03	26	270/06	56	285/10	65
850 mb.	320/03	24	015/03	29	265/04	47	290/07	57
<b>Port Hardy, B.C.</b>								
200 mb.	290/23	77	275/16	66	255/10	60	245/24	80
300 mb.	285/25	72	260/17	57	245/10	49	250/23	72
500 mb.	275/16	69	250/10	53	245/06	51	240/16	77
700 mb.	260/10	61	230/07	52	230/03	40	230/10	73
850 mb.	220/06	51	200/04	45	250/01	16	205/07	67
<b>Mould Bay, N.W.T.</b>								
200 mb.	325/15	80	280/08	60	275/07	64	275/10	78
300 mb.	335/14	68	295/08	43	275/12	68	285/11	61
500 mb.	345/11	63	305/06	32	270/08	57	295/07	49
700 mb.	350/09	67	320/03	28	265/05	54	305/04	47
850 mb.	350/08	68	320/02	17	260/05	51	325/03	37

## 6. TROPOPAUSE ALTITUDES AND TEMPERATURES IN CANADA

6.1. The conventional tropopause is, by World Meteorological Organization definition, defined to be the lowest level where the average lapse rate from that level to all levels within two kilometers above does not exceed  $2^{\circ}\text{C}$  per kilometer. With this definition as criteria for selection of the tropopause level, an analysis of tropopause data for the five year period 1955-1959 inclusive for Canadian stations for the months of February, May, August and November divided into two groups, stations south of latitude  $60^{\circ}$  and stations north of latitude  $60^{\circ}$ , revealed the following statistics:

TABLE II

### TROPOPAUSE MEAN TEMPERATURE ( $^{\circ}\text{C}$ ), MEAN ALTITUDE (km.) AND STANDARD DEVIATIONS

	<u>SOUTHERN STATIONS</u>		<u>NORTHERN STATIONS</u>	
	<u>Temperature</u>	<u>S.D.</u>	<u>Temperature</u>	<u>S.D.</u>
February	-56.6	6.1	-56.7	6.0
May	-54.9	6.3	-52.5	4.8
August	-54.6	5.3	-54.6	4.4
November	-56.5	6.3	-57.4	4.9
	<u>Altitude</u>	<u>S.D.</u>	<u>Altitude</u>	<u>S.D.</u>
February	9.10	1.41	8.16	1.30
May	10.22	1.57	8.87	1.60
August	11.17	1.48	10.11	1.09
November	9.83	1.72	8.70	1.21

6.2. An examination of these data reveals that the mean temperature at the tropopause is remarkably constant throughout the year. The seasonal variation is greatest in the north but the day to day variability is greater in the south as revealed by the higher standard deviation values there. The mean altitude of the tropopause, however, has a seasonal variation of more than two kilometers with the average for the northern stations about one kilometer lower than for the southern stations. The mean monthly pressure at the tropopause for any single month generally ranges from 200 to 300 millibars but may be between 400 and 300 millibars for some stations in the winter months and less than 200 millibars at other stations in the summer period.

## 7. LOWER STRATOSPHERIC CONDITIONS OVER CANADA

7.1. In the lower stratosphere the geographical distribution of temperature at any standard pressure level is generally in marked contrast to that existing in the troposphere. Except during the winter months, a somewhat warmer and lower

tropopause in northern Canada as compared to a generally higher and colder tropopause south of the Canadian border before isothermal conditions are reached manifests itself as a reversal of temperature gradient above the tropopause - that is at any standard pressure level in the lower stratosphere there is usually an increase rather than a decrease of temperature in a northward direction over Canada. As a result of this reversal in the thermal gradient there is a gradual decrease with altitude in the westerly wind component above the tropopause. During the summer months winds become light and variable near the 50 mb. level and then acquire an easterly component above that level.

7.2. During the winter months, probably because of the influence of the Arctic "night", the summer isothermal conditions in the lower stratosphere over northern Canada are replaced by a continued fall-off of temperature with height above the tropopause, and temperatures drop at times to  $-80^{\circ}\text{C}$  or colder in the 30 mb. to 10 mb. layer over the Arctic islands. This results in an increasing westerly flow over the Arctic in the winter from the tropopause up to the vicinity of the 30 mb. to 10 mb. layer and this phenomenon has been termed the "stratospheric jet". At that time the warmest air in the lower stratosphere lies over southern Canada with colder temperatures to the north and to the south. Sometime during the late winter or early spring each year there is a sudden  $30^{\circ}$  to  $40^{\circ}\text{C}$  warming usually within a two-week period in the Arctic stratosphere at which time the jet disappears and winds become light for the summer season.

7.3. From the data in Table III it can be seen that January winds continue to increase with altitude in the lower stratosphere at Mould Bay and also at Goose, whereas at Port Hardy where the influence of the stratospheric jet is not felt, the lower stratospheric wind decreases with altitude in January. In July there is a steady decrease in the westerly component up to the 50 mb. level at all three stations, then increasing easterly winds above that level. Constancy values are generally high at all levels from the tropopause to the 30 mb. level except during the changeover period from a westerly to an easterly component or vice-versa at which time the mean gradient is very light.

TABLE IIIVECTOR MEAN WIND AND CONSTANCY (5 YR. PERIOD)

	<u>JANUARY</u>		<u>APRIL</u>		<u>JULY</u>		<u>OCTOBER</u>	
	Wind (Deg/Mps)	Constancy (%)	Wind (Deg/Mps)	Constancy (%)	Wind (Deg/Mps)	Constancy (%)	Wind (Deg/Mps)	Constancy (%)
Goose, Nfld.								
30 mb.	255/34*	86*	205/02	15	095/05	81	265/09	81
50 mb.	250/23	88	245/04	60	100/02	54	270/07	81
100 mb.	245/21	88	260/08	76	265/06	71	265/14	83
150 mb.	250/20	84	265/10	77	265/11	73	270/20	81
200 mb.	245/16	64	270/12	69	265/16	71	270/24	73
Port Hardy, B.C.								
30 mb.	355/08*	80*	310/01*	27*	085/06	94	305/03*	71*
50 mb.	305/07*	89*	285/04	64	100/03	70	255/07	86
100 mb.	290/16	84	270/08	75	240/05	72	245/14	88
150 mb.	295/21	83	270/11	71	250/09	73	245/18	77
200 mb.	290/23	77	275/16	66	255/10	60	245/24	80
Mould Bay, N.W.T.								
30 mb.	310/40*	89*	330/06	53	080/03	81	285/16	93
50 mb.	305/31	91	305/06	54	060/02	50	275/13	93
100 mb.	310/21	89	290/07	66	285/03	53	270/10	88
150 mb.	315/17	86	285/07	60	280/05	66	270/09	84
200 mb.	325/15	80	280/08	60	275/07	64	275/10	78

\* Computations based on very limited data available

8. USES MADE OF UPPER AIR CLIMATOLOGY

8.1. This discussion so far has concerned long-term mean conditions for some particular month or period. There are, of course, wide day to day fluctuations in the weather pattern. The mean for a particular month for a particular place is the accumulative result from the passage of many ridges, troughs, lows and highs. It is, therefore, quite likely that the mean pattern as depicted for the month never actually occurred that month and similarly the long-term mean pattern for an area is probably not exactly duplicated in any one particular month. However, knowledge of the mean conditions can be quite useful especially in some instances when this information is combined with the known variability usually presented in the form of standard deviation.

8.2. Aviation interests make use of such information in their route planning, aircraft design, required fuel capacity design, etc. Instrument design manufacturers must have this information in order to provide adequate instruments for meteorological soundings, rocketry, missiles, balloons, etc. Defence interests require such information for calculation of nuclear fallout patterns, etc. Inversion characteristics and stability features are of interest to air pollution authorities and to agencies studying sound and radio propagation.

8.3. To the meteorologist, knowledge of the means and extremes in the upper air is useful in various ways. Such knowledge, of course, is directly used in long range forecasting since changes in the weather may, in some cases, be anticipated from certain departures in the mean. To the practising forecaster it is useful to be able to recognize current situations in relation to their normalcy as this information can be used in assessing the probability of normal or unusual weather. In the construction of prognostic upper air charts care must be taken not to move thickness lines into regions where such a thickness has never been recorded. To the research meteorologist the long-term averages provide the means of reducing complex and variable atmospheric processes into a form where it is possible to perform calculations on the various parameters with meaningful results.

June 1, 1965.

RLT/bb

Climatology Division,  
Meteorological Branch,  
315 Bloor Street West,  
Toronto 5, Ontario.