PASSAGE – *Persistent Airborne Sensor Suite for Arctic Geographical Environments – Weather Implications*

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Abstract

Canada has a mandate to assert its Arctic sovereignty, and one method of presence being considered is the High Altitude Airship (HAA). This report presents an assessment of the Arctic weather conditions at high altitude, as well as conditions at various sites, from ground level up to the operating altitude. The assessment indicates that operation at high altitudes in winter should not be attempted. The highly unpredictable winds alone would make HAA launch and operation too risky. Summer winds at these altitudes are more predictable and lighter, though not zero, and occasional high winds do occur. The wind direction is not constant, and so it is doubtful that the wind could be used to generate a functional flight path. Summer is also reported to experience regular cloud cover, which means that, although the HAA may be employed in detection, it is unlikely to be able to perform identification. Depending on the HAA's performance ratings, it should be possible to find acceptable days for launch and descent at almost any chosen location.

A simple surveillance pattern shows that it is theoretically possible for the HAA to cover the Northwest Passage area within 14 days, though high winds could have a significant impact. Additionally, this report raises questions as to whether or not this is a cost effective solution to the Arctic surveillance problem, and further research is proposed.

Résumé

Le Canada a pour mandat d'affirmer sa souveraineté dans l'Arctique, et une des façons envisagées d'assurer une présence dans cette région est le dirigeable stratosphérique (high altitude airship – HAA). On trouvera dans le présent rapport une évaluation des conditions météorologiques à haute altitude dans l'Arctique, ainsi que les conditions météorologiques à différents sites, du niveau du sol à l'altitude de fonctionnement du dirigeable. L'évaluation indique qu'on ne devrait pas en tenter l'utilisation à haute altitude durant l'hiver. Les vents très imprévisibles à eux seuls en rendraient le lancement et le fonctionnement trop risqués. L'été, les vents à de telles altitudes sont plus prévisibles et moins forts, encore qu'ils ne soient pas nuls et qu'ils puissent être forts. La direction du vent n'est par ailleurs pas constante, et il est improbable qu'on puisse utiliser le vent pour produire une trajectoire de vol fonctionnelle. Durant cette saison, un couvert nuageux est fréquent, ce qui signifie que le HAA pourra être utilisé pour la détection, mais qu'il est peu probable qu'il puisse servir à l'identification. D'après l'évaluation de son rendement, il serait possible de déterminer des jours acceptables pour son lancement et sa descente à presque n'importe quel endroit choisi.

Le rapport indique qu'un simple modèle de surveillance montre qu'il est théoriquement possible pour le HAA de couvrir la zone du passage du Nord-Ouest en 14 jours, malgré de forts vents qui pourraient avoir un effet important. Il soulève également des questions sur le rapport coût-efficacité de cette solution de surveillance de l'Arctique, et propose une poursuite des recherches.

Executive Summary

PASSAGE – *Persistent Airborne Sensor Suite for Arctic Geographical Environments – Weather Implications*
Irene Collin; DRDC CORA TM 2013-128; Defence R&D Canada – CORA; August 2013.

Introduction/Background:
ES1. It is well-known that Canada has a considerable northern region with a harsh climate and difficult geographical features, sparsely populated and poorly connected in terms of communication and transportation. For these reasons among others, the monitoring and surveillance of the North is infrequent and irregular. However, Canada does have a mandate to affirm its sovereignty over all parts of the country, including the North, and this requires presence in some form, be it occupation or surveillance. Many concepts of presence are being considered, as well as many methods of surveillance. One such surveillance option is the object of this study: the High Altitude Airship (HAA).

ES2. An Applied Research Project (ARP) [1] was designed to investigate the possibility of employing HAAs in the Arctic. The purpose of this ARP, entitled, "Persistent Airborne Sensor Suite for Arctic Geographical Environments" (PASSAGE), is "to understand the technological challenges and potential solutions to operating and communicating over and monitoring the vast remote areas in the North using sensor-equipped payloads." Although the PASSAGE ARP ultimately proposes to "provide an analysis of fleet size, coverage, availability and basing, and payload capability to meet potential requirements based on experimental and modelling data for EO/IR, ELINT and radar systems operating in a northern environment", the present study is more limited, focusing primarily on weather and its implications on HAA employment.

Results:
ES3. It is found that, at high altitudes, the Arctic weather is extremely unpredictable in the winter. The winds, alone, should preclude any attempt at HAA operation. Summer conditions are much more manageable, with lighter winds, though high winds do occur. Wind direction is not constant.

ES4. Concerning the weather conditions from ground level up to the operating altitude, in all of the sites examined, there appear to be acceptable days to launch an HAA. These acceptable days exhibit very light winds throughout the ascent. Some locations show a greater temperature range from ground to high altitudes and some show a greater frequency of icing conditions, based on temperature and relative

humidity. However, icing may not present a problem. Cloud cover is to be expected throughout the Arctic, particularly over the waterways.

ES5. A simple figure-eight surveillance pattern is considered. This shows that it is theoretically possible for the HAA to cover the Northwest Passage area within 14 days, though high winds could have a significant impact on flight times and deviations.

ES6. Shipping traffic through the Northwest Passage is still sparse, and sea ice conditions are predicted to render navigation difficult to impossible for years to come.

Significance:

ES7. Although weather conditions are not ideal and do present risks, employing the HAA to provide Arctic surveillance does seem possible. But operation would be restricted to summer and to detection rather than identification, and the investment might be substantial. Also, the unproven technology of the HAA, coupled with the precautions regarding its use and the costs of implementing this novel technology, the sparse marine traffic, and the hazardous marine conditions are all factors that raise questions.

Future Plans:

ES8. This report brings to light issues that require additional research. Concerning the effects of weather on the HAA, manufacturers might be contacted for their recommendations on the conditions that the HAA could be expected to withstand. Launch site requirements could be co-ordinated with existing ground facilities. Surveillance patterns could be tested and compared. A computer simulation might be designed to test the effects of wind on the HAA's flight path. Since it is understood that the HAA will fail at some point, criteria and procedures for emergency descent should be devised, including ground locations and recovery procedures. Lastly, other surveillance options should be evaluated and a cost/benefit analysis should be performed to determine the best method of providing surveillance and establishing presence over Canada's North.

Sommaire

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<u>Introduction/contexte</u>
SA1. On sait que le Canada comprend une vaste région nordique où le climat est rude et que les particularités géographiques rendent difficile, et où la population est clairsemée et isolée en termes de communication et de transport. Pour ces raisons, entre autres, la surveillance du Nord est peu fréquente et irrégulière. Le Canada a cependant pour mandat d'affirmer sa souveraineté dans toutes les régions du pays, incluant le Nord, et cela exige une quelconque présence, qu'il s'agisse d'occupation ou de surveillance. De nombreux types de présence sont pris en considération, ainsi qu'un grand nombre de méthodes de surveillance. Une des options de surveillance étudiées, le dirigeable stratosphérique (HAA), constitue l'objet de la présente étude.

SA2. On a conçu un projet de recherche appliquée (PRA) [1] pour étudier l'utilisation possible des HAA dans l'Arctique. L'objet du présent PRA, qui a pour titre *Ensemble de capteurs aéroportés et durables pour les environnements géographiques arctiques* (PASSAGE), est de comprendre les défis technologiques et les solutions possibles relatives au fonctionnement, à la communication et à la surveillance portant sur d'immenses zones éloignées dans le Nord à l'aide de charges utiles dotées de capteurs. Le projet PASSAGE propose en fin de compte de fournir une analyse de l'envergure de la flotte, de sa couverture, de sa disponibilité et de son positionnement, ainsi que de la capacité d'une charge utile à répondre à des exigences possibles en fonction de données d'expérimentation et de modélisation pour les systèmes EO/IR, ELINT et radar fonctionnant dans un environnement nordique. La présente étude, plus limitée, porte principalement sur les conditions météorologiques et leurs effets sur l'utilisation des HAA.

<u>Résultats</u>
SA3. On constate que durant l'hiver, à des altitudes élevées, les conditions météorologiques de l'Arctique sont extrêmement imprévisibles. Les vents, à eux seuls, suffiraient à empêcher toute tentative d'utilisation d'un HAA. Les conditions estivales sont beaucoup plus faciles, les vents étant moins forts, bien que des vents plus violents puissent survenir. La direction du vent n'est pas constante.

SA4. Pour ce qui est des conditions météorologiques depuis le niveau du sol jusqu'à l'altitude de fonctionnement du dirigeable, dans tous les sites examinés, il semble y avoir des journées acceptables pour lancer un HAA, au cours desquelles les vents sont

très faibles durant tout le temps nécessaire à la montée. À certains endroits, l'écart de température entre le sol et les altitudes élevées est plus grand, et à d'autres endroits, la fréquence des conditions atmosphériques de givrage est plus élevée, selon la température et l'humidité relative. Le givrage peut toutefois ne pas représenter de problème. Il faut s'attendre à un couvert nuageux dans tout l'Arctique, en particulier au-dessus des cours d'eau.

SA5. On envisage un simple modèle de surveillance en huit. Cela montre qu'il est théoriquement possible pour un HAA de couvrir la région du passage du Nord-Ouest en 14 jours, malgré que des vents élevés puissent avoir un effet important sur les temps et les écarts de vol.

SA6. La circulation maritime dans le passage du Nord-Ouest n'est pas encore dense, et on croit que les conditions des glaces de mer rendront la navigation difficile à impossible pour les années à venir.

<u>Signification</u>

SA7. Bien que les conditions météorologiques ne soient pas idéales et qu'elles présentent des risques, l'utilisation d'un HAA pour assurer la surveillance de l'Arctique est envisageable. Cette utilisation serait cependant restreinte à l'été et à la détection plutôt qu'à l'identification, et l'investissement requis pourrait être substantiel. De plus, le fait que la technologie du HAA ne soit pas encore éprouvée, ainsi que les précautions nécessaires concernant son utilisation, les coûts d'implantation de cette nouvelle technologie, la faible circulation maritime et les conditions maritimes hasardeuses sont des facteurs à étudier.

<u>Recherches futures</u>

SA8. Le rapport met en lumière des aspects exigeant des recherches additionnelles. Pour ce qui est des conditions météorologiques que pourront affronter les HAA, on peut communiquer avec leur manufacturier pour obtenir des recommandations. Les exigences relatives au site de lancement peuvent être coordonnées à celles d'installations au sol existantes. Les modèles de surveillance peuvent être testés et comparés. On pourrait concevoir une simulation par ordinateur afin de tester les effets du vent sur la trajectoire de vol du HAA. Comme il est attendu que le HAA fera défaut à un moment ou à un autre, des critères et des procédures pour une descente d'urgence, incluant le lieu d'atterrissage et la procédure de récupération, doivent être préparés. Finalement, il faut évaluer d'autres options de surveillance et effectuer une analyse coût-bénéfice pour déterminer la meilleure façon d'établir une surveillance et une présence dans le Nord canadien.

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1. Introduction

1.1 Background

1. It is well-known that Canada has a considerable northern region with a harsh climate and difficult geographical features, sparsely populated and poorly connected in terms of communication and transportation. For these reasons among others, the monitoring and surveillance of the North is infrequent and irregular. However, Canada does have a mandate to affirm its sovereignty over all parts of the country, including the North, and this requires presence in some form, be it occupation or surveillance. Many concepts of presence are being considered, as well as many methods of surveillance. One such surveillance option is the object of this study: the High Altitude Airship (HAA).

2. An Applied Research Project (ARP) [1] was designed to investigate the possibility of employing HAAs in the Arctic. The purpose of this ARP, entitled, "Persistent Airborne Sensor Suite for Arctic Geographical Environments" (PASSAGE), is "to understand the technological challenges and potential solutions to operating and communicating over and monitoring the vast remote areas in the North using sensor-equipped payloads." Although the PASSAGE ARP ultimately proposes to "provide an analysis of fleet size, coverage, availability and basing, and payload capability to meet potential requirements based on experimental and modelling data for EO/IR, ELINT and radar systems operating in a northern environment", the present study is more modest, focusing primarily on weather and its implications on HAA employment.

1.2 Aim

3. The aim of this study is to provide some preliminary analysis work in support of PASSAGE, including a weather assessment, a proposed surveillance route and a brief discussion on the level of effort required for the Arctic region.

1.3 Assumptions

4. Following a survey of airship specifications and performance characteristics, certain numbers were decided upon as representative of the type of airship that could fulfill the surveillance requirement[1]. Thus, the HAA is assumed to operate at an altitude of between 60,000 and 70,000 feet, at a speed of 20 knots, and with an endurance of 14 days. It should be noted that these numbers are notional and may be adjusted as this

[1] This survey was performed and the final numbers provided by the ARP leader, Dr. Franklin Wong.

study progresses. The surveillance area to be covered is the Canadian Arctic Archipelago, comprising the collection of islands and waterways north of the Arctic mainland. Targets of interest are those on land or at sea, including such ships as commercial, cargo and cruise ships, and grounded aircraft requiring rescue. The exact type and size of target that should be detected will be determined further on during this study as sensors are researched and identified.

1.4 Outline

5. This report begins with an assessment of the weather conditions, first at the operating altitude, and then from ground level up to this altitude. The effects of weather on the HAA are discussed, along with some additional weather and employment considerations. A simple surveillance pattern is presented, with distances covered and the estimated times to make this circuit. This is followed by some comments on the current ice situation and ship traffic in the Arctic, factors which are related to the required level of surveillance effort. Finally, the report is summarised with conclusions and recommendations for further work.

2. Weather Considerations

6. This section describes the data chosen for extraction and the reasons behind these choices. The data are analyzed, some examples are provided and the results are summarised. Weather conclusions from other sources and the effects of weather conditions on the HAA are also discussed.

2.1 Weather Data

7. It was not easy finding the required weather data for this project. The information sought was winds aloft (direction and speed as a function of altitude, from ground level up to 90,000 feet), temperatures aloft (from ground level up to 90,000 feet), cloud cover, moisture and obscuration, and ground conditions (including wind, temperature, and rain/ snow/ fog/ mist). Ideally, the weather data would have consisted of historical averages, as well as extremes and their frequency, and seasonal variations.

8. The information was requested from Environment Canada, from the Meteorological Section in Greenwood, and from the Chief of Defence Intelligence Directorate of Meteorology and Oceanography, all of whom contributed, though not to the level of detail desired for this study. Finally, detailed and extensive data were provided by Dr. Pieter de Jong of the Operational Research and Analysis Directorate within 1 Canadian Air Division/Canadian NORAD Region Headquarters, the same data that he used in performing his HAA study [2].

9. These data were Canadian radiosonde measurements for the years 2002 to 2007, generally taken twice per day, at Zulu times of 00 and 12 (i.e. 7 p.m. and 7 a.m. Eastern Standard Time, respectively, or 8 p.m. and 8 a.m. in summer), on every day of the year. Occasionally, days were missed or a third measurement time was included. The data include pressure, altitude, temperature, relative humidity, wind speed and wind direction, for pressure levels of above 1000 hectopascals (hPa) to below 10 hPa, which correspond to altitudes from ground level up to 100,000 feet or more. (It should be noted that the measurements are taken per pressure level and not per altitude. This means that one specific altitude reading may not be found in a set of readings from one launch, and specific altitudes may not be repeated in the data from launch to launch. Similarly, specific pressure levels are neither necessarily found in every data set.) Understandably, not all radiosondes (or their balloons) operate perfectly with every launch: sometimes, there were gaps in some pressure levels or in certain measurements. However, the volume of data – two radiosonde launches per day, practically every day of the year, from ground to 100,000 feet – was considered more than sufficient to determine the weather status at the chosen locations.

2.2 At Altitude

10. Since the desired use of the HAA in this project is Arctic surveillance, the weather conditions were examined at a sampling of northern radiosonde sites, as shown on the radiosonde map of Figure 1, reproduced from de Jong's report [2], with site labels:

a. Cambridge Bay (YCB);
b. Eureka (WEU);
c. Inuvik (YEV);
d. Iqaluit (YFB); and
e. Resolute (YRB).

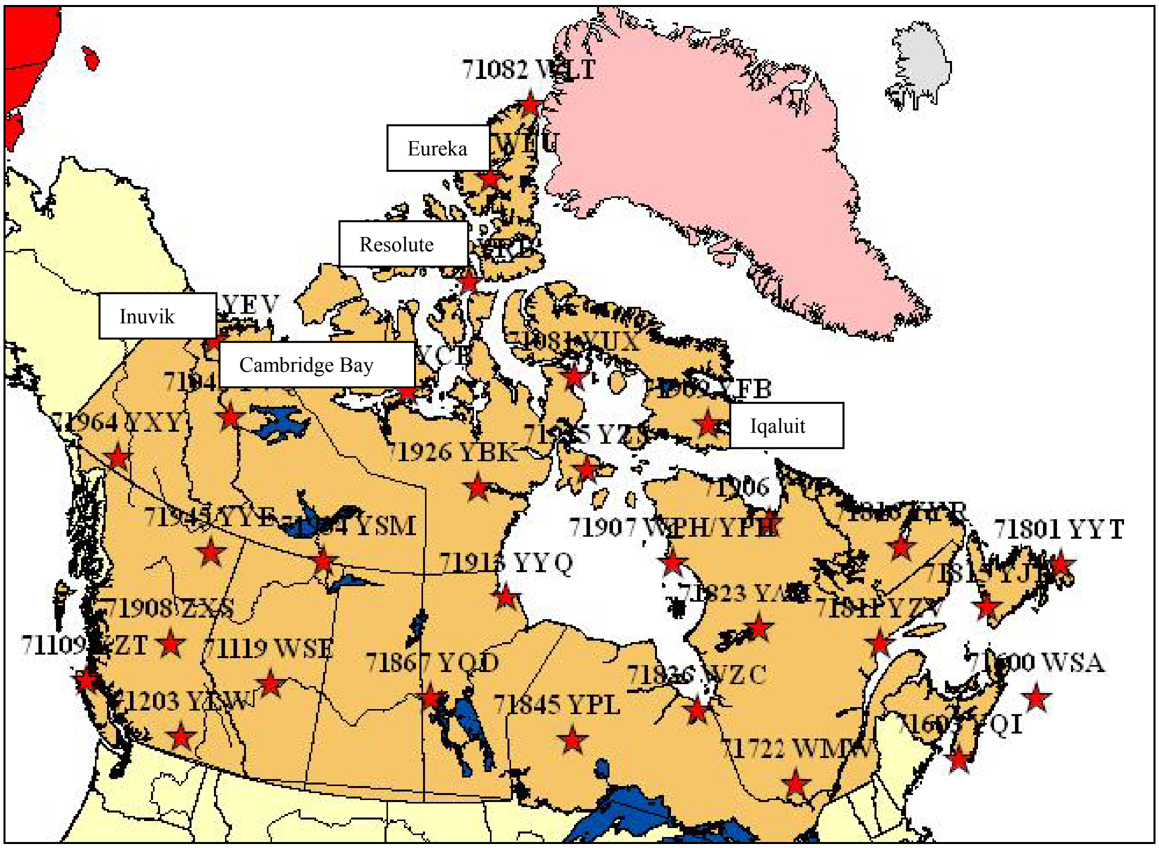

Figure 1: Map of Canadian Radiosonde Sites [2] – High Altitude Analysis

11. It has been stated that the operating altitude for the HAA is assumed to be between 60,000 and 70,000 feet. But, as discussed above, because it was difficult to obtain readings at the exact same altitude for each date and time, data were extracted at a pressure of 50 hPa, a value for which readings were almost always available. The data examined at 50 hPa were:

a. Altitude vs. Date;
b. Wind Speed vs. Date;
c. Temperature vs. Date; and
d. Relative Humidity vs. Date.

12. These data were also sampled by year. An example is shown below, in Figures 2 through 5: the graphs for Resolute for the year 2007. Averages were not used since it was thought that the complete range of fluctuation would be more illustrative of the actual weather behaviour than would a set of moderated values. Although it would be possible to extract and analyze the weather data for all locations, years and pressure levels, this was not thought to be necessary following observation of the results from the sample set, as discussed further on.

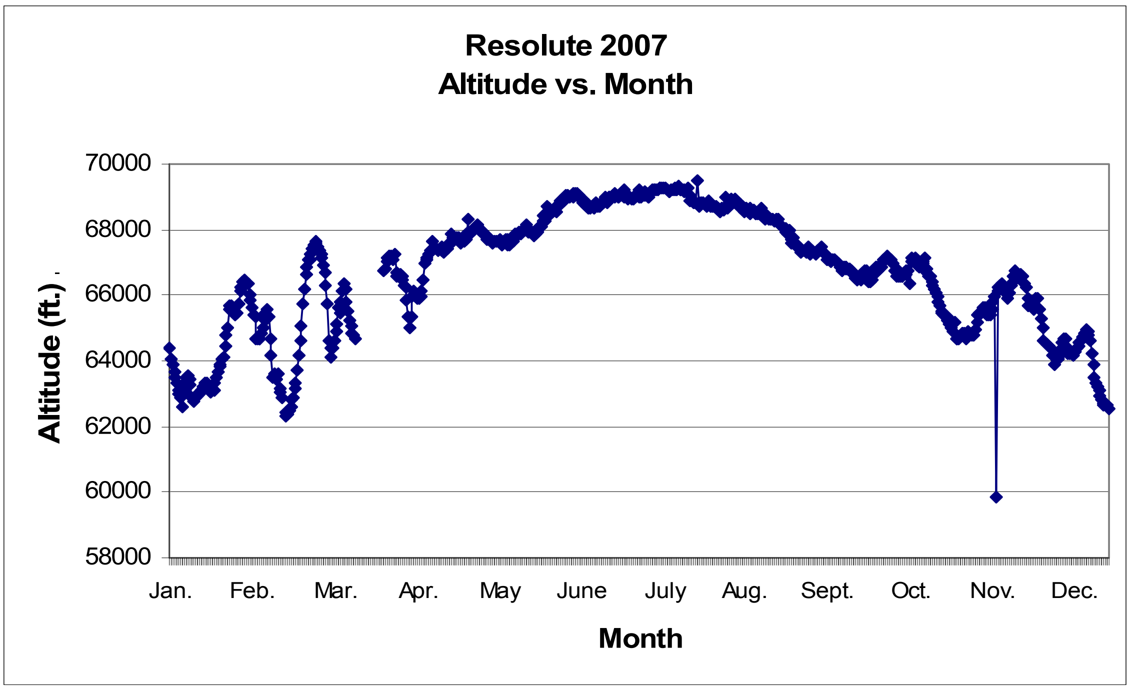

Figure 2: Resolute, 2007, Altitude vs. Month, 50 hPa

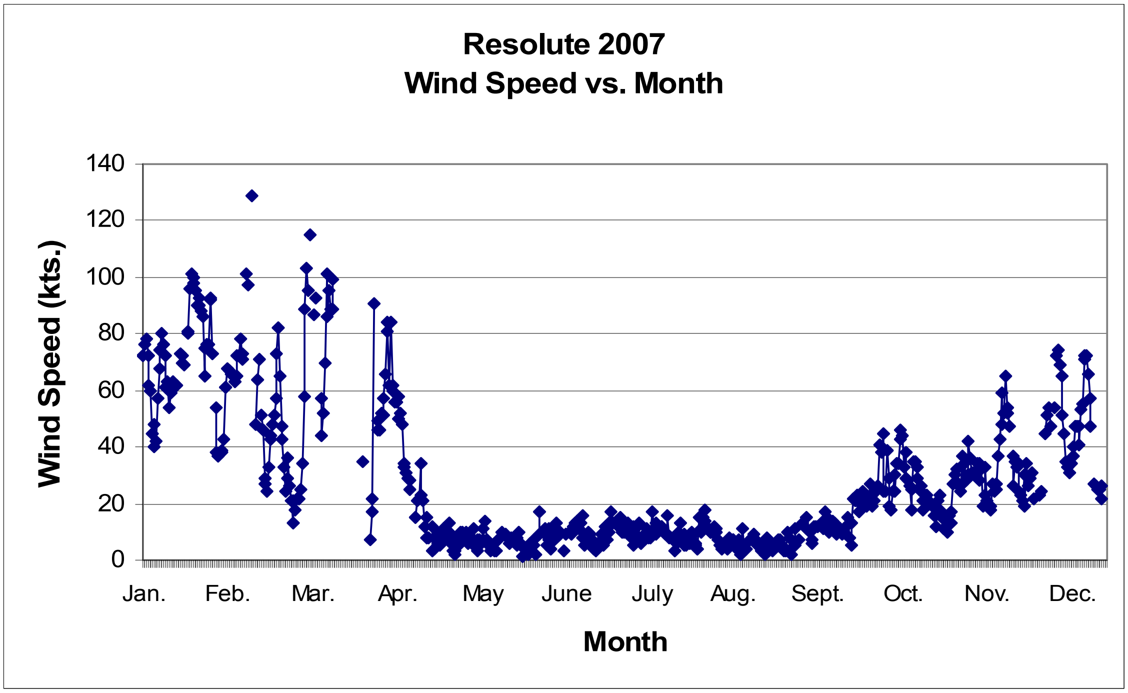

Figure 3: Resolute, 2007, Wind Speed vs. Month, 50 hPa

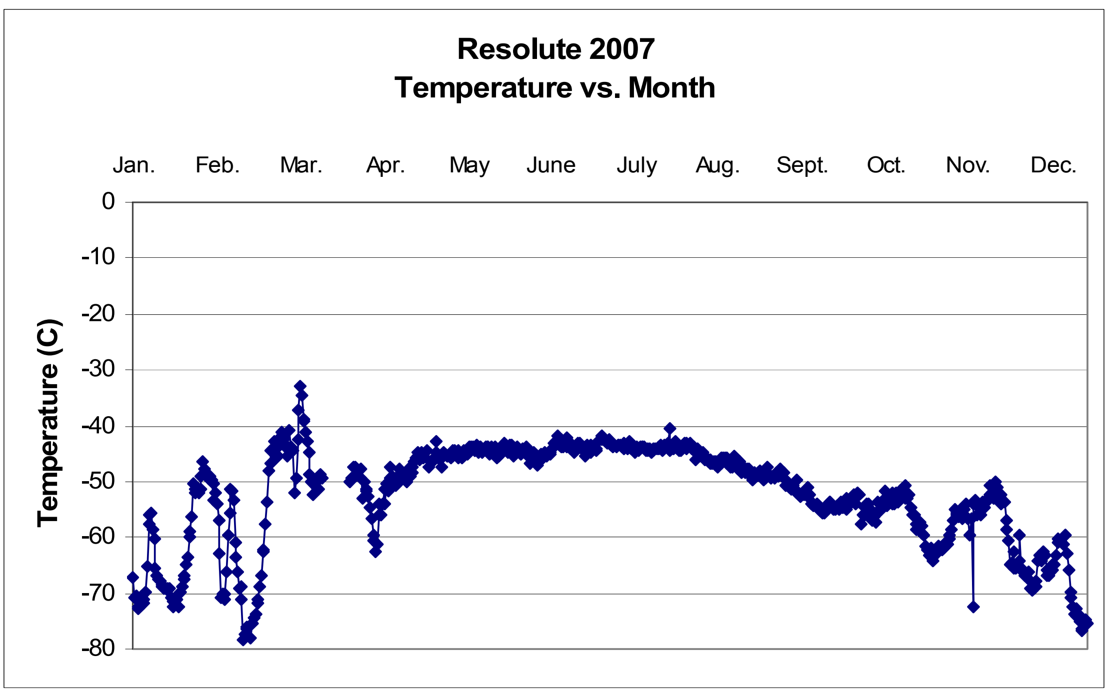

Figure 4: Resolute, 2007, Temperature vs. Month, 50 hPa

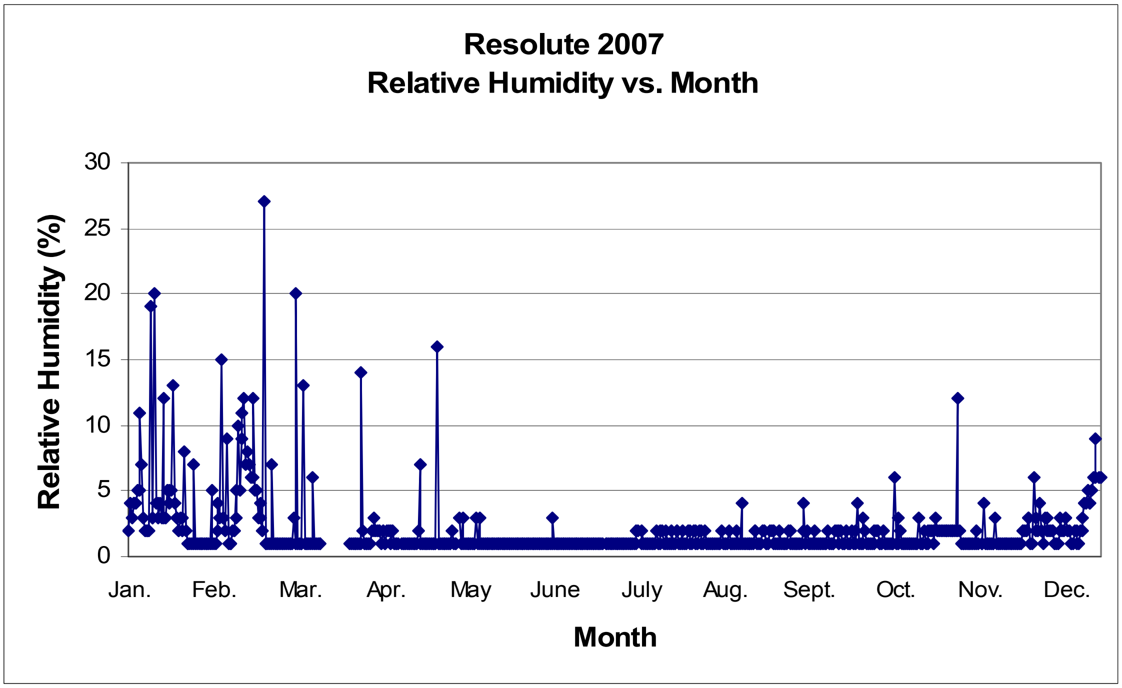

Figure 5: Resolute, 2007, Relative Humidity vs. Month, 50 hPa

13. Overall, the Resolute figures show a state of high variability in the winter months and more stable behaviour in the summer months. Figure 2 indicates that, with the exception of the November outlier, the 50 hPa pressure corresponds to an altitude range of approximately 62,000 feet to 69,000 feet. The range during the summer months is a bit tighter, at 67,000 feet to 69,000 feet, and without the fluctuation of the winter months.

14. According to Figure 3, typical winds in the months of January through April show speeds of 60 knots, and these winds can exceed 100 knots. The summer months show a marked drop, with all wind speeds falling below 20 knots, and an average wind speed below 10 knots.

15. The winter temperatures of Figure 4 display great variability, ranging from approximately -30 C. to -80 C. Summer temperatures are more stable, at approximately -45 C., with a range of less than 10 degrees.

16. Considering relative humidity, Figure 5 indicates high variability in the winter, with humidity levels often exceeding 10% and occasionally reaching or exceeding 20%. During summer, the humidity levels are consistently below 5%.

17. Charts for the other locations and years are presented in Annex A, and the information is summarized in Tables 1 through 5, below.

Table 1: Altitude Range for Northern Sites at 50 hPa

		Altitude (ft.)	
Location	**Year**	**Summer**	**Yearly**
Resolute	2007	67,000-69,000	62,000-69,000
	2003	68,000-69,000	63,000-69,000
Cambridge Bay	2005	67,000-69,000	62,000-69,000
Iqaluit	2003	67,000-69,000	63,000-69,000
Inuvik	2007	67,000-69,000	64,000-69,000
Eureka	2005	67,000-69,000	62,000-69,000

18. As in the Resolute example, the altitude range in summer, generally at 67,000 feet to 69,000 feet, is smaller than in winter, at approximately 63,000 feet to 69,000 feet.

19. Wind measures are displayed in Tables 2 and 3. For all of the sites, winter winds may simply be characterized as "variable", with highly fluctuating wind speeds. Average wind speeds are in the range of 30 to 41 knots, with maximum speeds over 100 knots in all cases. In four of the six cases, the average wind speed plus one standard deviation is at least 60 knots, and the wind speeds exceed 50 knots in the range of 12% to 39% of the time. Wind direction is discussed further on.

Table 2: Winter Wind Characteristics for Northern Sites at 50 hPa

		Wind: Winter (Sept.-Apr.)				
		Speed (kts.)			Values	
Location	**Year**	**Aver.**	**Std.Dev.**	**Max.**	**> 50 kts.**	**Direction**
Resolute	2007	40	26	129	31%	W (63%)
	2003	41	25	125	39%	W (60%)
Cambridge Bay	2005	40	29	200	30%	W (60%)
Iqaluit	2003	30	17	104	12%	W (59%)
Inuvik	2007	36	24	102	25%	W (84%)
Eureka	2005	30	22	118	18%	W (43%)

Table 3: Summer Wind Characteristics for Northern Sites at 50 hPa

		Wind: Summer (May-Aug.)				
		Speed (kts.)			Values	
Location	**Year**	**Aver.**	**Std.Dev.**	**Max.**	**> 50 kts.**	**Direction**
Resolute	2007	8	3	18	0%	E (56%)
	2003	9	7	86	< 1%	E (43%)
Cambridge Bay	2005	8	4	35	0%	E (50%)
Iqaluit	2003	13	15	165	2%	E (39%)
Inuvik	2007	8	4	22	0%	E (44%)
Eureka	2005	10	7	70	1%	E (51%)

20. With summer wind speeds typically below 20 knots and average summer winds of 8 to 13 knots, Table 3 shows the winds to be much lighter in summer than in winter. However, it should be noted that there can be high winds, even in the summer months, though only exceeding 50 knots at most 2% of the time. In contrast, winter winds are extremely variable and unpredictable, often exceeding 100 knots. To get a better sense of the magnitude of these winds, recall that 64 knots is rated as 12 on the Beaufort Scale[2], the highest rating on the scale, and described as "hurricane" force. Although Canadian Forces (CF) aircraft may have no trouble flying in these winds, airships are quite different in that their speeds are more typical of ships than aircraft. An airship may be capable of using predictable, constant "high" winds to fly from one location to another if the winds are favourable; however, it will not be able to maintain a course that diverges from such a wind, owing to its own low speed, and it will almost certainly not be able to withstand conditions of high turbulence [3]. Also, these "high" winds must still be below a certain threshold. Sources vary on the maximum wind speed that an airship can manage, ranging from 37 knots to 50 knots [3].

21. The data source provided wind direction in degrees. These numbers were classified more simply by dividing them into four quadrants:

a. East – 46-135 degrees;
b. South – 136-225 degrees;
c. West – 226-315 degrees; and
d. North – 316-45 degrees.

The tables indicates that, in the first row, i.e. Resolute 2007, the predominant summer wind is from the east, 56% of the time, and the predominant winter wind is from the west, 63% of the time. The last row, i.e. Eureka, shows the predominant winter wind to be from the west, 43% of the time. (Although not stated in the table, for Eureka, the northerly direction is almost as frequent.) It is interesting to observe that, although the winter winds are predominantly westerly, the summer winds are predominantly easterly.

[2] The Beaufort Wind Force Scale, devised by Sir Francis Beaufort in 1805, provides a standard form of wind measurement which relates wind speed with observed conditions on land or at sea.

Table 4: Temperature Range for Northern Sites at 50 hPa

Location	Year	Temperature (C) Summer	Temperature (C) Winter
			variable and colder
Resolute	2007	-40 to -50	-30 to -80
	2003	-40 to -50	-40 to -75
Cambridge Bay	2005	-40 to -50	-40 to -80
Iqaluit	2003	-40 to -50	-40 to -75
Inuvik	2007	~-45 to -50	-30 to -70
Eureka	2005	-40 to -50	-40 to -85

22. Table 4 compares the summer and winter temperatures at 50 hPa. The winter temperatures may be characterized as variable and colder, with ranges of -30 C or -40 C down to -70 C or -80 C. It can be seen that the ranges of summer temperatures, although still cold, are narrower and more predictable, between -40 C and -50 C.

Table 5: Relative Humidity for Northern Sites at 50 hPa

		Relative Humidity			
Location	**Year**	**Summer**		**Winter**	
		Average	**Std.Dev.**	**Average**	**Std.Dev.**
Resolute	2007	1%	1%	2%	3%
	2003	3%	5%	4%	8%
Cambridge Bay	2005	3%	3%	4%	7%
Iqaluit	2003	4%	10%	5%	10%
Inuvik	2007	1%	0%	2%	1%
Eureka	2005	3%	3%	5%	6%

23. Concerning relative humidity, the differences between summer and winter are not as marked as are some of the other parameters. Table 5 shows the tendency toward lower values in summer and slightly greater variability in winter (the result of more high-value spikes, which can be seen on the charts), though there may not be a significant difference between the seasons. In any case, the effects of these differences in relative humidity would not be nearly as important as the effects of wind on the performance of the HAA.

24. These data, graphs and tables of northern locations at high altitude form a picture of the weather conditions that may be encountered by the HAA in operation. Across the locations and years, there is a high degree of similarity amongst the measurements, be they of wind, temperature, altitude or relative humidity. Judging by the extreme fluctuations in wind alone, it would seem ill-advised to attempt operations in the winter months. Summer weather is more predictable, with altitude and relative humidity more constant, temperature range smaller, and winds lighter, averaging 8 to 13 knots for the

sample locations and generally below 20 knots (though occasionally exceeding 50 knots). But high altitude weather conditions are not the only factor affecting the operation of the airship: the conditions from ground to altitude must also be taken into consideration, as discussed in the next section.

2.3 From the Ground Up

25. As previously stated, weather data were only available for certain sites across Canada. Since most of these sites were not coincident with existing CF bases, wings or stations, it was decided to examine the weather at a sampling of northern or western sites, some of which would be fairly close (i.e. the closest radiosonde sites) to potential CF launch locations. The following sites, shown on Figure 6, were examined:

a. Baker Lake (YBK);
b. Coral Harbour (YZS);
c. Fort Nelson (YYE);
d. Resolute (YRB);
e. Stony Plain (WSE); and
f. Whitehorse (YXY).

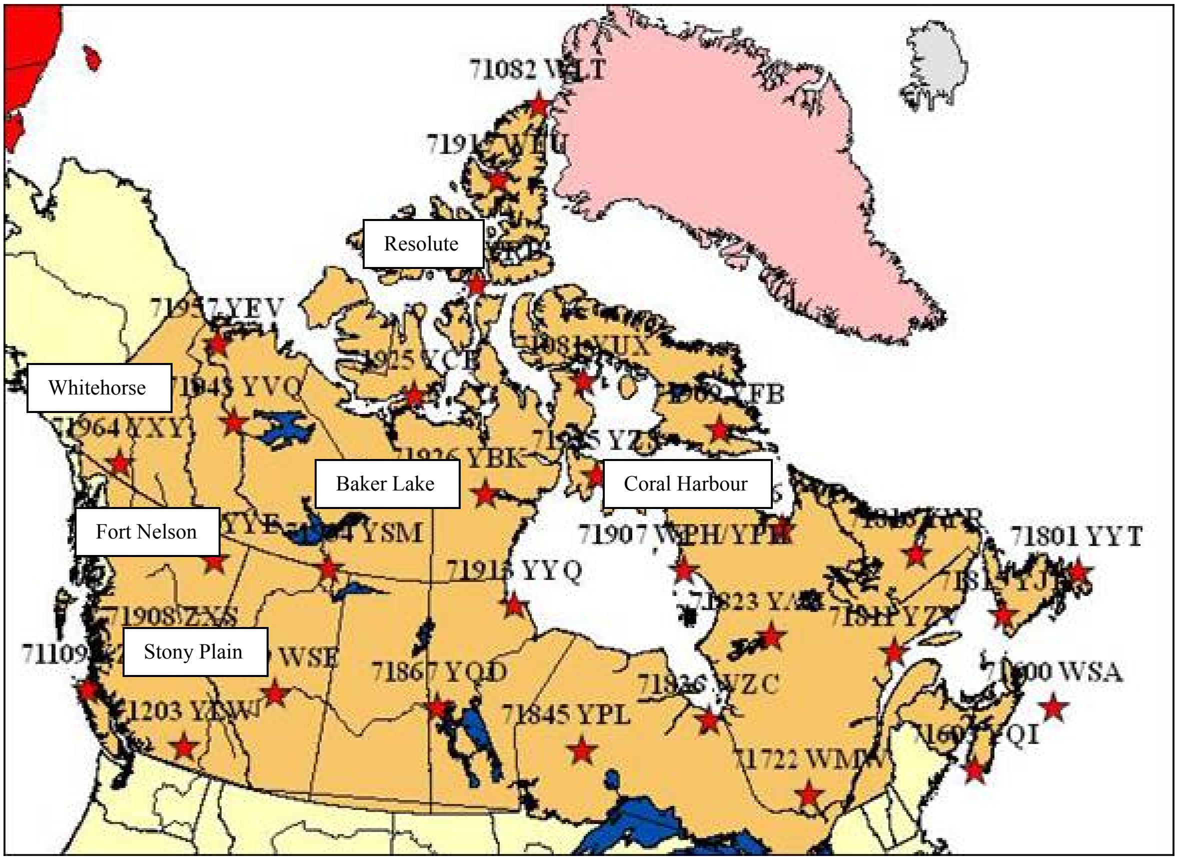

Figure 6: Map of Canadian Radiosonde Sites [2] – Launch Analysis

26. The weather data were scanned for days with light wind throughout the radiosonde balloon ascent. In this case, the term, "light wind", implies that most of the wind readings are under 20 knots, and few, if any, readings are over 30 knots. This includes all readings from ground level up to an altitude of 90,000 feet, above which, winds may become erratic and gusting. Additionally, this is above the assumed HAA flight altitude of 60,000 to 70,000 feet. These days of light wind were infrequent, but all of the chosen locations had some such days beginning in April or May, which is probably the earliest time of year that flights would be desired or even possible, considering the unpredictability of northern winter weather.

27. The aim of this analysis was not to find the ideal location for HAA launch, since no site would be chosen solely on the basis of wind and other weather factors, particularly if it is not at least a current CF station, but to investigate the likelihood of ever finding acceptable launch weather in any of the sampled locations. As in the case of the high altitude data, the actual readings were used rather than average values since observing the full range of fluctuation was desired. At first glance, conditions in most locations would not appear to be ideal for launching a vulnerable, slow-moving HAA, so

finding any suitable days at all, based on the wind criteria, was a relatively rare achievement.

28. The data examined for the sampled sites are:

a. Wind Speed vs. Altitude;
b. Temperature vs. Altitude; and
c. Relative Humidity vs. Altitude.

29. Charts for these data at all locations and various dates in April and May are shown in Annex B. (Although charts are only shown for the year 2007, other years were examined and similar results were observed.) The results are compiled in Table 6. This table shows the location, date, time, maximum wind speed (below 90,000 feet for the reasons stated above), average wind speed, predominant wind direction with the fraction of readings for which this direction is prevalent, and throughout the ascent, temperature range and relative humidity range, along with the altitude at which the relative humidity reaches its low point. The average wind speed and direction are the averaged values of all readings for the specified date and time. A wind direction in the format "direction 1 (X%)/direction 2" signifies that direction 1 is the predominant direction, X% of the time, with direction 2 almost as frequent (e.g. for Resolute, May 30, 00Z, the wind direction of N (36%)/E means that the predominant direction is North, occurring 36% of the time, with East almost as frequent). A wind direction in the format "direction 1/direction 2 (X%) means that direction 1 and direction 2 are equally frequent, at X% (e.g. Fort Nelson, May 7, N/S (32%)).

Table 6: Results for Sites on Calm Days

Location	2007	Time	Wind Speed (kts.) Maximum*	Wind Speed (kts.) Average	Wind Direction	Temperature Range (C)	Relative Humidity (%)
Baker Lake	May 21	00Z	30	16	W (55%)	0 to -60	87 to 2 (42kft.)
		12Z	27	17	W (52%)	2 to -62	90 to 2 (41kft.)
Coral Harbour	April 28	00Z	24	15	S (44%)	-6 to -58	97 to 2 (35kft.)
		12Z	26	14	S (54%)	-7 to -53	99 to 2 (33kft.)
	May 1	00Z	22	10	E (35%)	-7 to -55	98 to 2 (33kft.)
		12Z	30	11	E (45%)	-8 to -55	98 to 2 (32kft.)
Fort Nelson	April 17	12Z	8	2	N (42%)	6 to -55	92 to 1 (35kft.)
	April 18	00Z	22	11	W (39%)	11 to -56	78 to 1 (35kft.)
	May 7	12Z	6	2	N/S (32%)	7 to -54	97 to 2 (30kft.)
Resolute	May 30	00Z	13	8	N (36%)/E	-9 to -56	92 to 1 (36kft.)
		12Z	25	14	N (50%)	-8 to -53	94 to 1 (33kft.)
Stony Plain	May 31	00Z	16	10	N (32%)/E	23 to -65	49 to 2 (50kft.)
		12Z	20	11	W (36%)/S	17 to -64	88 to 2 (47kft.)
Whitehorse	April 12	00Z	24	13	S (43%)	4 to -56	82 to 2 (30kft.)
		12Z	27	11	S (39%)	-4 to -57	88 to 1 (35kft.)
	April 22	00Z	24	12	E (39%)/S	10 to -56	91 to 2 (38kft.)
		12Z	33	16	E (38%)	5 to -57	100 to 1 (40kft.)
	May 20	00Z	17	9	E (56%)	12 to -53	96 to 1 (38kft.)
		12Z	34	13	E (53%)	6 to -57	96 to 1 (40kft.)

* Below 90,000 ft.

30. First of all, the table shows that these light wind days do not occur on the same dates across the different sites, nor are morning (i.e. 12Z) or evening (i.e. 00Z) ascents consistently better or worse. This indicates that there is less predictability than there might be. Wind speeds occasionally exceed 30 knots, but most sites show maximum wind speeds between 15 and 30 knots. Most of the average wind speeds are between 7 and 15 knots. Wind direction is fairly distributed over the compass points, with no particular direction showing dominance over the others. Even the prevailing wind direction only occurs at most 56% of the time and as little as 32% of the time.

31. As stated above, the dates were carefully chosen for consistently light winds. If, on the other hand, launch conditions do not have to be so strict and the HAA can be assumed to manage short periods (i.e. minutes) of strong winds, acceptable launch days could be found more frequently, probably during almost any week. According to Jamison et al [3], an HAA can be expected to ascend at a rate of one minute per 1000 feet, which implies a 70-minute ascent to reach 70,000 feet. If high winds were to occur for a few minutes during this ascent, the deviation from course would probably be tolerable and the HAA would probably withstand the experience (unless the winds were exceptionally high, e.g. over 50 knots).

32. Table 6 shows that, at ground level, the temperatures range from below the freezing point to well above, with a high of 23 C at Stony Plain. A typical profile from the Annex B graphs would start around the freezing point (slightly above or below), decrease to the lowest temperature, then gradually increase, with fluctuation. The lowest temperatures generally occur between the altitudes of 27,000 and 34,000 feet, and range from -53 to -65 C, although there are exceptions. For Fort Nelson, the temperature decreases, rises, then further decreases before rising again at 71,000 to 93,000 feet. Three of the six Whitehorse profiles show similar behaviour to those of Fort Nelson, except the local minima are less pronounced, giving the graph more of a consistently decreasing appearance, with minimum temperatures occurring between 80,000 and 92,000 feet. The data show that the greatest temperature ranges (i.e. from high to low during one radiosonde launch) occur in Stony Plain, with 81 and 88 degree differences between highest and lowest temperatures. The smallest ranges occur in Resolute (45 and 47 degree ranges) and Coral Harbour (between 46 and 52 degree ranges for the four days and times).

33. Concerning relative humidity, most sites show a range of 80% to 100% at low altitudes dropping down to 1% to 2% somewhere between 30,000 and 50,000 feet. The profiles do not decrease uniformly since these graphs reflect the cloud formations and weather conditions on particular days, and weather will always show some variability and elements of unpredictability.

34. There are two potential flying problems associated with temperature: icing, which depends on relative humidity, and material fatigue, which does not. From the references regarding icing [4, 5], it seems that the general rule is that icing may occur at temperatures ranging from slightly above freezing to about -20 C, if the relative humidity reaches or exceeds 70%. The charts of Annex B show that these conditions coincide, for some of the sites, anywhere from ground level to 18,000 feet. Icing conditions are met most frequently in Coral Harbour and least frequently, or rather, never in Stony Plain (for the sampled dates). In the case of Stony Plain, in one chart, the relative humidity does not exceed 70%, and in the other, the near-ground-level readings exceeding 70% relative humidity coincide with temperatures too warm for icing, and the higher altitude readings (i.e. 24,000 to 25,000 feet) coincide with temperatures too cold. Second to Stony Plain is Baker Lake, with very few readings consistent with icing. Fort Nelson and Resolute show slightly more frequent icing conditions being met, though these occurrences are still fairly rare.

35. If icing were to occur, how great a problem is it expected to be? Sources discuss the operation of airships in ice/snow/freezing rain conditions, and state that the principal effect is the accumulation of ice on projecting structures, although some accumulation may also occur on the airship envelope [6]. It seems that, although significant weight may be added and control may be impaired, the majority of cases report that the effects are within the capability of the airship: it can fly, it can remain buoyant and it can be manoeuvred and landed without incident [7, 3]. So, although it is useful to note the

conditions for icing at the sampled sites, icing may not be a major constraint (and possibly, no constraint at all) to the flight of the HAA.

36. Material fatigue is a problem associated with temperature fluctuation. As previously stated, in one ascent, the HAA may be subjected to ground temperatures above freezing (e.g. Stony Plain ground temperatures were above 20 C.), decreasing to temperatures below -60 C., a range of more than 80 centigrade degrees. In addition to this temperature variation, there is the factor of solar radiation at high altitudes, causing super-heating of the buoyant gas. Such temperature fluctuations between day and night cause volumetric expansion and contraction of the gas which further stresses the HAA fabric. This problem is further discussed below.

37. Regardless of launch location, it should not be impossible to find suitable launch days in April or May, after the unpredictable winter weather has subsided. For the days analyzed, the winds were principally in the range of 7 to 15 knots, although sometimes over 30 knots, with no predominant direction; temperatures ranged from above freezing at ground level to below -60 C. at the lowest point (not the highest altitude); and the relative humidity was high at ground level and at low altitudes, tapering off to 1-2% between 30,000 and 50,000 feet.

38. If very stringent wind conditions are required, as sought for the ascent weather data analyzed in this report, ideal launch days may not appear on cue. Consequently, launching one HAA to relieve another may require planning and spontaneous adjustments to the timing. Similarly, ideal descent days will require even more careful planning. According to Jamison [3], ascent takes approximately one minute per thousand feet and descent takes about one minute per 200 feet; thus, reaching 70,000 feet will take about 70 minutes, and the corresponding return to ground will take about 350 minutes. Therefore, if extreme weather conditions, such as thunderstorms, are forecast during the days that the HAA is scheduled to descend, it may be forced to alter the time or location of landing, and its replacement HAA may have to be launched early or wait until conditions improve. Additional weather constraints, such as these, were obtained from other sources of information. Many of these constraints are important, and are presented in the next section.

2.4 Further Weather Considerations

39. Regarding cloud cover, Laska [8] reports regular cloud cover in the summer over the Northwest Passage and Arctic region. According to the National Snow and Ice Data Center [9], the Arctic ocean areas in particular are 80% to 90% covered by summer stratus clouds from June to September. Bearing this in mind, visibility is not expected to be good, so equipping the HAA with Electro-Optical/Infra-Red (EO/IR) sensors may not provide much utility. Since EO/IR sensors would be the instrument of target

identification, this also means that identification would rarely be possible, as this requires photographic images of the ship's name, not merely the ship's classification.

40. Jamison [3] states that there will be fabric degradation as a result of ultraviolet radiation at high altitudes, as well as the temperature variations that raise and lower the internal helium pressures, causing expansion and contraction of the materials, as previously mentioned. Gusting winds and turbulence may compound the situation, with the additional stress that these produce. This constant combination of stresses may weaken the hull fabric, making it more subject to tearing and to helium leakage.

41. Although airships that have been damaged by many small holes have been able to descend in complete control, large tears will destroy the airship. Such tears can happen if control is lost close to the ground, during ascent or descent (a contributing factor being the airship's huge momentum), and the airship is blown into some structure or object. Weakening of the fabric or seams can also result in "unzipping", or a long tear in the hull material, allowing the lifting gas to escape quickly [3]. The result in this case would probably be catastrophic.

42. Apart from large or small holes, there will always be some helium leakage through the airship skin. Jamison [3] states that helium leakage may be the binding constraint to airship endurance. With time and use, the leakage will only increase. For conventional aerostats, Lee [10] reports a helium leakage rate of 0.02-0.035 cubic feet per square foot of aerostat surface area per day. This translates to a "loss of approximately 200 cubic feet of helium per day for a 7000 cubic foot aerostat". With pressurization of the helium gas and additional leakage through the seams and valves, this will increase, but should be within 300 cubic feet per day.

43. There are materials that can withstand very harsh conditions, as evidenced by the Raven Aerostar Super Pressure Balloon, manufactured for NASA [11]. In January/February of 2011, the Super Pressure Balloon was flown for 23 days at 111,000 feet in Antarctica, and brought down intact, without incident. These conditions would not be identical to those of the HAA at 70,000 feet, since the winds at 111,000 feet could be considerably higher and the temperatures milder, but they are nonetheless similar. As well, the operation of the HAA is different from that of the balloon since the HAA is expected to either fly a controlled route or maintain a position as required, so the structures are different and they certainly appear so. However, the materials may be the same or similar. The costs may be proportional to the properties of the materials, which means that a viable HAA may require an investment in suitably durable materials[3].

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[3] Regarding HAA costs, it should be noted that the HAA investment may be substantial. Jamison [3] cites past airship costs of $7.5 to $75 million, whereas the U.S. Army's super-blimp [www.dailymail.co.uk/.../US-Armys-150m-super-**blimp-high-altitude-airship**-crash-landing-hours-launch.html] launched (and crash-landed after three hours of ascent) in July of 2011 reportedly cost $150 million to build.

Lesser materials may either fail from the start or degrade rapidly to the point of being unusable after a few flights. Regardless, the ratings and tolerances of all materials will have to be scrutinized.

44. On the point of HAA failure, it should be understood that the HAA will ultimately fail. According to Jamison [3], this will happen as the result of a strong gust of wind. The eventual degradation of the fabric might also lead to failure. In either case, some provision should be made so that the payload can separate from the HAA, descend to earth and be easily located and recovered.

45. One weather element not as yet mentioned is thunderstorms. The assumption of this study is that an HAA would not be launched if a thunderstorm is imminent. Nor would thunderclouds reach the operating altitude of the HAA. However, if an unpredicted thunderstorm and its expansive winds were to reach the vicinity of the HAA during a required descent, it is possible that the HAA, being as slow-moving as it is, would not be able to resist the strong winds and would be drawn into the thunderstorm. If this were to occur, the HAA could undergo severe damage and might not survive.

46. Supposing an HAA is constructed to withstand the weather conditions imposed on it, another question is, will an HAA, constrained by this study's assumptions, be capable of covering the required area of the Northwest Passage? This is the subject of the next section.

3. One Surveillance Pattern

47. Prior to estimating the number of airships that would best fulfill the surveillance needs of the Arctic, the benefit provided by one HAA should be assessed. This section looks at one method in which an HAA, operating alone, might be employed to perform surveillance over the Northwest Passage. Distances are calculated, as well as the time required to make this circuit, using the nominal HAA speed. In practice, several HAAs might be employed simultaneously; however, this section simply examines one possible case of using one HAA, what it might achieve and what its limitations might be.

48. To measure the distances and the associated times of covering the Northwest Passage, a simple route was configured. This route is a figure-eight over the area, shown in Figure 7. This shape was chosen because the middle sections (i.e. the crossing part of the figure-eight) are covered more frequently than the other sections of the figure. The figure-eight follows the numbered points sequentially, with the final point (marked “11”) also being the starting point (“1”). Although this map shows straight lines connecting the points, the distances were actually calculated as great circle distances by the tool, GPS Visualizer [12].

Figure 7: Arctic Route, Figure-Eight

49. Summing up the 10 pieces of the figure-eight route, the total distance is 4176 nautical miles. Using a nominal speed of 20 knots, the time involved is 209 hours. With a return trip to Cold Lake, as a sample starting location, another 100 to 110 hours might be added, resulting in a total trip time of about 320 hours. This falls within the 14-day (or 336-hour) nominal endurance for the airship, so the circuit appears to be feasible. But from the weather analysis, it is known that there is wind. On a good day, the winds could be benign, averaging 8-13 knots, as shown in Table 3. But what if several hours of unusually strong winds were to occur? If there were several periods of 80-knot winds lasting a total of 24 hours during this two-week circuit, the HAA could be blown off course by 1920 nautical miles (assuming the HAA could actually survive such winds). This is a substantial distance compared to the total circuit length of 4176 nautical miles and, at the HAA's speed of 20 knots, it would take four days to return to its course.

50. This simple calculation shows that, before investing in an HAA, the flight performance numbers will have to meet the requirements of the expected tasks. The HAA's speed and endurance will have to exceed the assumed notional values to circumvent dangerous conditions, such as thunderstorms, and to allow for unanticipated delays caused by difficult weather events during flight and descent.

51. It can now be seen that, with a sufficient investment[4], it should be possible to construct a durable HAA, and, under the assumed conditions, the HAA should be able to cover the greater part of the Northwest Passage. But how much coverage is required? An assessment is provided in the following section.

[4] According to Jamison [3], considering that the airship carries many of the same systems as fixed-wing aircraft, such as "flight control and mission avionics, propulsion, electrical systems and environmental control", as well as gas management systems and ground handling systems, "there is no reason to believe that an airship's unit cost should be significantly less costly than that of a fixed-wing aircraft."

4. Quantity of Effort

52. There appear to be many cautions as well as many unknowns connected with the employment of HAAs in the Arctic. Such employment may require a significant investment, both in terms of effort and money. Furthermore, the HAA technology is not yet proven, so even a considerable investment may not yield a commensurate result. Prior to making any investment, it might be appropriate to quantify the current surveillance needs. Although current ship traffic numbers should ultimately be examined, sufficient or reliable data were not available at the time of this publication. However, some insight can be gained from immediately available information, one set being the Trenton search and rescue incident data for the years 1994 to 2004. For this data set, the total number of incidents is 3314. The number of incidents occurring north of 60º latitude (i.e. the border between the provinces and the territories) is 165, which is just less than 5% of the total. The number of incidents occurring north of 70º latitude (i.e. the southern border of the Arctic Archipelago, including the Northwest Passage; in 2012, the Arctic Circle latitude was 66º 33'44" or 66.5622º) is 22, which is less than 1% of the total. This means that in the 11 years of incident data, an average of two incidents per year occurred in this Arctic area.

53. Regarding ship traffic, in 2009, seven ships travelled through the Northwest Passage, and in 2010, there were 18 such ships. The website of Live Marine Information [13] was observed over several dates in July of 2012, and this indicated that there were, at most, three ships in the Davis Strait off the coast of Greenland, two entering Hudson Strait from Davis Strait, one in Hudson Bay, one in Baffin Bay, and none in the Northwest Passage. A 2011 Norwegian study on Arctic marine traffic [14] reported that "current shipping demand… involves up to 22 seasonal trips." Most of these go directly to Churchill in Hudson Bay. This study's map of Arctic shipping activity (2004) shows no more than 20 ships travelling through the Northwest Passage. The study notes that shipping through the Northwest Passage will be limited since there are no adequate deep water ports. As well, "from a navigational point of view, the Northwest Passage will be the last area where the multiyear ice will disappear and shipping through this Passage will remain risky even in the summer season. The ice models indicate that the ice conditions will be too heavy for any commercial shipping." This statement is formulated by reports from the Canadian Ice Service, from the Arctic Marine Shipping Assessment of Transport Canada [15] and from the Insurance Journal [16].

54. With such sparse ship traffic through the Northwest Passage and such predictions of difficult to impossible navigational conditions, how much effort should be devoted to surveillance of this area? Should an area comprising less than, presumably, 1% of the national surveillance requirement receive any more than 1% of the national surveillance resources? It should be assumed that the foreseeable requirement will limit the magnitude of the effort. For how many years will the Northwest Passage be in a precarious ice situation and navigationally hazardous? Is the HAA the best method of

providing surveillance? Is it the most economical? According to various sources, including Goodyear [17, 18], the Sky Station Blimp [19] and, most importantly, the United States Defense Advanced Research Projects Agency (DARPA) Integrated Sensor Is Structure (ISIS) [20], the airship will have a life expectancy of between five and 14 years, that of the ISIS being 10 years. Is such a life expectancy worth the estimated initial investment and maintenance costs? These questions should be considered and further reliable data should be analyzed prior to committing to these unproven ventures.

5. Conclusions and Recommendations

5.1 Conclusions

55. Canada has a mandate to assert its Arctic sovereignty, and one method of presence being considered is the HAA. Since the Arctic presents a severe weather challenge, some weather research was required. From the compilation of various sources of information and the analysis of weather data, it appears that operation at high altitudes in winter should not be attempted. The highly unpredictable winds alone, frequently gusting over 80 knots, would make HAA launch and operation too risky. Summer winds at these altitudes are more predictable and lighter, though not zero, averaging 8 to 13 knots for the sampled sites, but occasionally exceeding 50 knots. The wind direction is not constant, and so, it is unlikely that the wind could be used to generate a functional flight path. Summer is also reported to experience regular cloud cover, which means that, although the HAA may be employed in detection, it will rarely be able to perform identification. Depending on the HAA's performance ratings, it should be possible to find acceptable days for launch and descent at almost any chosen location. These days would have low winds (bearing in mind that there were never any days with no wind in the radiosonde data), and with no forecast of thunderstorms. Certain locations seem less prone to icing conditions, though icing may not be a huge problem for HAA operation.

56. One simple surveillance pattern showed that it is theoretically possible for the HAA to cover the Northwest Passage area within 14 days. However, high winds could have a significant effect on the HAA, taking it way off course and resulting in flight delays. Similarly, provision would have to be made for descent delays due to undesirable weather events. Subsequent studies may explore these problems in detail.

57. Although weather conditions are not ideal and do present risks, employing the HAA to provide Arctic surveillance does seem possible. But does it make sense? This will necessitate further research. The unproven technology of the HAA, coupled with the precautions regarding its use and the costs of implementing this novel technology, the sparse marine traffic, and the hazardous marine conditions are all factors that raise questions. Is this the best course of action to pursue? The next phase of this study may offer some answers.

5.2 Recommendations for Further Work

58. This report brings to light issues that require additional research. Concerning the effects of weather on the HAA, manufacturers might be contacted for their recommendations on the conditions that the HAA could be expected to withstand.

Launch site requirements could be co-ordinated with existing ground facilities. Surveillance patterns could be tested and compared. A computer simulation might be designed to test the effects of wind on the HAA's flight path. Since it is understood that the HAA will fail at some point, criteria and procedures for emergency descent should be devised, including ground locations and recovery procedures. Lastly, other surveillance options should be evaluated and a cost/benefit analysis should be performed to determine the best method of providing surveillance and establishing presence over Canada's North.

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Annex A: Weather Graphs at Altitude of 50 hPa

Cambridge Bay, 2005

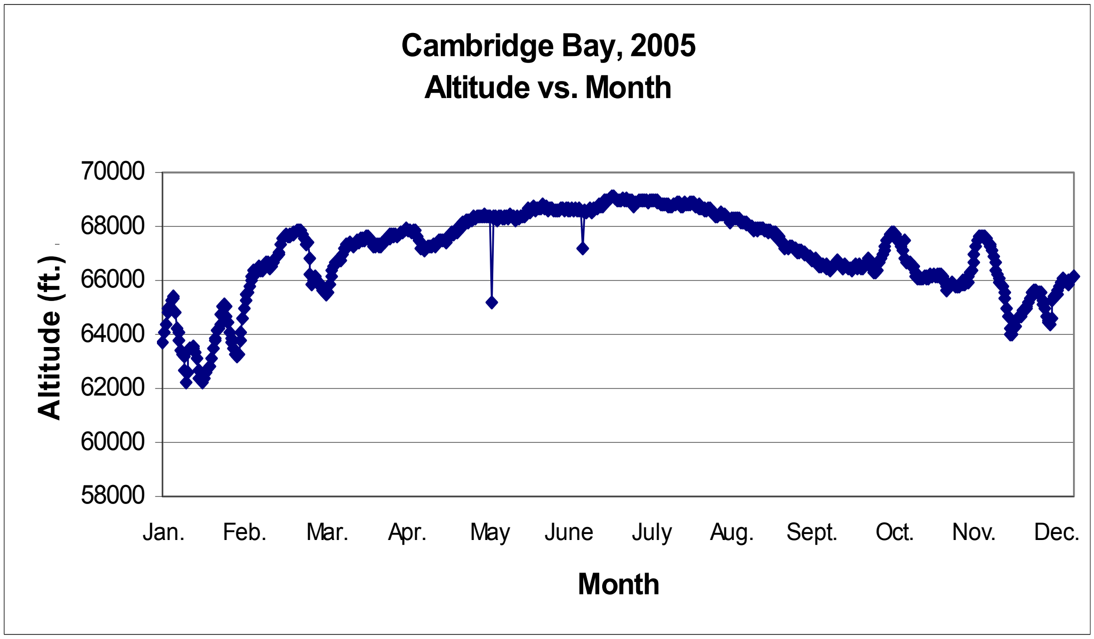

Figure A 1: Cambridge Bay, 2005, Altitude vs. Month, 50 hPa

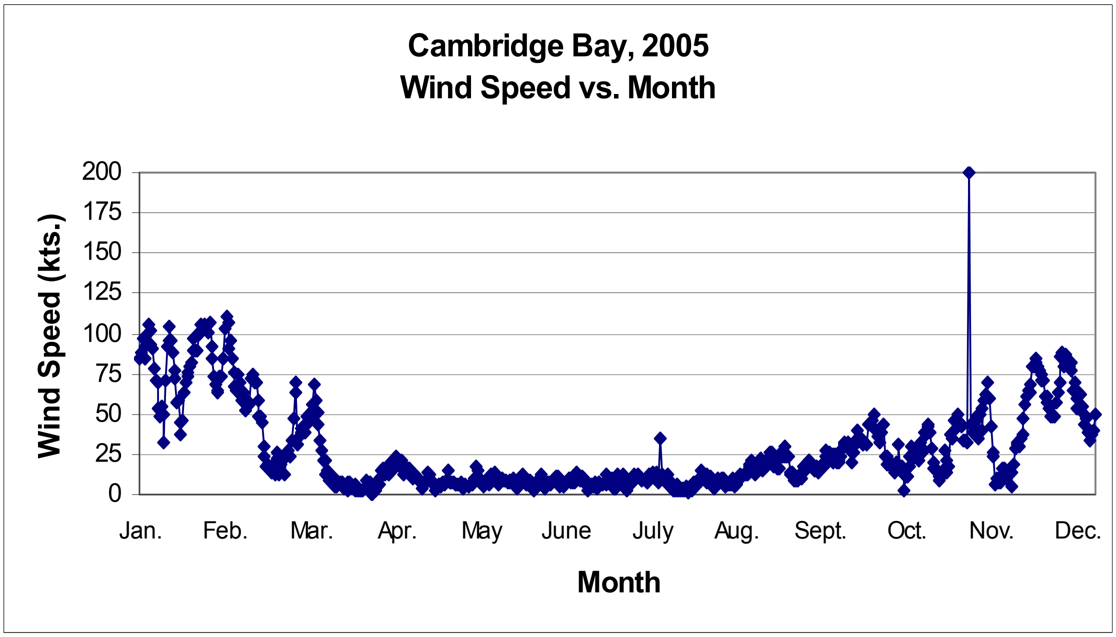

Figure A 2: Cambridge Bay, 2005, Wind Speed vs. Month, 50 hPa

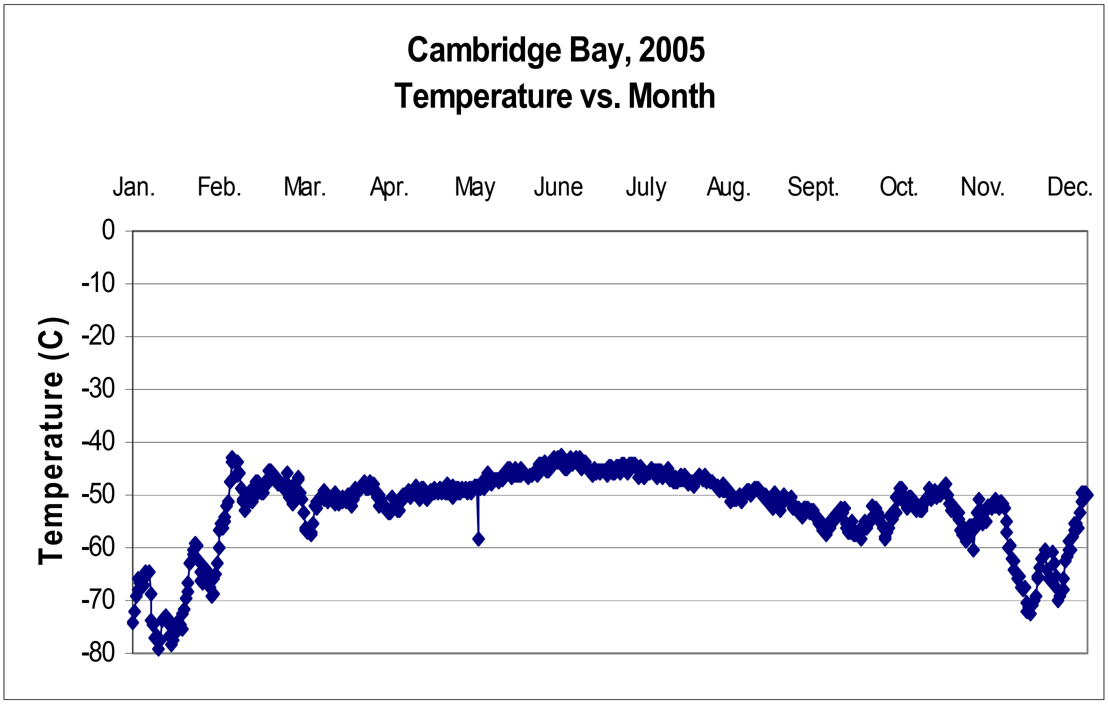

Figure A 3: Cambridge Bay, 2005, Temperature vs. Month, 50 hPa

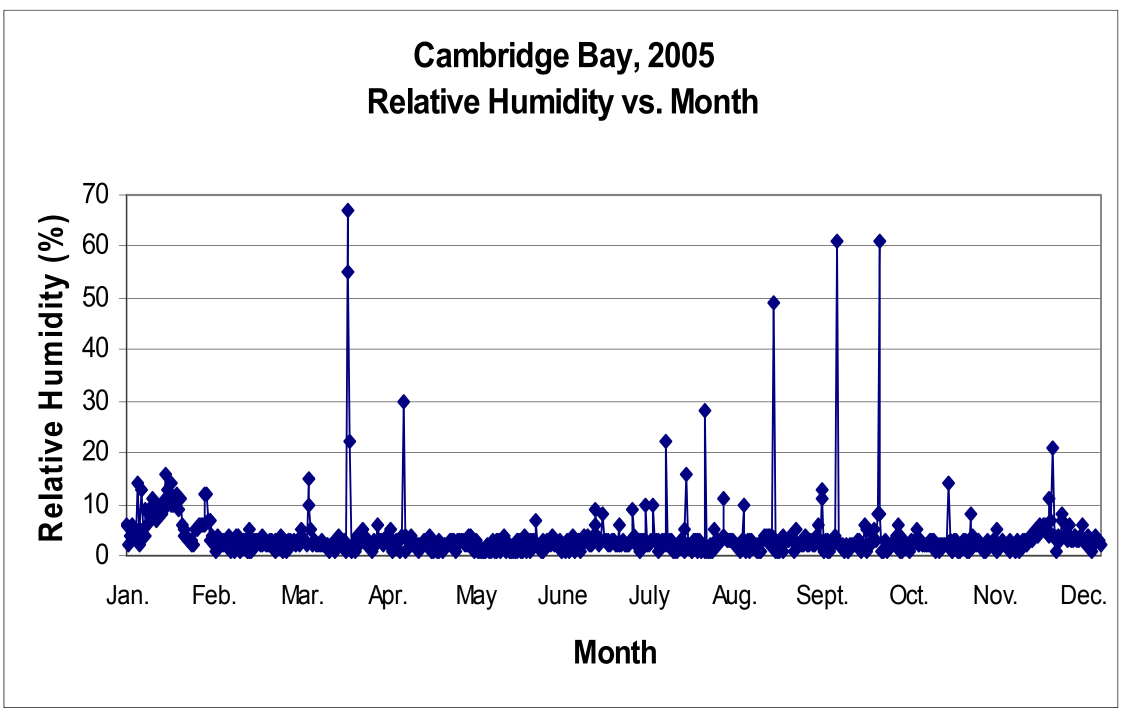

Figure A 4: Cambridge Bay, 2005, Relative Humidity vs. Month, 50 hPa

Eureka, 2005

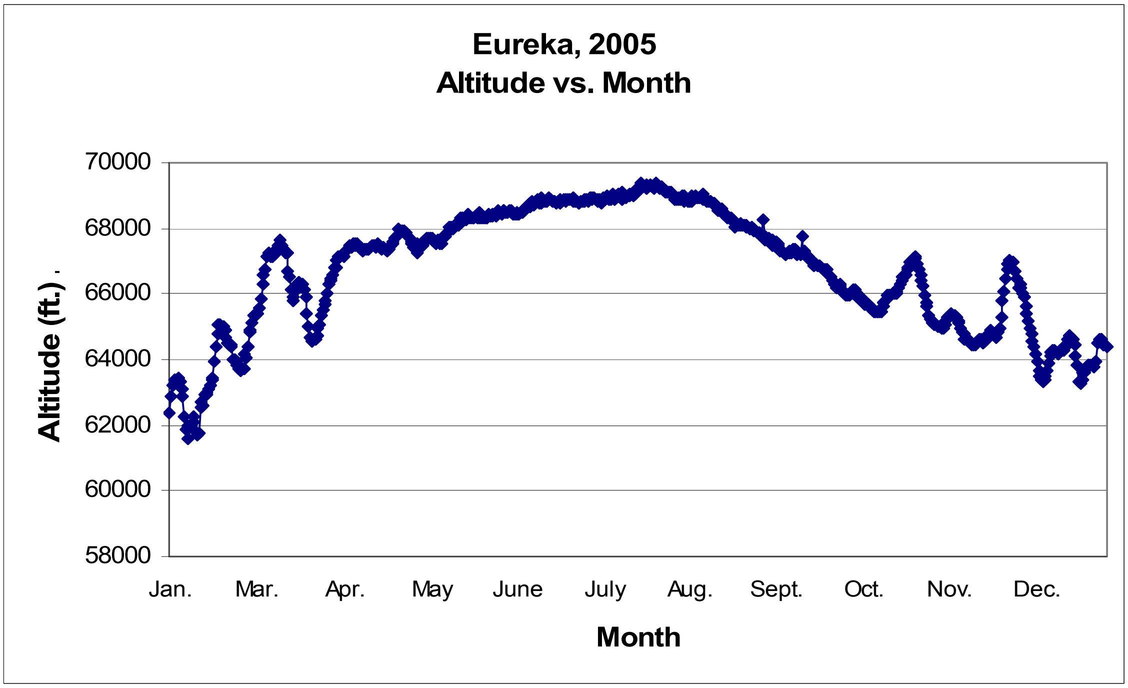

Figure A 5: Eureka, 2005, Altitude vs. Month, 50 hPa

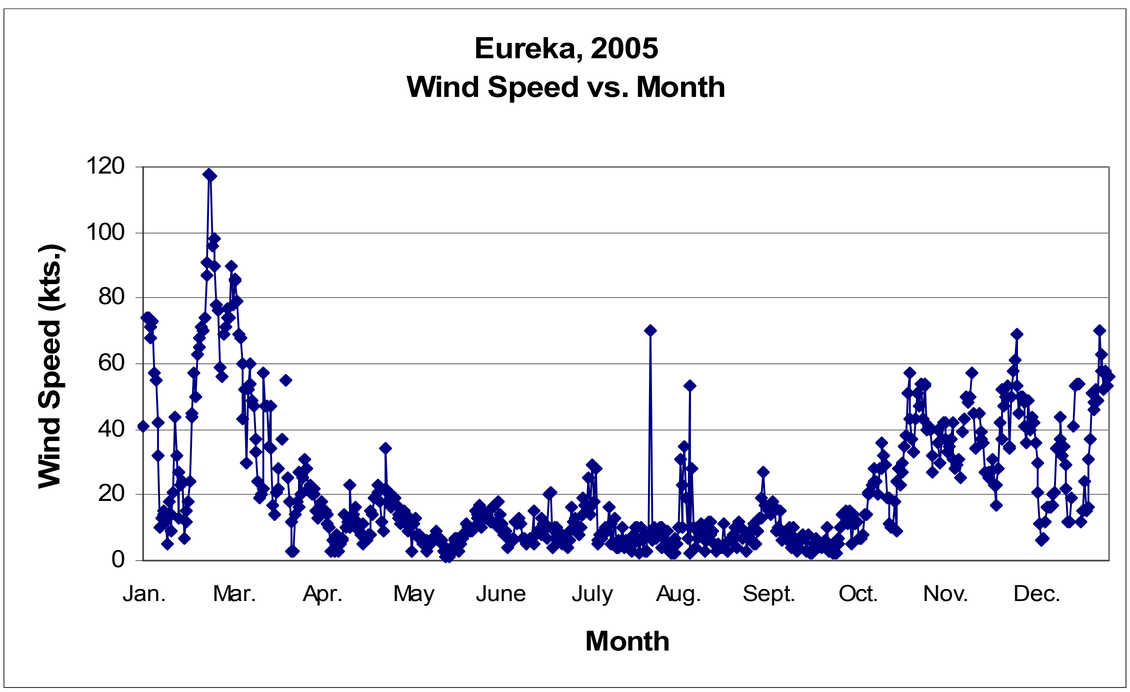

Figure A 6: Eureka, 2005, Wind Speed vs. Month, 50 hPa

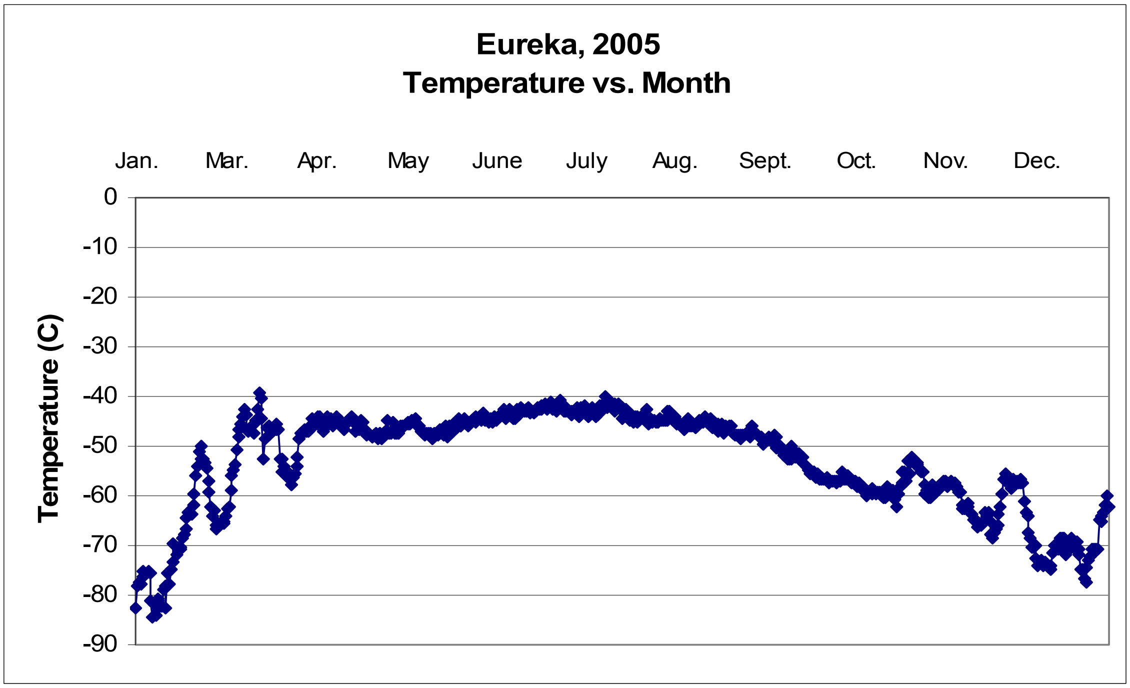

Figure A 7: Eureka, 2005, Temperature vs. Month, 50 hPa

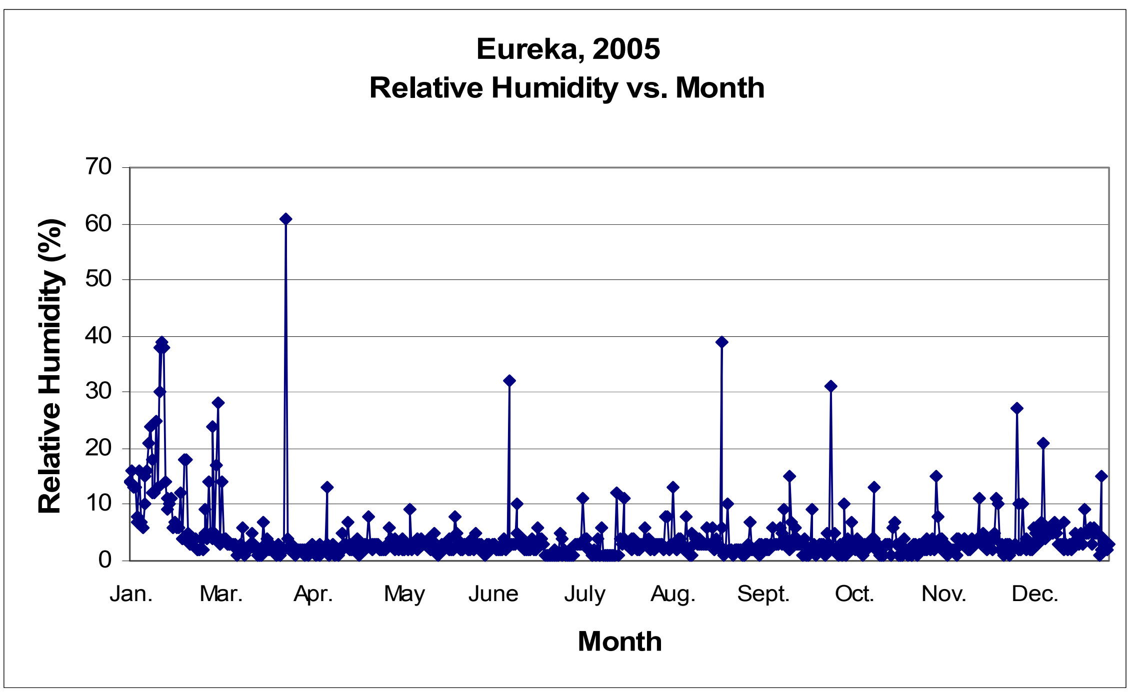

Figure A 8: Eureka, 2005, Relative Humidity vs. Month, 50 hPa

Inuvik, 2007

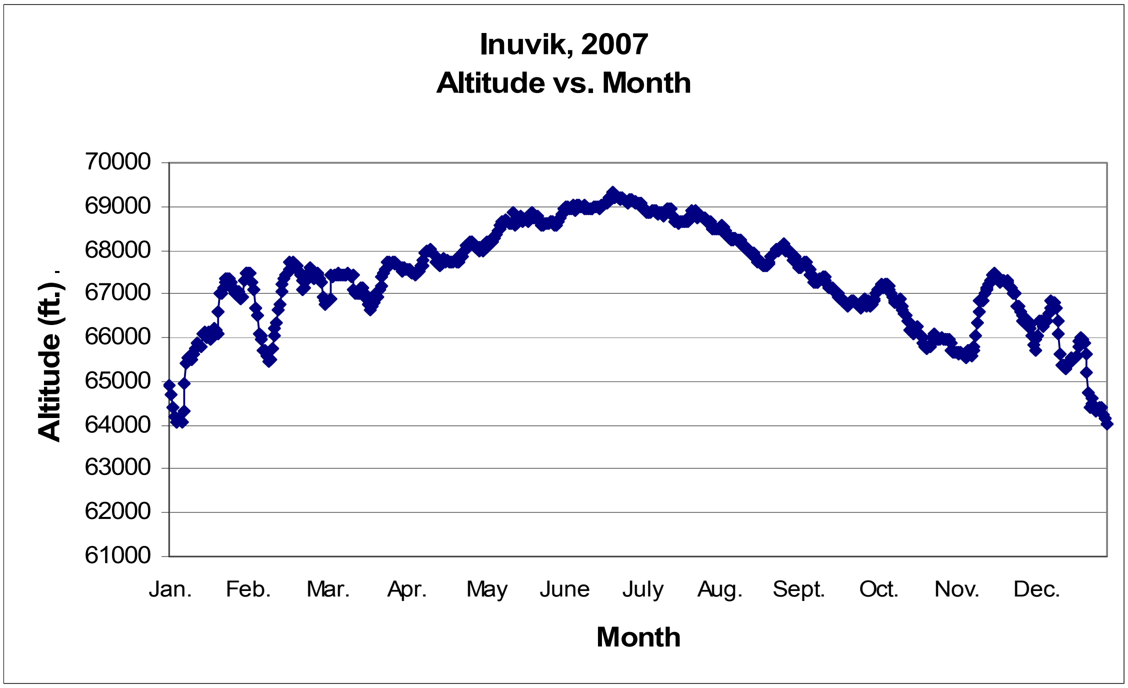

Figure A 9: Inuvik, 2007, Altitude vs. Month, 50 hPa

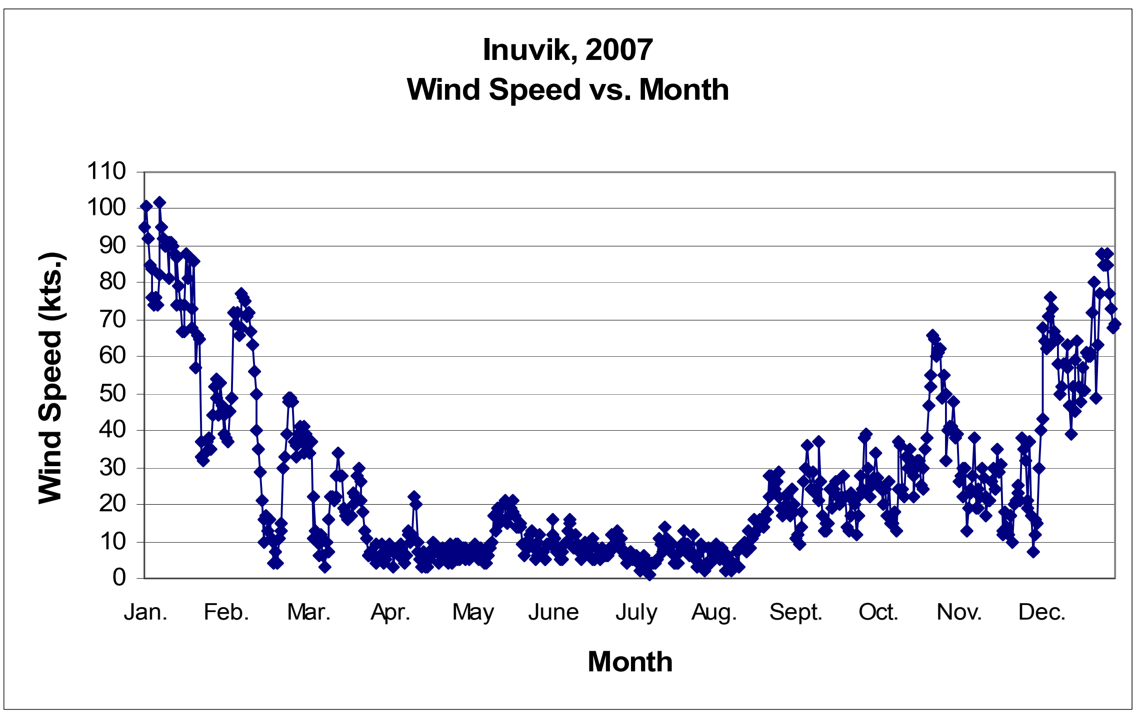

Figure A 10: Inuvik, 2007, Wind Speed vs. Month, 50 hPa

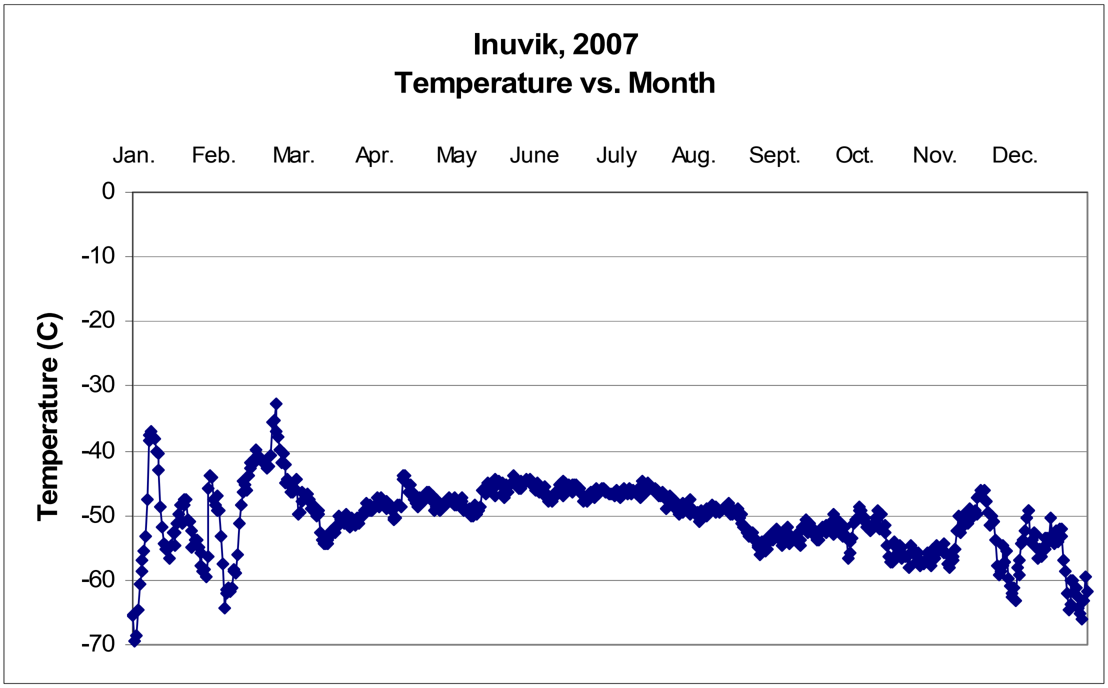

Figure A 11: Inuvik, 2007, Temperature vs. Month, 50 hPa

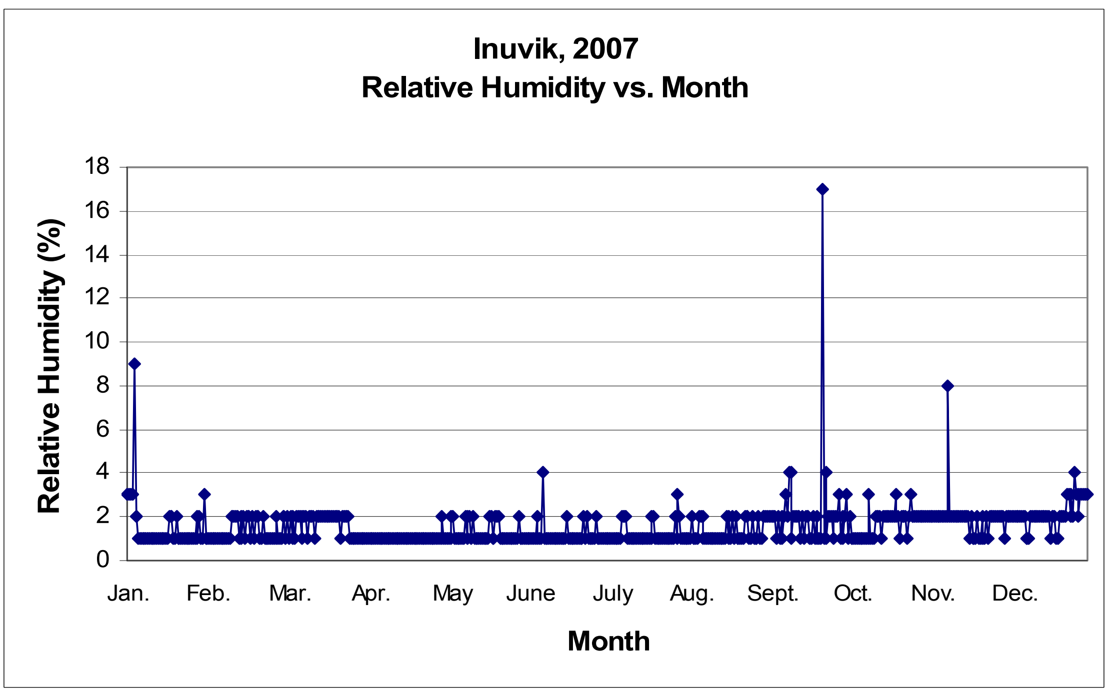

Figure A 12: Inuvik, 2007, Relative Humidity vs. Month, 50 hPa

Iqaluit, 2003

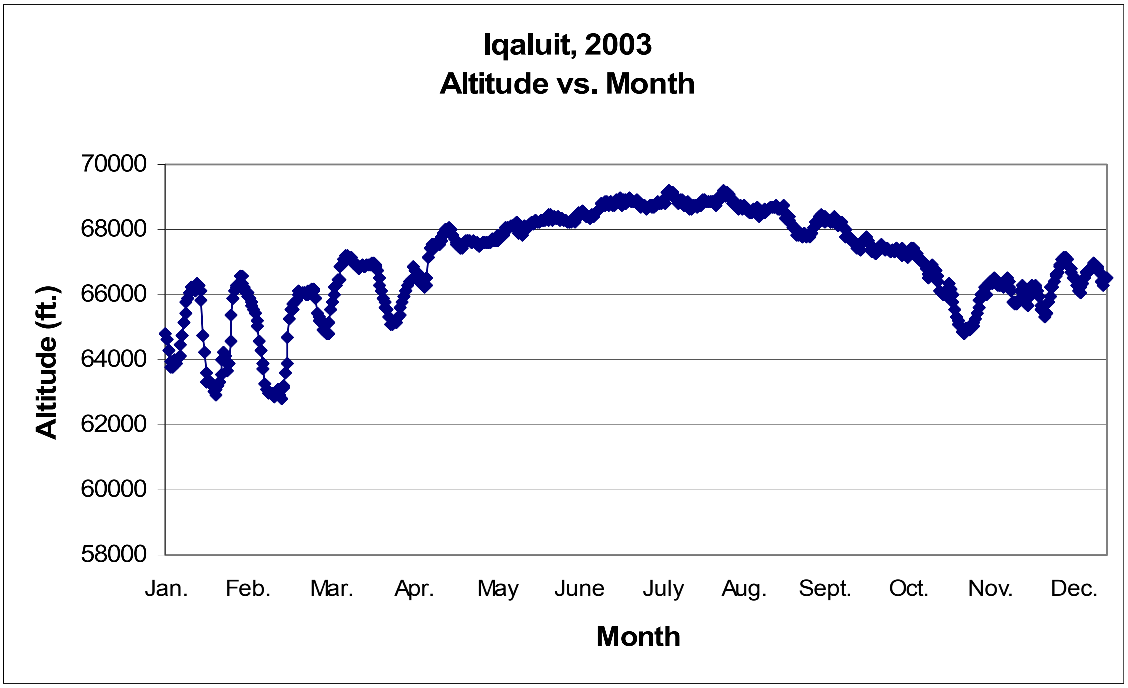

Figure A 13: Iqaluit, 2003, Altitude vs. Month, 50 hPa

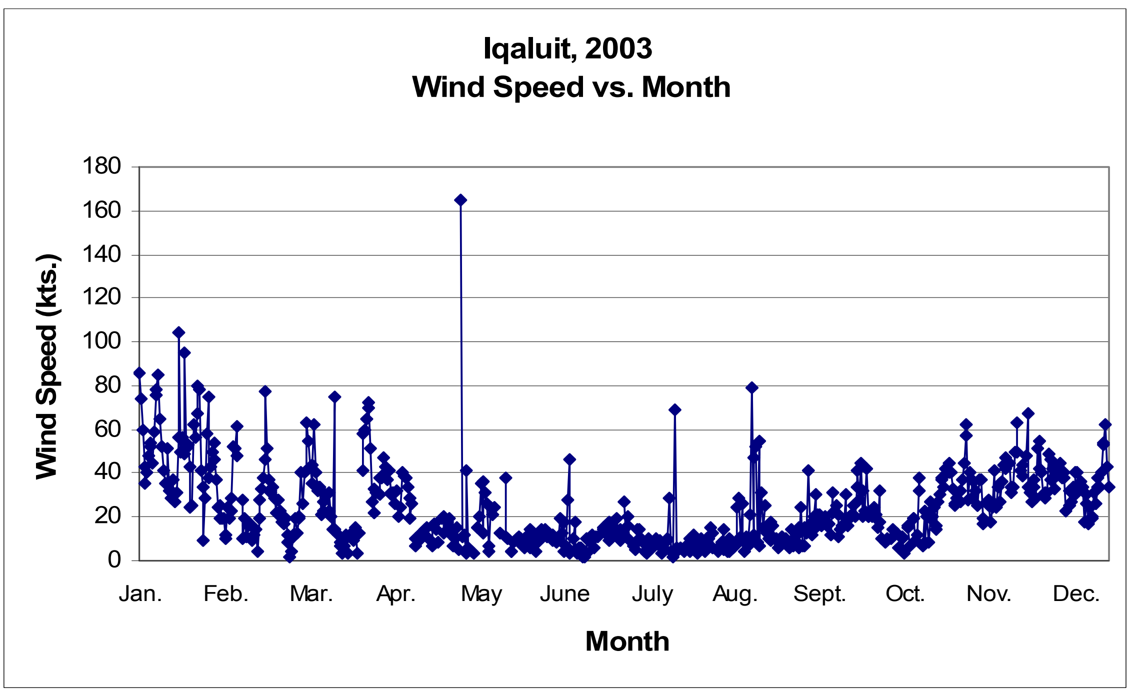

Figure A 14: Iqaluit, 2003, Wind Speed vs. Month, 50 hPa

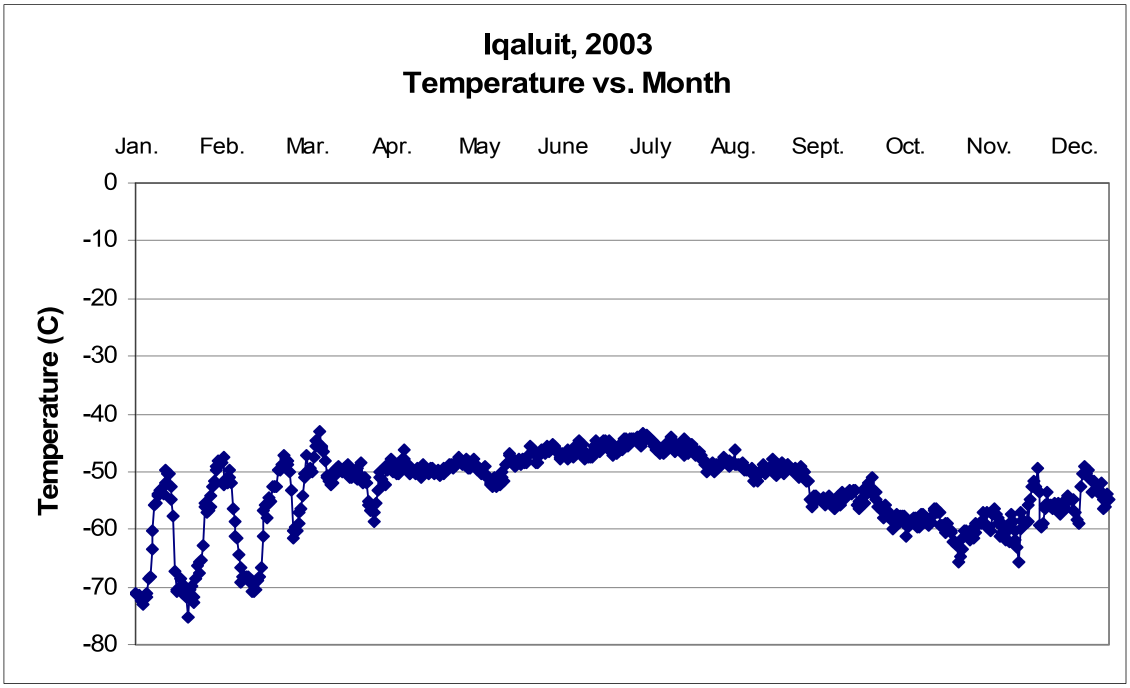

Figure A 15: Iqaluit, 2003, Temperature vs. Month, 50 hPa

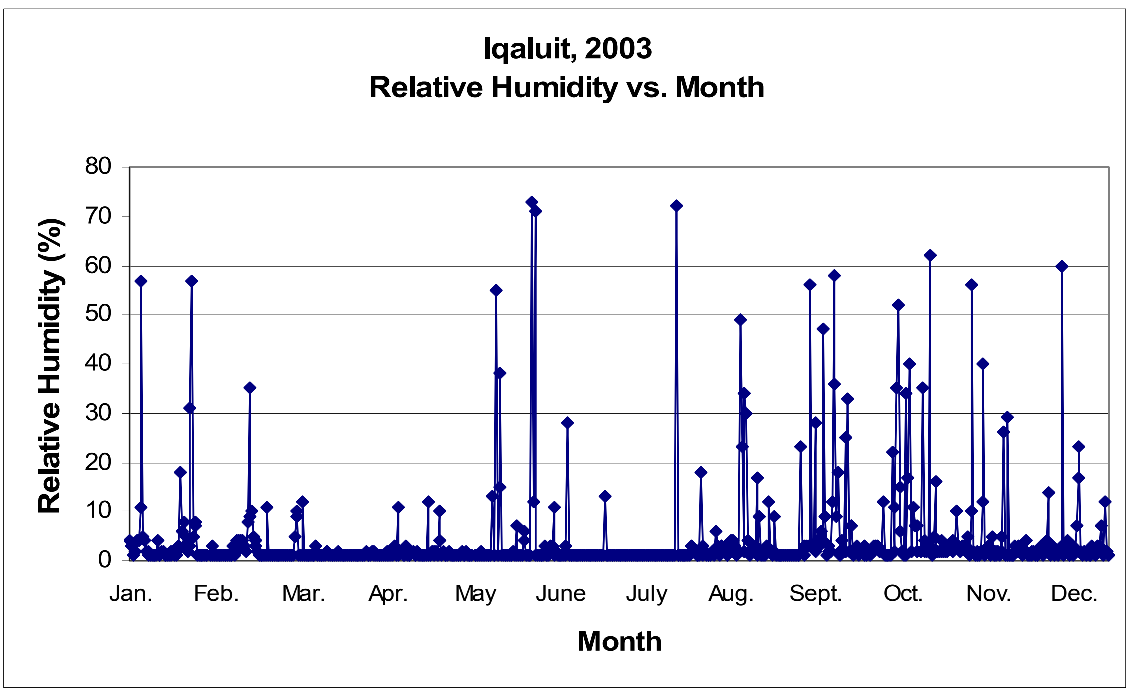

Figure A 16: Iqaluit, 2003, Relative Humidity vs. Month, 50 hPa

Resolute, 2003

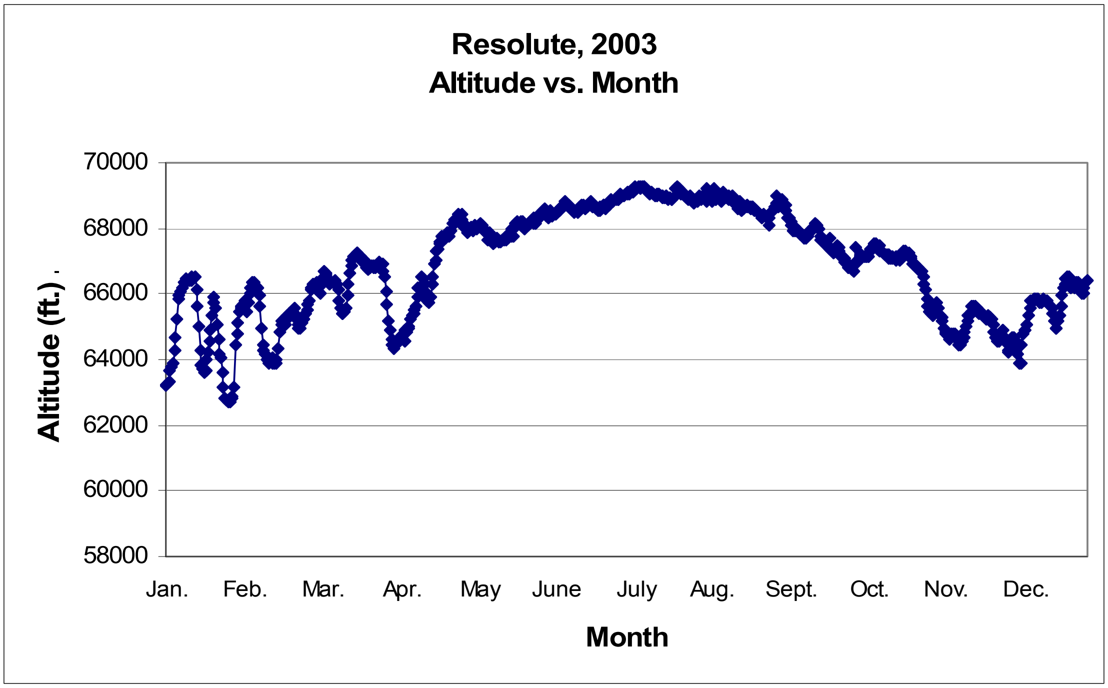

Figure A 17: Resolute, 2003, Altitude vs. Month, 50 hPa

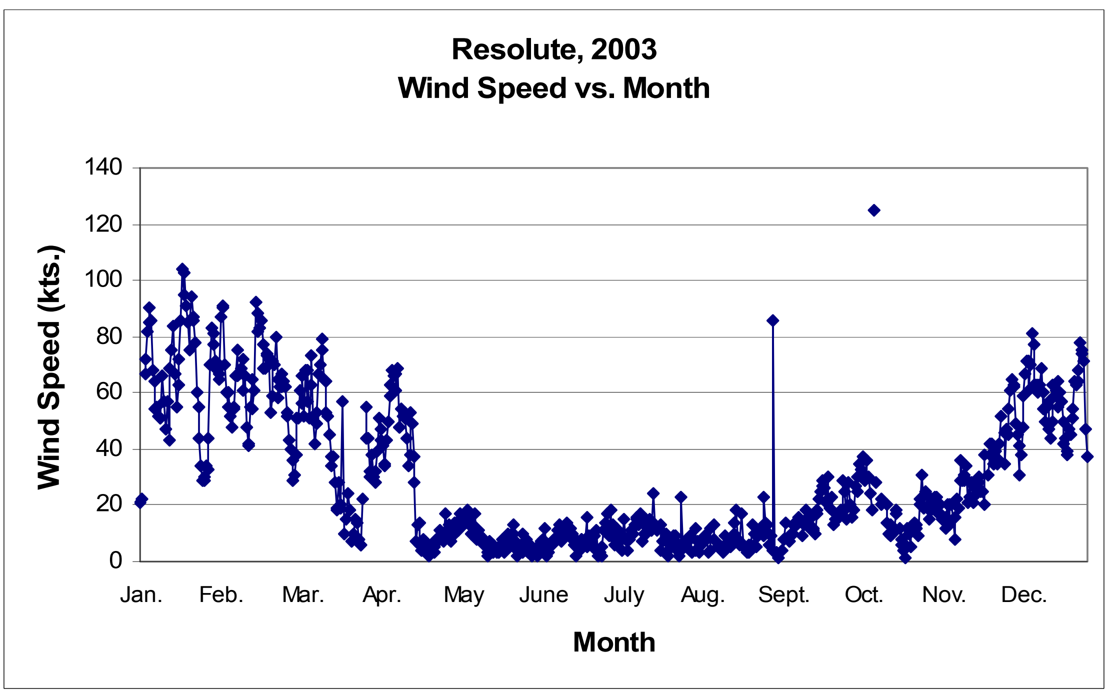

Figure A 18: Resolute, 2003, Wind Speed vs. Month, 50 hPa

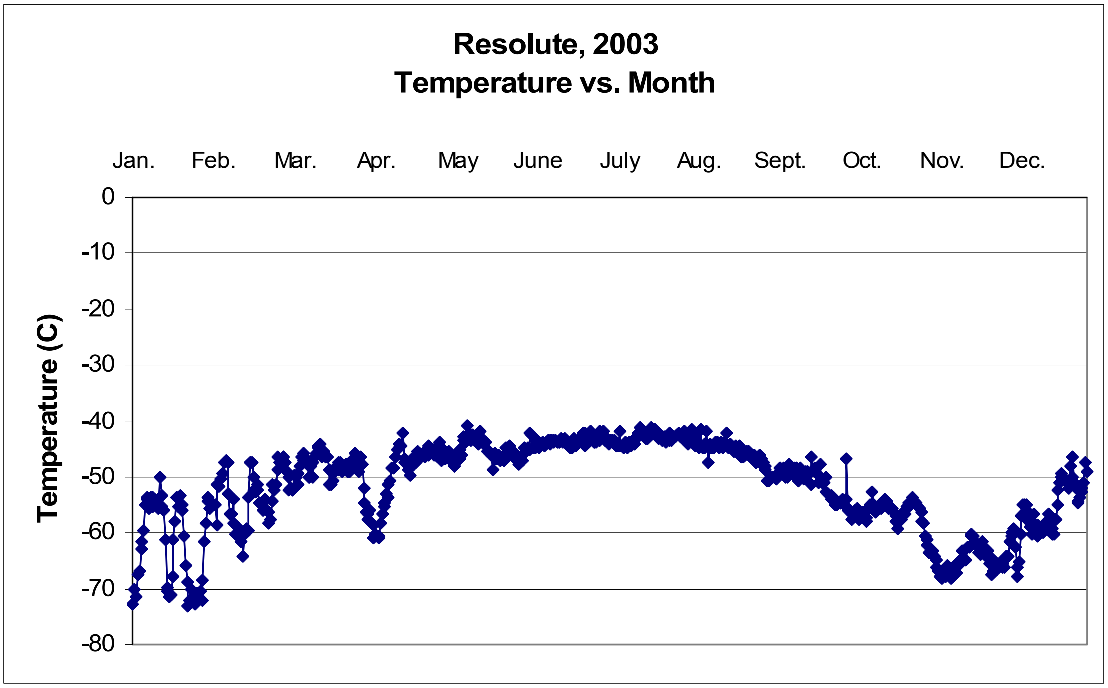

Figure A 19: Resolute, 2003, Temperature vs. Month, 50 hPa

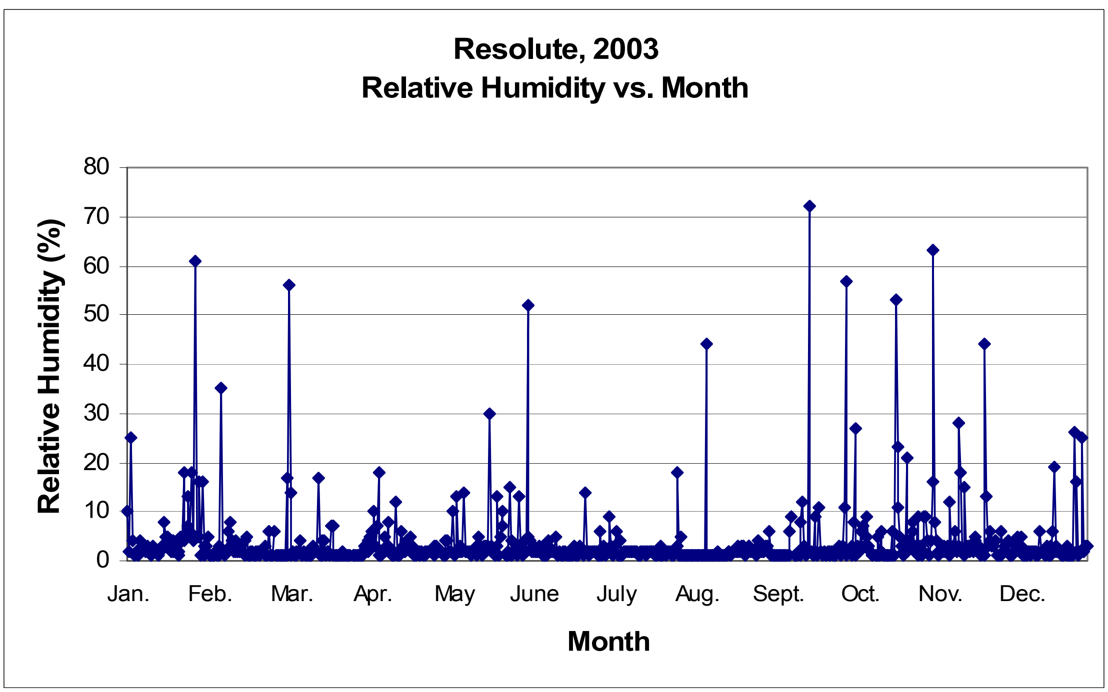

Figure A 20: Resolute, 2003, Relative Humidity vs. Month, 50 hPa

Annex B: Weather Graphs from the Ground Up

Baker Lake, 2007 May 21

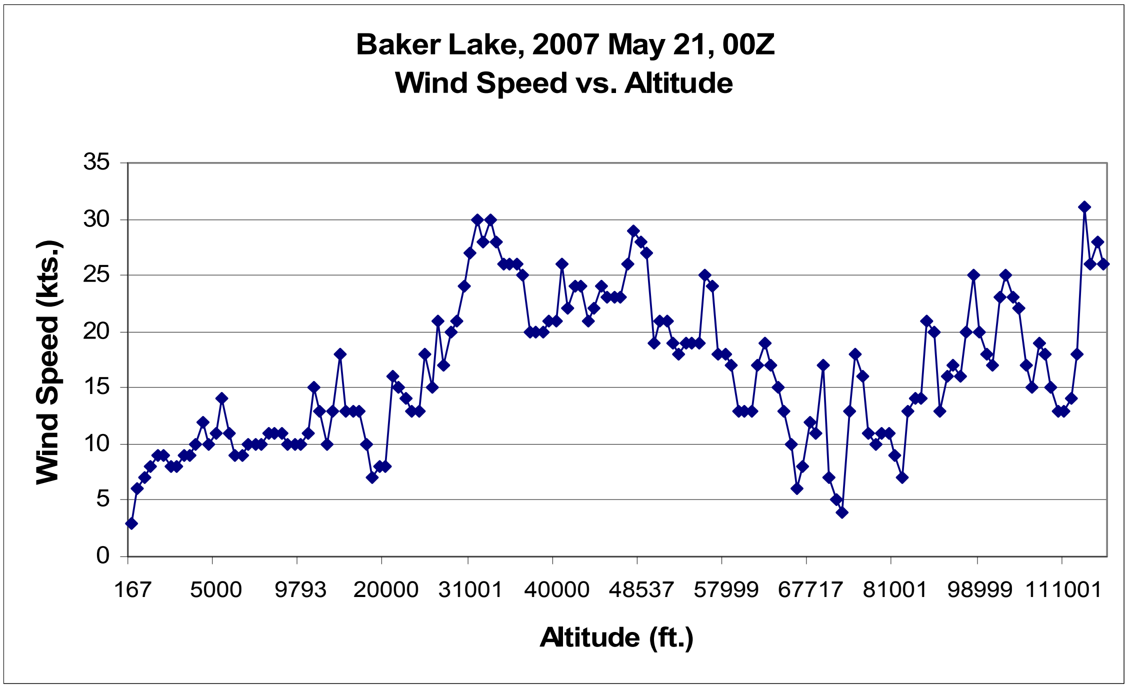

Figure B 1: Baker Lake, 2007 May 21 00Z, Wind Speed vs. Altitude

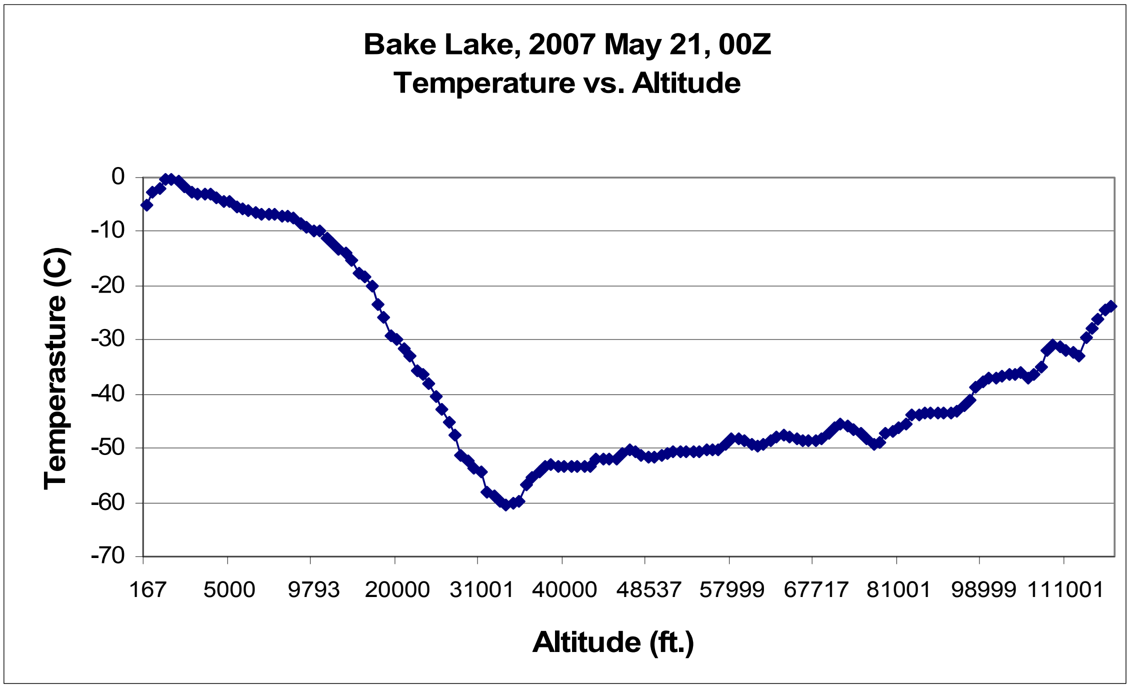

Figure B 2: Baker Lake, 2007 May 21 00Z, Temperature vs. Altitude

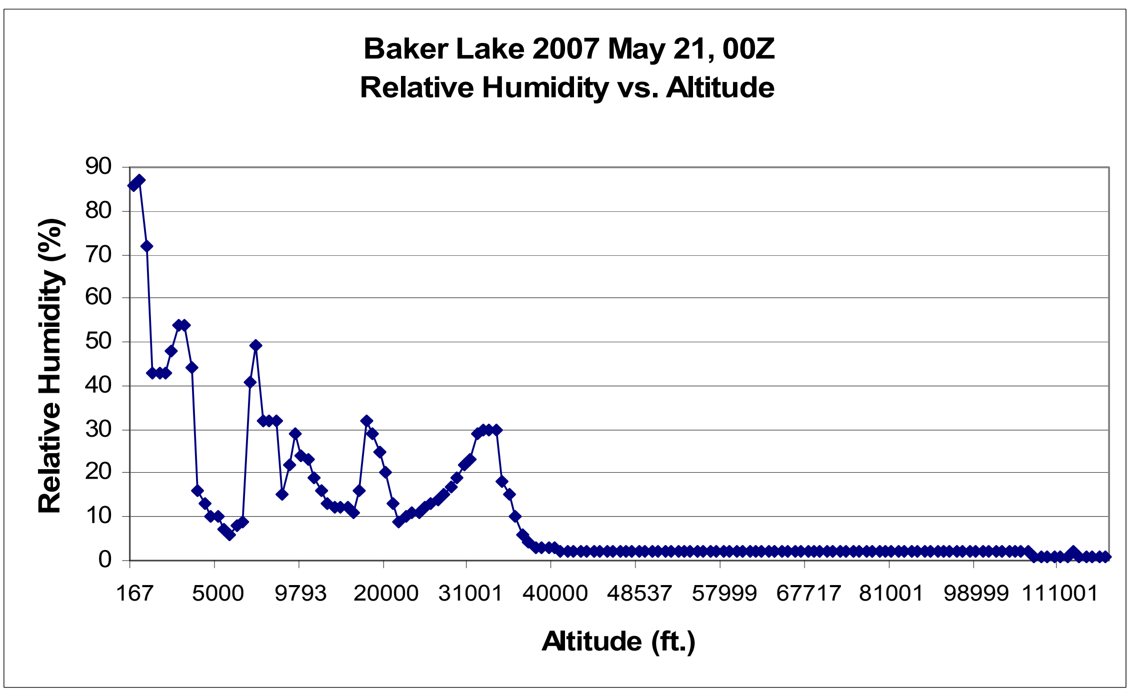

Figure B 3: Baker Lake, 2007 May 21 00Z, Relative Humidity vs. Altitude

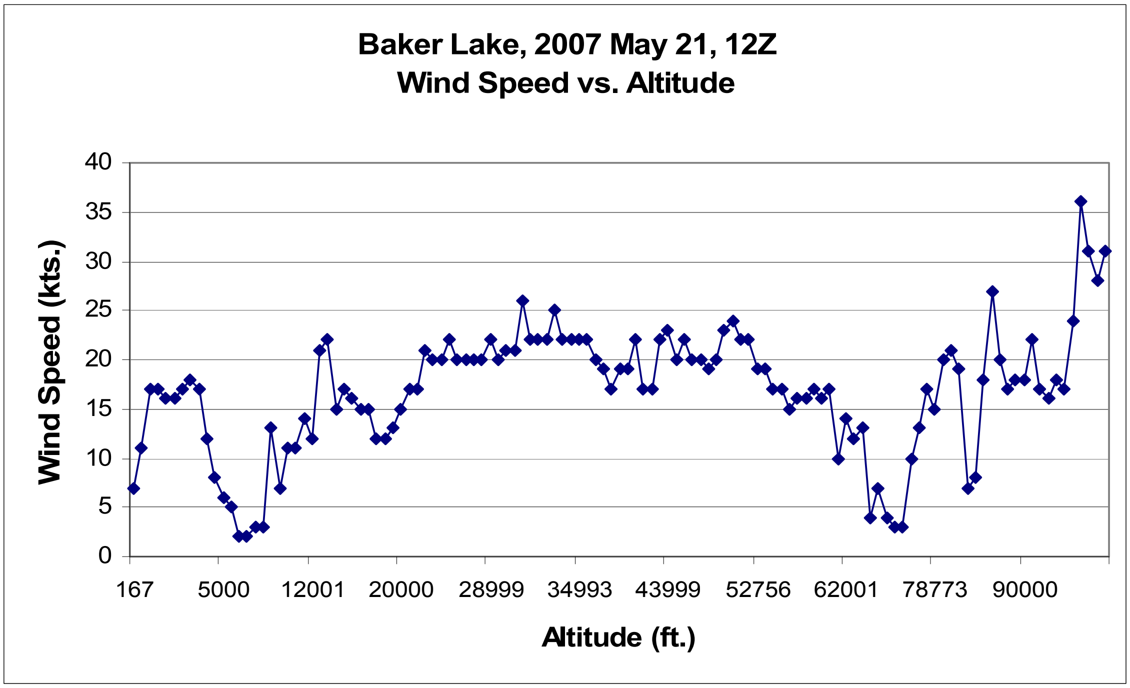

Figure B 4: Baker Lake, 2007 May 21 12Z, Wind Speed vs. Altitude

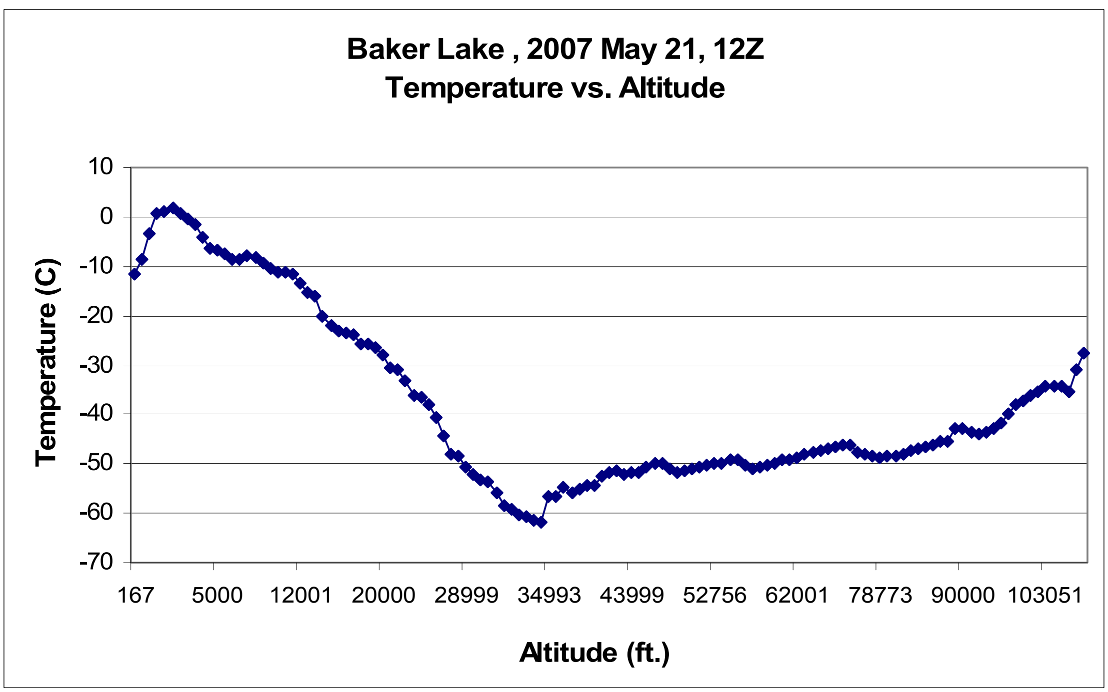

Figure B 5: Baker Lake, 2007 May 21 12Z, Temperature vs. Altitude

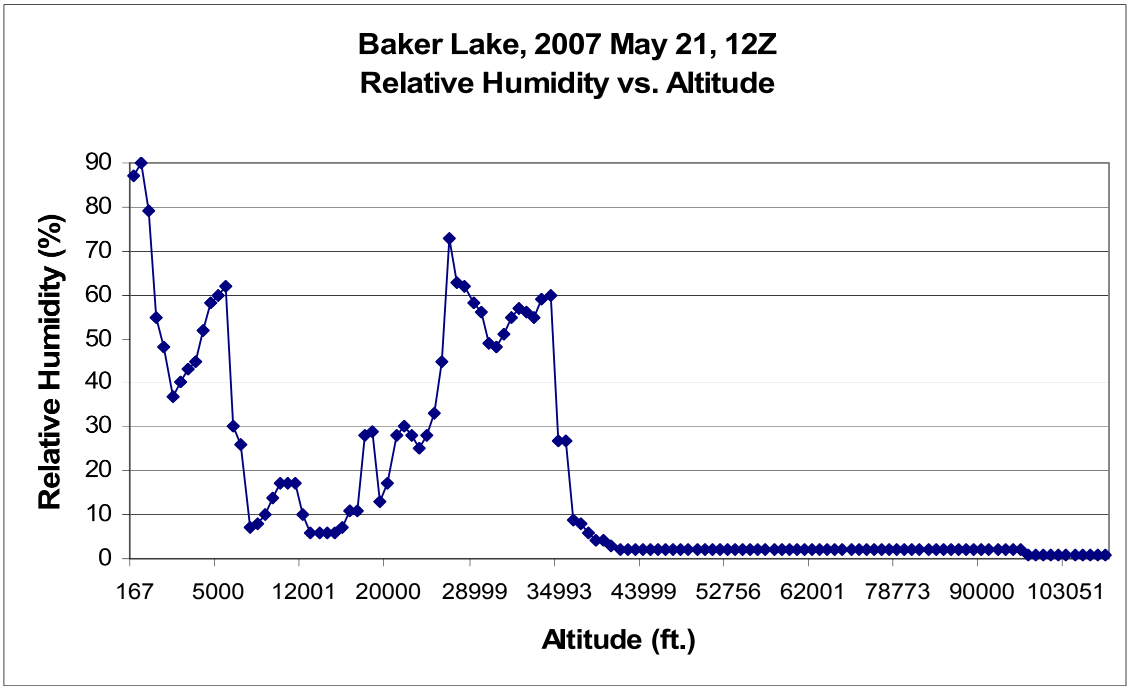

Figure B 6: Baker Lake, 2007 May 21 12Z, Relative Humidity vs. Altitude

Coral Harbour, 2007 April 28

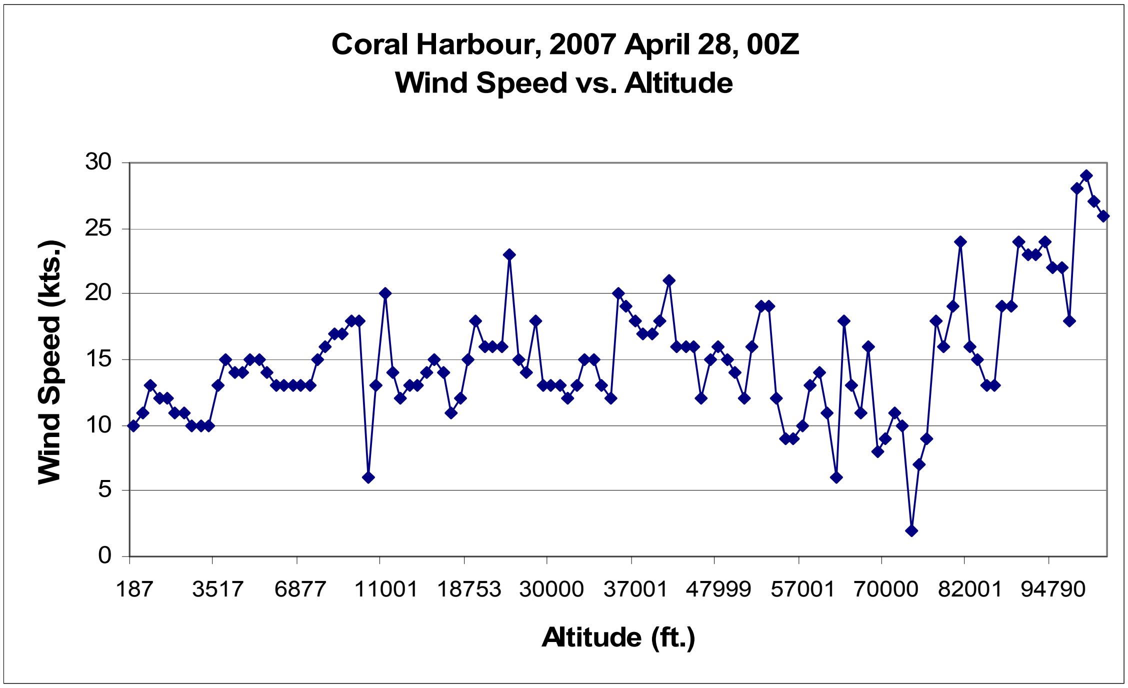

Figure B 7: Coral Harbour, 2007 April 28 00Z, Wind Speed vs. Altitude

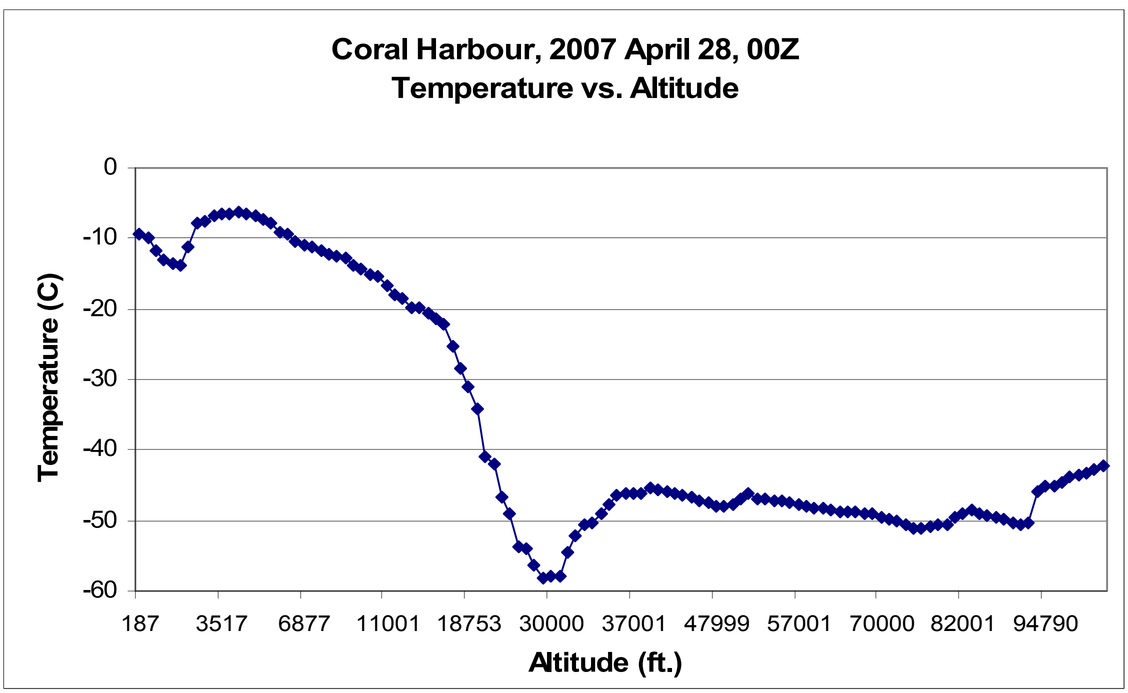

Figure B 8: Coral Harbour, 2007 April 28 00Z, Temperature vs. Altitude

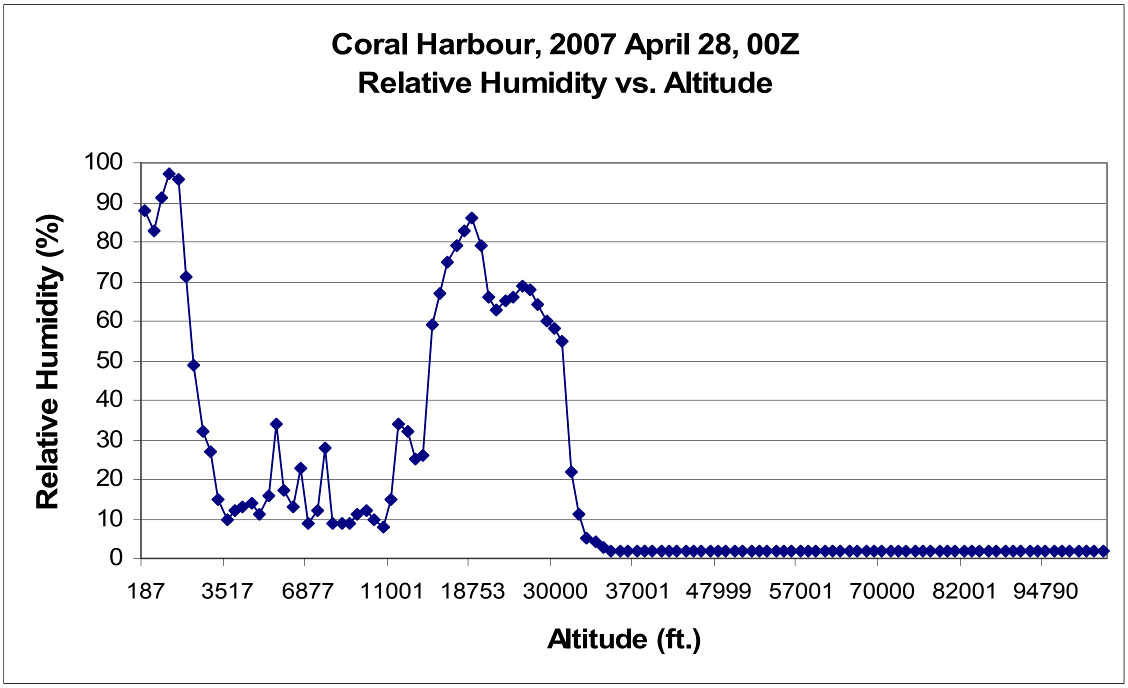

Figure B 9: Coral Harbour, 2007 April 28 00Z, Relative Humidity vs. Altitude

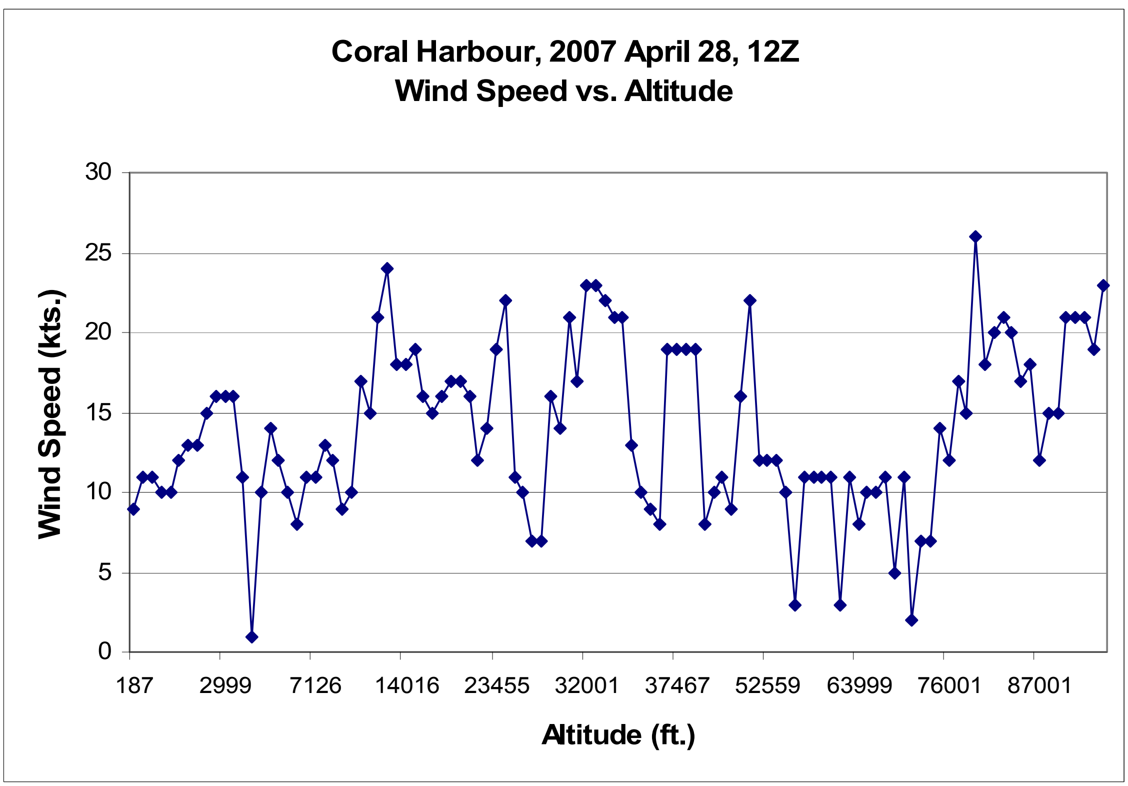

Figure B 10: Coral Harbour, 2007 April 28 12Z, Wind Speed vs. Altitude

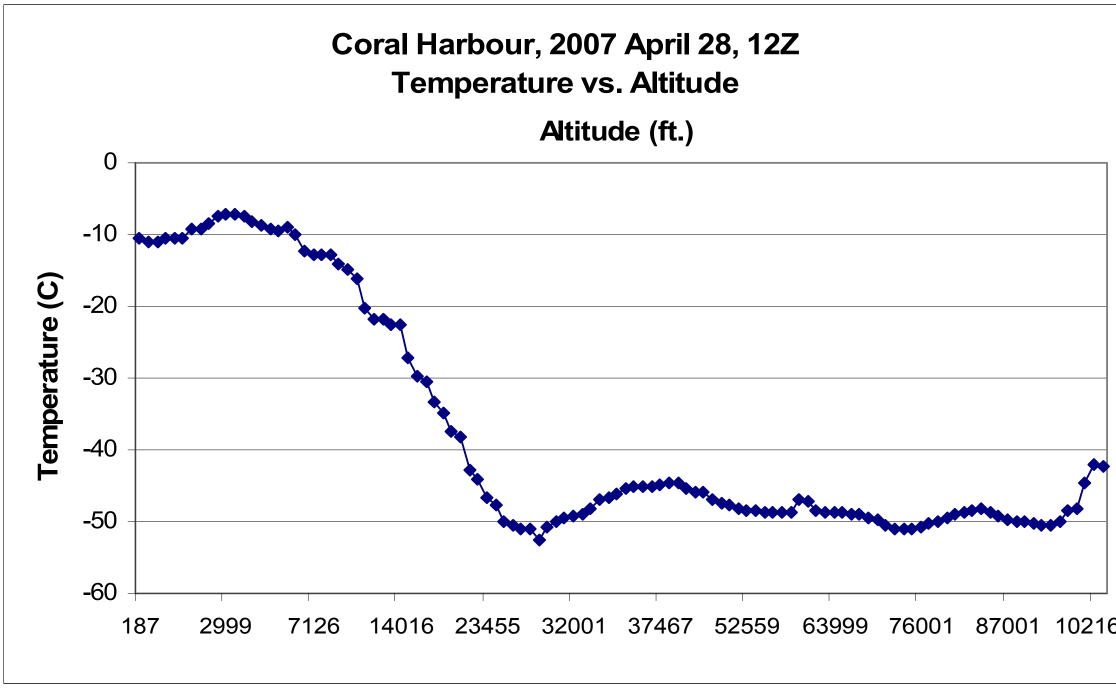

Figure B 11: Coral Harbour, 2007 April 28 12Z, Temperature vs. Altitude

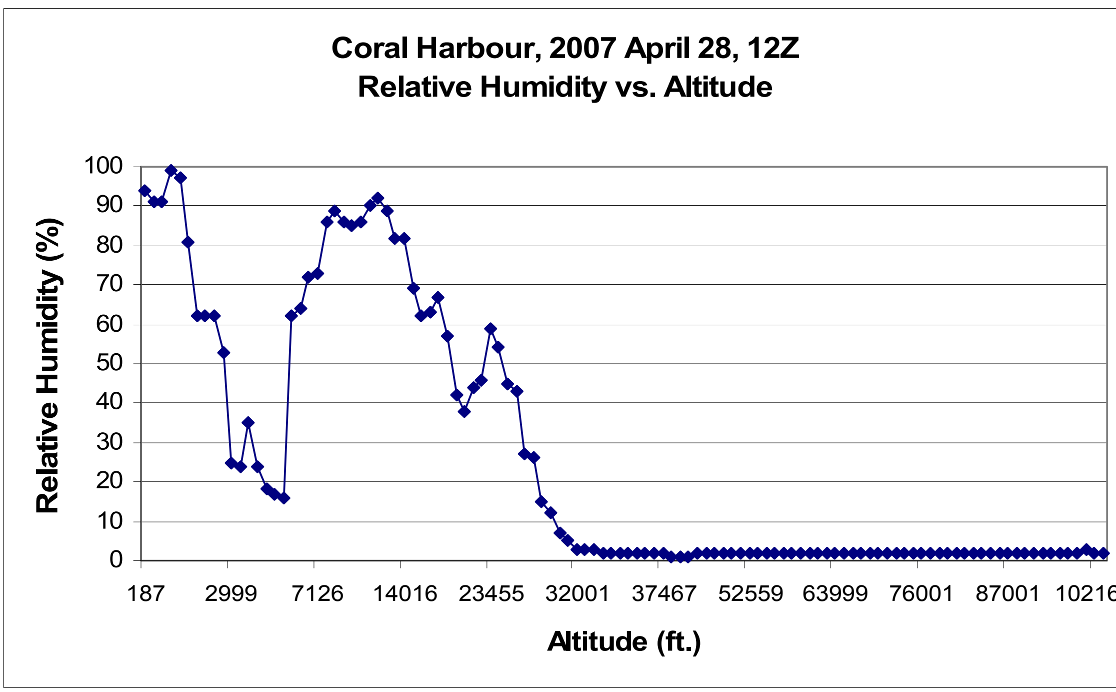

Figure B 12: Coral Harbour, 2007 April 28 12Z, Relative Humidity vs. Altitude

Coral Harbour, 2007 May 1

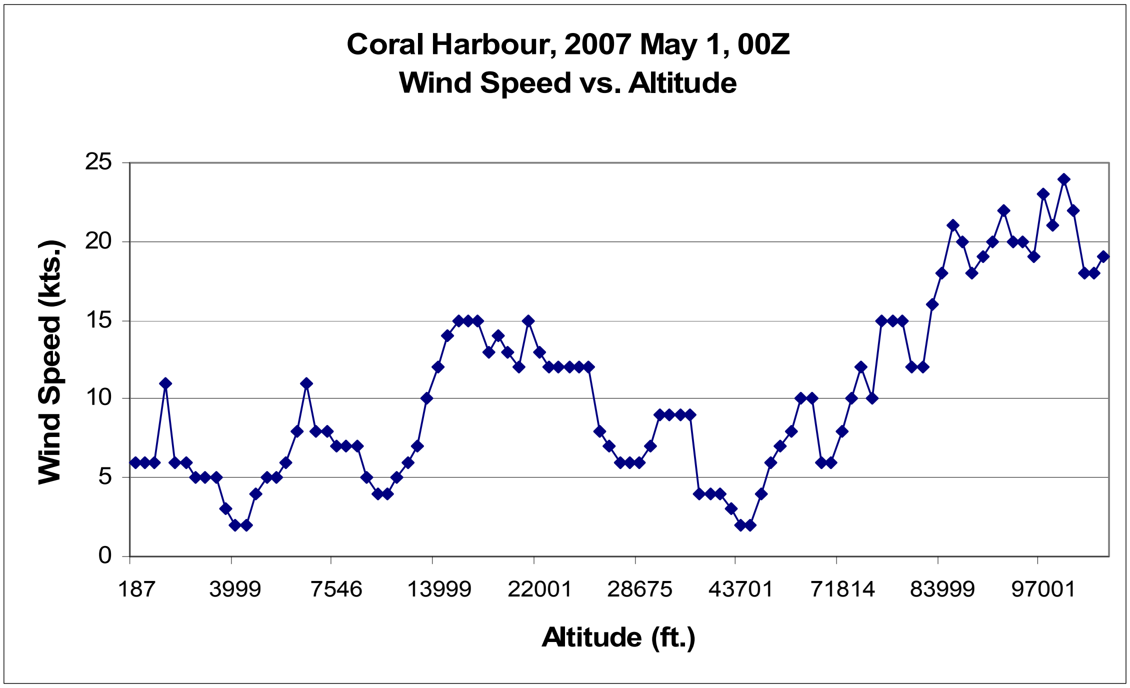

Figure B 13: Coral Harbour, 2007 May 1 00Z, Wind Speed vs. Altitude

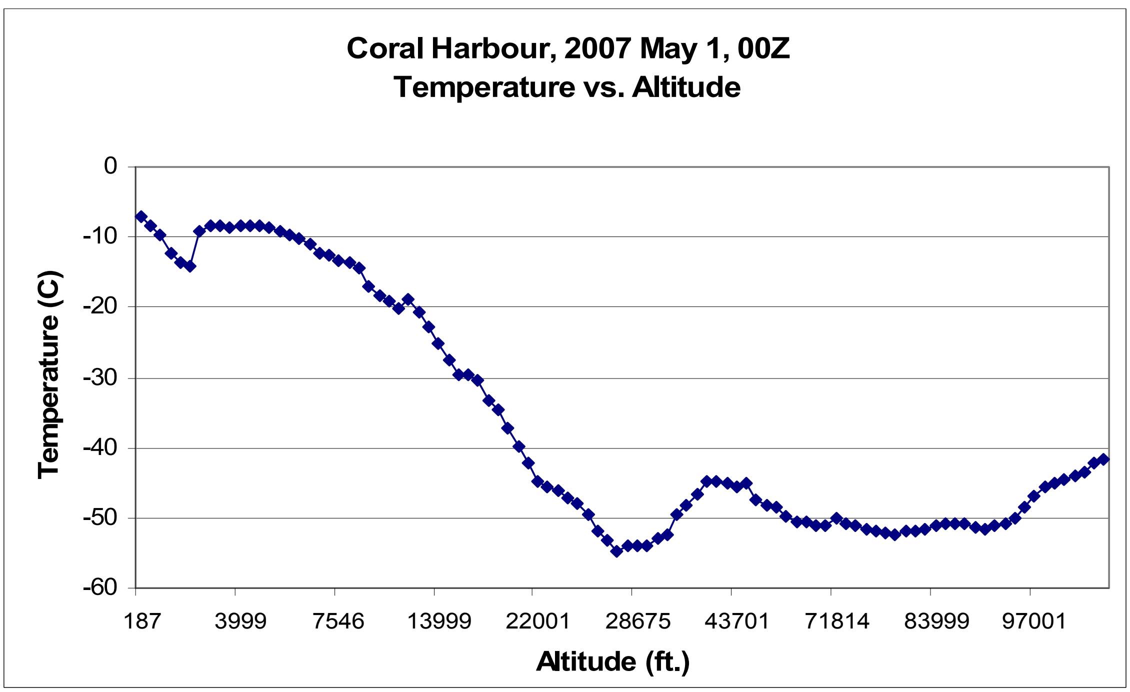

Figure B 14: Coral Harbour, 2007 May 1 00Z, Temperature vs. Altitude

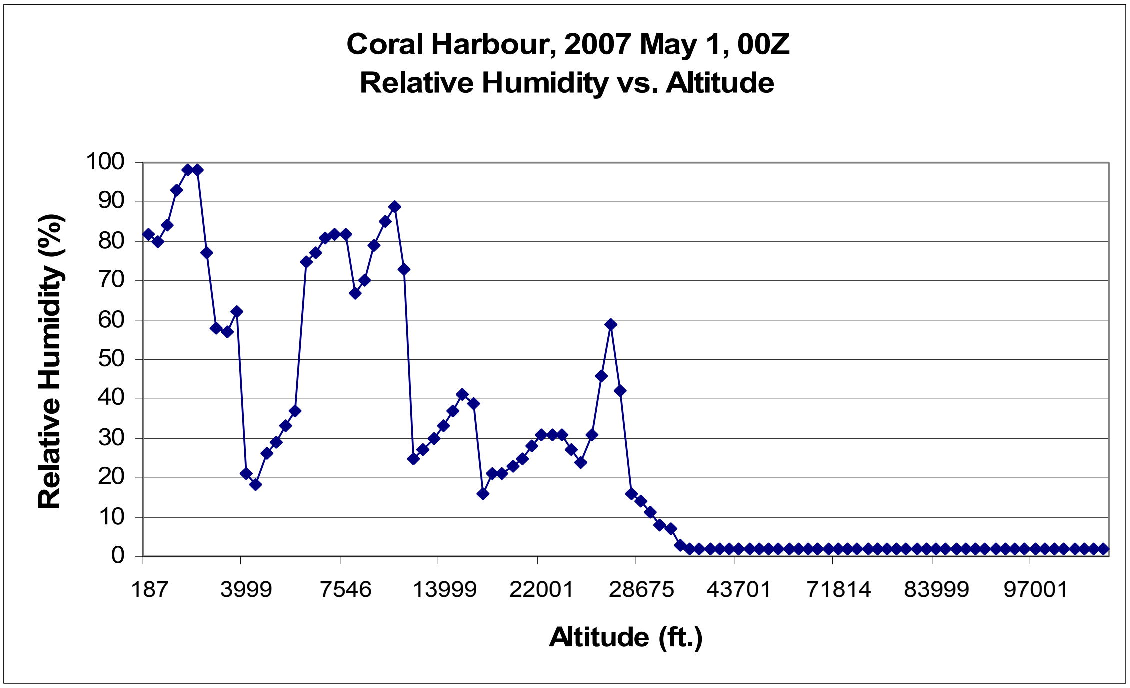

Figure B 15: Coral Harbour, 2007 May 1 00Z, Relative Humidity vs. Altitude

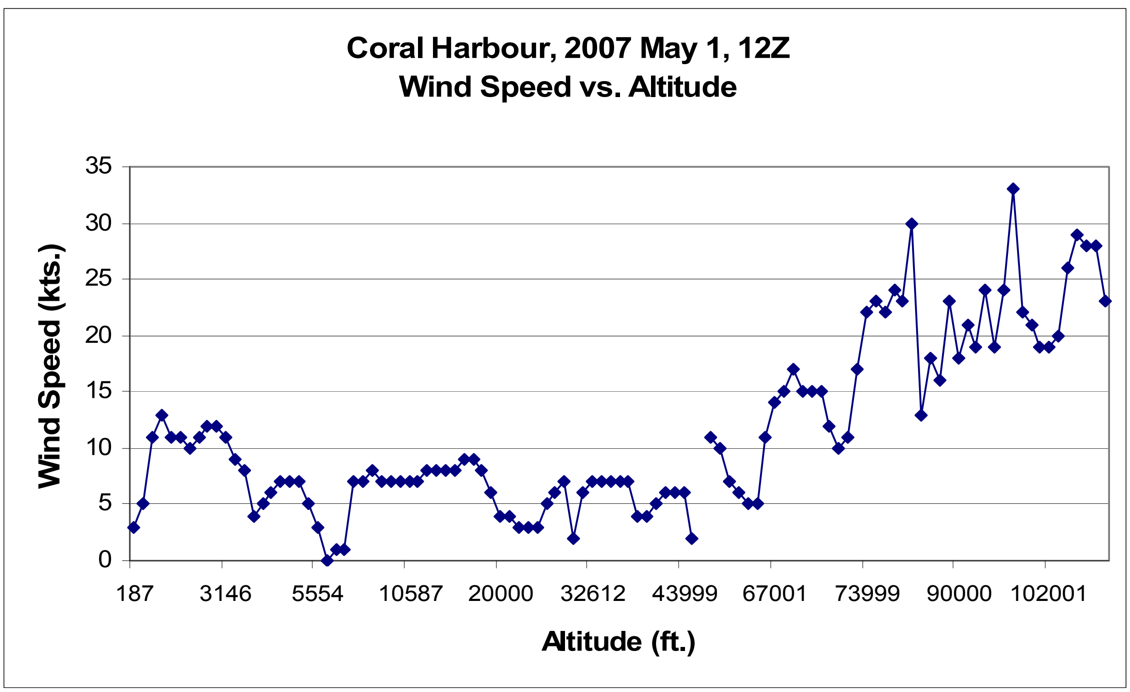

Figure B 16: Coral Harbour, 2007 May 1 12Z, Wind Speed vs. Altitude

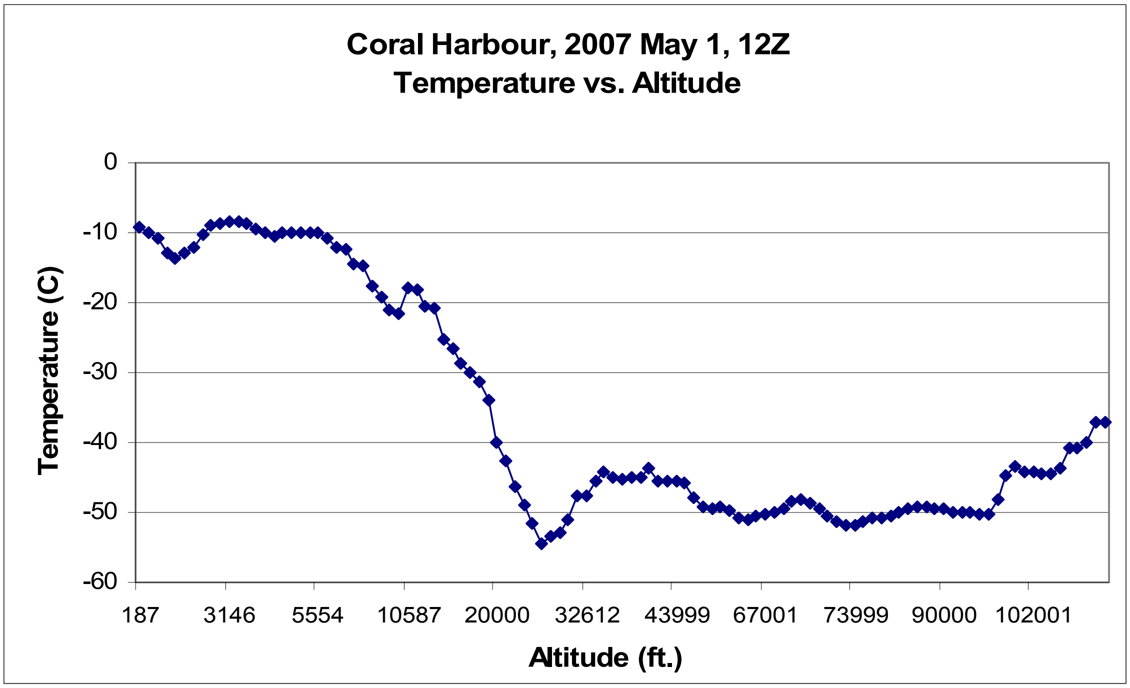

Figure B 17: Coral Harbour, 2007 May 1 12Z, Temperature vs. Altitude

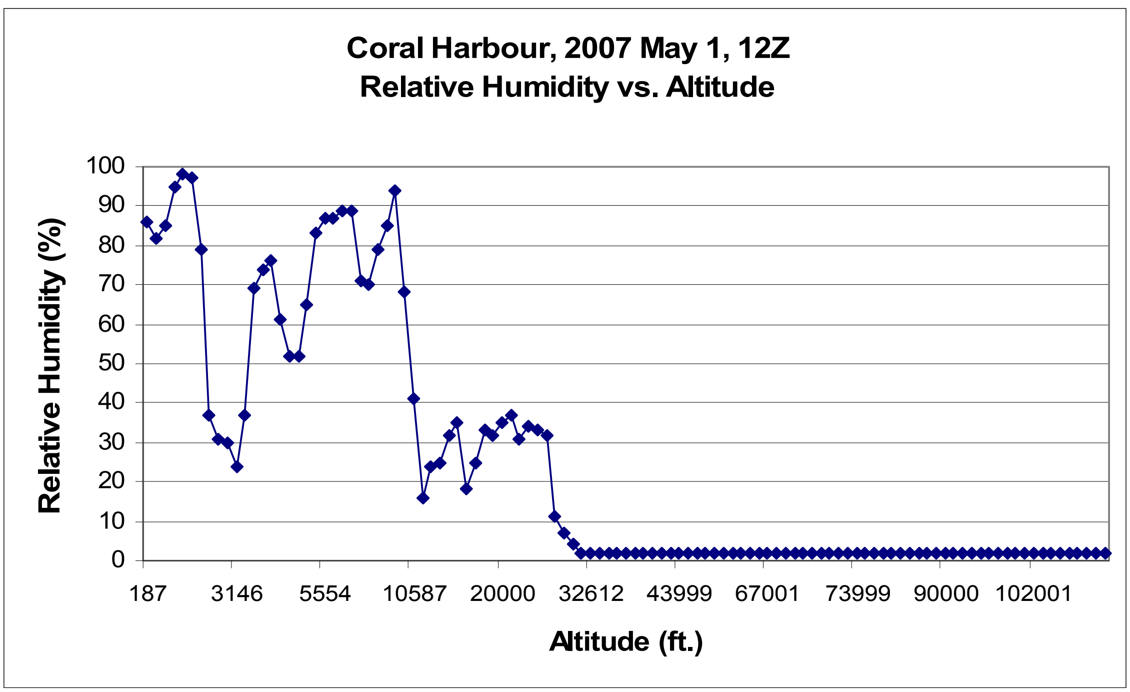

Figure B 18: Coral Harbour, 2007 May 1 12Z, Relative Humidity vs. Altitude

Fort Nelson, 2007 April 17

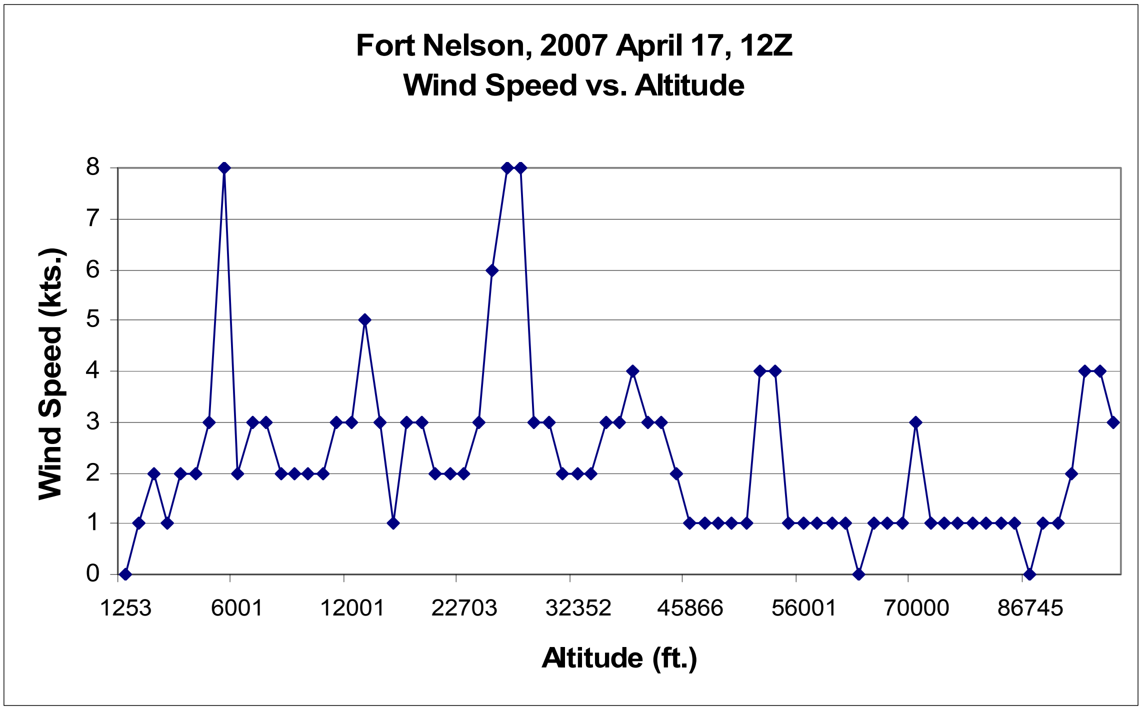

Figure B 19: Fort Nelson, 2007 April 17 12Z, Wind Speed vs. Altitude

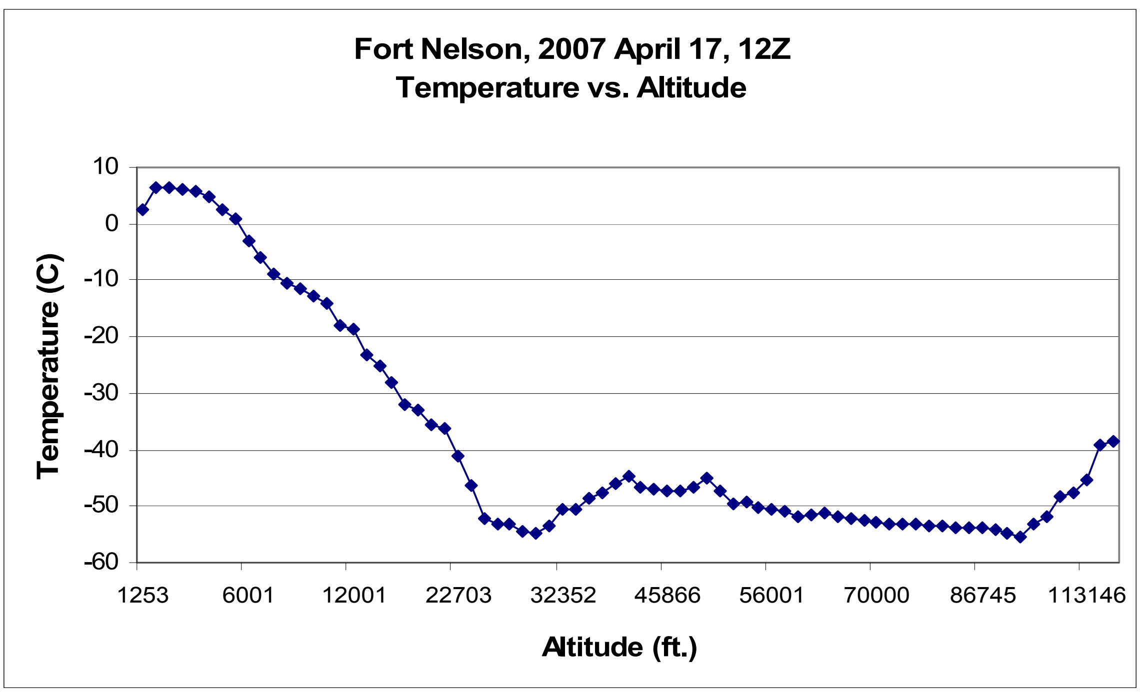

Figure B 20: Fort Nelson, 2007 April 17 12Z, Temperature vs. Altitude

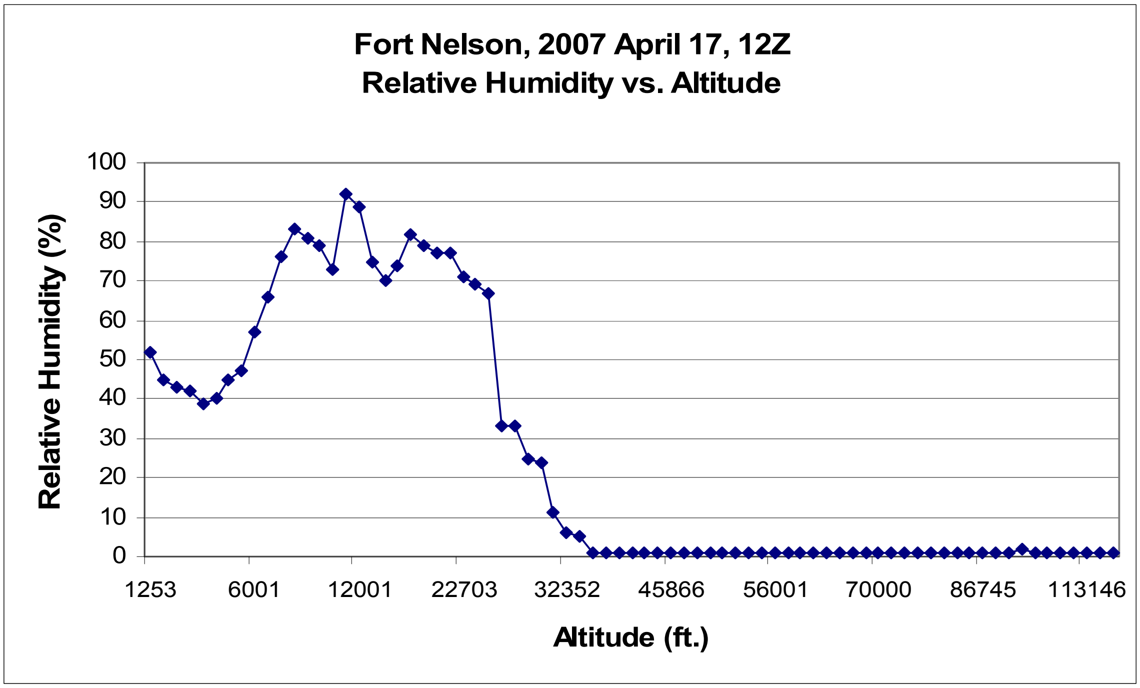

Figure B 21: Fort Nelson, 2007 April 17 12Z, Relative Humidity vs. Altitude

Fort Nelson, 2007 April 18

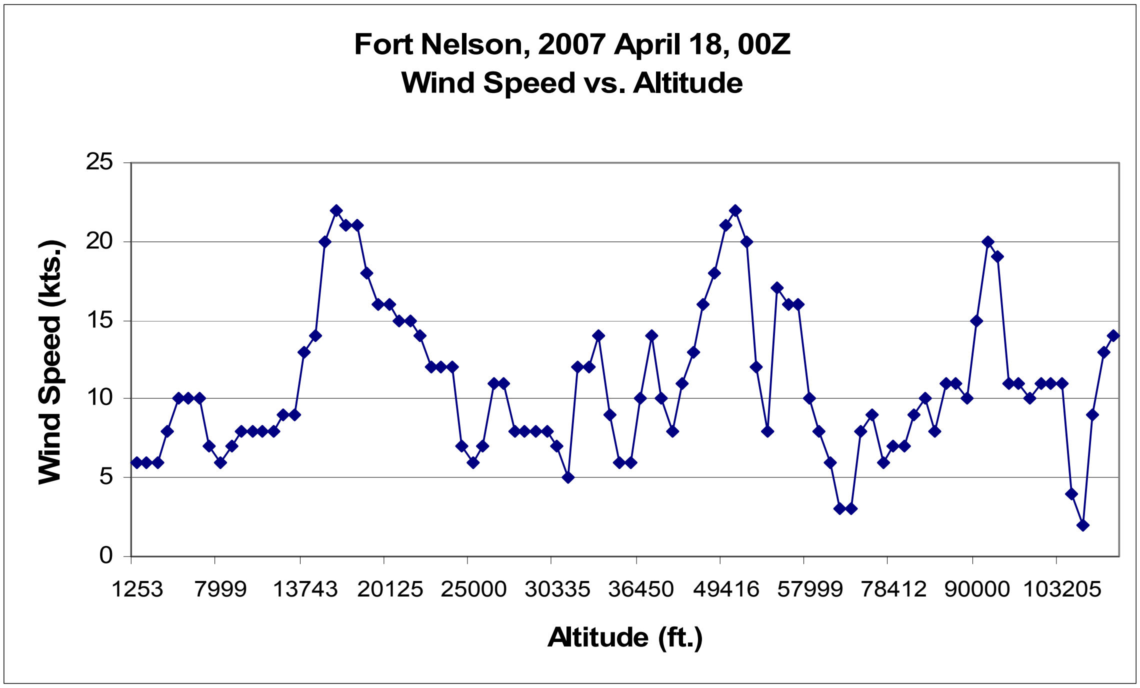

Figure B 22: Fort Nelson, 2007 April 18 00Z, Wind Speed vs. Altitude

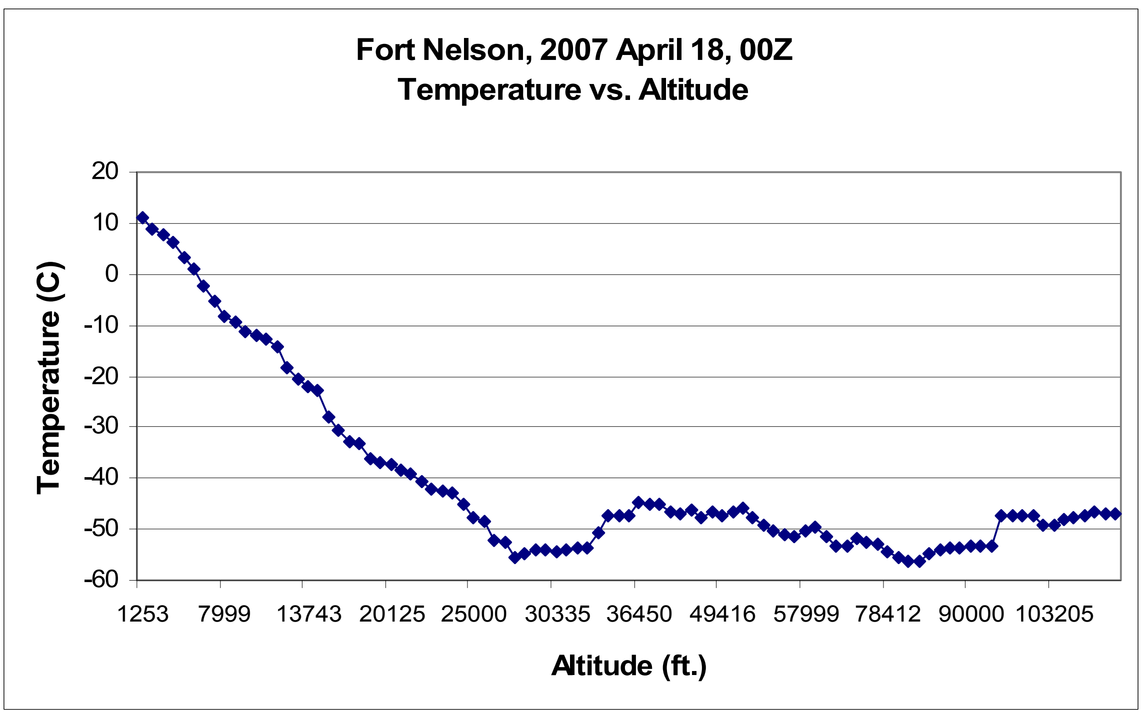

Figure B 23: Fort Nelson, 2007 April 18 00Z, Temperature vs. Altitude

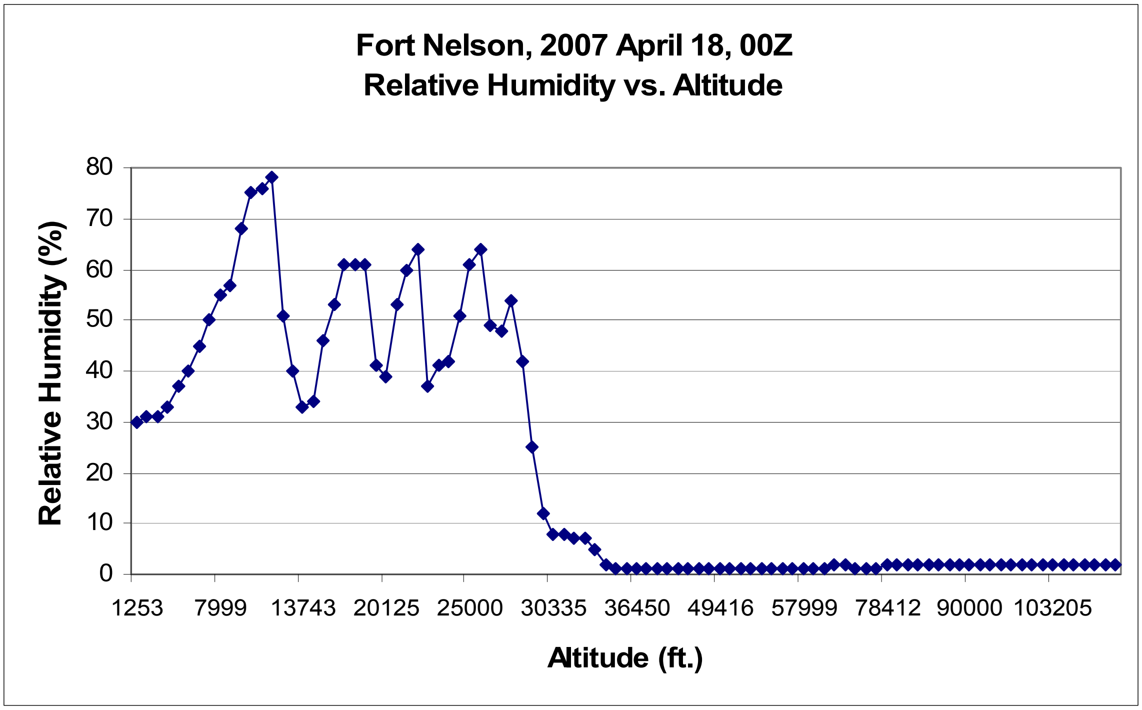

Figure B 24: Fort Nelson, 2007 April 18 00Z, Relative Humidity vs. Altitude

Fort Nelson, 2007 May 7

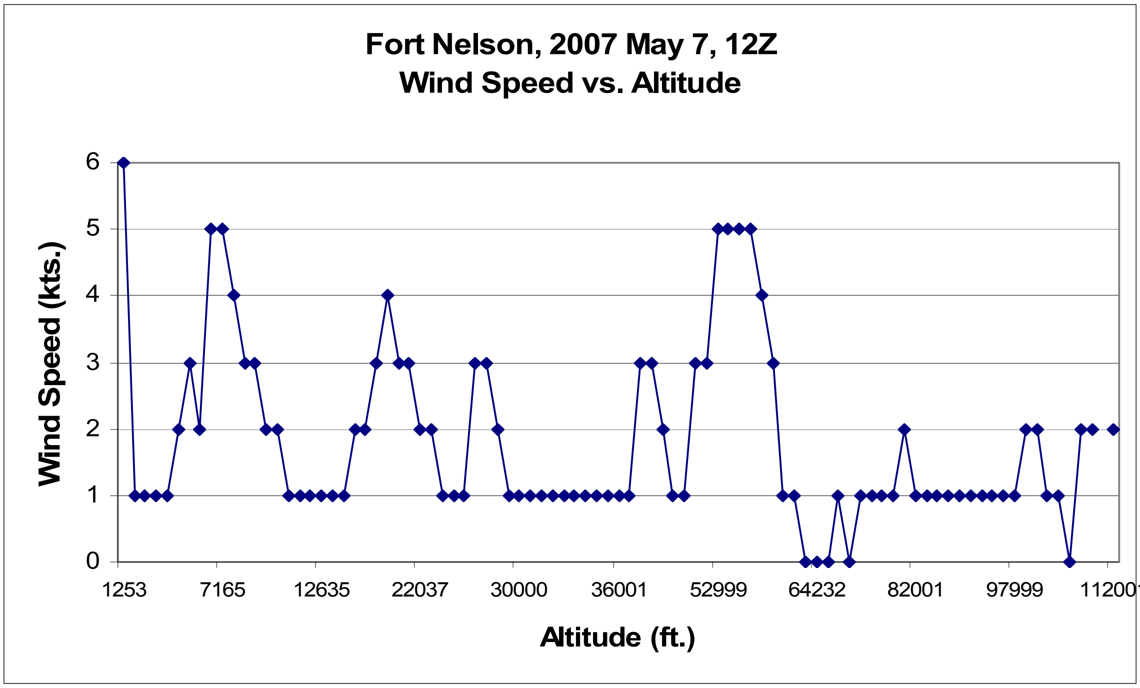

Figure B 25: Fort Nelson, 2007 May 7 12Z, Wind Speed vs. Altitude

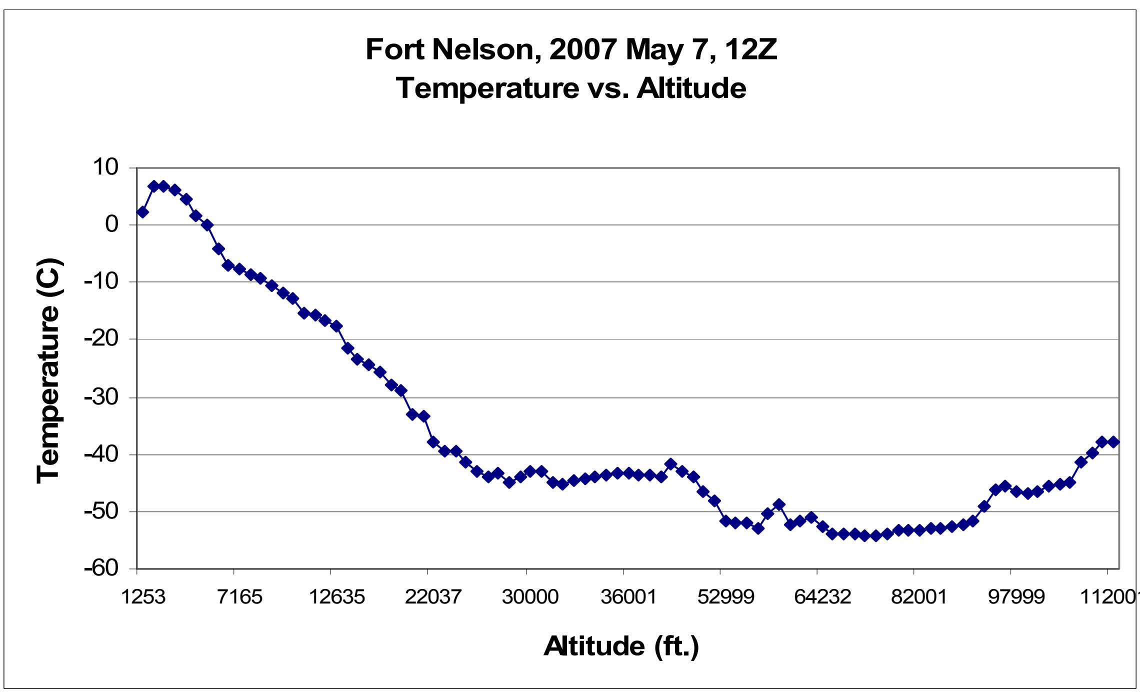

Figure B 26: Fort Nelson, 2007 May 7 12Z, Temperature vs. Altitude

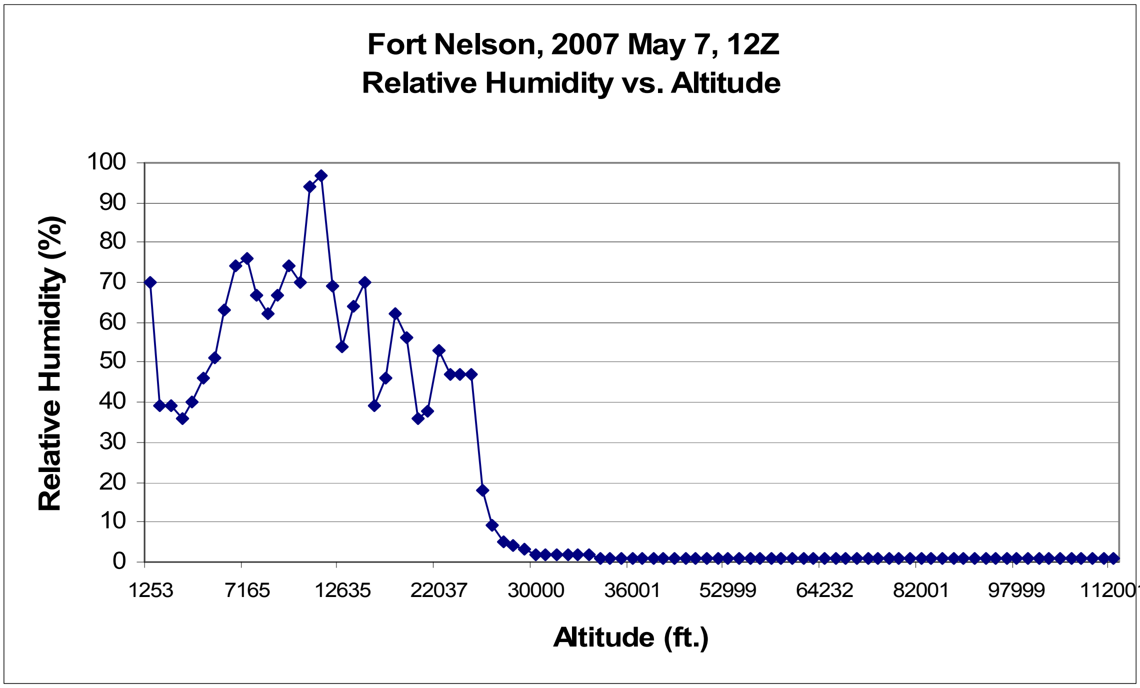

Figure B 27: Fort Nelson, 2007 May 7 12Z, Relative Humidity vs. Altitude

Resolute, 2007 May 30

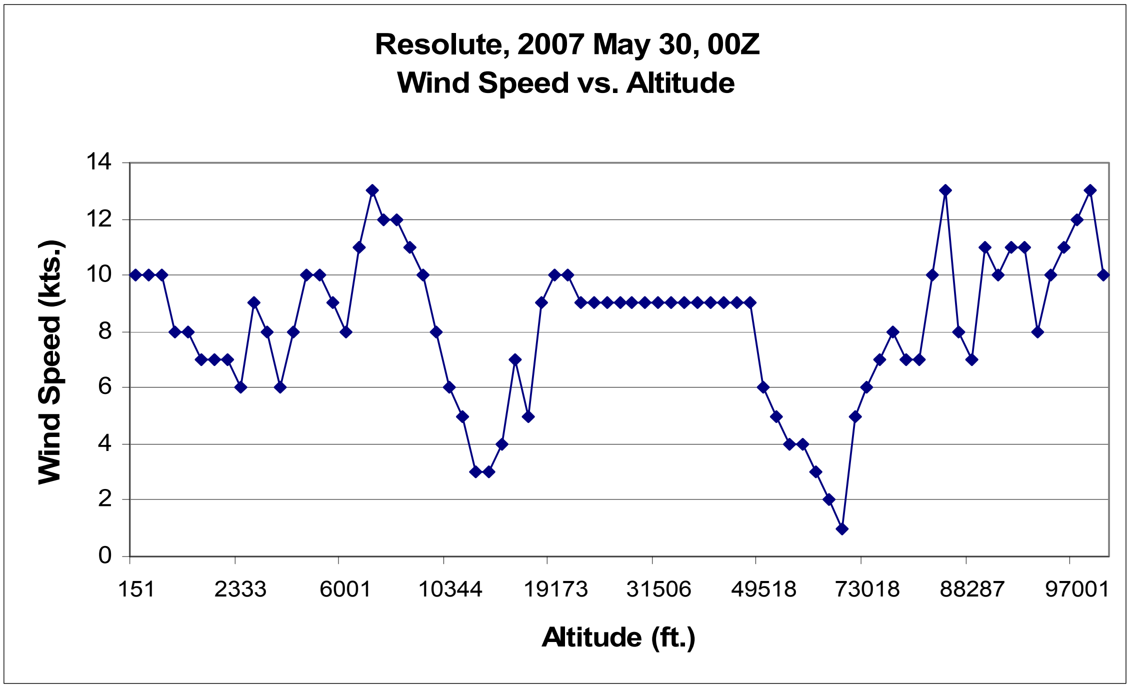

Figure B 28: Resolute, 2007 May 30 00Z, Wind Speed vs. Altitude

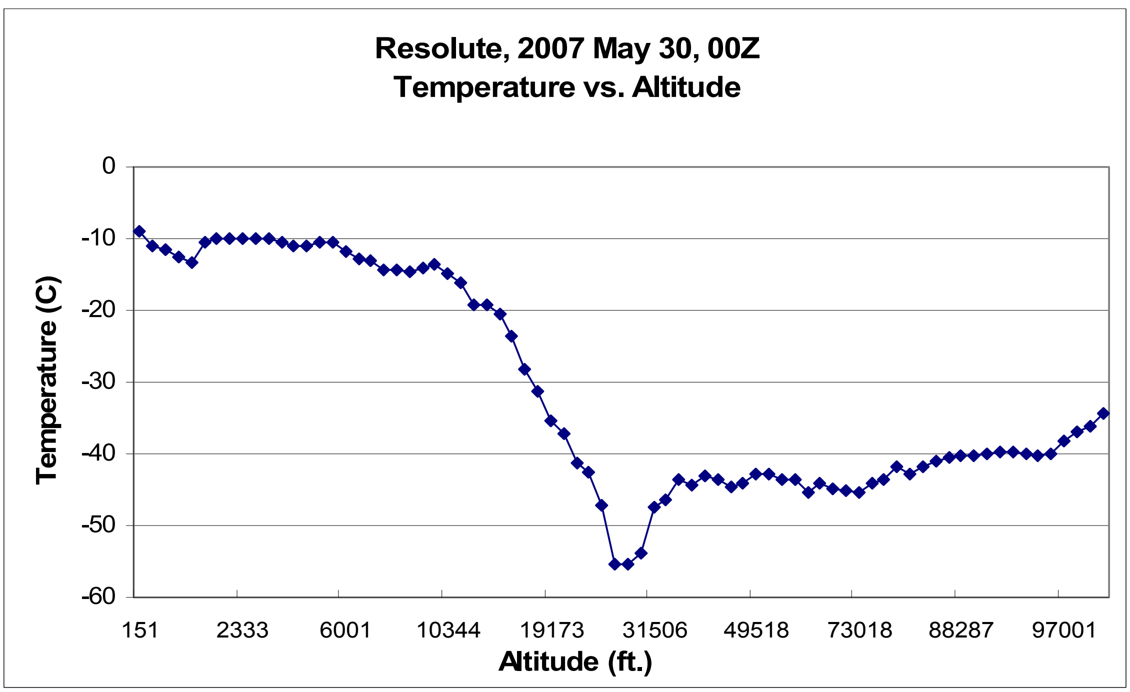

Figure B 29: Resolute, 2007 May 30 00Z, Temperature vs. Altitude

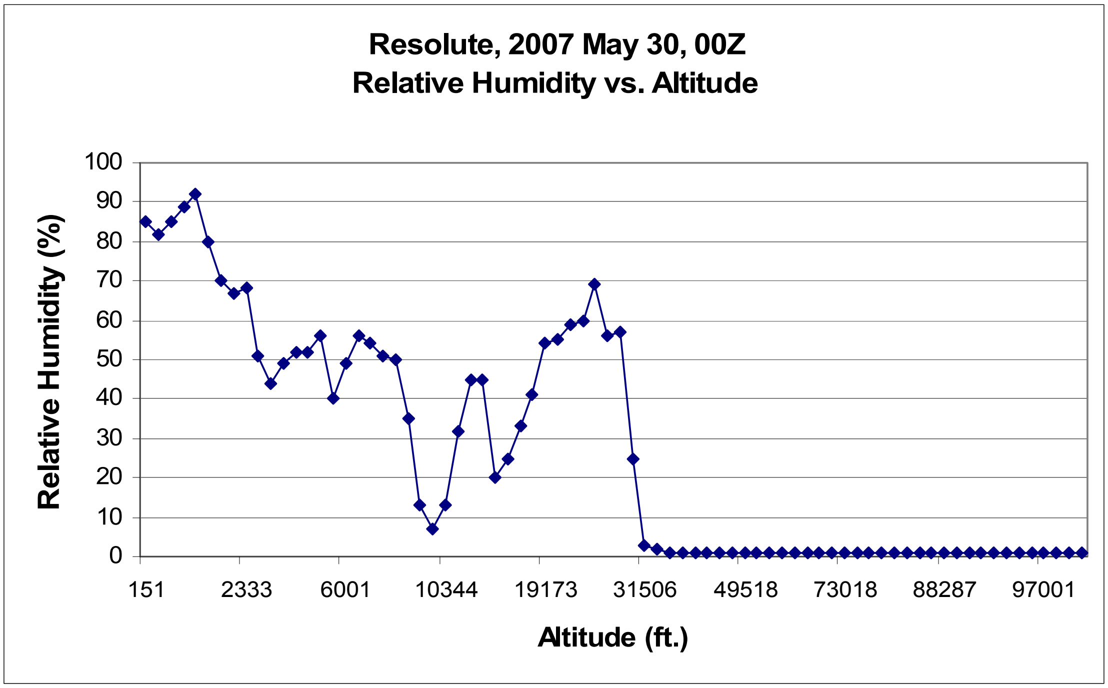

Figure B 30: Resolute, 2007 May 30 00Z, Relative Humidity vs. Altitude

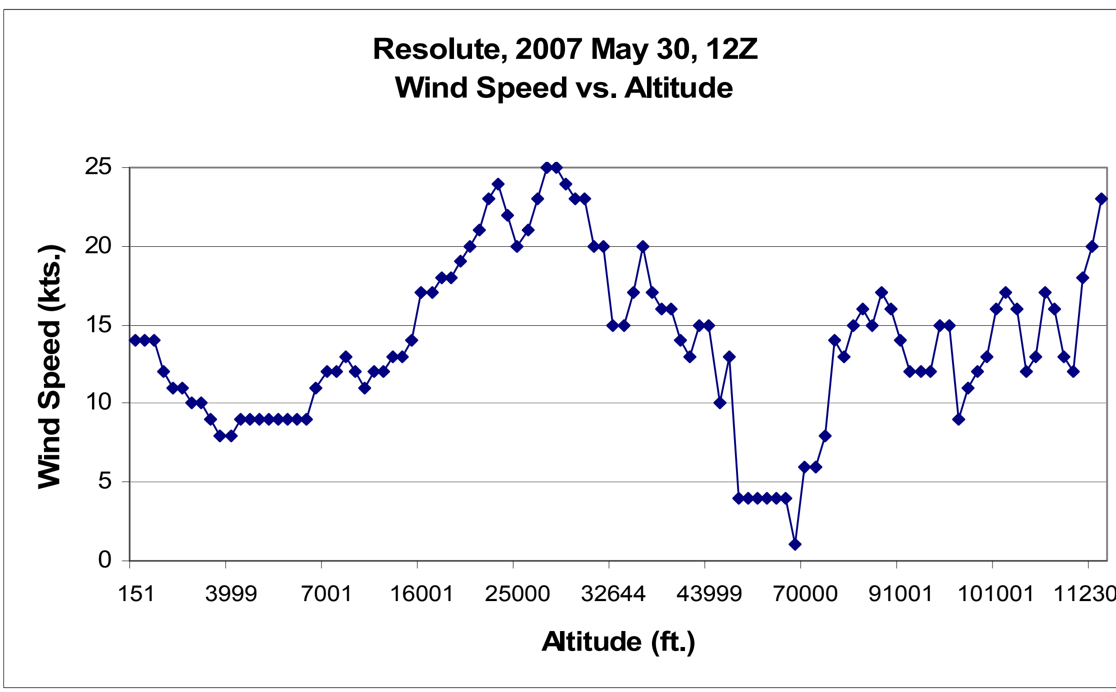

Figure B 31: Resolute, 2007 May 30 12Z, Wind Speed vs. Altitude

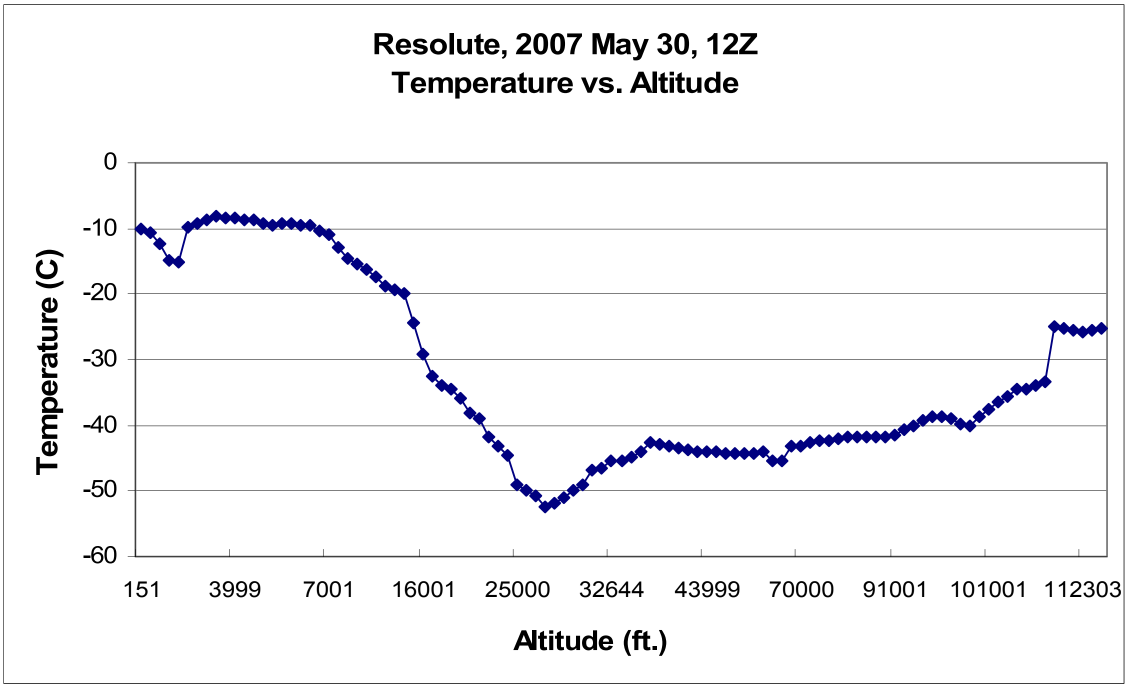

Figure B 32: Resolute, 2007 May 30 12Z, Temperature vs. Altitude

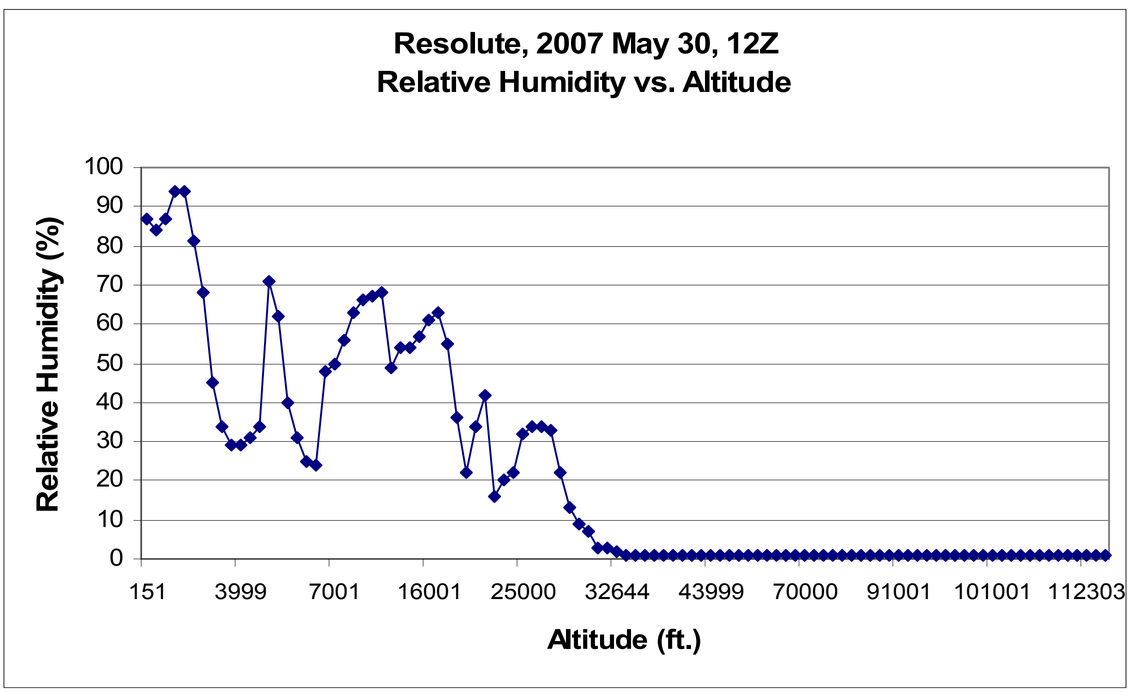

Figure B 33: Resolute, 2007 May 30 12Z, Relative Humidity vs. Altitude

Stony Plain, 2007 May 31

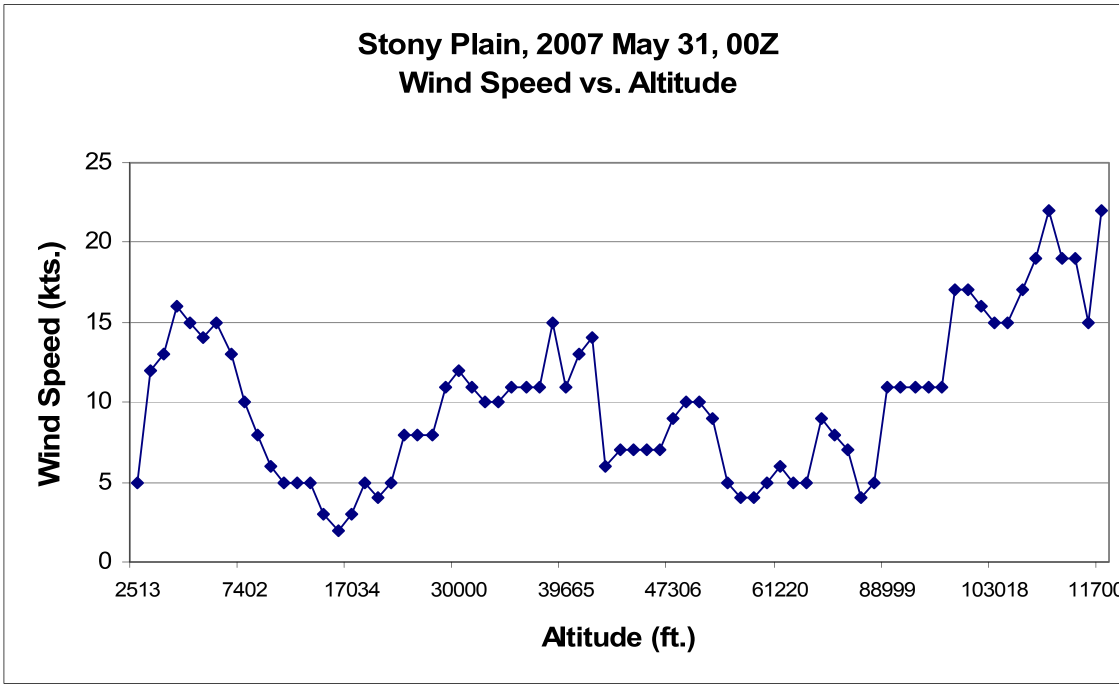

Figure B 34: Stony Plain, 2007 May 31 00Z, Wind Speed vs. Altitude

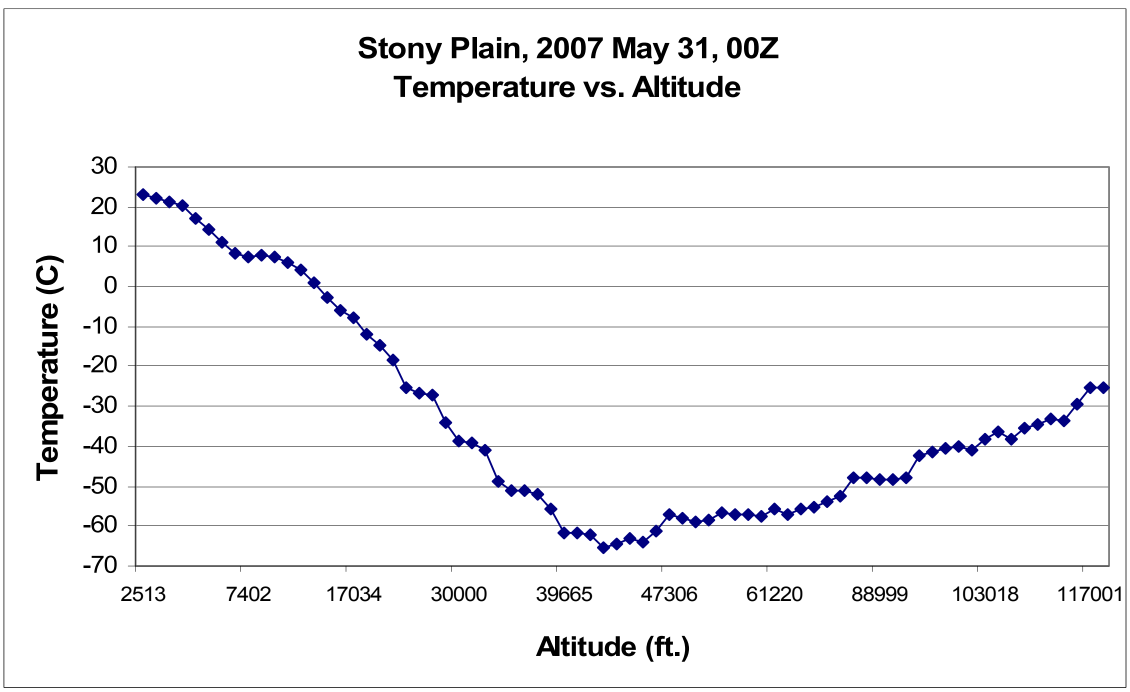

Figure B 35: Stony Plain, 2007 May 31 00Z, Temperature vs. Altitude

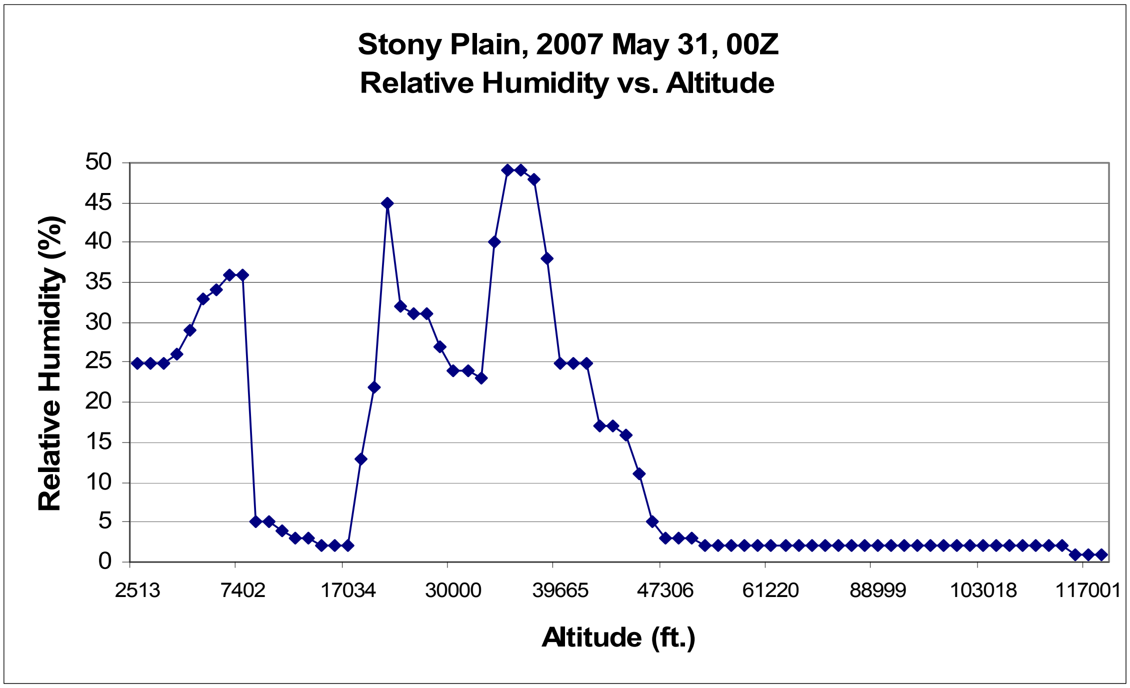

Figure B 36: Stony Plain, 2007 May 31 00Z, Relative Humidity vs. Altitude

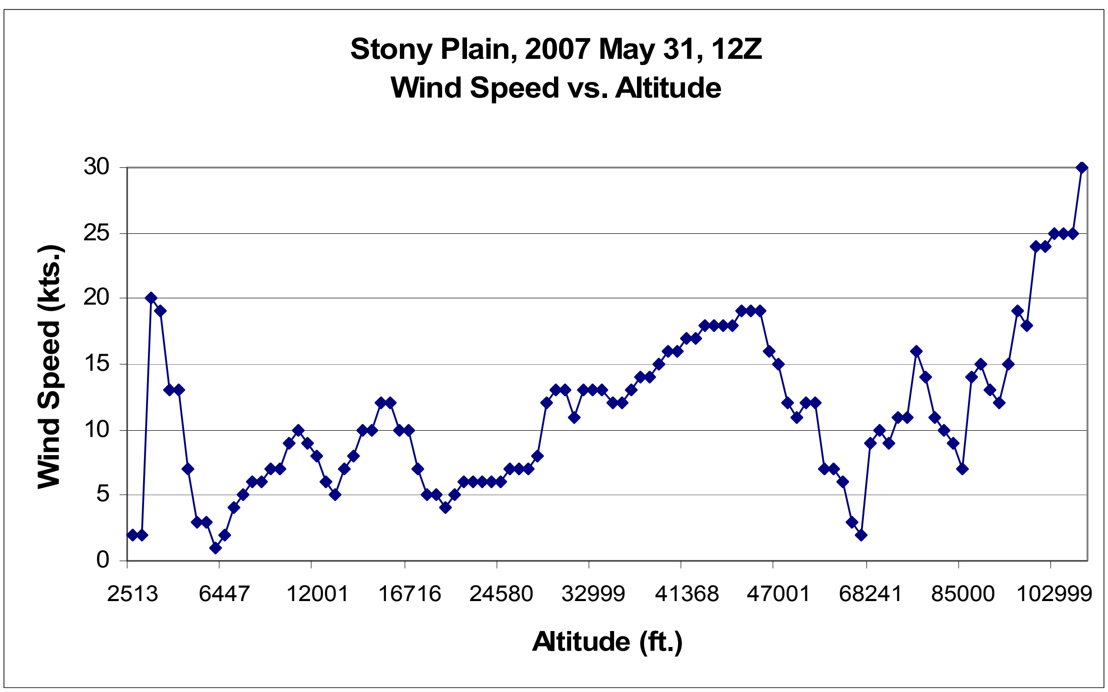

Figure B 37: Stony Plain, 2007 May 31 12Z, Wind Speed vs. Altitude

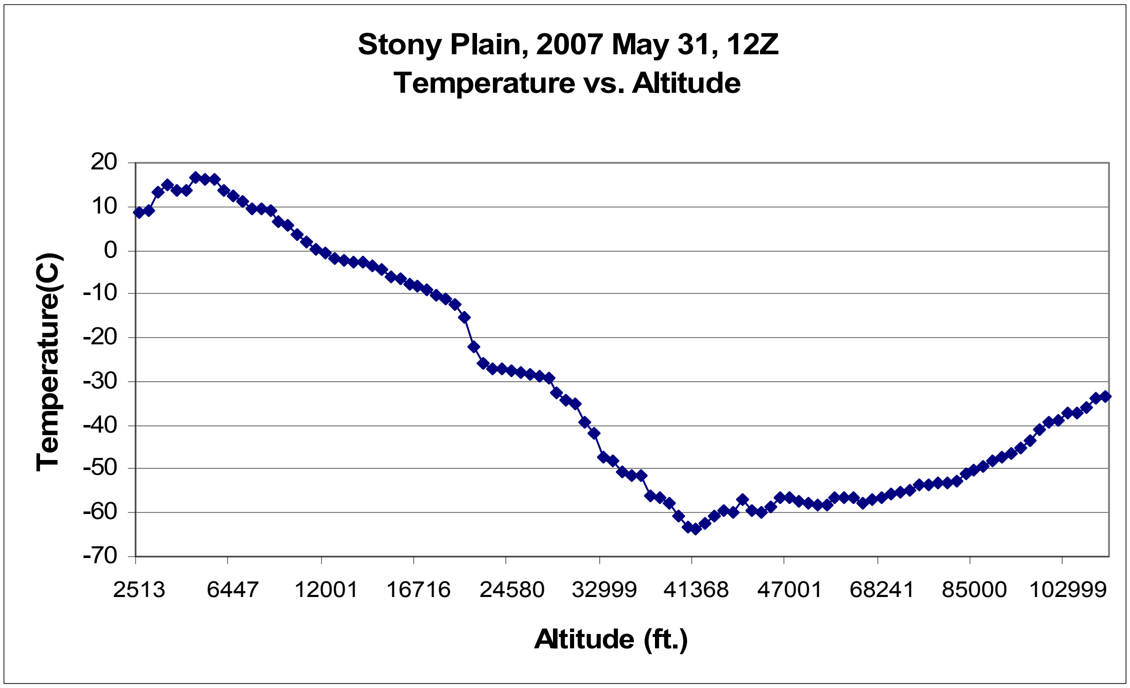

Figure B 38: Stony Plain, 2007 May 31 12Z, Temperature vs. Altitude

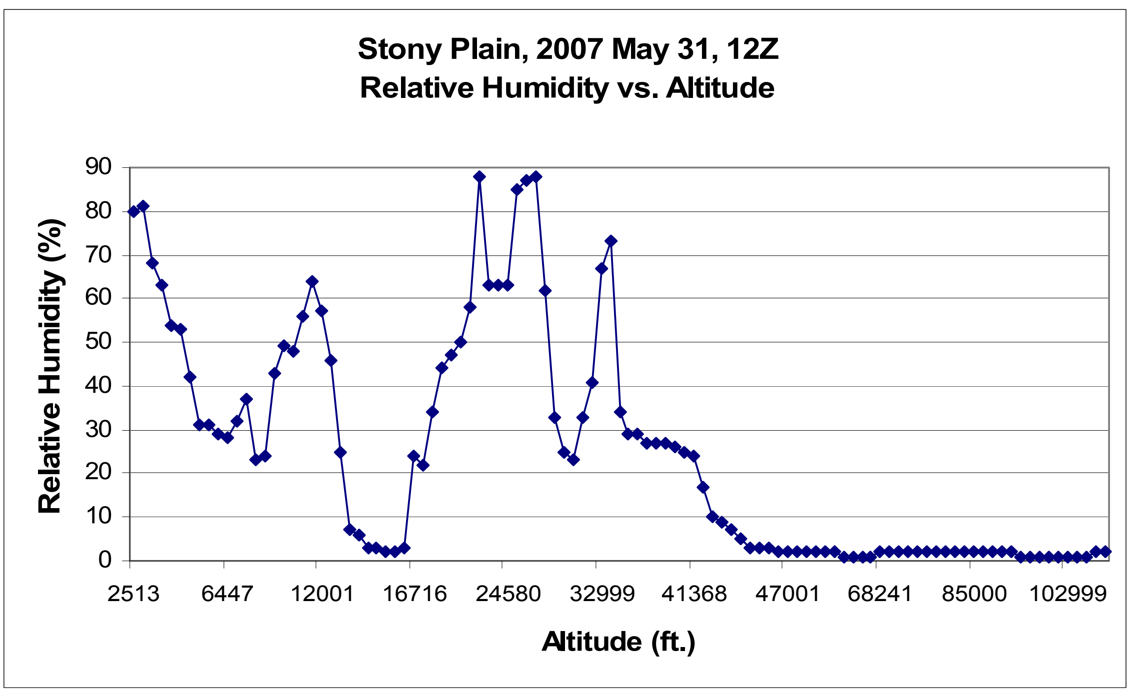

Figure B 39: Stony Plain, 2007 May 31 12Z, Relative Humidity vs. Altitude

Whitehorse, 2007 April 12

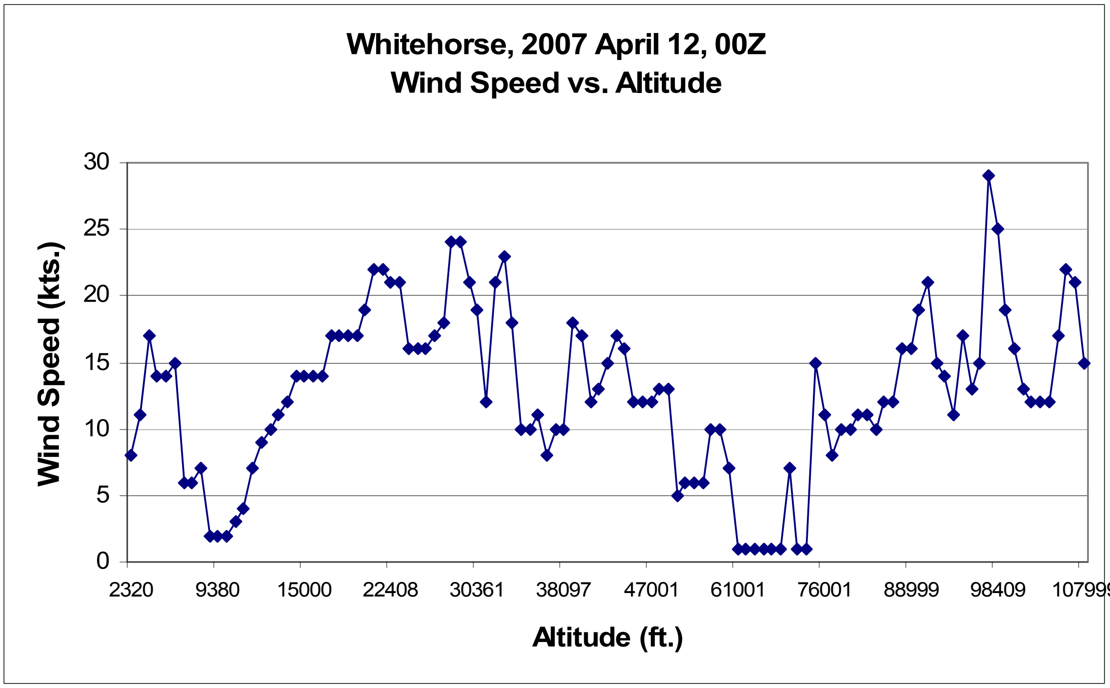

Figure B 40: Whitehorse, 2007 April 12 00Z, Wind Speed vs. Altitude

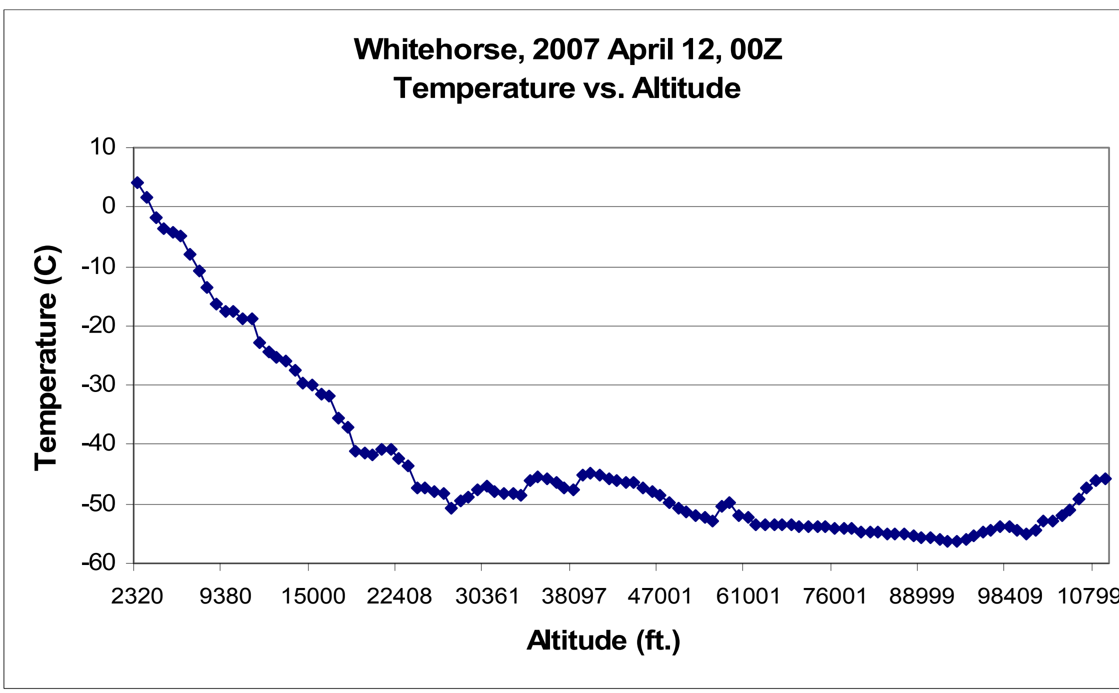

Figure B 41: Whitehorse, 2007 April 12 00Z, Temperature vs. Altitude

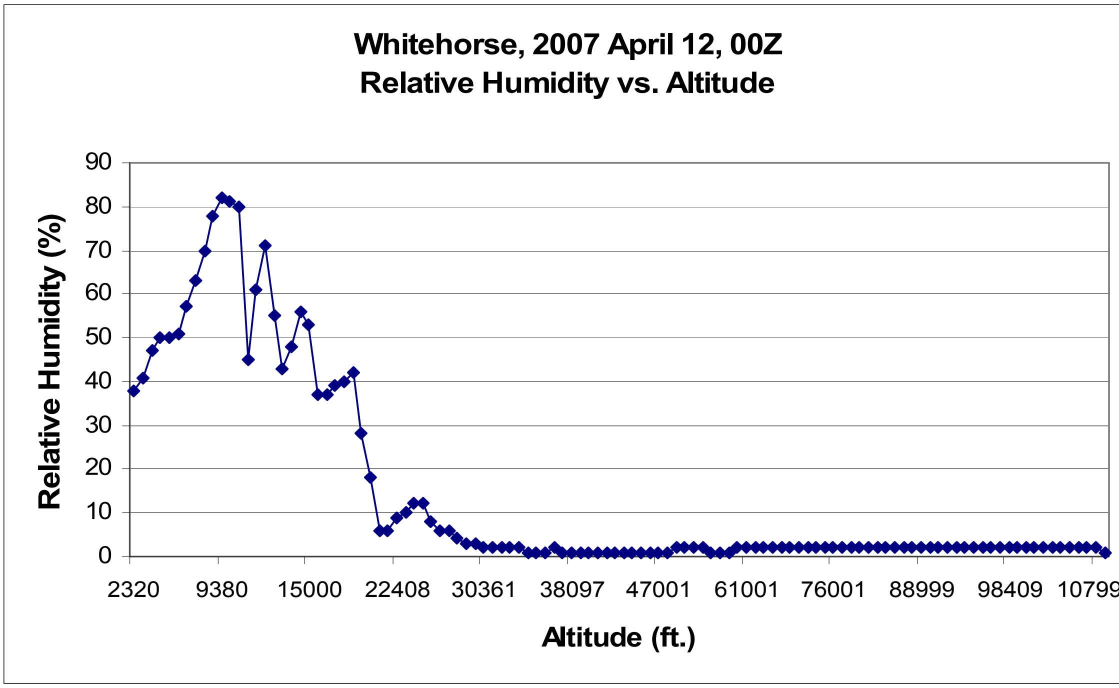

Figure B 42: Whitehorse, 2007 April 12 00Z, Relative Humidity vs. Altitude

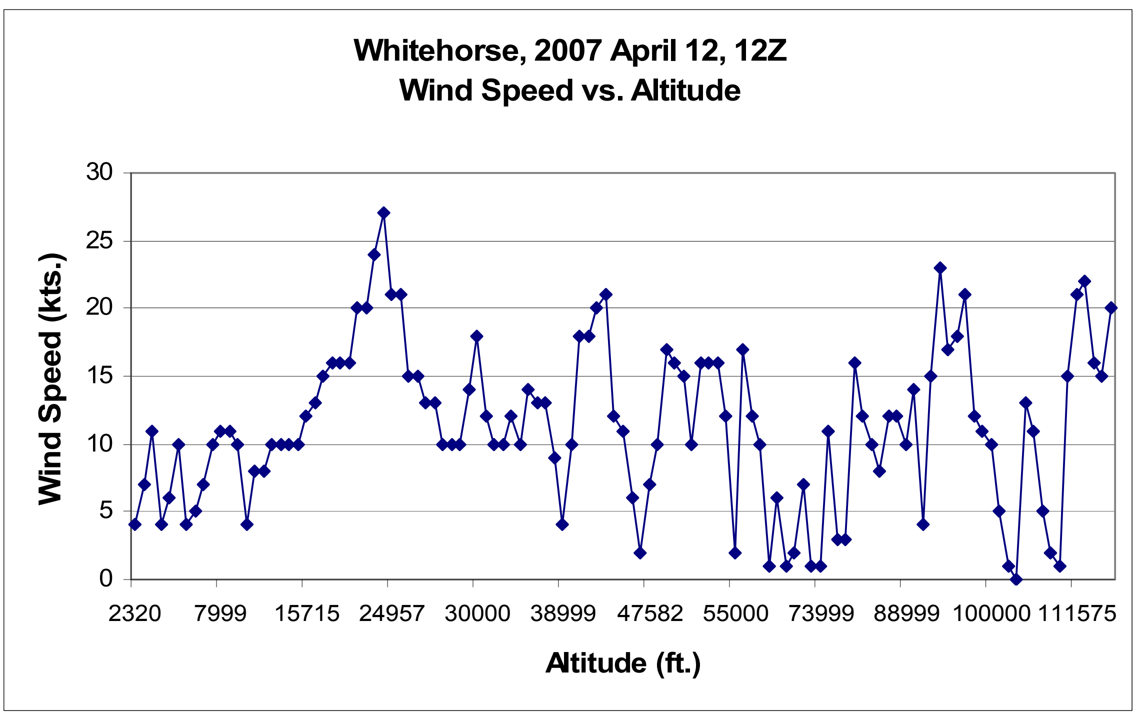

Figure B 43: Whitehorse, 2007 April 12 12Z, Wind Speed vs. Altitude

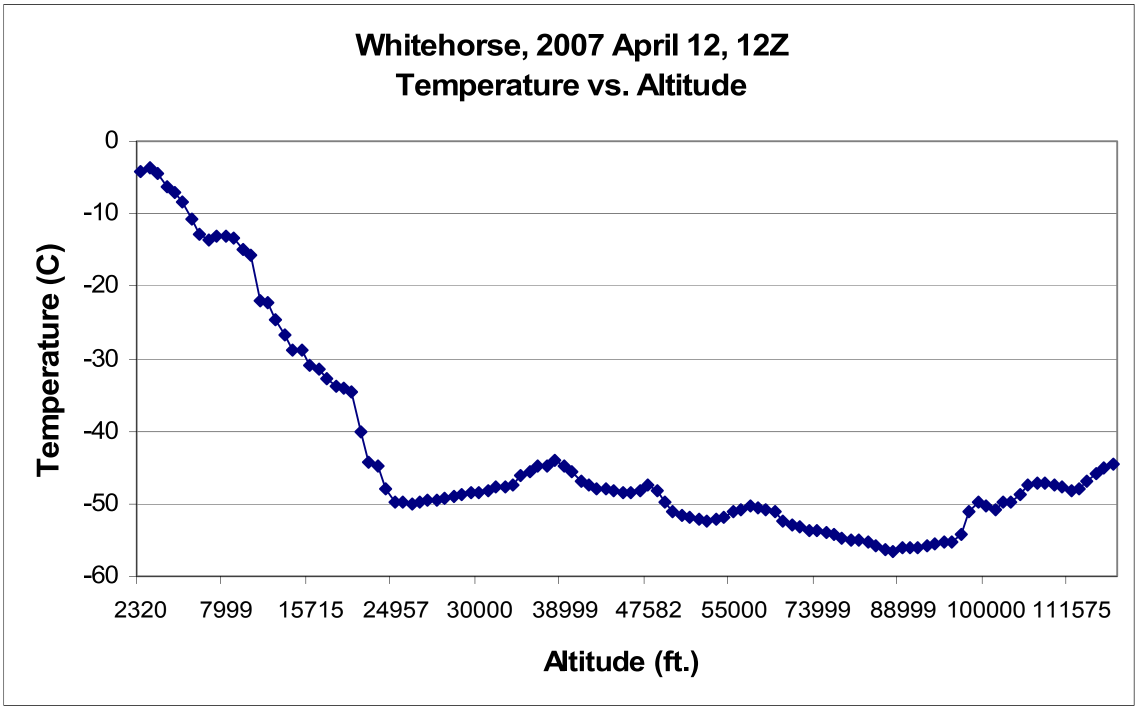

Figure B 44: Whitehorse, 2007 April 12 12Z, Temperature vs. Altitude

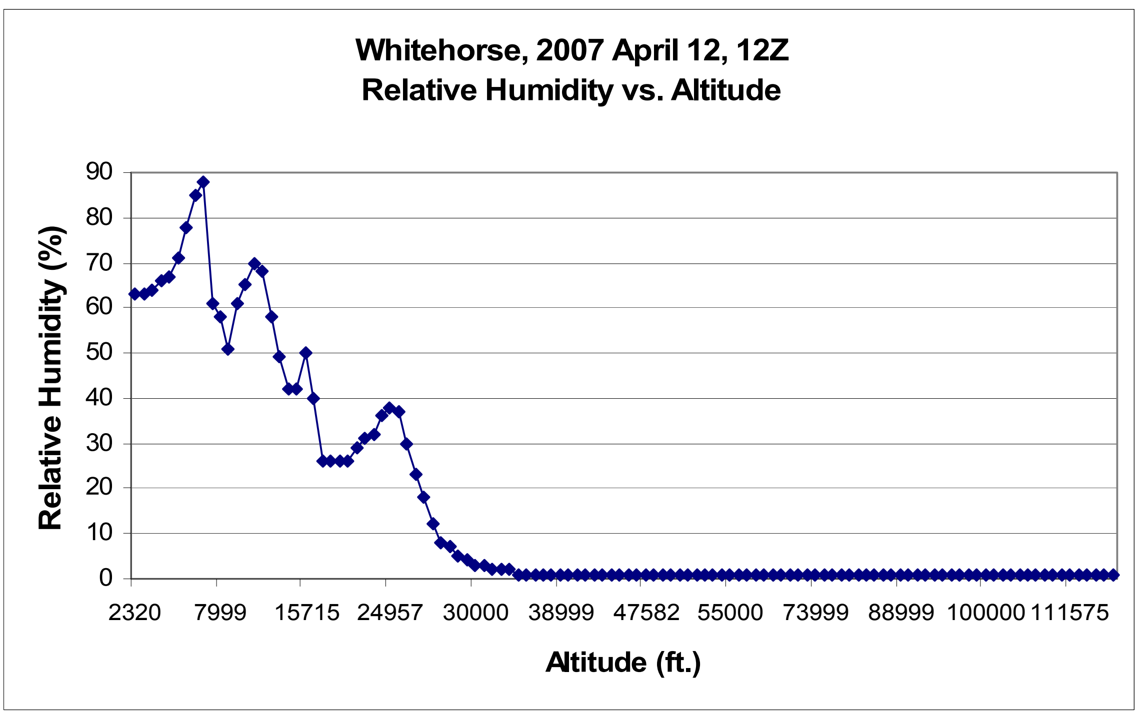

Figure B 45: Whitehorse, 2007 April 12 12Z, Relative Humidity vs. Altitude

Whitehorse, 2007 April 22

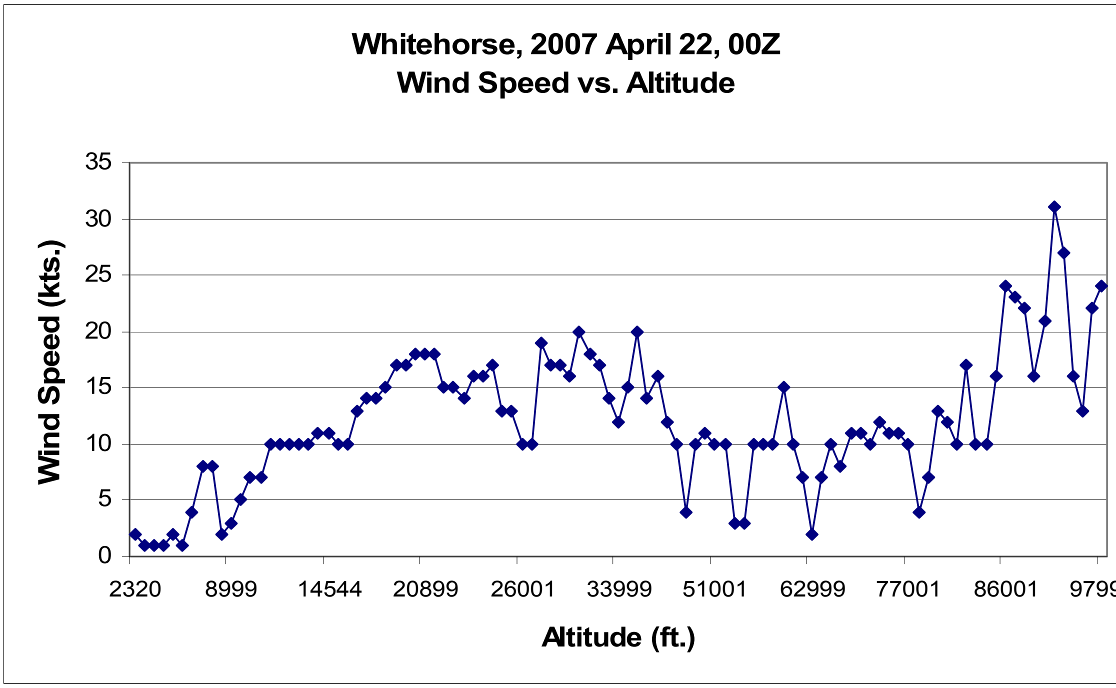

Figure B 46: Whitehorse, 2007 April 22 00Z, Wind Speed vs. Altitude

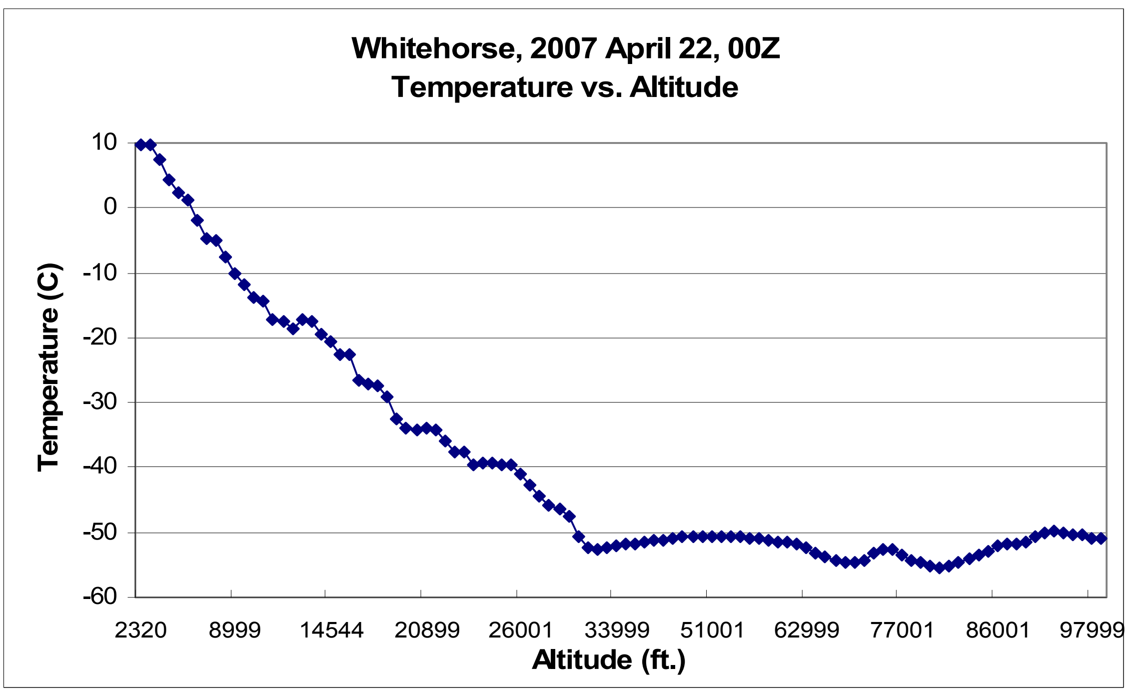

Figure B 47: Whitehorse, 2007 April 22 00Z, Temperature vs. Altitude

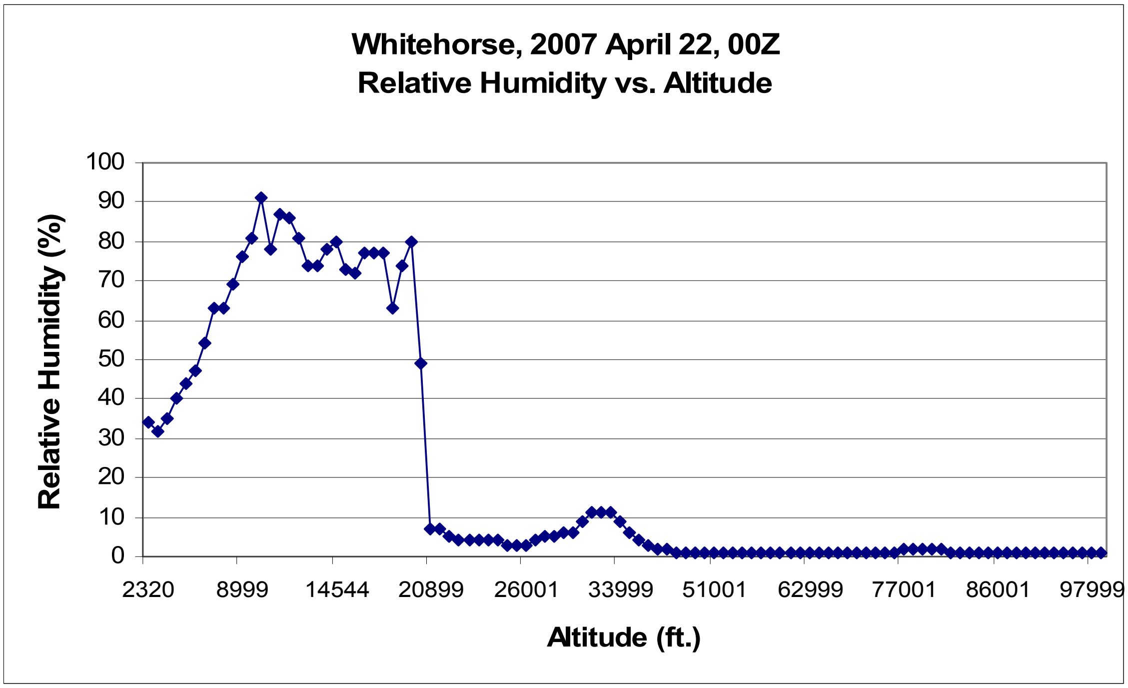

Figure B 48: Whitehorse, 2007 April 22 00Z, Relative Humidity vs. Altitude

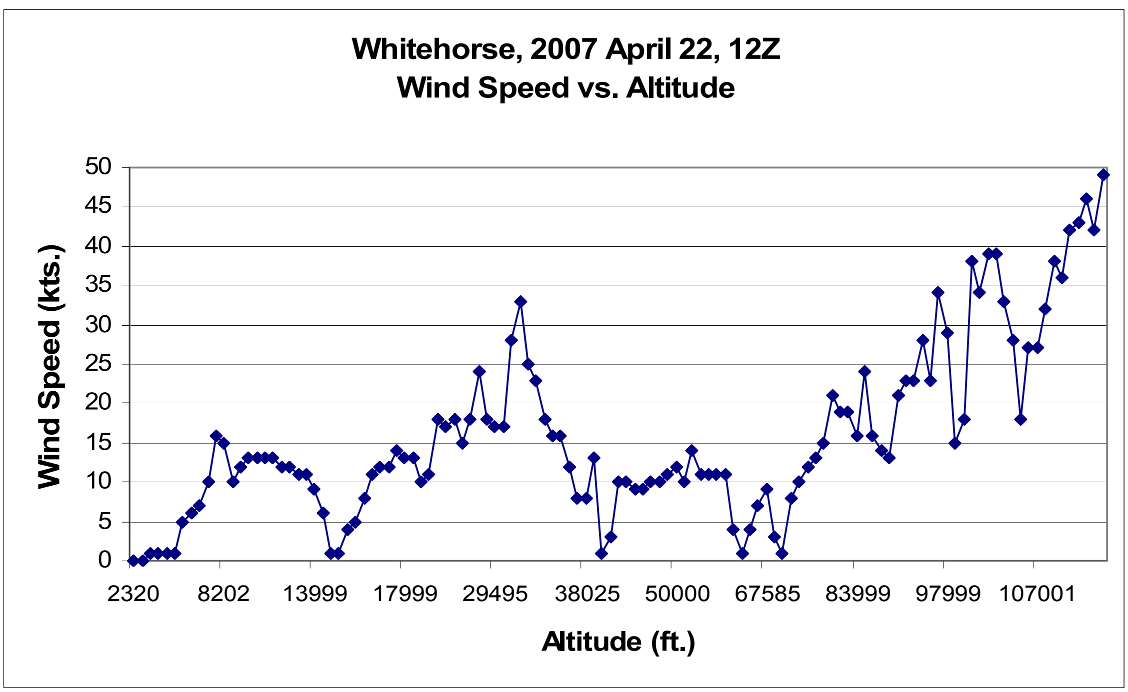

Figure B 49: Whitehorse, 2007 April 22 12Z, Wind Speed vs. Altitude

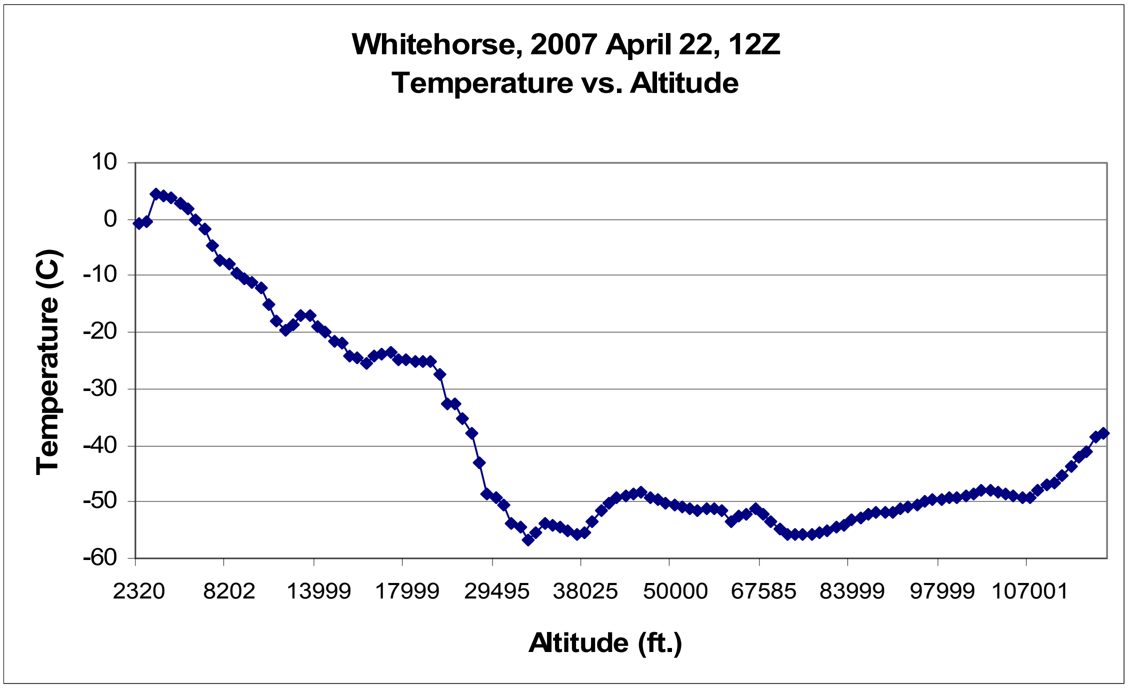

Figure B 50: Whitehorse, 2007 April 22 12Z, Temperature vs. Altitude

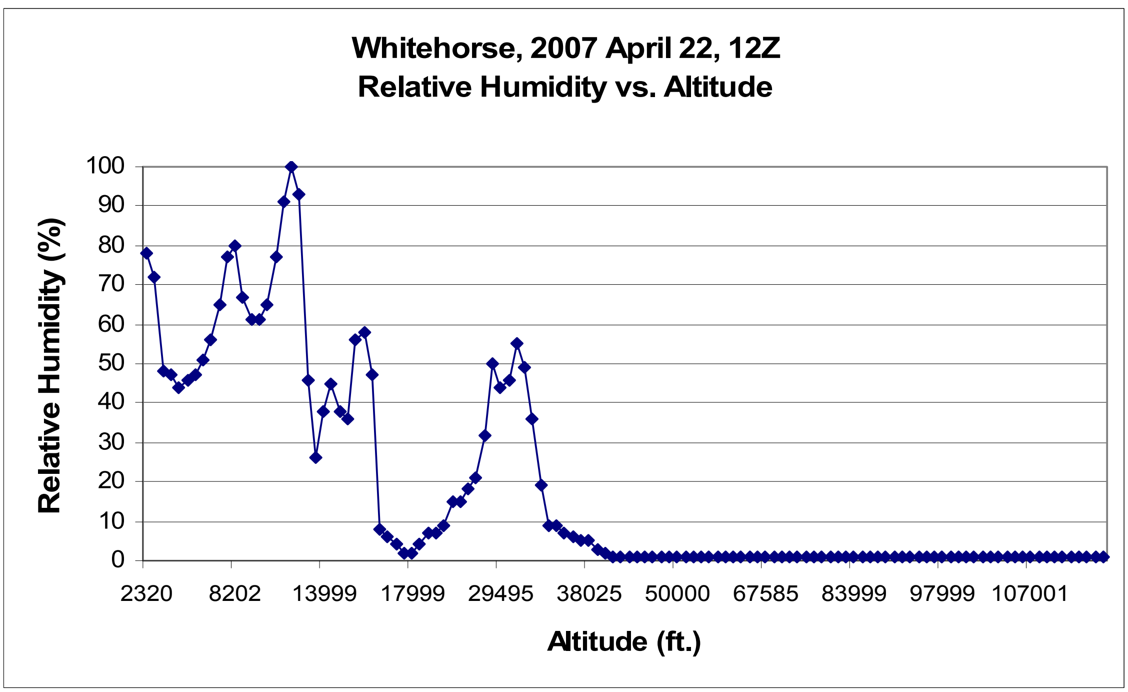

Figure B 51: Whitehorse, 2007 April 22 12Z, Relative Humidity vs. Altitude

Whitehorse, 2007 May 20

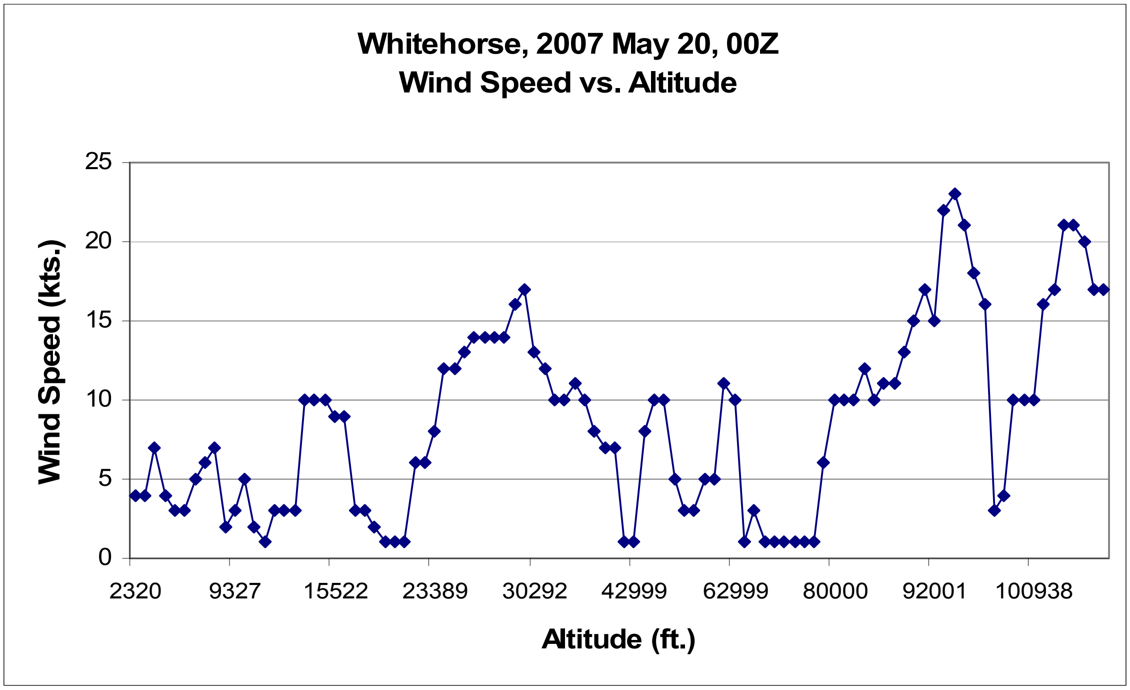

Figure B 52: Whitehorse, 2007 May 20 00Z, Wind Speed vs. Altitude

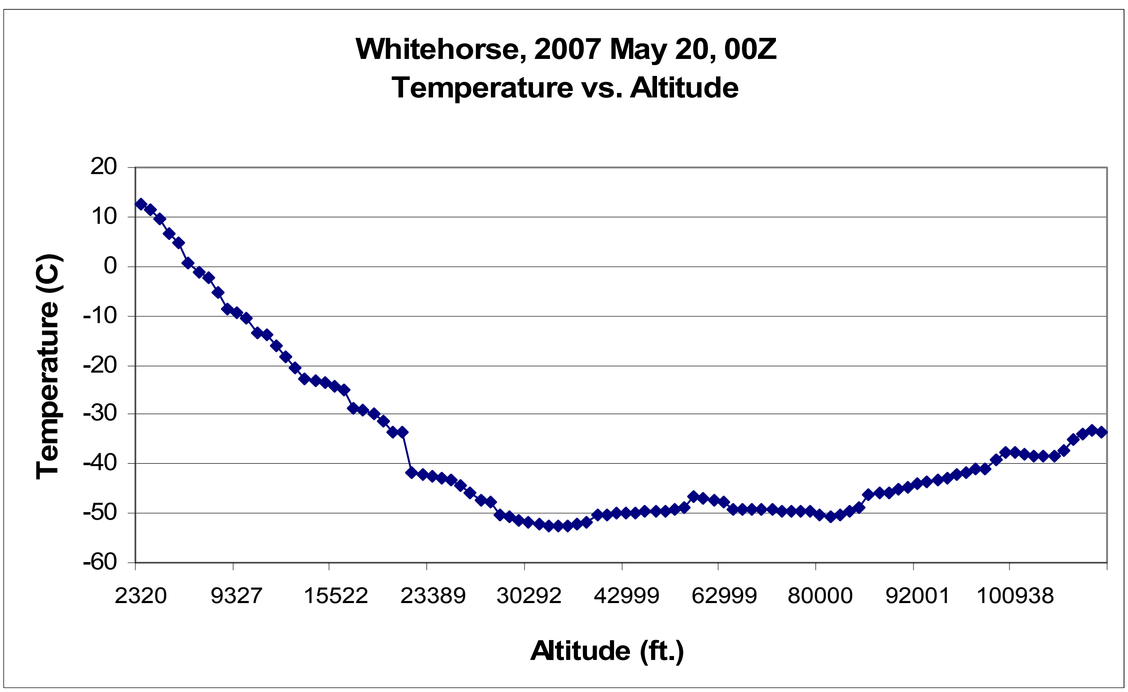

Figure B 53: Whitehorse, 2007 May 20 00Z, Temperature vs. Altitude

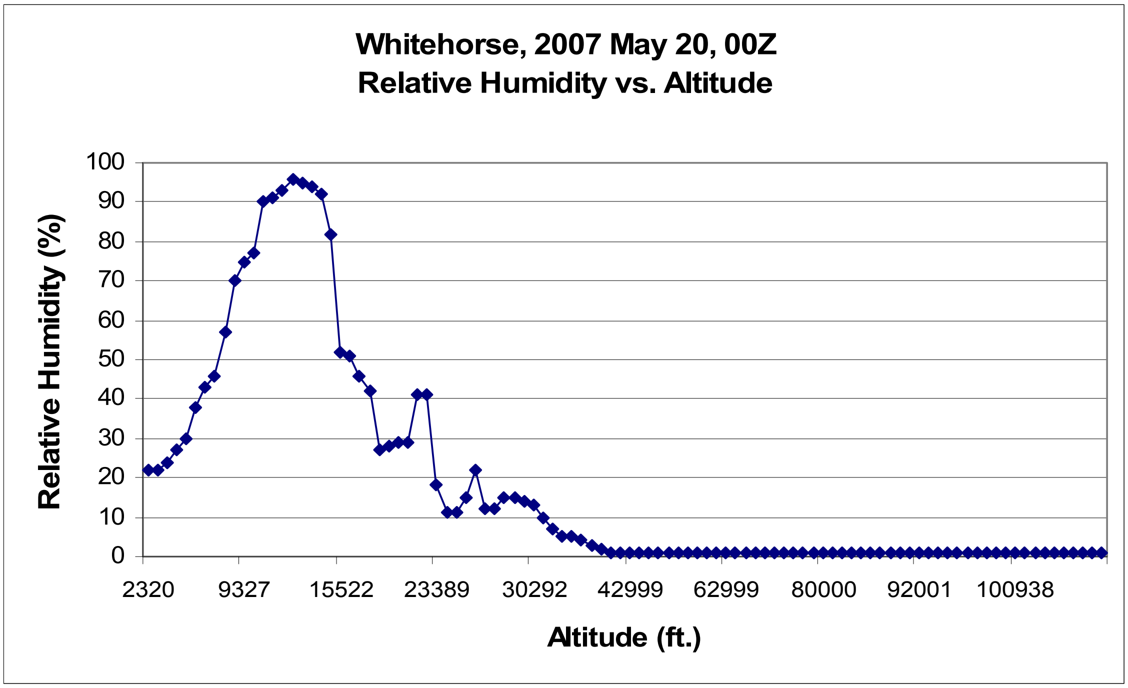

Figure B 54: Whitehorse, 2007 May 20 00Z, Relative Humidity vs. Altitude

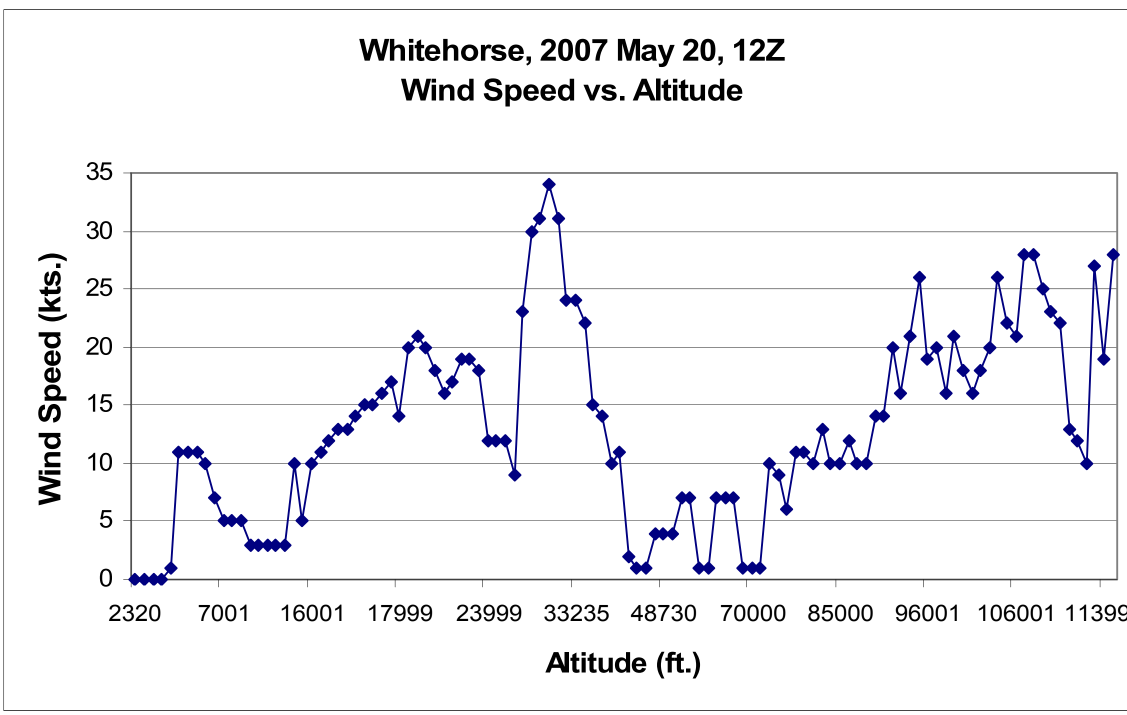

Figure B 55: Whitehorse, 2007 May 20 12Z, Wind Speed vs. Altitude

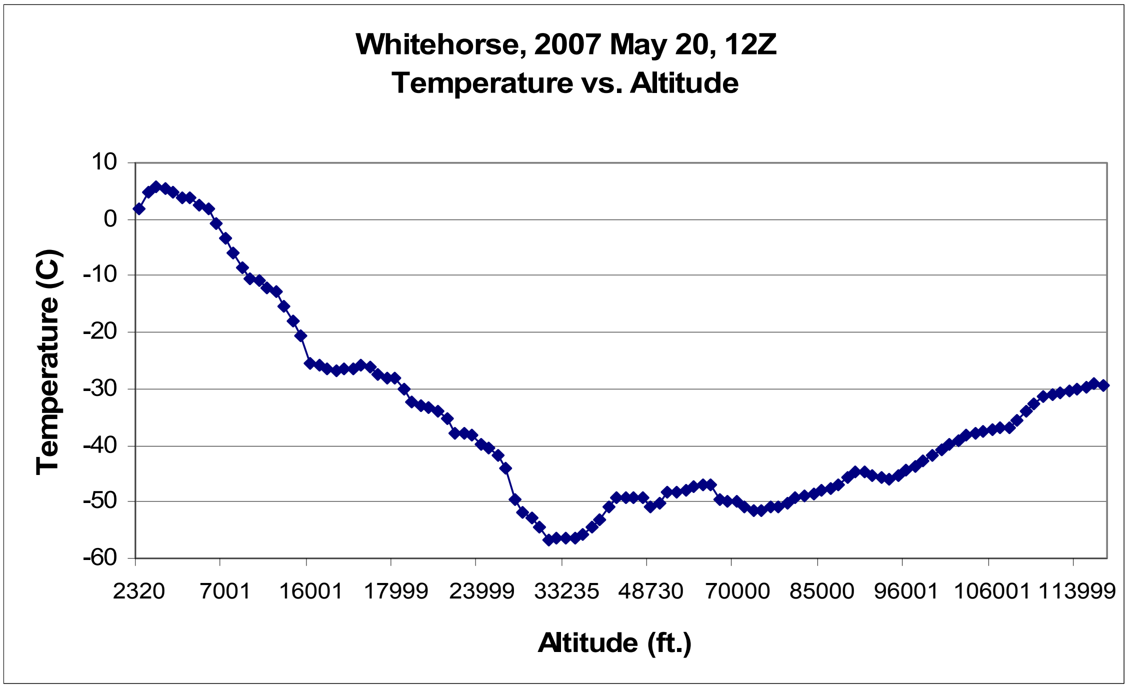

Figure B 56: Whitehorse, 2007 May 20 12Z, Temperature vs. Altitude

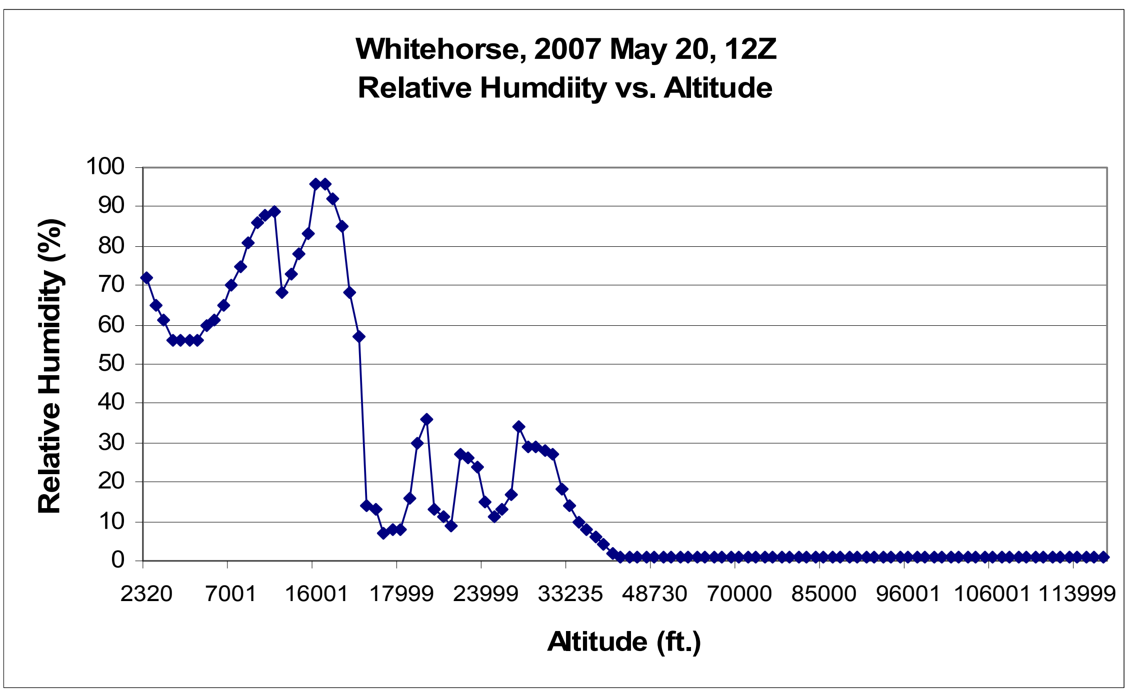

Figure B 57: Whitehorse, 2007 May 20 12Z, Relative Humidity vs. Altitude

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13. ABSTRACT: Canada has a mandate to assert its Arctic sovereignty, and one method of presence being considered is the High Altitude Airship (HAA). This report presents an assessment of the Arctic weather conditions at high altitude, as well as conditions at various sites, from ground level up to the operating altitude. The assessment indicates that operation at high altitudes in winter should not be attempted. The highly unpredictable winds alone would make HAA launch and operation too risky. Summer winds at these altitudes are more predictable and lighter, though not zero, and occasional gusts do occur. The wind direction is not constant, and so, it is doubtful that the wind could be used to generate a functional flight path. Summer is also reported to experience regular cloud cover, which means that, although the HAA may be employed in detection, it is unlikely to be able to perform identification. Depending on the HAA's performance ratings, it should be possible to find acceptable days for launch and descent at almost any chosen location.

A simple surveillance pattern shows that it is theoretically possible for the HAA to cover the Northwest Passage area within 14 days, though high winds could have a significant impact. Additionally, this report raises questions as to whether or not this is a cost effective solution to the Arctic surveillance problem, and further research is proposed.

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