7A.7 REQUIREMENTS ANALYSIS FOR SNOWFALL MEASUREMENTS OVER CANADA FROM SPACE

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1 Introduction

The Global Precipitation Mission (GPM) is a proposed follow-on mission to the Tropical Rainfall Measurement Mission (TRMM) with a launch date of 2008 (Sheppard et al, 2002). It is a joint NASA-NASDA mission and is composed of constellation of radiometers and a dual frequency active radar (14GHz, 35GHZ), in addition to the TRMM instrument package, to improve the temporal sampling. Using the passive microwave instruments, GPM will provide coverage up to 68° latitude compared to the 40° limit of TRMM and will provide near-global coverage of precipitation with a 3 hour update at high spatial resolution. The GPM radar will be used for algorithm development and validation. They have a sensitivity of around 18 dBZ or about 0.5 mm/h of water equivalent (Sekhon and Srivastava, 1970; Marshall and Gunn, 1952). ESA is proposing to participate in GPM through the contribution of a satellite with microwave radiometers with an active radar proposed as an option (Mugnai and Testud, 2002).

A climatological analysis of surface snow fall measurements and vertical profiles of radar data was conducted to determine the radar specifications for Canada. This paper will describe the analysis and requirements for precipitation measurements in Canada.

2 Precipitation in Canada

2.1 Climatology

Figures 1 and 2 show the climatology of total precipitation and snowfall in Canada and are provided as background information regarding the spatial distribution of precipitation in Canada. While they are the official precipitation maps in Canada, they are based on sparsely distributed surface gauges and are therefore inherently smoothed and coarse in resolution compared to fine scale radar data. In addition, the data has not been corrected for wind effects. In general, there is a broad north-south gradient in precipitation with significant orographic influences. The impact of coastal and mountain effects is evident.

The snowfall distribution has much more structure with the same broad structure as the total precipitation map. Fig. 2 shows the ratio of snow to total precipitation for Ottawa, Yellowknife and Alert and illustrate that in the far north, snow constitutes about 90% of the total precipitation. Even for Ottawa, the contribution of snow is about 30%.

2.2 Characteristics of Cold Season Precipitation

In order to determine the technical specifications for the spaceborne radar, the characteristics and climatologies of precipitation rate must be known. In this section, we present an analysis of synoptic (6 hourly) measurements of snow water equivalent and vertical profiles of reflectivity during precipitation to make the case for enhanced sensitivity of a spaceborne radar.

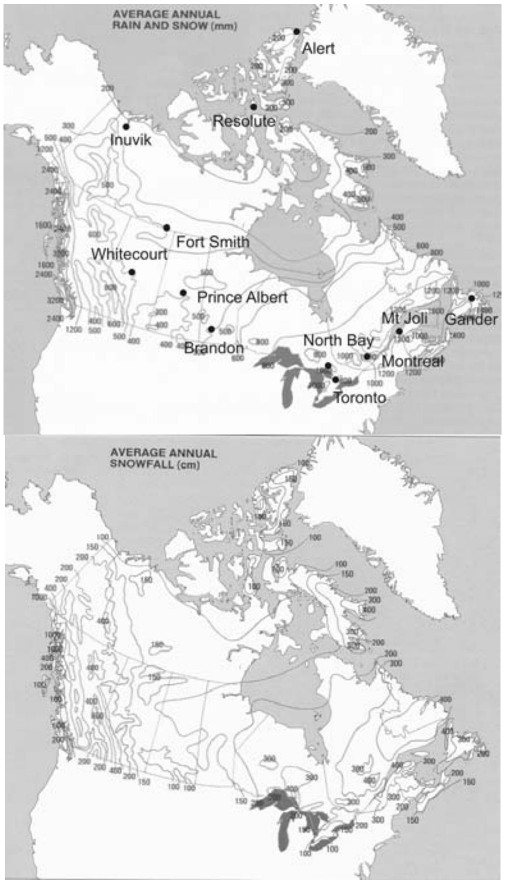

Figure 1 Mean Annual Precipitation and Snowfall in Canada 1961-1990.

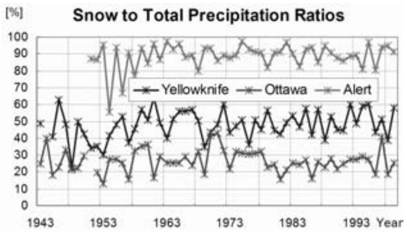

Figure 2 Ratio of snow to total precipitation for Ottawa, Yellowknife and Alert (courtesy of R. Stewart.)

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2.3 Analysis of Synoptic Observations

Within the MSC network, snowfall accumulations from Nipher snow gauges made every six hours, are melted and reported as snowfall water equivalent. Goodison et al (1998) describe how this data are corrected for wind and wetting effects. Analyses of this data to estimate the importance of light snow fall from twelve stations are presented here (Fig. 1). The stations are selected along north-south and east-west transects across Canada. Toronto and Montreal are included for comparative purposes.

The term Snowfall Water Equivalent (SFWE) is defined as the the water equivalent of the snow that fell during the observation period. The data from 30 years (1961-1990) are computed as frequency (total number of observations) histograms (not shown) with the snowfall water equivalent category bins described in Table 1. The accumulations are based on synoptic stations that report the measurements every 6 hours. By dividing the amounts by 6, the average snowfall rate for the observation period is computed. For snow fall events that are shorter than 6 hours, the average snow fall rate during the event would be higher.

Table 1 Frequency bins for snowfall rate analysis

	SFWE Range	Average Amount	Low Rate	High Rate	Average Rate
1	TR - .25	0.125	0.00	0.04	0.02
2	.26 - .50	0.38	0.04	0.08	0.06
3	.51 - 1.0	0.755	0.09	0.17	0.13
4	1.01 - 1.5	1.255	0.17	0.25	0.21
5	1.51 - 2.0	1.755	0.25	0.33	0.29
6	2.01 - 2.5	2.255	0.34	0.42	0.38
7	2.51 - 3.0	2.755	0.42	0.50	0.46
8	3.01 - 3.5	3.255	0.50	0.58	0.54
9	3.51 - 4.0	3.755	0.59	0.67	0.63
10	4.01 - 4.5	4.255	0.67	0.75	0.71
11	4.51 - 5.0	4.755	0.75	0.83	0.79
12	5.01 - 6.0	5.505	0.84	1.00	0.92
13	6.01 - 7.0	6.505	1.00	1.17	1.08
14	7.01 - 8.0	7.505	1.17	1.33	1.25
15	8.01 - 9.0	8.505	1.34	1.50	1.42
16	9.01 - 10.0	9.505	1.50	1.67	1.58
17	10.01 -	10.505	1.67	1.83	1.75

The snowfall amount frequencies (total number of observations in each category) are multiplied by the average amount in each category to produce distributions of the total snow fall amounts. An example is presented in the top graph on Fig. 3 for Brandon, Manitoba which is in the middle of the domain. Cumulative probability distributions of the snowfall amounts (bottom graph, Fig. 3) as a function of the minimum average snow fall rate are determined in order to assess the importance of each snow fall category to the overall snow accumulation. The cumulative probability distribution of the occurrence of each snowfall category is also computed.

The snowfall rate corresponding to 18 dBZ is approximately 0.5 mm/h of water. This is the nominal sensitivity of the proposed spaceborne radars. Depending on the type of snow and many other factors, the relationship between reflectivity and snowfall rate is approximate. For convenience, ***0.5 mm/h and lower will be used as the definition of light snow.*** Hence, category 7 and lower represents light snow.

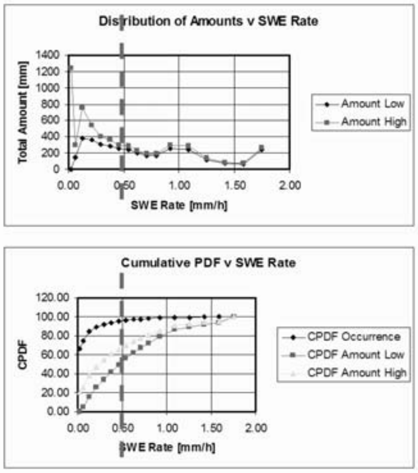

Figure 4 Snowfall Water Equivalent Analysis for Brandon, Manitoba which is approximately in the middle of the domain. The vertical line marks ~0.5 mm/h water equivalent or ~18dBZ.

Table 2 summarizes the results for the twelve stations in the analysis. The most obvious observation is that for all stations in this study, over 80% of the snowfall reports occur as light snow. The lower limit of 80% is for the two stations in Eastern Canada (Mont Joli and Gander) which are heavily influenced by moist Atlantic extra-tropical cyclones. The farther north, the greater the frequency of light snow events. In the far north (Alert, Resolute, Fort Smith) and in the Prairies (Whitecourt, Prince Albert, Brandon), the snow is almost 100% light snow. For Toronto and Montreal, the number of light snow events is 80 and 90%, respectively.

In terms of the contribution to total precipitation amount and accumulation, the analysis shows that the contribution of light snow to the total snowfall is at least ~20% for the Eastern Canadian locations, ~40% for Toronto and Montreal, ~60% or more in the Prairies and ~80% or more in the far north.

Radar reflectivities of 10, 5 and 0 dBZ which correspond roughly to 0.2, 0.1 and 0.07 mm/h of snow water equivalent, respectively. This corresponds to the 4th, 3rd and 2nd categories (and points on the graphs), respectively. Hence, even at 0 dBZ, the trace and snow fall rates of less than 0.07 mm/h would NOT be detected.

For Alert, the most northern station, as the reflectivity threshold is increased from 0, 5 to 10 dBZ, the percentage of missed light snow events rises from 80, 95 to 97% and the percentage of missed snowfall (amount) increases from 30, 40 to 60%, respectively. In contrast, the corresponding statistics for Gander are 55, 70, 75 (occurrence) and 10, 15, 20%. The mean precipitation amount error will decrease from 60% at 18 dBZ to approximately 15% at 0 dBZ. Note that this analysis overestimates the missed events if the snowfall durations were less than the total observation period. There is insufficient information in the record to estimate the duration of snowfall observations.

Table 2 Percentage of Missed Occurrence or Missed Snowfall Amounts as a Function of Reflectivity Threshold from SFWE

	Occurrence				**Amount**			
dBZ	18	10	5	0	18	10	5	0
mm/h	.4	.2	.1	.07	.4	.2	.1	.07
Alert	99	96	93	83	84	65	51	30
Resolute	99	97	96	87	84	68	55	32
Inuvik	99	94	90	78	83	60	46	25
Ft Smith	98	93	87	76	75	52	37	21
Whitecourt	94	84	77	61	66	38	26	12
Prince Albert	97	91	85	72	67	46	33	17
Brandon	95	89	84	74	57	37	27	15
North Bay	90	79	72	58	48	27	18	8
Mont Joli	82	69	60	44	35	18	11	4
Gander	83	73	66	53	28	15	11	5
Toronto	93	86	81	71	45	28	20	11
Montreal	87	78	70	56	37	21	14	6

2.4 Analysis of VPR data From Toronto and Montreal

The data from an existing field studies were used to examine the radar reflectivity (dBZ) characteristics during snowfall events. The Alliance Icing and Research Study (AIRS-I) took place near Mirabel airport north of Montreal in the winter of 1999/2000 (Isaac et al, 2001). The data were collected by a vertically pointing X-band radar operated by McGill U. Fig. 4 gives the distribution of reflectivity as a function of height during times when the observer (at the surface) reported snow. Reflectivity values were always less than 30 dBZ. The most frequent value was around 20 dBZ near the surface, decreasing to 15 dBZ at 2 km, and to 8 dBZ at 4 km. The sharp cut off in the lower reflecitivity values is due to the sensitivity limitations of the radar.

Fig. 5 (left) gives the corresponding echo counts as a function of height (regardless of reflectivity value). There is a steady decrease in echo frequency with increasing height. A similar analysis of dBZ characteristics was carried out from data collected by the MSC portable Ka band radar during snow events in the winter of 2001/02. The radar was operated in a vertically pointing mode at the MSC radar station at King City (near Toronto). Fig. 5 (right) gives the echo frequency as a function of height. There is a very sharp decrease in echo frequency between 1.5 km and 2.5 km, with a gradual decrease thereafter indicating that the Toronto site is more frequently affected by lower level cloud systems (in part due to its proximity to the Great Lakes) than is the case in the Montreal area.

For both datasets, an analysis was performed to assess the proportion of echoes that exceed a prescribed dBZ threshold – defined as the probability of detection (POD). Data below 4 km with dBZ > -10 dBZ were used. It was assumed that echoes weaker than -10 dBZ are not significant for snowfall detection. The results are shown in Fig. 6. The POD for the Mirabel data increases from about 0.15 with a detection threshold of 20 dBZ, to 0.55 at 10 dBZ, 0.82 at 0 dBZ, and to 1.0 at –10 dBZ. For the King City data, the PODs are much lower. The POD at 5 dBZ is 0.22, increasing to 0.50 at 0 dBZ, to 0.75 at –5 dBZ, and then 1.0 at –10 dBZ. This is further support for the contention that the snowstorms in Montreal are deeper and have higher dBZ than those at King City. The analysis of the King City data was truncated at 5 dBZ due to receiver saturation.

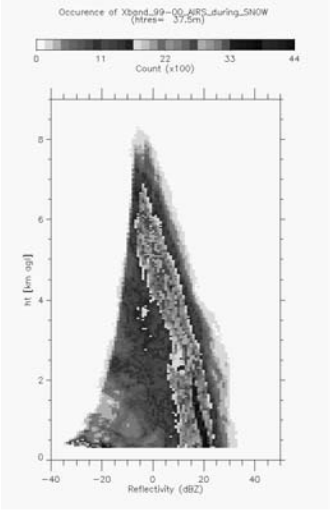

Figure 4 Histogram of counts of McGill vertically pointing X-band radar reflectivity versus height when the local observing station was reporting snow during the 1999-2000 AIRS I field project. Histogram counts are shown in 1 dB reflectivity and 37.5m height intervals.

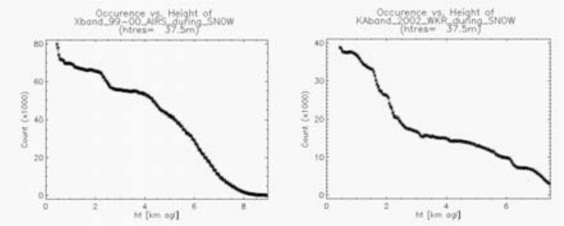

Figure 5 Occurrence of the McGill (left) and Toronto (right) vertically pointing X-band radar reflectivity returns versus height when the local observing station was reporting snow during the 1999-2000 AIRS I field project and 2001-2002 winter seasons.

The analysis was performed for the lowest 4 km. Analysis for a shallower near-surface layer would show a greater POD. However, depending on the scientific application, the detection of precipitation aloft can be important and significant.

The final analysis examined the effect of the low level blind zone on POD for the Mirabel data. The lowest level PODs were compared to the POD of the lowest useable radar bin (300 m) under the assumption of 4 different blind zones, up to 0.5 km, 0.75, 1.0 and 2.0 km (Fig. 7). A blind zone to 0.5 km has little effect on POD. For a blind zone up to 0.75 km, the PODs decrease in a linear fashion with minimum thresholds above 12 dBZ to a maximum of 0.06 at 20 dBZ, i.e. if there were a blind zone up to 0.75 km the POD with a threshold of 20 dBZ would be 6% less than it would otherwise be. With a 1 km blind zone, the decrease in POD becomes more dramatic. PODs corresponding to thresholds above 0 dBZ suffer to a maximum decrease of 10% by 20 dBZ. A blind zone up to 2 km shows POD decreases in excess of 20%.

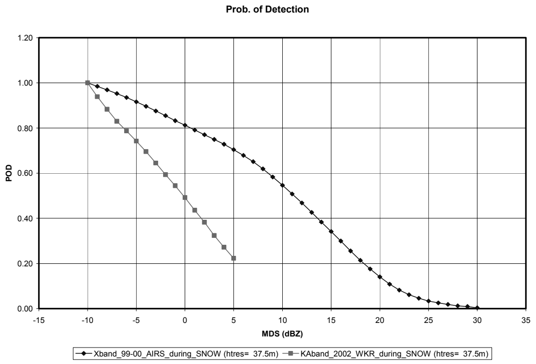

Figure 6 Probability of detecting returns above a minimum detectable signal (MDS) value for the -◆- AIRS I X-band and -■- King Ka-band snow event datasets. Data below 4 km was used.

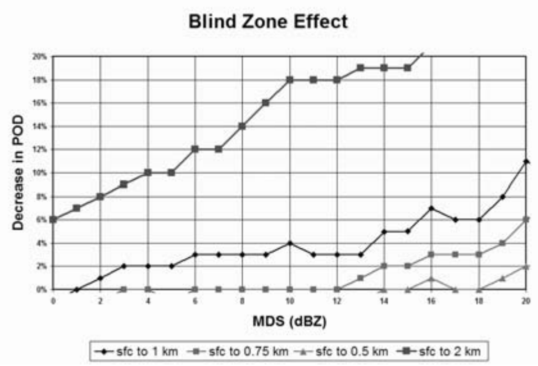

Figure 7 AIRS I X-band radar probability of detection difference between lowest useable radar level, 300 m, and four blind zone heights as a function of increasing MDS.

In summary, the analysis shows that for the Montreal data set and for a MDS of 18 dBZ, 80% of the reflectivity data would not be detected. This is comparable to the SFWE analysis which shows that 87% of the data would be missed. The following table presents the results from this analysis in the same form as the previous table for comparative purposes. The number within brackets is from the SFWE analysis. The radar analysis shows that fewer reports would be missed compared to the SFWE analysis (as expected). The radar analysis is more accurate and the SFWE analysis overestimates (upper bound) the number of missed events.

Typical VPR's from Finland (Pohjola and Koistinen, 2002) shows a maximum reflectivity value is a maximum of -2.8 dBZ and falls to -15 dBZ at 5 km. They also show the frequency distribution of the top of the precipitation echo in the month of March 2001 showing that 50% of the echo tops are below 3 km. Holroyd (1989) indicate 5dBZ as the MDS to get radar precipitation accumulation amounts correct.

Table 3 Percentage of Missed Occurrence of Reflectivity Threshold from Radar VPR's

	Occurrence			
dBZ	18	10	5	0
Montreal	80 (87)	45 (78)	30 (70)	20 (56)
Toronto	NA (93)	NA (86)	80 (81)	50 (71)

3 Summary

Analysis of surface snowfall measurements indicate that light precipitation (below ~0.5 mm/h water equivalent) contributes substantially to the total precipitation in Canada and that this contribution roughly increases with latitude. Analyses of vertical profiles of reflectivity provide greater precision to this estimate and support that conclusion. It also indicates that a blind layer of 500 meters is tolerable. The analysis also provides information on the distribution of snowfall with reflectivity and shows that the probability distribution of occurrence is highly skewed.

The case is made that light snow (<0.5 mm/h, 18 dBZ) conditions represent a very high component of the snowfall reports and a significant contribution to the total snowfall accumulation for all parts of Canada and other northern countries. The contribution of light snow is more significant as one moves inland (away from the Atlantic and Pacific coasts) and from south to north. In the Prairies and farther north, the snow is composed predominantly of light snowfall. It should be noted that the SFWE analysis overestimates (upper bound) the contribution of light snow but it is not clear by how much. While moderate and heavy snow fall will be detectable and may be adequate in mid-latitiudes.

4 References

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