Wind sensing techniques and methods for wide geographic area avalanche forecasting

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Abstract: The paper reviews past and present methods for wind sensing used in British Columbia with a focus on the avalanche forecasting and control industries. Instrumentation, data presentation and data sharing methods are reviewed and successes and deficiencies are identified. A simple cumulative numeric format for summarizing wind stress at the point of measurement is presented along with suggested applications for industry.

Keywords: wind sensing, snow drifting, snow transport, snow loads, field measurements

1. History

Gauging the wind must have been a component of avalanche forecasting since the beginning of the activity perhaps a hundred years ago in BC. Back then, visual estimates of winds at mountain top winds would surely of been the norm, and empirical intuition would of lead to "guestimates" when cloud ceilings inhibited the observers ability to see.

The Second World War brought the first significant technological instruments (aside from Binoculars) to BC and Alaska that could aid a person in need of high elevation wind data. Radiosondes introduced and coordinated by WMO programs were in use by the middle World War II in Prince George and Annette Island (Alaska Panhandle) if not elsewhere. Twice daily balloon tracking, (by radar) coupled with known rise rates provided sound indications of winds above sea level. Their data, plus additional Radiosondes added later (Vernon, 1960 & Port Hardy), have been fundamental inputs to forecast models for decades. They also remain in use today at heli-ski operations, at highways avalanche programs and elsewhere.

The evolution of transportation and mine development also contributed to early installations of higher elevation weather stations in BC. The data from stations made its way back to federal weather forecasters in Vancouver and elsewhere by teletype and by other means. Old Glory, at the Paulson Summit (1943-1968 @2400 Meters) and the Hedley Mine weather stations are examples of upper level sites that operated in the middle part of the last century. The extent to which these stations contributed to any avalanche forecasting is unclear to the author. It is clear that in 1956, the National Research Council and Parks Canada formally commenced development of methods and practices of weather observations related to avalanche forecasting in Rogers Pass (Freer, 1980). Part of this process would have been the development of wind sensing methods from upper elevation stations at Mt Abbott and later at Fidelity.

Many mines operated in avalanche prone terrain in BC throughout twentieth century. Some had active avalanche forecasting programs that surely had developed systematic methods for wind measurements near avalanche start zones. Prior to establishment of the CAA infoex bulletin late in the century, the extent that these operations contributed to wide area interpolations of winds for forecasters and other users is also unknown to the author.

Alpine wind sensing matured in BC in the 1970's with two innovations. Automatic weather stations with wind sensors started to appear on mountain tops and coordinated weather observing programs for ski areas and highways operations were introduced. These innovations were coordinated in part by the federal Atmospheric Environment Service, and their data used in provincial weather forecasting operations. The method and basis for a wide area alpine sensing and reporting system was thus born in BC.

The 1980's and 1990's saw significant refinement in automated wind sensing equipment and growth in the number of upper elevation remote automated weather stations (RAWS) which made wind measurements. The reliability of sensing varied considerably throughout the BC avalanche triangle and at a few stations, remains a problem today. Rime, ice and high winds (>250Km/Hr) combined with difficult site access are the major causes of problems. Table 1 lists methods for combating sensor riming and icing problems at BC MoT. Redundant sensing, as used in offshore weather buoys, is also being promoted for all mountain top sites.

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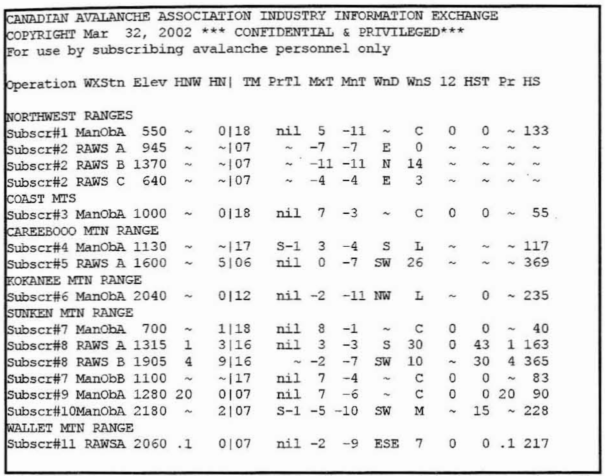
Deriming method	# of Sites	Comment
Bendy Mast	11	Introduced in 1998
Alcohol Deicing (Kiwi Squirt)	3	Support cost is high at remote sites
AC Electric Heaters	2	Reliable. Site must have AC Power
Redundant Sensors	6	
Other	1	Propane Water Heater
None	7	
Total sensors deployed	30	14 RMY 05103 16 Phil Taylor

***Table 1**. MoT installed base of deriming systems for mountain top (and near mountain top) wind sensing. BC MoT 2002*

As of today, more than 50 automatic sensors run at or near mountain tops for the benefit of ski area, heli-ski, and industrial avalanche forecasting. Data can be shared by avalanche proffessionals through the CAA infoex (example Figure 1). Manual wind observations are also reported in the infoex and remain a data component in support of wide area avalanche forecasts.



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Operation WXStn Elev HNW HN| TM PrTl MxT MnT WnD WnS 12 HST Pr HS

NORTHWEST RANGES
Subscr#1 ManObA  550  ~    0|18  nil  5  -11  ~   C   0   0  ~ 133
Subscr#2 RAWS A  945  ~    ~|07   ~  -7  -7   E   0   ~   ~  ~  ~
Subscr#2 RAWS B 1370  ~    ~|07   ~ -11  -11  N  14   ~   ~  ~  ~
Subscr#2 RAWS C  640  ~    ~|07   ~  -4  -4   E   3   ~   ~  ~  ~
COAST MTS
Subscr#3 ManObA 1000  ~    0|18  nil  7  -3   ~   C   0   0  ~  55
CAREEBOOO MTN RANGE
Subscr#4 ManObA 1130  ~    ~|17  S-1  3  -4   S   L   ~   ~  ~ 117
Subscr#5 RAWS A 1600  ~    5|06  nil  0  -7  SW  26   ~   ~  ~ 369
KOKANEE MTN RANGE
Subscr#6 ManObA 2040  ~    0|12  nil -2  -11 NW   L   ~   0  ~ 235
SUNKEN MTN RANGE
Subscr#7 ManObA  700  ~    1|18  nil  8  -1   ~   C   0   0  ~  40
Subscr#8 RAWS A 1315  1    3|16  nil  3  -3   S  30   0  43  1 163
Subscr#8 RAWS B 1905  4    9|16    ~ -2  -7  SW  10   ~  30  4 365
Subscr#7 ManObB 1100  ~    ~|17  nil  7  -4   ~   C   0   0  ~  83
Subscr#9 ManObA 1280 20    0|07  nil  7  -6   ~   C   0   0 20  90
Subscr#10ManObA 2180  ~    2|07  S-1 -5 -10  SW   M   ~  15  ~ 228
WALLET MTN RANGE
Subscr#11 RAWSA 2060 .1    0|07  nil -2  -9  ESE  7   0   0 .1 217
```

***Figure1**. Sample of a CAA Infoex Bulletin issued daily throughout the winter. Manual wind observations are coded using letter codes.*

2. Current data access methods

Synoptic wind data for avalanche related work can be accessed at least by these possible means. 1. Word of mouth communications. 2. Chart renderings via Websites. 3. CAA Infoex 4. Time series strip charts. 5. Direct communications with weather stations.

Charts showing 1500-Meter Radiosonde winds (Fig. 2) and RAWS time series strip charts (Fig. 3) are at most forecasters disposal at least at some point during the day. The latter usually provides several days of hourly averaged data. Common word of mouth messages used to share information about winds normally include comments on wind duration, strength and direction. For example, "Inflow winds shook my windows all night, couldn't sleep for a darn", is a possible coffee time comment. Information of a similar sort is available from RAWS observations, rendered on strip charts. To assess winds at many stations over a large area, several strip charts would normally be analyzed.

As with the infoex, RAWS chart data includes temperatures, precipitation in some form, and winds. When previewing wind data, the forecaster may have to consider a bias due to ice or rime on a sensor. Certain manual weather observations may also be merged into a plot (eg. Air Temperature). At MoT the duration of a plot can vary from days to a full season.

3. Analysis

At MoT, time series charts of hourly data provide the favored means of weather data analysis related to avalanches. Often data quality or accuracy may be a bigger issue than how the data is rendered. A plot, known internally as a "stormpro plot", only shows data from one or two weather stations in most cases. Scalar data plots nicely on these charts and interpretation is fairly intuitive. Wind data with it's circular component is less intuitive on strip charts and a wind rose plot is available outside of stormpro to assist with interpretation.

It is also interesting to note that a typical 1 week stormpro plot contains approximately 20Kb of data and may take several minutes to analyze. In the last season at MoT, weather data accumulated at a rate of 2 to 3Mb per week or the equivalent of about 100 weekly stormpro plots. As a homogeneous fluid flowing in time and space, weather data lends itself to a more coupled approach to data rendering. The volume of data also implies a need for greater data reduction and summation to make it easier for users to digest, to understand and to share.

Radiosonde wind data is also available and free to the avalanche community. Being rendered on weather maps, it also provides the observer with the opportunity to take in a bigger picture of the weather as a whole. The limitations of this data are the twice daily sample rates, the distances from avalanche paths, and the topological and thermal dynamics of start zones not accounted for in the readings. Multiple observations are also inconvenient to couple together for making long term wind field calculations.

Using these various renderings, estimates of snow volume transports are possible but a potentially tedious task. Many hours or days of records may need scrutiny to make an estimate. To the author's knowledge there are no operational systems in BC to reduce or cumulate this data to aid in the task. While such summaries are common for snowfall and precipitation, accumulation and interpretation of wind data with respect to

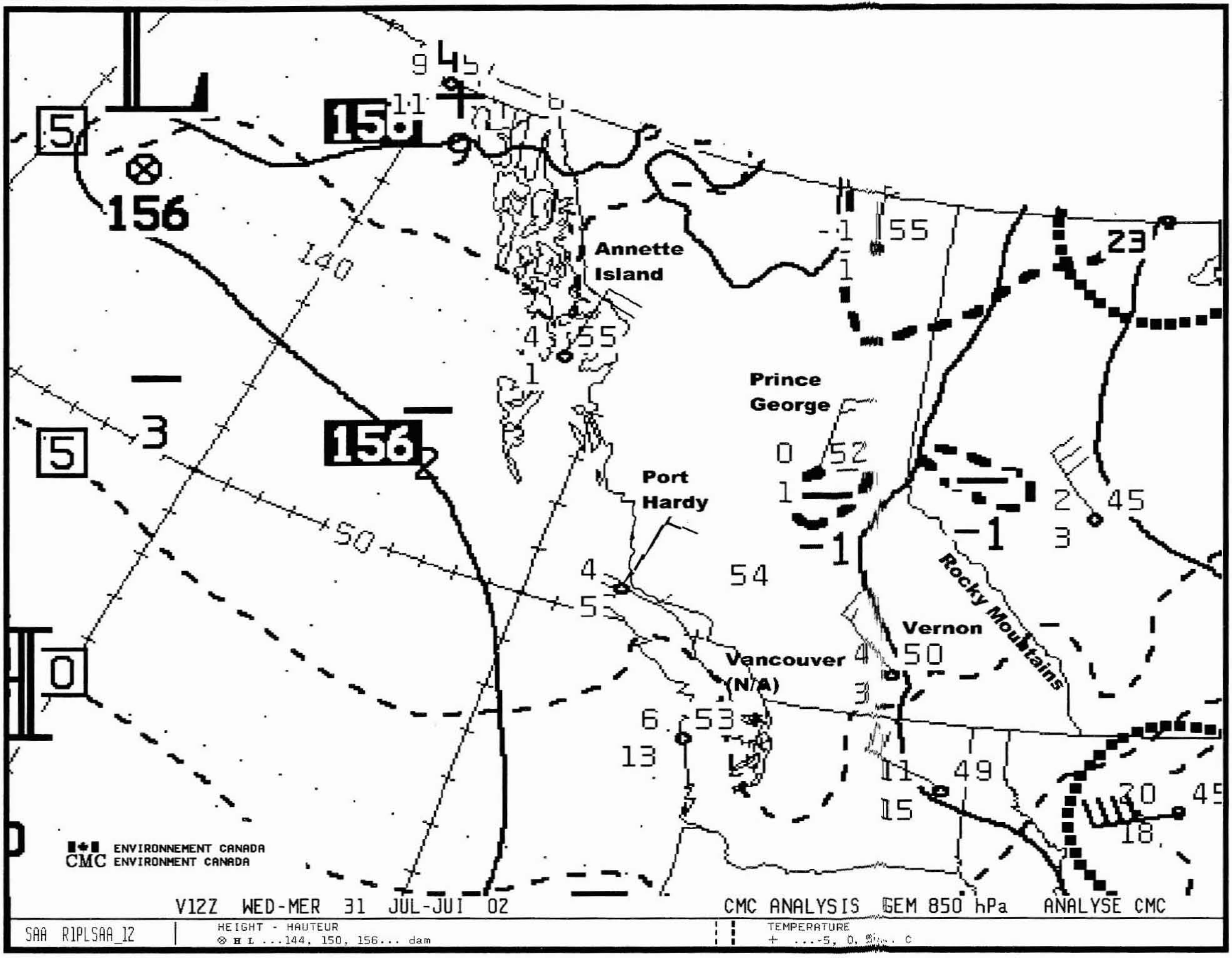

Figure 2. *850hPa (~1500 Meter) synoptic wind data from 5 available Radiosondes in BC and the Alaska pan handle. 4AM and 4PM PST data is available from weatheroffice.ec.gc.ca. Flags point to the source of the wind and are tagged with 5 or 10 knot handles. Note the lack of data for Southeast BC and the Rocky Mountains*

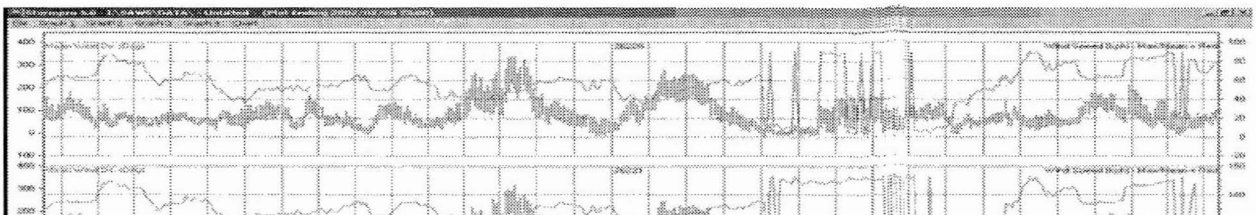

Figure 3. *Time Profile from Avalanche Weather Station. Winds, Air Temperatures and Precipitation are plotted.*

avalanche paths are left to the eye and mind of the forecaster.

In terms of information sharing systems around the BC industry, wind data generally consists of only a spot indication of 1 hour in an entire day. Given once daily rates of information sharing as with the infoex, a large portion of hourly wind records collected are not shared or summarized for users.

It is generally accepted that blowing snow is a complex, nonlinear phenomenon affected by wind, topology, temperature and by the snow surface condition. Research periodically shows a low correlation exists between wind data alone and total snow drift transport volume. Factors such as snow surface condition are also significantly involved. Despite this complexity, knowledge of wind force over time remains a vital component to quantifying accumulations relevant to avalanche potential and size.

If multiple observations of wind speed and direction are reduced to one or two parameters, the result should be easier to digest, share and use in snow drift estimations. Reducing the data at the point of observation (in a datalogger) would allow for the most flexible access and dissemination of such values.

4. Technology and standards

Data output standards for MoT weather stations have been significantly enhanced this year with new data fields for several measurements including winds. New data fields provide additional data to remote databases making information available to weather data users that did not exist in the past. In the area of winds, new data fields are defined for redundant wind sensors, for wind data quality reporting, and there are new fields to report 12 hour cumulative numerical wind rose data.

Twelve hour summary schemes are not new in weather sensing. Summary and data reduction methods based in dataloggers have been used on sensor data since the introduction of this tool over 25 years ago. However, such techniques have not been applied to wind data for BC MoT stations, nor do they exist in CAA Weather Observation Guidelines.

The 12 hour wind rose fields are a first attempt to put an automatic numerical data reduction technique to use for wind data at BC highways and are the primary subject of the rest of this paper. Implementation at the datalogger level will make this data available across the widest possible spectrum of data access.

Another standard important to automatic wind sensing is instrument height. In Canada, the conventional height for wind sensors is 10 meters; a standard based on many factors with airport measurements probably being a dominant part. On mountain tops, research shows wind sensors should be sufficiently above the snowpack to allow ground effects to be minimized. That said, the topological effects of peaks & ridges should not be ignored, nor the dynamics of snow movement. An important consideration is that roughly 90% of snow transported into start zones moves in the first meter above the snowpack. Also ridge tops may be subject to venturi effects which may not be detectable 10 meters above a ridge. In general a sensibly picked height of 6 to 10 meters would be appropriate for mountain top wind data to be used in an accumulated measurements. Confirmation of the speed height profile at a site would also make sense if the sensor is primarily for local area use.

Lastly, high elevation wind sensors shouldn't be deployed without a supporting deicing or deriming system.

5. Numeric, cumulative snow volume potential numbers as a concept

The wind rose schema described hereafter has been devised to describe a time series of wind data with as few terms as possible, in a format most relevant to avalanche risk caused by transported snow.

The concept is based on generally accepted principles from wind driven snow transport research and on the ideas of the author. Research generally shows there are two main modes of wind driven snow transport, which have significantly different affects on avalanche paths. To discriminate the snow movement potential of each mode, two separate numbers would be required.

One number would represent winds up to 26 meters per second, or winds associated mainly with snow drifting near the snow surface layer. This is also called saltation layer drift. The number will be known as the Drift Volume Potential or DVP rose value. Deposits from this type of transport are more likely to end up in avalanche start zones and account for the bulk of transported snow. The second number represents stronger winds above 17m/s, or speeds at which blowing snow generally can commence. These are winds that cause suspended particle drift associated with deposition over much wider geographic areas and are also associated with sublimation. This number is called the Blow Volume Potential or BVP rose value.

5.1 Numeric format and computation

DVP and BVP numbers are five digit, base 10 coded number pairs. Both are 5 digit numerical wind rose representations of wind speed and direction. Only wind field information is conveyed in these numbers. They are not biased for temperature or other factors involved in wind transported snow.
To best mimic snow volume transport potential, wind speed will be rendered in the third power. The numbers will reflect the generally acknowledged relation that a doubling in wind speed increases horizontal transport by a factor of eight. (Perla, et al, 1976, Meister, 1986).

The magnitude values will range from 0 to 9 and represent accumulations of wind speeds over the past twelve hours in each of four quadrants. Values will be continuous meaning that they will not have any reset intervals. The values will update hourly at approximately 0 minutes. Figure 4 shows DVP and BVP values as a function of wind speed.

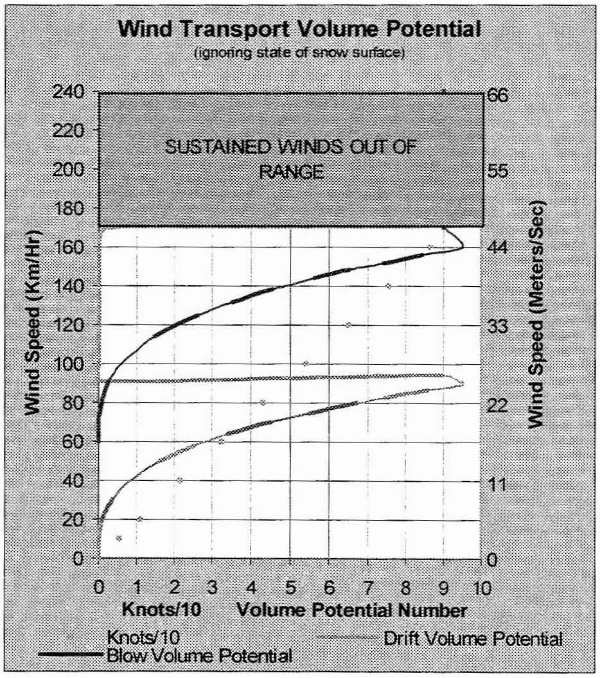

Figure 4. *Alternating dark and light lines show the wind range depicted by each Blow and Drift Volume Potential Number. Numbers represent wind speed as a cubic to mimic the potential volume of snow moved given a change in wind speed.*

The general form of the numbers is
NESW.D where
N is a force from the North ie 316 thru 45 Degrees
E is a " East ie 46 thru 135 Degrees
S is a " South ie 136 thru 225 Degrees
W is a " West ie 226 thru 315 Degrees
D is the reduced dominant wind direction over the last 12 hours in 8 point compass format, specifically;
0 = No Wind 1 = North 2 = Northeast 3 = East
4 = Southeast 5 = South 6 = Southwest 7 = West

N, E, S and W are of the form Z, where Z is the Snow Transport Volume Potential roughly described by

$$Z = \int_{t}^{t-12} ((u / k) - x)^{3}$$

Where
u = wind speed in meters/sec
k = a constant
x = a wind speed offset in meters/sec
x = 0 for drifting wind calculations
x = 16.66 m/s for blowing winds
t = time in hours

In all cases u values are sorted into appropriate quadrants for computation based on speed weighted hourly resultant mean wind directions. Each u will be initialized to 0 prior to commencing a sort and hourly mean u values > 26m/s will not be used in DVP calculations.

Value D, the dominant direction digits, will be the speed weighted, 12 hour Resultant Mean Wind Direction of hourly means for each DVP and BVP data set.

The Campbell Scientific CR10X datalogger Wind Vector (P69) instruction can be used for sample data reduction. The lowest level integration period for wind data should be 5 seconds and should be the basis for hourly computed means. DVP and BVP computations will use a datalogger resident 12 hour time series of hourly computed means as a data source.

Table 2 contains a reference chart to convert BVP and DVP numbers to more common wind speed units.

5.2 DVP & BVP Notes and Examples

DVP and BVP numbers should always be used as pairs. The reason is that only wind strengths within the appropriate ranges of each number are used to compute each number. DVP numbers of less than 9 do not mean the higher wind speed BVP numbers will be 0.

```
Example #1
       NESW.X    Comment
DVP = 2040.4      0 to 26 m/s speeds
BVP = 0030.5     15 to 44 m/s speeds
```

Over the last 12 hours a wind field was present with a drift volume potential of 2 out of the north and 4 out of the south. There was also a period during this time when a blowing snow wind field with volume potential of 3 was present out of the south. The dominant wind directions during the last 12 hours were southeast for the drifting winds and south for blowing winds. It can also be deduced from example 1 that over the past 12 hours more than twice as much snow could potentially of been transported onto north aspect slopes as on south aspects due to winds.

Volume Potential Number Pair Conversion Table *					
KM/H	Meter/S	MPH	Knots	Blow_VP	Drift_VP
0	0.00	0	0.0	**0**	**0**
10	2.78	6	5.4		
20	5.56	12	10.8		
30	8.33	19	16.2	**0**	**1**
40	11.11	25	21.6		
50	13.89	31	27.0	**0**	**2**
58	16.11	36	31.3	**0**	**3**
60	16.67	37	32.4		
65	18.05	40	35.1	**0**	**4**
70	19.44	43	37.8	**0**	**5**
75	20.83	47	40.5	**0**	**6**
80	22.22	50	43.2	**0**	**7**
83	23.05	52	44.8	**0**	**8**
87	24.17	54	46.9	**0**	**9**
90	25.00	56	48.6		
95	26.39	59	51.3	**1**	**0**
100	27.78	62	54.0		
110	30.55	68	59.4		
114	31.66	71	61.5	**2**	**0**
120	33.33	75	64.8		
125	34.72	78	67.5	**3**	**0**
130	36.11	81	70.1		
132	36.66	82	71.2	**4**	**0**
138	38.33	86	74.5	**5**	**0**
140	38.89	87	75.5		
144	40.00	89	77.7	**6**	**0**
148	41.11	92	79.9	**7**	**0**
150	41.66	93	80.9		
153	42.50	95	82.6	**8**	**0**
157	43.61	98	84.7	**9**	**0**
160	44.44	99	86.3		
180	50.00	112	97.1	**9**	**9**
200	55.55	124	107.9	Sustained Winds	
220	61.11	137	118.7	Out of Range	
240	66.66	149	129.5		
260	72.22	162	140.3	**9**	**9**
X	X / 3.6	X / 1.6093	X * 0.5396		
When BVP<>1 BVP = (((X / 3.6 -16.666) /30)^3)*12 Period =12 Hours					
When DVP<> 1 DVP = ((X / 97.2)^3)*12 Period = 12 Hours					
* Table represents sustained 12 hour winds. Other number pair combinations are possible.					

Table 2. *Blow and Drift Volume Potential Number pair lookup table. Numbers should be used as a pair.*

Example #2

```
NESW.X    Comment
DVP = 1810.2    0 to 26 m/s speeds
BVP = 0000.1    15 to 44 m/s speeds
```

Over the past 12 hours strong winds typical of drifting snow persisted out of the northeast (the dominant direction). Some north winds were also present at speeds above 26m/s but were insufficient to transport substantial amounts of blowing snow in normal circumstances. Southwest aspect start zones may have been substantially loaded depending on snow surface conditions and other factors such as temperature.

6. Conclusions

Two numbers have been proposed to reduce and render wind field data and the potential for wind transported snow accumulated over longer time periods. Number formats are simple to facilitate the easy communication and sharing of wind field information.

Diurnal or Semi diurnal summaries of weather data have proved successful in wide coverage area avalanche forecasting. In BC wind field data has not previously been reduced or summarized as have snow fall or air temperature information.

Wind information at mountain tops is available in BC's avalanche triangle. Improved methods to reduce, render and share the data could benefit the industry and the public.

BC highways collect large amounts of weather, snowpack and avalanche data. Academia, research and the avalanche industry could benefit from closer cooperation given the on line information that is potentially valuable for modelers.

Application and use of wind information in avalanche forecasting is more complex than other common weather data. Wind data alone may not always be an indication of increasing or decreasing hazard levels unless coupled with other information such as field observations.

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Notes: