THE EFFECT OF ALTITUDE AND LATITUDE ON NEW ENGLAND SNOWFALL ESTIMATES

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INTRODUCTION

In a previous paper (1) it was stated that in estimating snowfall in New England, the formula of one inch of snow for every thirty-five feet increase of altitude approximated existing averages. This was double that of Stone's (2) and, further, still inaccurate to cover the majority of circumstances. This paper attempts to take into account the effect of latitude, a factor over-looked in previous formulas, and to introduce corrected formulae that lowers the percentage of error.

EFFECT OF LATITUDE

To completely isolate the effect of latitude is impossible. The factors of temperature and altitude must be considered in some respect. It is obvious that the snowfall differences between coastal stations of Northern and Southern New England is a matter of latitude and temperature, and not of altitude. For example, the latitude difference between Portland, Me. and New Haven, Conn. is 2° 23'. The average snowfall differs by thirty-five inches, and the altitude difference is about fifty-five feet. If altitude were the main factor in this case, we would expect a snowfall difference of only a few inches. Assuming that latitude is the only factor, it is found

TABLE I

Sample Cases Adhering to a Snowfall Increase of 15" per °Latitude

Station	Lat	Alt (ft)	Snowfall (in)	D-M Temp
Portland, Me.	43° 39'N	61	69	24°F
New Haven, Conn.	41° 16'N	6	34	30°F
Greenville, Me.	45° 27'N	1061	109	17°F
Salisbury, Conn.	41° 59'N	1015	61	26°F
Lebanon, N. H.	43° 18'N	550	70	22°F
Keene, N. H.	42° 56'N	490	60	25°F

that snowfall would increase northward at the rate of about fifteen inches per degree of latitude. It was found that this increase could be applied with favorable results to those stations which had the same general characteristics, that is to say, if they were about the same altitude, both were coastal or mountain stations, same general terrain, etc., plus a December-March temperature difference greater than three degrees Fahrenheit. (See Table I page 57) The increase of 15" per ° latitude does not hold unless this temperature difference exists, although all other factors are present. Consider the following:

Station	Lat	Alt (ft)	Snowfall (in)	D-M Temp
Eastport, Me.	44° 54'N	75	73	24°F
Portland, Me.	43° 39'N	61	68	24°F

Although there is a latitude difference of one and a quarter degrees between these two stations, the snowfall difference is but four inches, and both stations have the same average winter temperature. The same result was found in all cases of this type investigated.

It is not clear why a temperature difference of three degrees or more is required for the above mentioned increase of snowfall with latitude. Perhaps it is mere chance. However, there are too many restrictions placed upon this rule for general usage, but it does afford an insight to the fact that there is an important relationship between snowfall and latitude in New England.

EFFECT OF ALTITUDE

Stone (2) has previously computed a formula in which he found that for every seventeen and one-half feet increase of altitude, snowfall increased one inch. The method of determining this formula is as follows: selected snowfall totals were taken along a line from the Massachusetts coast to the White Mts. and a straight line was drawn to approximate the gradient. The average increase of snowfall with elevation was obtained by dividing the average gradient of snowfall from the vicinity of the coast to the mountains by the average rise in the land. The starting point was fifty feet above sea level with a snowfall average at that point of forty-five inches.

This appears to be the most direct and least complicated approach. However, from the Massachusetts coast to the White Mts. covers a latitude spread of about two degrees. As stated above, latitude has its effects although they are not clearly isolated. The use of this formula westward from the Massachusetts coast to the Berkshires of Massachusetts and Connecticut is not very reliable, far exceeding the author's expectations in percentage of error. Stone estimated errors of plus or minus 10-30% with the use of the formula, but errors of double these values were found when tested for the above areas. It was assumed that by considering latitude in the formula, these errors could be corrected and even lowered below the 10-30% range.

Using the same method but for the individual stated, new formulas were computed. (Table II) For example, the base value of Maine was derived by averaging the altitude and snowfall for the stations along the coastal plain with elevations under one hundred feet. The average of six stations

TABLE II

Formulas for Estimating Snowfall in New England

State	Base	Incr Snfl per Incr Alt
Maine	64" at 46'	1" per 25'
New Hampshire	53" at 50'	1" per 30'
Vermont	53" at 50'	1" per 30'
Massachusetts	42" at 53'	1" per 40'
Connecticut	34" at 50'	1" per 35'

revealed a height of forty-six feet and an average snowfall of sixty-four inches. From the coast a line was drawn to the area of highest elevations, but not to the point of maximum elevation. Stone's method, as explained above, was followed to completion, and the average increase of snowfall with altitude for Maine was found to be one inch for every twenty-five feet. The same procedure was followed in computing the average increase for Massachusetts and Connecticut. Since New Hampshire has a small coastal area and Vermont none at all, the average increase of snowfall with altitude was assumed to be mid-way between the figures computed for Maine and Massachusetts.

By computing this average increase of snowfall with altitude for each state, the factor of latitude is included in respect to both the base point and as the altitude increases. It is probably this factor that accounts, in the over-all picture, for the improvement in results over Stone's formula.

RESULTS

The main purpose for computing these formulas was to reduce the percentage of error in the estimates. Stone found the error to be plus or minus 10-30%. Stations with snowfall averages of twenty years or more were used in testing both methods. These numbered an even one hundred, exclusive of the stations used in computing the base.

TABLE III

Test Results of Formulas - Increase of Snowfall with Altitude

% Error	Number of Cases	
	Revised	Stone's
<10%	73	31
11-20%	17	21
>20%	10	48

The revised formulas show that 73 of the 100 cases tested had an error of ten percent or less as against 31 cases in that category for Stone's formula. Errors greater than 20% occurred in 10 cases with the new formulas, while the majority of cases fell into this category using Stone's formula. (See Table III)

The stations used ranged in elevation from 100 feet to 2300 feet. No adjustments were made as regards exposure. Thus, if a station lay in a snow-shadow, the percentage of error would necessarily be greater than expected, and the computed average greater than the actual average.

In general, the new formulas under-estimate actual averages. Results are good up to about 2000 feet. (Table IV) The number of stations above 2000 feet are not sufficient to give an absolute test for higher elevations. Mt. Washington at 6262 feet has an October to May snowfall average of 176 inches over an eighteen year period. Computing the average by formula gives a result of 260 inches. By Stone's formula the expected average is 400 inches. It is quite possible that maximum snowfall does not occur on the peaks of the higher mountains in New England, but somewhere below the crest of the mountains. More probable is the possibility that the rate of increase decreases above 1500 feet.

TABLE IV

Distribution of Percentage of Error with Altitude

Altitude (ft)	Percentage of Error		
	10%	11-20%	20%
100-500	31	10	2
501-1000	28	4	4
1001-1500	11	1	2
1501-2400	3	2	2

CONCLUSION

Although there is a slight improvement with the revised formulas, they are still unsatisfactory for other than approximation. There are too many variable factors involved for complete accuracy, the greatest of these being snowfall itself. More observations are required of snowfall between the two and five thousand foot levels before the formulas can be safely used for estimates at those elevations. At best, the formulas may be used as a guide for further experimentation.

REFERENCES

1. Galway, J.G., 1950: New England Snowfall Averages, read before the Eastern Snow Conference, Lake Placid, N.Y., February 1951.

2. Stone, R.G., 1934: Snow for Skiing in New Hampshire. Ski Annual, 1934, pp 62-69.

APPENDIX I

Example of the Use of the Formulas

Station: Eustis, Me.

Altitude: 1190 feet

Average Snowfall: 110 inches

Maine Formula: Base 64" at 46' Increase, 1" per 25'

At an elevation of 46 feet average snowfall is 64 inches. Subtracting the base elevation from the station elevation gives a difference of 1154 feet. At an increase of 1" per 25' additional snowfall equals 46". (By dividing 25 into 1154)

46" plus base of 64" equals 110", estimated snowfall.

All computations to the nearest inch.