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AN ANALYSIS OF THE PENNER-HARLEY Q PF TECHNIQUE ALONG THE B.C. COAST

BY

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ABSTRACT

The Penner-Harley method is employed to obtain QPF's from actual data at Annette and Tatoosh Island. The QPF's are calculated including and excluding an orographic term. Correlation coefficients are computed between observed and calculated precipitation rates at the radiosonde stations and also at adjoining stations. The results illustrate some of the difficulties encountered in obtaining accurate forecasts in this area. An analysis of the technique provides valuable information concerning the probability of occurrence or non-occurrence of precipitation.

ANALYSE DE LA TECHNIQUE DE PRÉVISION QUANTITATIVE DES PRÉCIPITATIONS
DE PENNER-HARLEY LE LONG DE LA CÔTE DE LA COLOMBIE-BRITANNIQUE

par

Stephen Nikleva

RÉSUMÉ

L'auteur utilise la méthode de Penner-Harley pour obtenir les prévisions quantitatives des précipitations à partir de données recueillies à Annette et à l'île Tatoosh. Il calcule les prévisions quantitatives des précipitations en incluant et en excluant un terme orographique. Il calcule des coefficients de corrélation entre les taux de précipitation observés et calculés aux stations de radiosondage ainsi qu'aux stations voisines. Les résultats illustrent certaines des difficultés que présente l'obtention de prévisions précises dans cette région. Une analyse de cette technique donne des renseignements utiles sur la probabilité de précipitation ou de non-précipitation.

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1. Introduction

The Penner-Harley QPF Technique provides an operational method of obtaining precipitation forecasts that take account of topographic effects. This method achieved good results in the Toronto area (1) and it is felt that a further test in an area where terrain is effective will be useful.

2. Method

The Penner-Harley Technique is used to compute the precipitation rate at Annette and Tatoosh Island at 0000Z and 1200Z for the period October 7, 1965 to February 28, 1966. Radiosonde data and synoptic charts are employed to derive the various parameters and the procedure followed is essentially the one described in Circular-4139, TEC-544, "The Determination of Spot Values of Vertical Velocity and Precipitation Rate". The value of the vorticity advection term is obtained by use of the geostrophic advection scale on the Central Analysis Office 500 mb vorticity analysis and the thickness advection is calculated in the same fashion by measuring areas on the PAWC 500 mb thickness analysis. The remainder of the upper air data necessary to complete the computations is derived from radiosonde data. Surface friction and instability are not considered although they are undoubtedly important along the coast and would have to be included in the final technique. The determination of an orographic effect for stations on the coastline presents difficulties as the theory does not provide for an orographic contribution in the area contiguous to the mountains; yet synoptic experience suggests that an increase of precipitation occurs some distance upwind from the actual slope. To meet this problem, QPFs are calculated excluding and including the orographic term. The terrain parameters required for the orographic term are inferred from the smoothed topographic contour chart (1).

QPF values are compared with observed rainfall occurring at the radiosonde station and also with the rainfall at an adjoining station. The computed rate in inches per six hours valid at raob time is correlated with the mean values of six hourly precipitation amounts that bracket the time of observation.

The accuracy of the method is judged by plotting the observed and computed rates to form a scatter diagram and calculating the correlation coefficient. The actual scatter diagrams are not included in this paper; instead, contingency tables are prepared from the diagrams to facilitate a study of the method. The observations are divided into three groups with approximately the lower half of observed precipitation rates in one group. The other half of the observations is evenly divided to form two more groups. This is an arbitrary division, but it enables one to form an estimate of the relative accuracy of the method in forecasting large or small precipitation rates.

3. Tatoosh Island

The average yearly rainfall at Tatoosh is 76 inches which is approximately the amount of the lowest average rainfalls recorded along the West Coast of Vancouver Island. The lowest values may still include an orographic influence; however, it appears reasonable to assume that the general uplifting due to Vancouver Island and the Western Washington Mountains does not make an appreciable contribution to the rainfall at Tatoosh, and the observed amount is probably indicative of the nonorographic rainfall occurring in this area with possibly a contribution due to surface friction near the coastline. As a first approximation a QPF is computed without an orographic term. A scatter diagram is constructed and when neglecting the points at the origin (zero forecast and zero observed) a correlation coefficient of .45 is obtained. Table 1 is prepared from this data.

It can be seen that zero precipitation is forecast much too frequently, as there are 154 forecasts while only 94 cases are actually observed. There are 79 cases when precipitation is forecast and precipitation occurs. 37 are in the correct category giving 47% accuracy for this event. If the method is used as an indicator of rain occurrence, then it will forecast the occurrence or non-occurrence of rain correctly 68% of the time. If we consider only the cases when rain is forecast to occur in the two largest groups then it is evident that some rain occurs in 36 out of the 37 cases.

TABLE 1

Tatoosh

QPF - no orographic

Observation	0	01-11	12-19	20-	Total
0	86	7	1	0	94
01-11	44	26	12	3	85
12-19	18	9	3	1	31
20-	6	8	9	8	31
Total	154	50	25	12	241

Correlation coefficient .45

68% correct forecasts of occurrence or non-occurrence of precipitation.

47% categories correct when precipitation forecast and precipitation occurs.

The computed QPF values are compared to the observed values at Tofino which is near enough so that values for the large scale parameters can be considered to be applicable to both stations. Tofino, however, averages about 50% more rain than Tatoosh. If it is assumed this results from an extension of the lifting occurring over the mountains immediately to the east then the influence of the Vancouver Island Mountains should be evident. To see if this is so, two new sets of QPF's incorporating an orographic effect are computed in the following way.

The equation for the orographic vertical velocity (1) is

$$\omega_m = -g \rho_o \vec{V}_o \cdot \nabla H (P/P_o)^{2.5}$$

1. To evaluate $\vec{V}_o \cdot \nabla H$, the component of the 3000 ft. wind along the normal (taken as 220 deg.) to the smoothed terrain is employed in equation 1 with a value of .01 for the slope. As a means of identification this will be referred to as the PAWC term.
2. The second procedure is the same as above except that the orographic effect is restricted to cases with wind directions within 30 degrees of the normal. This is similar to the recommended procedure (1) with the exception that winds not perpendicular to the slope are slightly less than recommended, as the component along the 220 degree line is used rather than the full speed. This will be referred to as the Harley orographic term. It can be seen that the maximum difference for an individual report is 15%. The average effect is less and will certainly be negligible for the purpose of this investigation. It is thought worthwhile to test the PAWC procedure since a sharp discontinuity in the orographic effect at an angle of 30 degrees to the mountains seems to impose a much too critical condition, especially in view of the excessively indented coastline. The possibility of a gradual decrease in orographic component, therefore, seems to warrant a trial. The correlation coefficient between Tofino's observed precipitation and the non-orographic QPF is .27. Tables 2 and 3 show the improvement resulting from the inclusion of an orographic term.

The increase in correlation coefficient from .27 to .63 by the inclusion of the orographic term at Tofino is significant at the 5% level using Fisher's Z' transformation. The difference in the PAWC and Harley correlation coefficients is not statistically significant, however, in all cases when the observed precipitation is greater than .32 inches (36 cases) any change in the

TABLE 2

Tofino

QPF - Harley Orographic

Observation	0	01-15	16-35	36-	Total
0	77	8	3	1	89
01-15	39	27	16	3	85
16-35	6	13	7	8	34
36-	6	5	6	16	33
Total	128	53	32	28	241

Correlation coefficient .51

74% correct forecasts of occurrence or non-occurrence of precipitation.

50% categories correct when precipitation forecast and precipitation occurs.

TABLE 3

Tofino

QPF - PAWC Orographic

Observation	0	01-15	16-35	36-	Total
0	75	6	6	2	89
01-15	31	20	26	8	85
16-35	4	10	10	10	34
36-	1	3	6	23	33
Total	111	39	48	43	241

Correlation coefficient .63.

79% correct forecasts of occurrence or non-occurrence of precipitation.

46% categories correct when precipitation forecast and precipitation occurs.

corresponding QPF brought about by using the PAWC rather than the Harley term results in an improvement. Nine such cases occur out of the total of 36. This may be due to the fact that southerly winds are correlated with approaching low pressure centres and, therefore, also with large precipitation amounts. The inclusion of this component can, therefore, be expected to improve the correlation. Table 3 indicates that in 116 cases, rain is forecast and rain occurs. In this group, 53 are forecast correctly resulting in 46% accuracy. The occurrence or non-occurrence of rain is forecast accurately 79% of the time. 91 forecasts occur in the two largest categories and rain is observed in 83 of these cases. When the QPF is .12 or greater, therefore, a forecast of the occurrence of precipitation is correct 90% of the time. The QPF's incorporating the orographic terms are then compared with Tatoosh. Inclusion of the PAWC term increases the correlation coefficient to .48 and the occurrence or non-occurrence of rain is forecast correctly 79% of the time. In the rain forecast and rain occurs group, 39% of the categories are correct. Slightly better results are obtained using the Harley term (Table 4).

TABLE 4

Tatoosh

QPF - Harley Orographic

Observation	0	01-11	12-19	20-	Total
0	12	8	3	1	94
01-11	33	22	12	18	85
12-19	11	6	3	11	31
20-	2	3	3	23	31
Total	128	39	21	53	241

Correlation coefficient .52.

76% correct forecasts of occurrence or non-occurrence of precipitation.

47% categories correct when precipitation forecast and precipitation occurs.

The inclusion of the orographic term results in decreasing the number of forecasts of zero precipitation and increases the number of correct forecasts in the largest category. However, if we examine the relative accuracy of forecasting the largest amounts, we find that the greater number of correct forecasts is accomplished by forecasting the category much more frequently rather than more accurately. This is reflected in the correlation coefficients which vary only slightly for the three cases (.42 to .52"). Table 4 has the greatest number of correct forecasts in the rain forecast and rain occurs group with 48 cases. The accuracy of 47% is, however, the same as in Table 1.

4. Annette

A similar analysis is carried out for Annette for the same period. This station is located at the northern end of the Hecate Depression between the Insular and Coastal Mountains and it is not obvious what the effects of topography will be. The average annual precipitation is 97 inches. Three QPF's are computed using the same procedure outlined for Tatoosh with the difference that the 5000 ft. wind is used. The direction normal to the mountains is taken as 240 degrees and the value of the slope as .014. Tables 5, 6, and 7 are derived from the plotted scattered diagrams.

TABLE 5

Annette

QPF - No Orographic

Observation	0	01-11	12-27	28-	Total
0	100	6	6	0	112
01-11	49	25	4	1	79
12-27	21	13	3	1	38
28-	4	16	16	1	37
Total	174	60	29	3	266

Correlation coefficient .36.

68% correct forecasts of occurrence or non-occurrence of precipitation.

36% categories correct when precipitation forecast and precipitation occurs.

TABLE 6

Annette

QPF - Harley Orographic

Observation	0	01-11	12-27	28-	Total
0	100	8	4	0	112
01-11	42	23	11	3	79
12-27	17	11	8	2	38
28-	2	12	15	8	37
Total	161	54	38	13	266

Correlation coefficient..35.

73% correct forecasts of occurrence or non-occurrence of precipitation.

42% categories correct when precipitation forecast and precipitation occurs.

TABLE 7

Annette

QPF - PAWC Orographic

Observation	0	01-12	12-27	28-	Total
0	94	13	3	2	112
01-11	27	26	19	7	79
12-27	8	10	15	5	38
28-	1	0	9	27	37
Total	130	49	46	41	266

Correlation coefficient .64.

80% correct forecasts of occurrence or non-occurrence of precipitation

58% categories correct when precipitation forecast and precipitation occurs.

A correlation coefficient of .36 is calculated when the observed precipitation is compared with the non-orographic QPF. Surprisingly, this value is not improved using Harley's orographic term (Table 6), however, there is a greater percent of correct forecasts of rain occurrence and an increase in the total number of correct forecasts of precipitation rate. Although the Harley term gives little improvement in the correlation coefficient, use of the PAWC orographic term results in a significant increase from .36 to .64 (Table 7). This is significant at the 5% level using Fisher's Z' transformation. It is evident that the wind is an important factor but that our initial choice of wind direction for the Harley orographic term is incorrect. An examination of the data suggests the southerly component of the wind is the cause of the increased accuracy resulting from the use of the PAWC term. A new orographic term is computed employing the 3000 ft. wind in the sector 150-220 degrees. The scatter diagram produces a slightly higher coefficient than the previous example (Table 8).

TABLE 8
Annette

QPF - 150-220 Deg Orographic

Observation	0	01-11	12-27	28-	Total
0	100	5	3	4	112
01-11	35	18	13	13	79
12-27	7	5	12	14	38
28-	0	2	4	31	37
Total	142	30	32	62	266

Correlation coefficient .69.

80% correct forecasts of occurrence or non-occurrence of precipitation.

54% categories correct when precipitation forecast and precipitation occurs.

This method over-forecasts heavy precipitation as approximately 2/3 of the forecasts are in the two highest categories which contain only 1/2 of the total observations. It can be seen that for the 94 forecasts in the upper two ranges, some rain occurs in 87 cases. For these cases which comprise 3/4 of the total computed rain cases, the percent accuracy of forecasts of rain occurrence is 93%. The computed QPF values are also compared to the observed values at Prince Rupert where the average annual precipitation of 94 inches is nearly identical to Annette. Correlation coefficients are lower in all cases. Harley's orographic QPF's yield a coefficient of .29. Rain occurrence is forecast correctly 68% of the time and 38% of the categories are correct when rain is forecast and rain occurs. A slight improvement is noted with the PAWC term (Table 9) which gives the best results.

TABLE 9

Prince Rupert

QPF - PAWC Orographic

Observation	0	01-11	12-27	28-	Total
0	82	13	7	4	107
01-11	33	23	22	9	87
12-27	14	10	10	11	44
28-	1	3	7	17	28
Total	130	49	46	41	266

Correlation coefficient .40.

72% correct forecasts of occurrence or non-occurrence of precipitation.

45% categories correct when precipitation forecast and precipitation occurs.

The percent of categories forecast correctly in the rain forecast and rain occurs class is 58% at Annette where the topographical component is probably more accurately delineated. The other three stations have values ranging from 44% to 47%. These figures are only valid for the ranges chosen and will vary for a different choice of forecast intervals.

In addition to forecasting precipitation rates it is evident that the method can be a useful tool for forecasting the probability of occurrence or non-occurrence of precipitation. Even in the case of Tatoosh, where the correlation coefficient is only .45, it is found that in the cases where precipitation is forecast to occur in the two largest categories precipitation occurs in 36 cases out of 37 giving an accuracy of 97% for this event. At Annette an examination of the actual data used in table 8 reveals that some precipitation always occurs when the QPF is .38 or larger. As this event occurs 47 times in a total of 166 cases of precipitation occurring or forecast to occur, it can be a valuable forecast aid. It is evident that an analysis of the results of the QPF technique shows promise of providing a measure of the probability of the occurrence or non-occurrence of rain.

If the samples can be considered to be representative of conditions in this area, regression lines can be computed from the scatter diagrams and used to obtain an empirical correction to the Penner-Harley QPF. It is planned to test this on 66-67 winter data to ascertain if the regression equations derived from this data remain stable.

It is evident that useful information can be obtained by a simple application of the method, and a consideration of surface friction, instability and possibly an empirically derived orographic term will produce improved results. It must be kept in mind that the "forecasts" used in this study are based on actual data and the measure of the forecast usefulness of the technique will depend on how accurately the parameters can be forecast and how sensitive the resulting precipitation forecast is to errors in the forecasts of the individual parameters.

The 3000 ft. wind in the 150-220 degree sector is also used to compute an orographic term. This procedure results in a correlation coefficient of .38. There is a 71% accuracy in forecasting rain occurrence and 35% of the categories are correct when rain is forecast and occurs. It is interesting to note that the orographic effect that produces such a marked improvement at Annette does not improve the accuracy of the results at Prince Rupert, and this illustrates the difficulty of evaluating the orographic effect obtained from a smoothed topographical chart.

5. Conclusion

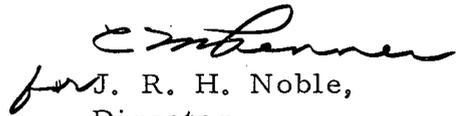
The correlation coefficient computed for Tatoosh where the orographic contribution is not dominant is .45. This correlation coefficient is statistically highly significant but much lower than the values obtained at Toronto (1). Part of this difference can be ascribed to the use of spot values as a measure of the observed precipitation rate and to the neglect of surface friction which can be expected to be an important influence near the coastline. Another factor is that the large scale vertical velocity as measured by Pennér's formula may not be as accurately computed in this area due to a less accurate analysis along the coast. It would also appear that the respective contributions of vorticity and thickness advection to vertical velocity could very well differ in both areas. Along the West Coast much of the precipitation occurs with decaying systems and cold troughs where the relationships between thickness advection and vertical motion are quite different from those found in the classical frontal disturbance more common over the eastern half of North America.

At Tofino and Annette, where topographical effects are important, a better relationship is evident. As these stations are not on the actual mountain slopes the orographic effect is not straightforward, however, it appears there is an increase in precipitation due to a backing up of the orographic effect of the mountains combined with smaller scale local effects. The difficulty in obtaining an overall topographic effect along the coast is evident in the case of Prince Rupert where a term that produces a striking improvement at one station does not alter the result at a nearby station although the smoothed topographical map indicates similar conditions and even an examination of the actual large scale topography does not suggest such a critical difference. The PAWC orographic term gives higher correlation coefficients than the Harley term for 3 out of 4 stations and in the 4th case results are nearly the same. More data is needed, however, before a separation of the contributing factors is possible.

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APPROVED,


for J. R. H. Noble,
Director,
Meteorological Branch.

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