~~Dr. H. Glahn~~
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STUDIES IN THE SPECIFICATION OF PRECIPITATION TYPE FROM OBSERVED UPPER-AIR SOUNDINGS

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1. INTRODUCTION

The vertical temperature and moisture structure of the atmosphere, as obtained from the radiosonde observation (RAOB), is an important consideration for short-range forecasts of precipitation (precip) type. In this study, we used statistical methods to determine the characteristics of the RAOB associated with liquid, freezing, and frozen precip. In this respect, a forward screening technique known as the Regression Estimation of Event Probabilities (REEP) (Miller, 1964) was used to develop linear regression equations that relate parameters from the RAOB's with precip type observed at the same time as the RAOB; that is, the equations "specify" (as opposed to "predict") precip type.

The results of this study may be useful in a number of ways. For example, with the implementation of the Automation of Field Operations and Services (AFOS) program (Klein, 1978; Wilkins and Johnson, 1975) the capability will exist to display and analyze the RAOB with a local minicomputer. The specification equations developed in this study can rapidly be evaluated on the AFOS computer for use in a "nowcasting" (very short-range forecast) sense. Also, those parameters found to be important could be derived from RAOB's forecasted by the Techniques Development Laboratory's (TDL's) boundary layer model (BLM) (Long, et al., 1978). That is, the Model Output Statistics (MOS) (Glahn and Lowry, 1972) approach could be used with BLM output to develop precip type prediction equations for 12- to 24-h projections. Such MOS forecasts are presently available within the National Weather Service (Bocchieri, 1979a) based on the Limited-area Fine Mesh (LFM) model (Gerrity, 1977; National Weather Service, 1971). However, since the BLM has greater vertical resolution than the LFM within the lowest 1600 m, MOS precip type forecasts based on the BLM may be more accurate than those based on the LFM.

In this paper, frozen precip is defined as snow, sleet (ice pellets), or snow mixed with sleet; freezing precip includes freezing rain, freezing drizzle, or freezing rain or drizzle mixed with snow or sleet; and the liquid category consists of rain or rain mixed with snow or sleet.

In section 2, the predictors[1] derived from the RAOB's are described, and references to authors who have used many of these parameters previously are given. Section 3 describes the statistical development of the specification equations, and section 4 presents verification of the equations for both developmental and independent data samples. The verification results indicate that specification of the liquid and frozen categories was excellent, but the system had some difficulty with freezing precip.

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[1] The word predictor will be used in this paper even though the equations developed _specify_ precip type.

2. THE POTENTIAL RAOB PREDICTORS

Table 1 describes the predictors that were derived from the RAOB's. Heights are given in terms of height above station; also, when vertical interpolation was necessary, it was done linearly with respect to height.

Parameters were derived from both the temperature and wet-bulb temperature profiles. The wet-bulb temperature was used to help account for the evaporational cooling effect. As explained by Penn (1957), evaporational cooling takes place as precip falls through unsaturated air between the clouds and the ground. The effect is especially pronounced when very dry air is present in low levels. Lumb (1960, 1961, and 1963) and Booth (1973) also found the wet-bulb temperature to be important for rain-snow discrimination in the British Isles. Lumb indicated that cooling by evaporation during precip of moderate intensity can reduce the wet-bulb depression to a small fraction of its original value within an hour or two; as saturation is approached, the temperature of the air should approach the wet-bulb temperature.

In Table 1, predictors 1 through 18 are rather simple and include temperature, wet-bulb temperature, and wind components at the surface and mean values of these parameters for various layers aloft. The mean temperature within a layer is analogous to a thickness type variable such as 1000-500 mb thickness. Many investigators, including Wagner (1957), Younkin (1967), and Glahn and Bocchieri (1975), have used various thicknesses as predictors because it's generally easier to predict thickness than, let's say, temperatures at specific levels. Other studies in which thickness was used are referred to by Brenton (1973) who extensively reviewed the state of the art in snow forecasting.

For predictors 19 through 26 in Table 1, both the temperature and wet-bulb temperature profiles were examined in relation to the 0°C isotherm to derive parameters defining the warm layer (or layers) and freezing level in the RAOB. In this respect, a warm layer is defined as a layer in which the temperature, or the wet-bulb temperature, is > 0°C. Predictors 19 and 23 define the depth of the warm layer, and predictor 20 (24) defines the area between the temperature (wet-bulb temperature) profile and the 0°C isotherm in the warm layer. In cases where more than one warm layer existed, the depths and areas were summed. The areas were computed by a numerical integration technique known as the trapezoidal rule (Kaplan, 1959). Predictors 21 and 25 define the height of the top of the warm layer; for multiple warm layers, the highest warm layer was used. Predictors 22 and 26 define the height of the lowest freezing level.

Predictors similar to 20 and 24 were used by Burnash and Hug (1970) and Lumb (1961 and 1963) to help determine the downward penetration of snow. The idea, of course, is that the greater the depth, or area, of the warm layer the greater is the chance the precip in the form of snow would melt when falling through the layer. The height of the freezing level has been found to be useful for rain-snow discrimination by a number of investigators including Murray (1952), Boyden (1964), Pandolfo (1957), Booth (1973), and Lumb (1960).

Predictors 27 through 36 were designed specifically to help discriminate freezing precip from other types. The design was based on the conditions generally associated with freezing precip: "...a shallow wedge of cold air and a sharp rise in temperature aloft to a peak temperature, warmer than freezing, generally at some level between 850 and 700-mb..." (Young, 1978). It should be noted that freezing drizzle and freezing rain are both included in the freezing precip category in this study. However, the charactersitics of a freezing drizzle RAOB can be quite different than those of a freezing rain RAOB. Young, for instance, showed representative RAOB's for freezing rain and freezing drizzle and found that temperatures near the surface and aloft were generally colder for freezing drizzle than for freezing rain.

In this study, we computed composite temperature and dew point profiles for both freezing rain and freezing drizzle. The data sample consisted of 127 freezing drizzle and 94 freezing rain RAOB's from the 48 stations in Table 2 for the period October through April, 1972-73 through 1976-77. The composite RAOB's, shown in Fig. 1, indicate the following: (1) In agreement with Young, freezing drizzle RAOB's were, in the mean, colder than freezing rain RAOB's. (2) The saturated layer for freezing rain was, in the mean, much deeper than the saturated layer for freezing drizzle. (3) The composite freezing rain RAOB, showing a warm layer over a surface-based cold layer, is similar to typical freezing rain RAOB's shown by Young and other investigators. However, the composite freezing drizzle RAOB shows no warm layer aloft; this differs from the typical freezing drizzle RAOB shown by Young.

With respect to this last result, Young showed a RAOB which, he said, was "... an unusual case of freezing drizzle, with no temeprature above 0°C at any level". We found that this circumstance was not so unusual. That is, 44% of the freezing drizzle RAOB's used to compute the composite had no temperature above 0°C at any level; however, this was true for only 2% of the freezing rain RAOB's. Therefore, an almost necessary condition for freezing rain is a surface-based cold layer with a warm layer aloft, but, for freezing drizzle, the warm layer is not necessary. Apparently, when freezing drizzle occurs with no temperatures above 0°C at any level, the coalescence of super-cooled water drops is predominantly responsible for the growth of drizzle drops, and the clouds are warm enough so that they are unlikely to contain ice-crystals (Mason and Howorth, 1952).

In view of the above discussion, predictor 27 is a binary type variable that equals 1 if the surface temperature is $\leq$ 0°C <u>and</u> a warm layer exists aloft; otherwise, this variable equals 0. The conditions for ZR(T) to equal 1 were characteristic of almost all freezing rain RAOB's and a majority of the freezing drizzle RAOB's used to compute the composite soundings. The design of predictors to specifically discriminate freezing drizzle from other precip types <u>when no warm layer exists aloft</u> was left for future research.

Predictor 28 is the depth of the surface-based cold layer, with respect to temperature, when ZR(T)=1; and predictor 29 is the area between the temperatue profile and the 0°C isotherm in the surface-based cold layer when ZR(T)=1. If ZR(T)=0, both of these predictors equal 0. Predictors 30 and 31 are interactive or product type variables; when ZR(T)=1, for example, they define the depth and area of the warm layer, respectively, with respect to temperature. Young also experimented with variables similar to predictors 28 through 31 and found them to have some merit. However, he didn't include them in his forecast method. Also, Mahaffy (1961) emphasized the importance of the depth of the warm layer for the occurrence of freezing rain.

3. SPECIFICATION EQUATIONS

To develop the specification equations, the RAOB predictors in Table 1 were included in the REEP screening computer program. In the REEP procedure, a subset of effective predictors is objectively selected from a large set of potential predictors to use in multiple linear regression equations. The equations developed give estimates of the probabilities of occurrence of a given set of binary-type predictands. In this application, precip type is categorized into three binary-type predictands; liquid, freezing, and frozen. The predictands are called binary because, in the developmental phase, each predictand is assigned a value of 1 or 0 in a given case depending, respectively, upon whether that particular precip type occurs or doesn't occur. The potential predictors can be either in binary or continuous form. A good description of the screening procedure can be found in Glahn and Lowry (1972); also, Klein and Glahn (1974) give applications of REEP within the TDL.

Two data samples, called samples 1 and 2, were used in the development of the specification equations. Sample 1 was used to develop the equations, and sample 2 was used to determine the number of predictors to include in the equations. Sample 1 consisted of 1200 GMT RAOB's matched with precip type observed at 1200 GMT; for sample 2, 0000 GMT data were used. In this context, sample 2 was considered to be an independent sample. For both samples, data were combined from the 48 RAOB stations listed in Table 2 for the winter seasons (September through April) of 1972-73 through 1976-77 (6067 precip cases for sample 1 and 5245 precip cases for sample 2). The RAOB data were obtained on magnetic tape from the National Climatic Center in Asheville, North Carolina and consisted of pressure, temperature, relative humidity, and wind measurements at both mandatory and significant levels. Within TDL, these data are error checked and reformatted into a form more acceptable to our statistical analysis programs.

With sample 1, 10 REEP equations were developed containing 2, 4, 6,..., 18, and 20 predictors. Each equation was then evaluated with data from sample 2, and the Brier score (Brier, 1950) was computed. The results, shown in Fig. 2, indicate that the Brier score steadily improved (decreased) out to about 12 predictors; after that, there was very little change in the score. Therefore, we included 12 predictors in the specification equations.

Table 3 shows the 12 predictors in the order determined by the REEP screening procedure. The additional reduction of variance (RV) after each predictor was chosen, the total reduction of variance, and the observed relative frequency for each precip type are also shown. Note that all the predictors are in binary form, that is, they can have only two values 0 or 1. For example, if the $\overline{T}$ (sfc-1000) is $\leq -1.0°C$ for a particular case, then the first predictor has a value of 1; otherwise, it has a value of 0.

The $\overline{T}$ (sfc-1000) was chosen first because of its contribution to the RV of the liquid category. Note that this predictor, by itself, accounted for much of the total RV of the liquid and frozen categories but very little of the total RV of freezing precip. Obviously, the $\overline{T}$ (sfc-1000) alone is not sufficient for discriminating freezing precip from other types.

The second and third predictors, ZR(T)·W.L. DEPTH(T) and C.L. DEPTH(T_W), were chosen because of their contribution to the RV of freezing precip. These predictors were designed specifically for the freezing precip category, and, together, these two binaries accounted for much of the total RV of freezing precip. Note that ZR(T)·W.L. DEPTH(T) was also picked as the sixth and eighth predictors and the C.L. DEPTH(T_W) as the twelfth predictor in the form of different binaries. These results indicate that the depth of the warm layer, and, to a lesser degree, the depth of the surface-based cold layer, if such layers exist, are important factors with respect to the occurrence of freezing precip. It's interesting that the C.L. DEPTH(T_W) and the C.L. AREA(T_W) (the eleventh predictor) define the depth and area of the surface-based cold layer with respect to the wet-bulb temperature, not the dry-bulb temperature. A possible explanation is that the RAOB is usually started prior to the surface observation. Therefore, due to the evaporational cooling effect, the actual temperature in the lowest 1000 m or so at the time of the surface observation could resemble the wet-bulb temperature more than the dry-bulb temperature at the time the RAOB is started.

The fourth predictor, W.L. DEPTH(T), was chosen because of its contribution to the RV of frozen precip; it also makes a significant contribution to the liquid category. Remember that this predictor defines the depth of the warm layer, if one exists, irrespective of whether the Sfc T is $\leq$ 0°C. It's also chosen as the seventh predictor in the equation. As indicated previously, the depth of the warm layer is a factor in determining whether precip in the form of snow would melt when falling through the layer.

Each of the other predictors chosen made relatively smaller contributions to the reductions of variance and included $\overline{T}$ (500-2500), W.L. AREA(T), ZR(T)·W.L. AREA(T), and C.L. AREA(T_W). Note that the predictors defining the areas of the warm and cold layers were among the last several predictors chosen. Apparently, these area-type predictors could contribute relatively little once predictors defining the depths of the warm and cold layers and mean temperatures for specific layers were already in the equations.

The total RV was very high for liquid and frozen precip, about 89% and 85% respectively, but much lower for freezing precip, about 41%. The relatively low frequency of occurrence of freezing precip, about 3%, contributes to the difficulty in its specification. Also, part of the problem is due to the fact that many of the RAOB's associated with freezing drizzle, which was included with freezing rain in the freezing category, had temperatures $\leq$ 0°C at all levels (see discussion for Fig. 1 in section 2). The predictors used in this study would have difficulty in discriminating between freezing drizzle and frozen precip for such RAOB's.

Table 4 shows the constants and coefficients in the specification equations. With this information, the probability of liquid, freezing, and frozen precip can be computed for any given case. From Table 4, we can determine those atmospheric conditions which would provide the maximum possible probability of each precip type; however, it should be noted that there is no guarantee that this set of conditions would exist simultaneously in reality. For instance, with regard to freezing precip, if ZR(T)=0 and ZR(T_W)=0 for a particular case, then predictors 6 through 12 automatically equal 0. This would result in about a -63% contribution to the probability of freezing precip. In fact, for this case, the maximum possible probability of freezing precip would be only about 9%. On the other hand, if ZR(T)=1 and ZR(T_W)=1 for a particular case, then the maximum possible probabiliy of freezing precip would be about 94% under the following conditions: $\bar{T}$ (sfc-1000) $\leq$ -1.0°C, $\bar{T}$(500-2500) > -6.0°C, W.L. DEPTH(T) > 1200 m, W.L. AREA(T) > 750°C·m, C.L. DEPTH(T_W) > 800 m, and C.L. AREA(T_W) $\leq$ 4000°C·m. This last condition seems to put a limit on how cold the wet-bulb temperature in the surface-based cold layer can be, given the C.L. DEPTH(T_W) > 800 m. The reason may be that the colder and deeper this layer is the greater is the chance that the water drops would freeze before hitting the surface; that is, sleet might result.

In a similar manner, conditions giving the maximum or minimum possible probability of frozen or liquid precip could also be deduced from Table 4.

4. VERIFICATION

We verified the REEP specification equations for both developmental and independent data samples. For this verification, the developmental sample consisted of samples 1 and 2 (see section 3) combined. Remember that sample 1 was used to develop the equations, and sample 2 was used to determine the number of predictors to include. The independent sample consisted of 0000 GMT and 1200 GMT data combined from the 48 stations in Table 2 for the winter season of 1977-78.

The REEP equations specify the probability of each of the precip types given that precip occurs. For this verification, the probability estimates were transformed into a best category by picking the precip type category with the highest probability. The verification scores included the bias, post-agreement, and prefigurance[2].

The verification results for both developmental and independent samples, shown in Table 5, indicate that the scores were generally similar for both samples. There was some deterioration in the scores for freezing precip, but it's not considered to be serious. For the purposes of further discussion, verification scores were computed for the developmental and independent data samples combined. The contingency table and scores for

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[2] The bias = B/C, the post-agreement = A/B, and the prefigurance = A/C, where A is the number of correct specifications of the event, B is the total number of specifications of the event, and C is the number of observations of the event.

the combined sample, shown in Table 6, indicate the following: (1) The bias shows that the liquid and frozen categories were specified to occur about as often as they did occur. However, the system tended to slightly underestimate the frequency of freezing precip. (2) The post-agreement indicates that, when the system specified liquid and frozen precip, it was correct 98% and 92% of the time, respectively. However, for freezing precip, it was correct 61% of the time. (3) The prefigurance shows that, when liquid and frozen precip occurred, they were correctly specified 97% and 95% of the time, respectively. When freezing precip occurred, it was correctly specified 53% of the time.

It's interesting that about 42% of the observed freezing precip cases were specified as frozen by the system. Many of these cases were freezing drizzle cases that occurred with RAOB's which had temperatures ≤ 0°C at all levels. For such RAOB's the specification equations in Table 4 would give a maximum probability of about 8% for freezing precip and a minimum probability of about 75% for frozen precip!

5. SUMMARY AND CONCLUSIONS

Linear screening regression was used to derive relationships between predictors computed from RAOB's and concurrent observations of precip type (liquid, freezing, and frozen). Experiments showed that the specification equations should include about 12 predictors. Statistical screening indicated that the following parameters were important: the mean temperature in the surface-1000 m and 500-2500 m layers; the depth of the warm layer, if one exists, with respect to the temperature profile; the area between the temperature profile and the 0°C isotherm in the warm layer; the depth of the surface-based cold layer, if one exists, with respect to the wet-bulb temperature profile; and the area between the wet-bulb temperature profile and the 0°C isotherm in the surface-based cold layer.

Verification of the specification equations on both developmental and independent data samples indicated that the scores were generally stable, except that some minor deterioration of the scores occurred for freezing precip. The system showed excellent discrimination ability for liquid and frozen precip but had some difficulty with freezing precip.

Part of the problem with the freezing precip category was due to the fact that freezing drizzle, which was included with freezing rain in this category, can occur with a RAOB in which the temperature is ≤ 0°C at all levels (no warm layer). In part of this study, it was found that about 44% of freezing drizzle RAOB's examined had no warm layer. For such "cold" RAOB's, the specification equations produce a very low probability of freezing precip and a very high probability of frozen precip. Further research needs to be done to develop predictors to help discriminate between freezing drizzle and frozen precip in cases when the RAOB has no warm layer.

In addition to being interesting in an academic sense, the results obtained in this study should be useful in the following ways: (1) At stations that routinely take RAOB's, or nearby stations, the regression equations in Table 4 can be rather easily evaluated in real time (for instance, on an AFOS minicomputer) for the purpose of "nowcasting". (2) The parameters found to be important can be calculated for upper-air soundings forecasted by TDL's boundary layer model. The MOS approach can then be used to obtain short- to medium-range forecasts of precip type.

The use of locally observed RAOB's to update centrally-generated MOS precip type guidance is the subject of a later paper (Bocchieri, 1979b).

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Table 1. A description of the RAOB predictors.

Predictor	Description
1. Sfc T	Surface temperature.
2. $\overline{T}$ (sfc-500)	Mean temperature in the surface-500 m layer.
3. $\overline{T}$ (sfc-1000)	Mean temperature in the surface-1000 m layer.
4. $\overline{T}$ (sfc-1600)	Mean temperature in the surface-1600 m layer.
5. $\overline{T}$ (sfc-3000)	Mean temperature in the surface-3000 m layer.
6. $\overline{T}$ (sfc-6000)	Mean temperature in the surface-6000 m layer.
7. $\overline{T}$ (500-2500)	Mean temperature in the 500-2500 m layer.
8. Sfc T_w	Same as 1 except wet-bulb temperature was used.
9. $\overline{T}_w$ (sfc-500)	Same as 2 except wet-bulb temperature was used.
10. $\overline{T}_w$ (sfc-1000)	Same as 3 except wet-bulb temperature was used.
11. $\overline{T}_w$ (sfc-1600)	Same as 4 except wet-bulb temperature was used.
12. $\overline{T}_w$ (sfc-3000)	Same as 5 except wet-bulb temperature was used.
13. $\overline{T}_w$ (sfc-6000)	Same as 6 except wet-bulb temperature was used.
14. $\overline{T}_w$ (500-2500)	Same as 7 except wet-bulb temperature was used.
15. Sfc U	Surface "u" wind component.
16. Sfc V	Surface "v" wind component.
17. $\overline{U}$ (500-2500)	Mean "u" in the 500-2500 m layer.
18. $\overline{V}$ (500-2500)	Mean "v" in the 500-2500 m layer.
19. W.L. DEPTH(T)	Warm layer depth with respect to temperature.
20. W.L. AREA(T)	Area between the temperature profile and the 0°C isotherm in the warm layer.
21. W.L. TOP(T)	Height of top of warm layer with respect to temperature.
22. HGT FREEZ LEV(T)	Height of the lowest freezing level with respect to temperature. If the Sfc T $\leq$ 0°C, then this parameter equals 0.

Table 1 Continued.

	Predictor	Description
23.	W.L. DEPTH(T_w)	Same as 19 except wet-bulb temperature was used.
24.	W.L. AREA(T_w)	Same as 20 except wet-bulb temperature was used.
25.	W.L. TOP(T_w)	Same as 21 except wet-bulb temperature was used.
26.	HGT FREEZ LEV(T_w)	Same as 22 except wet-bulb temperature was used.
27.	ZR(T)	A binary predictor that equals 1 if Sfc T $\leq$ 0°C <u>and</u> a warm layer exists aloft; otherwise, it equals 0.
28.	C.L. DEPTH(T)	The depth of the surface-based cold layer, with respect to temperature, when ZR(T)=1.
29.	C.L. AREA(T)	Area between temperature profile and the 0°C isotherm in the surface-based cold layer when ZR(T)=1.
30.	ZR(T)·W.L. DEPTH(T)	The product of parameters 19 and 27.
31.	ZR(T)·W.L. AREA(T)	The product of parameters 20 and 27.
32.	ZR(T_w)	Same as 27 except wet-bulb temperature was used.
33.	C.L. DEPTH(T_w)	Same as 28 except wet-bulb temperature was used.
34.	C.L. AREA(T_w)	Same as 29 except wet-bulb temperature was used.
35.	ZR(T_w)·W.L. DEPTH(T_w)	Same as 30 except wet-bulb temperature was used.
36.	ZR(T_w)·W.L. AREA(T_w)	Same as 31 except wet-bulb temperature was used.

Table 2. The 48 RAOB stations used in this study to compute composite freezing rain and freezing drizzle soundings.

WBAN NO.	STATION	WBAN NO.	STATION
3860	Huntington, W. Va.	23044	El Paso, Tex.
3937	Lake Charles, La.	23047	Amarillo, Tex.
3940	Jackson, Miss.	23050	Albuquerque, N. Mex.
12912	Victoria, Tex.	23062	Denver, Colo.
13723	Greensboro, N.C.	23066	Grand Junction, Colo.
13873	Athens, Ga.	23154	Ely, Nev.
13880	Charleston, S.C.	23194	Winslow, Ariz.
13897	Nashville, Tenn.	24011	Bismarck, N. Dak.
13963	Little Rock, Ark.	24021	Lander, Wyo.
13967	Oklahoma City, Okla.	24023	North Platte, Neb.
13985	Dodge City, Kans.	24090	Rapid City, S. Dak.
13996	Topeka, Kans.	24127	Salt Lake City, Utah
14607	Caribou, Maine	24128	Winnemucca, Nev.
14733	Buffalo, N.Y.	24131	Boise, Idaho
14735	Albany, N.Y.	24143	Great Falls, Mont.
14764	Portland, Maine	24157	Spokane, Wash.
14826	Flint, Mich.	24225	Medford, Oreg.
14842	Peoria, Ill.	24232	Salem, Oreg.
14847	Sault St Marie, Mich.	93729	Cape Hatteras, N.C.
14898	Green Bay, Wisc.	93739	Wallops Island, Va.
14918	Intl Falls, Minn.	94008	Glasgow, Mont.
14936	Huron, S. Dak.	94240	Quillayute, Wash.
22010	Del Rio, Tex.	94789	New York, N.Y.
23023	Midland, Tex.	94823	Pittsburgh, Pa.

Table 3. The 12 predictors included in the precip type specification equations in the order determined by the REEP procedure. The developmental sample consisted of 1200 GMT data combined from the 48 stations (Table 2) for the winter seasons of 1972-73 through 1976-77. The number in brackets refers to the number of the predictor in Table 1.

	Predictor	Binary Limit	Additional Reduction of Variance (%)		
			Liquid	Freezing	Frozen
1.	$\overline{T}$ (sfc-1000) [3]	≤ -1.0°C	82.05	1.43	77.44
2.	ZR(T)·W.L. DEPTH(T) [30]	≤ 550 m	1.28	31.85	0.76
3.	C.L. DEPTH(T_W) [33]	≤ 250 m	0.15	5.30	0.18
4.	W.L. DEPTH(T) [19]	≤ 300 m	3.88	0.07	4.43
5.	$\overline{T}$ (500-2500) [7]	≤ -6.0 °C	0.28	1.04	0.83
6.	ZR(T)·W.L. DEPTH(T) [30]	≤ 300 m	0.86	0.10	0.69
7.	W.L. DEPTH(T) [19]	≤ 150 m	0.58	0.08	0.45
8.	ZR(T)·W.L. DEPTH(T) [30]	≤ 1200 m	0.00	0.49	0.05
9.	W.L. AREA(T) [20]	≤ 750 °C·m	0.34	0.00	0.35
10.	ZR(T)·W.L. AREA(T) [31]	≤ 50 °C·m	0.05	0.32	0.00
11.	C.L. AREA(T_W) [34]	≤ 4000 °C·m	0.00	0.35	0.06
12.	C.L. DEPTH(T_W) [33]	≤ 800 m	0.01	0.43	0.11
	Total Reduction of Variance	=	89.47	41.47	85.36
	Relative Frequency of Occurrence (%)	=	62.83	2.98	34.18

Table 4. The constants and coefficients in the REEP specification equations for liquid, freezing, and frozen precip. The numbers in brackets refers to the number of the predictor in Table 1. The predictors are arranged by type.

	Predictor	Binary Limit	Coefficients Liquid	Freezing	Frozen
		Constant	20.19	63.35	16.46
1.	$\bar{T}$ (sfc-1000) [3]	$\leq$ -1.0°C	-17.93	+7.99	+9.94
2.	T (500-2500) [7]	$\leq$ -6.0°C	-5.83	-6.82	+12.65
3.	W.L. DEPTH(T) [19]	$\leq$ 150 m	-28.48	+4.88	+23.60
4.	W.L. DEPTH(T) [19]	$\leq$ 300 m	-30.27	-4.56	+34.83
5.	W.L. AREA(T) [20]	$\leq$ 750°C·m	-16.04	-0.13	+16.17
6.	ZR(T)·W.L. DEPTH(T) [30]	$\leq$ 300 m	+34.90	+18.72	-53.62
7.	ZR(T)·W.L. DEPTH(T) [30]	$\leq$ 550 m	-6.38	-22.35	+28.73
8.	ZR(T)·W.L. DEPTH(T) [30]	$\leq$ 1200 m	+6.55	-13.84	+7.29
9.	ZR(T)·W.L. AREA(T) [31]	$\leq$ 50°C·m	+23.83	-27.23	+3.40
10.	C.L. DEPTH(T_W) [33]	$\leq$ 50 m	+20.95	-25.82	+4.87
11.	C.L. DEPTH(T_W) [33]	$\leq$ 800 m	-5.88	-15.60	+21.49
	C.L. AREA(T_W) [34]	$\leq$ 4000 °C·m	+5.04	+22.96	-28.01

Table 5. Verification of the REEP specification equations. The developmental sample (D) consisted of samples 1 and 2 combined (see section 3). The independent sample (I) consisted of data combined from 0000 GMT and 1200 GMT for the 48 stations in Table 2 for the winter season of 1977-78. The number of precip cases for each sample is shown in parentheses.

Verification Scores	Category Liquid D (7282)	I (1605)	Freezing D (277)	I (78)	Frozen D (3753)	I (976)
Bias	.99	.99	.88	.79	1.02	1.04
Post-Agreement	.98	.98	.62	.60	.92	.92
Prefigurance	.97	.97	.54	.47	.95	.96

Table 6. The contingency table (a) and resulting verification scores (b) for the REEP specification equations for the developmental and independent samples (see Table 5) combined.

(a)

Observed	Specified Liquid	 Freezing	 Frozen	Total
Liquid	8615	51	221	8887
Freezing	18	188	149	355
Frozen	173	67	4489	4729
Total	8806	306	4859	13971

(b)

Verification Scores	Category Liquid	 Freezing	 Frozen
Bias	0.99	0.86	1.03
Post-Agreement	0.98	0.61	0.92
Prefigurance	0.97	0.53	0.95

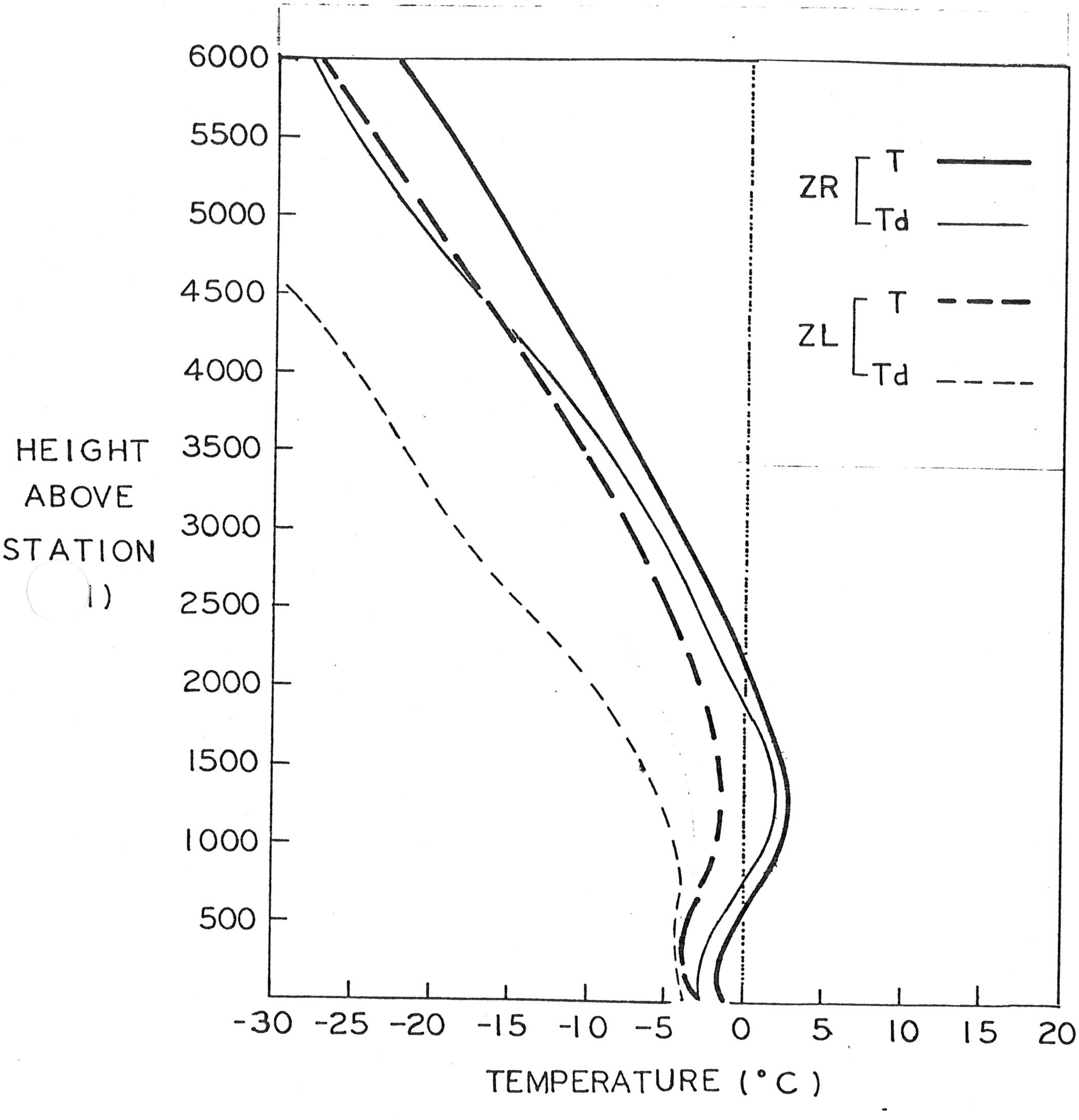

Figure 1. Composite temperature and dew-point profiles for freezing drizzle (ZL) and freezing rain (ZR). The sample consisted of 127 freezing drizzle and 94 freezing rain RAOB's from the period October through April, 1972-73 through 1976-77 for the 48 stations in Table 2.

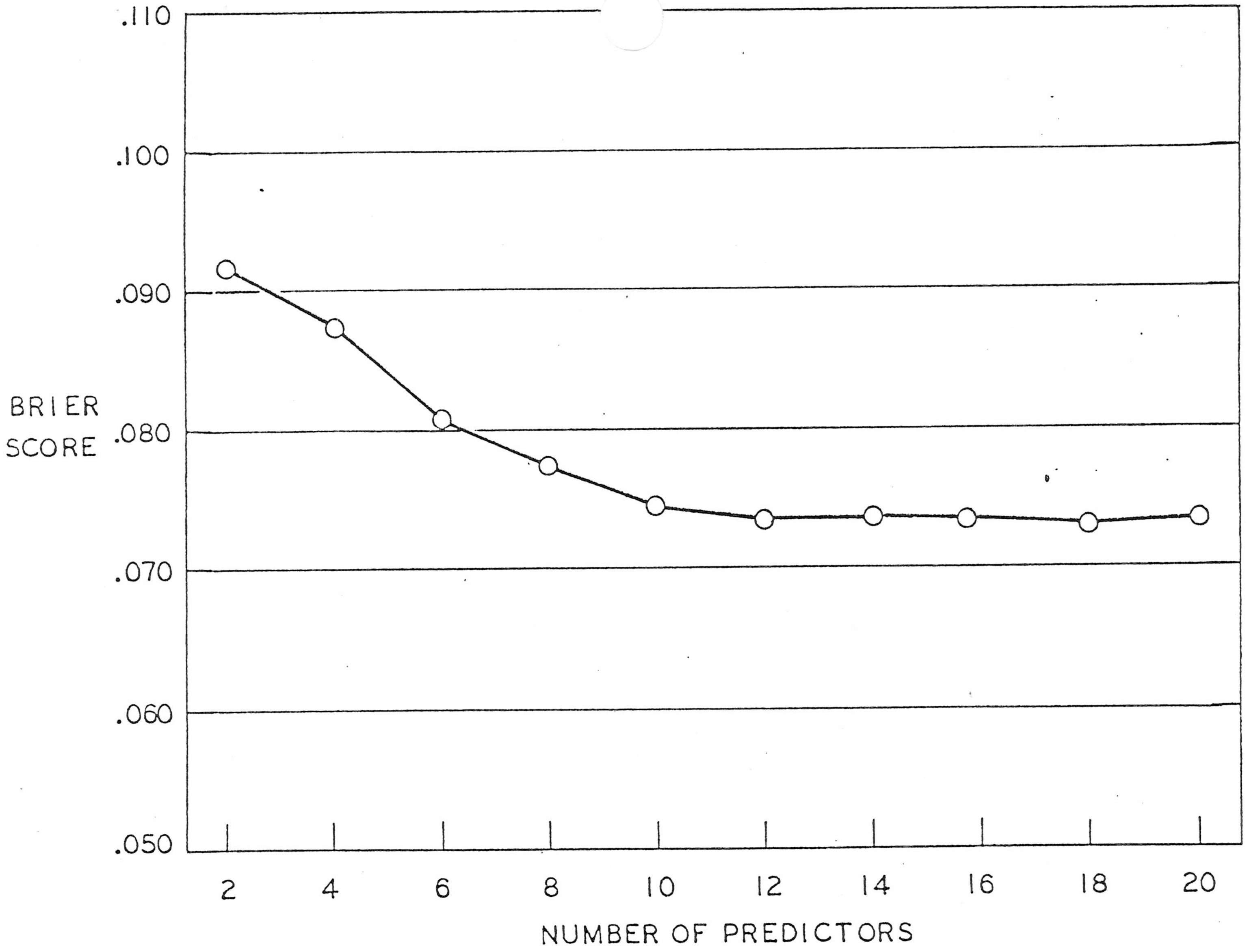

Figure 2. The Brier score computed for forecasts from each of 10 REEP precip type specification equations containing 2, 4, 6,...,18 and 20 predictors. The sample consisted of independent data combined from 48 stations (Table 2) for the winter seasons of 1972-73 through 1976-77.