# Forecasting

## AN ALGORITHM FOR FORECASTING PRECIPITATION TYPE

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### ABSTRACT

*An algorithm for forecasting precipitation type at a specific time that can be programmed on a microcomputer is described. This algorithm uses MOS forecasts of conditional probabilities of frozen and freezing precipitation, precipitation type, and surface temperature—all available in the FPC message on AFOS. In addition, the algorithm has the option of allowing control information, used for making decisions about precipitation type, to be selected by each user.*

## 1. INTRODUCTION

One of the most important parts of a weather forecast is the form predicted precipitation will take, that is, liquid, frozen, freezing, or some combination of these three. A system for providing objective guidance of conditional probabilities of frozen (POF) and freezing (POZ) precipitation categories, based on the MOS technique with use of LFM predictors, has been operational within the National Weather Service since September 1978 (Bocchieri and Maglaras (2), Bocchieri (3)). The latest version of this product was implemented in the fall of 1982.

This objective system also provides a categorical forecast (rain, snow, or freezing rain) (CAT) which is obtained by comparing POZ and POF to threshold values for the freezing rain and snow categories, respectively. In operations, POZ is compared with its threshold value first. If it exceeds its threshold, freezing rain is forecast and the procedure is ended. If POZ doesn't exceed its threshold, the next step is to determine if POF is higher than its threshold, and if it is, snow is forecast; otherwise rain is predicted. Threshold values for POF and POZ are derived through an iterative procedure on the developmental data that nearly maximizes threat score (4) while maintaining a bias (5) of about 1.0 for the snow and freezing rain categories. [For more details on this iterative procedure, see Bocchieri (3) and Bermowitz and Zurndorfer (6).]

The latest comparative verification of the CAT forecasts from the MOS system against those produced locally at the forecast offices (Carter et al. (7)) indicates that, overall, the guidance forecasts were the better of the two for the October 1984 - March 1985 cool season. Although comparative verifications for the previous two cool seasons were not as favorable for the guidance forecasts as in the 1984-85 cool season (Carter et al. (8, 9)), the MOS system for producing CAT

forecasts can certainly be considered a viable guidance product capable of providing useful categorical forecasts. Furthermore, the reliability of the POF and POZ forecasts are generally good although there is some tendency toward overestimating the relative frequency of POZ.

Another important weather element in forecasting precipitation type is the surface temperature. Primarily, it can serve as a"check" on the precipitation type forecasts. For example, snow or freezing rain would not be forecast if the temperature near the surface were too warm even though the vertical temperature profile above the surface was favorable for these events. An objective system for forecasting surface temperatures at 3-hr intervals (TEMP), also based on the MOS technique with use of LFM predictors, is available for this purpose (National Weather Service (10), Carte et al. (11)). No comparative verification of TEMP has been made; however, a comparison of MOS maximum/minimum temperatures against those prepared locally is routinely done (Carter et al. (7)). Although these have shown that the locally produced forecasts improve on MOS, at least some of this improvement is due to the valid period of the forecasts which tends to favor the locally produced product. Since TEMP equations are derived simultaneously with the maximum/minimum equations, it's not unreasonable to conclude that the MOS 3-hr temperatures are useful guidance.

The purpose of this paper is to describe an algorithm for forecasting precipitation type that uses the information contained in POF, POZ, CAT, and TEMP—all available in the FPC message on AFOS (National Weather Service (12)). This algorithm, which can be programmed on a microcomputer, is suitable for use as a forecasting tool. It also can be used as a learning aid for new forecasters lacking experience with MOS guidance.

## 2. THE PRECIPITATION TYPE ALGORITHM

The precipitation type algorithm is based on the author's experience working with MOS forecasts, both as a guidance tool and as part of the Techniques Development Laboratory's Computer Worded Forecast (CWF) program (Glahn (13)), as well as the experience of the people who developed the MOS precipitation type forecasts. In fact, many of the decisions that comprise the precipitation type algorithm are part of the original design of the CWF program (Heffernan and Glahn (14)) or were added when improvements were made (Bermowitz and Miller 15)). However, the algorithm discussed here is somewhat of an improvement over that of the

CWF since, with its use, it is possible for three precipitation types to occur in the same period whereas only two are possible in the CWF. Therefore, a phrase such as "snow changing to sleet or freezing rain and then rain," which cannot occur in the CWF, would be possible with the new algorithm. Since the CWF always uses the frozen and freezing categories when three precipitation types are possible, it would use the phrase "snow changing to sleet or freezing rain."

The precipitation type algorithm determines a precipitation type forecast at a specific time from forecasts of POF, CAT, and TEMP at that time. There are five possible precipitation type forecasts: sleet or freezing rain (16); snow; rain; mixed rain and snow; and mixed snow, sleet, and freezing rain. Since POF, POZ, CAT, and TEMP are available at the beginning, middle, and end of each standard 12-hr forecast period from both the 0000 and 1200 GMT cycles, precipitation type forecasts can be

made at each of these three times for each period. It should be noted that there is no TEMP forecast at the middle and end of the fourth period of the 1200 GMT cycle. This could hinder determination of precipitation type forecasts at those times. To overcome this, the duty meteorologist can provide appropriate forecasts of TEMP or, if a completely objective system is desired, the MOS maximum temperature for the fourth period, available on the FPC message, can be used as an approximation to TEMP at those two times.

The precipitation type algorithm is summarized in the flow chart shown in Figs. 1-3. In this flow chart and in the text, CAT = 1 means freezing rain, 2 means snow, and 3 means rain. Initially, values must be selected for the control constants LP1 through LP6 and LT1 through LT6 which are threshold values against which POF, POZ, CAT, and TEMP are compared when making decisions about precipitation type. This allows each user to select
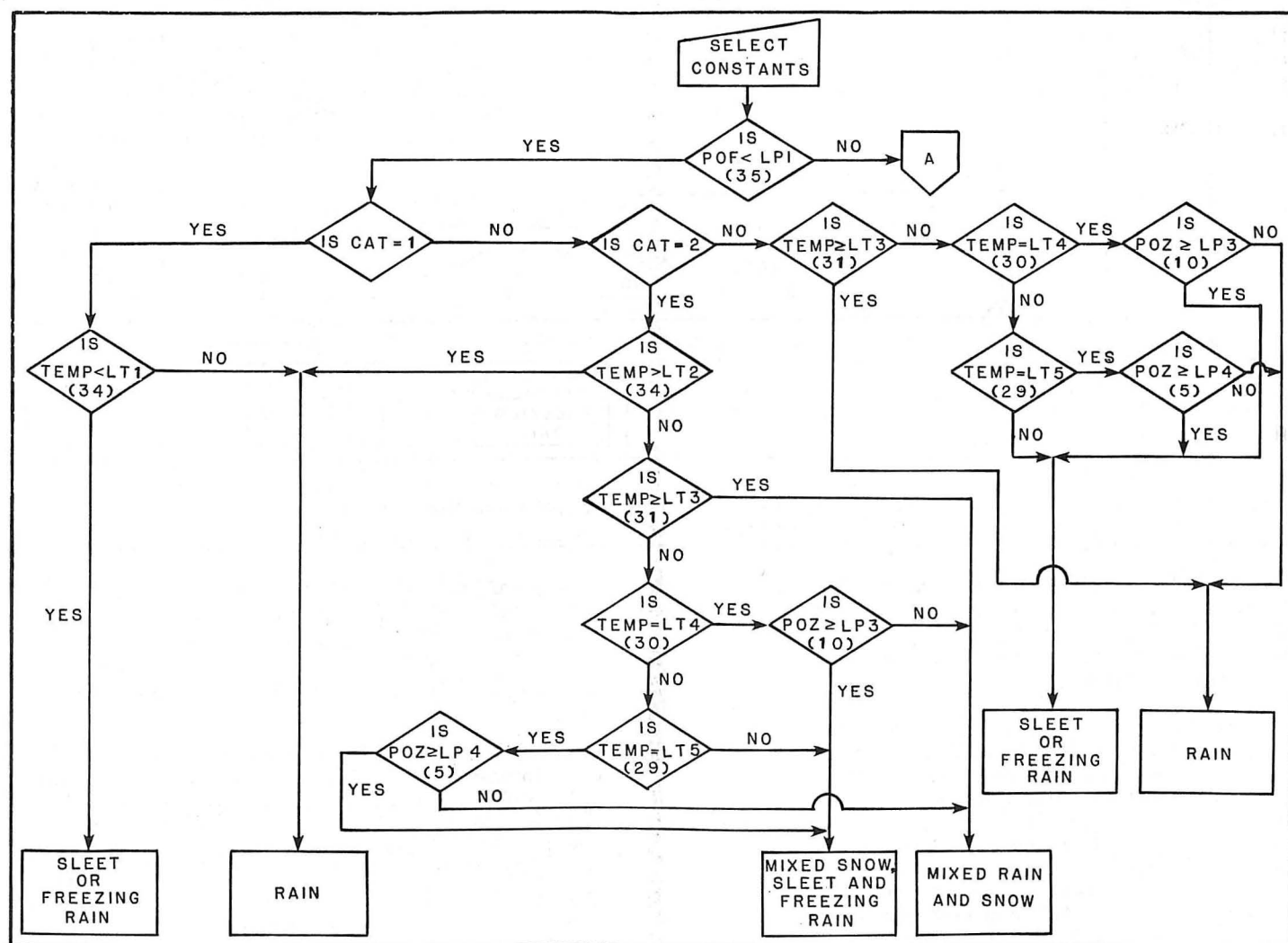


Fig. 1. Flow chart of decisions in the precipitation type algorithm. CAT = 1 means a categorical forecast of freezing rain, 2 means snow, and 3 means rain. LP1 through LP6 and LT1 through LT6 are control constants which are defined in the Appendix. Each user can select the most appropriate values for his/her location based on his/her experience. Suggested values are in parentheses.

Fig. 2.  Continuation of Fig. 1 from connector A.

the most appropriate values for his/her location based on his/her experience. Suggested values are shown in Figs. 1-3 and the Appendix, where the control constants are defined, and are used in the discussion that follows.

At each forecast projection, POF falls into a low, medium, or high range. POF is defined as low when < 35 percent, medium when $\geq$ 35 and $\leq$ 65 percent, and high when > 65 percent. As a first approximation to specifying precipitation type, these three divisions define rain (low POF), mixed rain and snow (medium POF), and snow (high POF) categories. However, within each of these categories, CAT, TEMP, and POZ can alter the first approximation of precipitation type.

## 2a.  Low Range POF

For POF in the low range, rain will be forecast except as noted in items 1, 2, and 3 below.

1)  Forecast sleet or freezing rain if:

a)  CAT = 1 and TEMP < $34^{o}$F,
b)  CAT = 3 and TEMP $\leq$ $28^{o}$F,
c)  CAT = 3, TEMP = $29^{o}$F, and POZ $\geq$ 5%, or
d)  CAT = 3, TEMP = $30^{o}$F, and POZ $\geq$ 10%.

In condition a, the surface temperature supports the CAT forecast of freezing rain. In conditions c and d, the forecast of rain given by CAT is changed to sleet or freezing rain because TEMP is sufficiently low and POZ provides some indication of freezing rain. For TEMP $\leq$ $28^{o}$F, freezing rain is indicated regardless of POZ (condition b).

2)  Forecast rain mixed with snow if:

a)  CAT = 2 and $31^{o}$F $\leq$ TEMP $\leq$ $34^{o}$F.

Here CAT indicates snow (POF exceeded its threshold for a forecast of the snow category but POZ did not) and with cold temperatures but, generally, not cold enough for freezing rain, snow
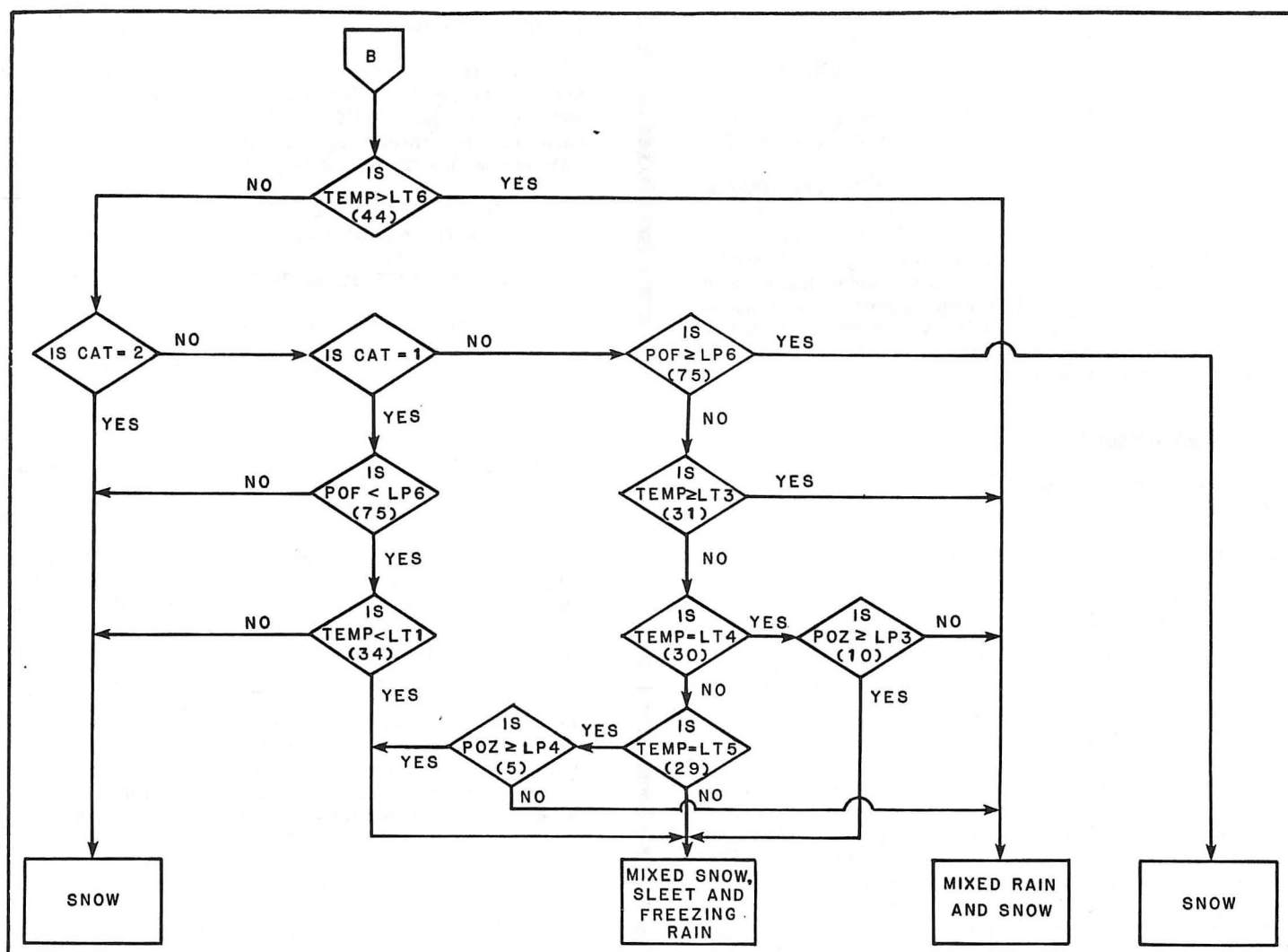
B

IS TEMP>LT6 (44)
NO / YES

IS CAT = 2
NO / YES

IS CAT = 1
NO / YES

IS POF ≥ LP6 (75)
YES / NO

IS POF < LP6 (75)
NO / YES

IS TEMP≥LT3 (31)
YES / NO

IS TEMP<LT1 (34)
NO / YES

IS TEMP=LT4 (30)
YES / NO

IS POZ ≥ LP3 (10)
NO / YES

IS POZ ≥ LP4 (5)
YES / NO

IS TEMP=LT5 (29)
YES / NO

SNOW

MIXED SNOW, SLEET AND FREEZING RAIN

MIXED RAIN AND SNOW

SNOW

Fig. 3. Continuation of Fig. 2 from connector B.

would be mixed with rain that would normally be expected with a low POF. It should be noted that the occurrence of CAT = 2 with POF in the low range is a rare event.

3) Forecast sleet or freezing rain mixed with snow if:

a) CAT = 2 and TEMP $\leq 28^\circ$F,
b) CAT = 2, TEMP = $29^\circ$F, and POZ $\geq$ 5%, or
c) CAT = 2, TEMP = $30^\circ$F, and POZ $\geq$ 10%.

As in item 2, CAT indicates snow and, similar to the discussion about item 1, TEMP and POZ indicate freezing rain instead of rain.

## 2b. Middle Range POF

For POF in the middle range, mixed rain and snow will be forecast except as noted in 1, 2, and 3 below.

1) Forecast rain if:

a) TEMP > $44^\circ$F.

Here the surface temperature is too warm to support snow mixed with rain; therefore, only rain is forecast. This is equivalent to lowering POF from the middle to low range.

2) Forecast snow if:

a) CAT = 2, 55% $\leq$ POF $\leq$ 65%, and TEMP $\leq 34^\circ$F.

In this case, POF is approaching the cutoff (65%) where it would be in the high range (snow) and, with a supporting CAT forecast of snow and a further supporting TEMP forecast, a change from mixed rain and snow to snow is reasonable.

3) Forecast sleet or freezing rain mixed with snow if:

a) CAT = 1 and TEMP < $34^\circ$,
b) CAT = 2, 35% $\leq$ POF < 55%, and TEMP $\leq 28^\circ$F,

c) CAT = 2, 35% $\leq$ POF < 55%, TEMP = $29^{\circ}$F, and POZ $\geq$ 5%,

d) CAT = 2, 35% $\leq$ POF < 55%, TEMP = $30^{\circ}$F, and POZ $\geq$ 10%,

e) CAT = 3, and TEMP < $28^{\circ}$F,

f) CAT = 3, TEMP = $29^{\circ}$F, and POZ $\geq$ 5%, or

g) CAT = 3, TEMP = $28^{\circ}$F, and POZ $\geq$ 10%.

These provisions for predicting sleet or freezing rain instead of rain mixing with snow have been discussed previously. The requirement in conditions b, c, and d for POF < 55% is needed to draw a distinction between these cases and that of item 2 for the middle range POF.

## 2c. High Range POF

For POF in the high range, snow will be forecast except as noted in 1 and 2 below.

1) Forecast rain mixed with snow if:

a) TEMP > $44^{\circ}$F,

b) CAT = < 3, 65% < POF < 75%, and TEMP $\geq$ $31^{\circ}$F,

c) CAT = 3, 65% < POF < 75%, TEMP = $30^{\circ}$F, and POZ < 10%, or

d) CAT = 3, 65% < POF < 75%, TEMP = $29^{\circ}$F, and POZ <5%.

In condition a, the surface temperature is rather warm for only snow to occur. A forecast of rain mixed with snow is equivalent to lowering the POF into the middle range. A CAT = 3 (rain) with 65% < POF < 75% in conditions b, c, and d would very rarely occur, but if it did, it could be interpreted to mean that even though POF was in the high range, it wasn't high enough to exceed its threshold to forecast snow. In addition, even though TEMP is low enough to forecast freezing rain mixed with snow, POZ is too low for freezing rain; therefore, rain mixed with snow is predicted.

2) Forecast sleet or freezing rain mixed with snow if:

a) CAT = 1, 65% < POF < 75%, and TEMP < $34^{\circ}$F,

b) CAT = 3, 65% < POF < 75%, TEMP = $30^{\circ}$F, and POZ $\geq$ 10%,

c) CAT = 3, 65% < POF < 75%, TEMP = $29^{\circ}$F, and POZ $\geq$ 5%, or

d) CAT = 3, 65% < POF < 75%, and TEMP = $28^{\circ}$F.

In condition a, freezing rain is indicated by CAT = 1. Since the freezing rain category is tested for exceeding its threshold before the snow category and, if it does, the snow category is not tested, it's possible that the snow category would have exceeded its threshold, too. With a supporting cold surface temperature, a forecast of freezing rain and snow is reasonable. Conditions b, c, and d are the same as conditions b, c, and d under item 1 for a high range POF, except here POZ has values higher than the pre-selected cutoffs so that freezing rain rather than rain is forecast with snow.

## 3. AN EXAMPLE

To illustrate the use of the precipitation type forecast system, the following example is presented. MOS values for TEMP, POF, POZ, and CAT for each of the three forecast periods for the 0000 GMT cycle are as follows:

| | 12Z | 18Z | 00Z | 06Z | 12Z | 18Z | 00Z |
|---|---|---|---|---|---|---|---|
| | (—TODAY—) | | (—TONIGHT—) | | (-TOMORROW-) | | |
| TEMP | 30 33 | 37 38 | 36 39 | 38 35 | 33 29 | 28 28 | 26 |
| POF | 44 | 33 | 23 | 17 | 27 | 61 | 73 |
| POZ | 34 | 34 | 24 | 26 | 27 | 6 | 4 |
| CAT | 1 | 1 | 3 | 1 | 1 | 2 | 2 |

It is further assumed that all the control constants LP1- LP6 and LT1-LT6 are specified as shown in Figs. 1-3.

For the "TODAY" period at the 1200 GMT forecast projection, POF is in the middle range. Therefore, in Fig. 1 the answer to "Is POF 35" is "No" and that to "Is POF 65" in Fig. 2 is "Yes." The next question in the flow is "Is TEMP 44" and since TEMP is $30^{\circ}$F, the flow continues to the question "Is CAT = 1." The answer is "Yes"; therefore, the next question to be asked is "Is TEMP 34." Since the answer is "Yes", the flow moves to a forecast of "Mixed snow, sleet, and freezing rain." Figs. 1-3 can also be used for the other forecast projections; however, for the sake of brevity, we will not go through all the details of the flow. At the second forecast projection (1800 GMT), POF is in the low range. Since a TEMP of $37^{\circ}$F does not support the CAT forecast of freezing rain (CAT = 1), the forecast is rain. For the third projection (0000 GMT), it is obvious that the forecast is also rain. Therefore, for the first period, the forecast is mixed snow, sleet, and freezing rain; rain; and rain, which could translate to a phrase such as "sleet or freezing rain mixed with snow changing to rain by midday" for a public weather forecast.

For the "TONIGHT" period at both the 0600 GMT and 1200 GMT projections, POF is in the low range and CAT = 1. However, a TEMP of $38^{\circ}$F cannot support freezing rain at 0600 GMT; therefore, rain is forecast. At 1200 GMT, the TEMP of $33^{\circ}$F is less than the threshold for a forecast of freezing rain. Thus, for the "TONIGHT" period, the forecast is rain; rain; and sleet or freezing rain, which could be interpreted as "rain changing to sleet or freezing rain after midnight" for a worded forecast.

For the "TOMORROW" period, POF is in the middle range at 1800 GMT but higher than 55 percent. Since CAT is 2 and TEMP is less than the threshold of $34^{\circ}$F, snow is the forecast. AT 0000 GMT, POF is in the high range and, since CAT and TEMP do not indicate otherwise, snow is again the forecast. Therefore, for the third period the forecast is sleet or freezing rain; snow; and snow. For a public weather forecast, this result could be phrased as "sleet or freezing rain changing to snow by midday."

c) CAT = 2, 35% $\leq$ POF < 55%, TEMP = 29°F, and POZ $\geq$ 5%,

d) CAT = 2, 35% $\leq$ POF < 55%, TEMP = 30°F, and POZ $\geq$ 10%,

e) CAT = 3, and TEMP $\leq$ 28°F,

f) CAT = 3, TEMP = 29°F, and POZ $\geq$ 5%, or

g) CAT = 3, TEMP = 28°F, and POZ $\geq$ 10%.

These provisions for predicting sleet or freezing rain instead of rain mixing with snow have been discussed previously. The requirement in conditions b, c, and d for POF < 55% is needed to draw a distinction between these cases and that of item 2 for the middle range POF.

## 2c. High Range POF

For POF in the high range, snow will be forecast except as noted in 1 and 2 below.

1) Forecast rain mixed with snow if:

a) TEMP > 44°F,

b) CAT < 3, 65% < POF < 75%, and TEMP $\geq$ 31°F,

c) CAT = 3, 65% < POF < 75%, TEMP = 30°F, and POZ < 10%, or

d) CAT = 3, 65% < POF < 75%, TEMP = 29°F, and POZ <5%.

In condition a, the surface temperature is rather warm for only snow to occur. A forecast of rain mixed with snow is equivalent to lowering the POF into the middle range. A CAT = 3 (rain) with 65% < POF < 75% in conditions b, c, and d would very rarely occur, but if it did, it could be interpreted to mean that even though POF was in the high range, it wasn't high enough to exceed its threshold to forecast snow. In addition, even though TEMP is low enough to forecast freezing rain mixed with snow, POZ is too low for freezing rain; therefore, rain mixed with snow is predicted.

2) Forecast sleet or freezing rain mixed with snow if:

a) CAT = 1, 65% < POF < 75%, and TEMP < 34°F,

b) CAT = 3, 65% < POF < 75%, TEMP = 30°F, and POZ $\geq$ 10%,

c) CAT = 3, 65% < POF < 75%, TEMP = 29°F, and POZ $\geq$ 5%, or

d) CAT = 3, 65% < POF < 75%, and TEMP = 28°F.

In condition a, freezing rain is indicated by CAT = 1. Since the freezing rain category is tested for exceeding its threshold before the snow category and, if it does, the snow category is not tested, it's possible that the snow category would have exceeded its threshold, too. With a supporting cold surface temperature, a forecast of freezing rain and snow is reasonable. Conditions b, c, and d are the same as conditions b, c, and d under item 1 for a high range POF, except here POZ has values higher than the pre-selected cutoffs so that freezing rain rather than rain is forecast with snow.

## 3. AN EXAMPLE

To illustrate the use of the precipitation type forecast system, the following example is presented. MOS values for TEMP, POF, POZ, and CAT for each of the three forecast periods for the 0000 GMT cycle are as follows:

| | 12Z | 18Z | 00Z | 06Z | 12Z | 18Z | 00Z |
|---|---|---|---|---|---|---|---|
| | (--TODAY--) | | (--TONIGHT--) | | (-TOMORROW-) | | |
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| POF | 44 | 33 | 23 | 17 | 27 | 61 | 73 |
| POZ | 34 | 34 | 24 | 26 | 27 | 6 | 4 |
| CAT | 1 | 1 | 3 | 1 | 1 | 2 | 2 |

It is further assumed that all the control constants LP1- LP6 and LT1-LT6 are specified as shown in Figs. 1-3.

For the "TODAY" period at the 1200 GMT forecast projection, POF is in the middle range. Therefore, in Fig. 1 the answer to "Is POF < 35" is "No" and that to "Is POF < 65" in Fig. 2 is "Yes." The next question in the flow is "Is TEMP > 44" and since TEMP is 30°F, the flow continues to the question "Is CAT = 1." The answer is "Yes"; therefore, the next question to be asked is "Is TEMP < 34." Since the answer is "Yes", the flow moves to a forecast of "Mixed snow, sleet, and freezing rain." Figs. 1-3 can also be used for the other forecast projections; however, for the sake of brevity, we will not go through all the details of the flow. At the second forecast projection (1800 GMT), POF is in the low range. Since a TEMP of 37°F does not support the CAT forecast of freezing rain (CAT = 1), the forecast is rain. For the third projection (0000 GMT), it is obvious that the forecast is also rain. Therefore, for the first period, the forecast is mixed snow, sleet, and freezing rain; rain; and rain, which could translate to a phrase such as "sleet or freezing rain mixed with snow changing to rain by midday" for a public weather forecast.

## 4. SUMMARY AND FUTURE WORK

An algorithm for forecasting precipitation type at a specific time that can be programmed on a microcomputer has been presented. This algorithm, which is summarized in Figs. 1-3, uses MOS forecasts of conditional probabilities of frozen and freezing precipitation, precipitation type, and surface temperature—all available in the FPC message on AFOS. In addition, it allows control information—threshold values against which the conditional probabilities of frozen and freezing precipitation, precipitation type, and surface temperature are compared when making decisions about precipitation type—to be selected by each user, if desired.

In the near future, the algorithm will be incorporated into the CWF program. This should improve the worded forecasts of precipitation type since use of the algorithm will allow three precipitation types to occur in the same period in the CWF, whereas only two are currently possible. When the algorithm is placed into the CWF program, an updated set of phrases describing precipitation type over a 12-hr period will be developed. Since there are five possible precipitation type forecasts at each of the beginning, middle, and end of a 12-hr forecast period, a total of 125 phrases will be required.

## ACKNOWLEDGEMENTS

### NOTES AND REFERENCES

1.  Mr. Bermowitz received his B.A. degree in Physics from Brooklyn College and his M.S. degree in Meteorology from New York University. Since joining the National Weather Service in 1967, he has worked for the Techniques Development Laboratory in the areas of numerical analysis and prediction, statistical forecasting, and most recently, computer worded forecasts. He also had a short assignment at WSFO, Washington, D.C.

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4.  Threat score = $H/(F+O-H)$ where $H$ is the number of correct forecasts of a category and $F$ and $O$ are the number of forecasts and observations of that category, respectively.

5.  Bias is the number of forecasts of a category divided by the number of observations of that category.

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16. Sleet is used with the freezing rain category in this algorithm since they can occur together in nature and there is no separate category for sleet in MOS.

## APPENDIX

Precipitation Type Algorithm Control Constants

| Constant | Description (Suggested Value) |
|---|---|
| LP1 | If POF is less than LP1, then POF is in the low range where rain is the most likely forecast. (35) |
| LP2 | If POF is greater than LP2, then POF is in the high range where snow is the most likely forecast. (65) |
| LP3 | If POZ is greater than or equal to LP3 and TEMP is equal to LT4, then sleet or freezing rain rather than rain is indicated. (10) |
| LP4 | If POZ is greater than or equal to LP4 and TEMP is equal to LT5, then sleet or freezing rain rather than rain is indicated. (5) |
| LP5 | If POF is in the middle range and greater than or equal to LP5, CAT indicates snow, and TEMP is less than or equal to LT6, then snow rather than rain mixed with snow is indicated. (55) |
| LP6 | If POF is in the high range and less than LP6 and CAT does not indicate snow, then snow mixed with rain or snow mixed with sleet or freezing rain rather than snow is indicated. (75) |
| LT1 | If TEMP is less than LT1, then sleet or freezing rain is indicated. (34) |
| LT2 | If POF is in the low (middle) range, CAT indicates snow, and TEMP is less than or equal to LT2, then rain |

| Constant | Description (Suggested Value) |
|---|---|
| | mixed with snow (snow) rather than (rain mixed with snow) is indicated. (34) |
| LT3 | If TEMP is less than LT3, then sleet or freezing rain rather than rain is indicated. (31) |
| LT4 | If TEMP is equal to LT4 and POZ is greater than or equal to LP3, then sleet or freezing rain rather than rain is indicated. (30) |
| LT5 | If TEMP is equal to LT5 and POZ is greater than or equal to LP4, then sleet or freezing rain rather than rain is indicated. (29) |
| LT3 | If TEMP is less than LT3, then sleet or freezing rain rather than rain is indicated. (31) |
| LT4 | If TEMP is equal to LT4 and POZ is greater than or equal to LP3, then sleet or freezing rain rather than rain is indicated. (30) |
| LT5 | If TEMP is equal to LT5 and POZ is greater than or equal to LP4, then sleet or freezing rain rather than rain is indicated. (29) |
| LT6 | If TEMP is greater than LT6 and POF is in the middle (high) range, then forecast rain (rain mixed with snow) rather than rain mixed with snow (snow). (44) |