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TRENDS IN SKILL AND ACCURACY OF NATIONAL WEATHER SERVICE POP FORECASTS

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ABSTRACT

Ramage (1982), in his paper "Have Precipitation Forecasts Improved?" analyzed 12 years of National Weather Service forecasts and concluded, "After the contribution of relative precipitation frequency was removed, accuracy improvement, amounting to about 1% in seven years could be detected only in the eastern and central region winter forecasts." This paper reports on a study undertaken to better understand Ramage's conclusions and to see whether they would hold over a longer period of record.

This report is based not only on the 12 years of data used by Ramage but also on 4 additional years. The scores used are percent correct, Brier score, and skill score. The effect of precipitation relative frequency was removed from the percent correct and Brier score. In general agreement with Ramage, there is only weak evidence of an improving trend in the 12-yr summer sample. However, there is strong evidence for an improving national trend in the 12-yr winter sample. Also, there is very strong evidence that the probability of precipitation forecasts improved over the longer period of record--1967-1982.

1. INTRODUCTION

Ramage (1982), in his paper "Have Precipitation Forecasts Improved?" analyzed 12 years of National Weather Service (NWS) forecasts with a view to determining accuracy trends. The main conclusions he reached related to the question he sought to answer, as summarized in his Abstract and his Conclusions and Outlook, are: "After the contribution of relative precipitation frequency was removed, accuracy improvement, amounting to about 1% in seven years, could be detected only in the eastern and central region winter forecasts." and "Except in winter in the eastern and central regions, any increase in accuracy from 1966 to 1978 has been negligible, with improvement even harder to achieve in summer. At least in precipitation forecasting, the great technological developments of the duodecennium have apparently belied the expectations of their proponents."

These conclusions were based on an analysis of 12 years of data published by the NWS Office of Meteorology (OM)[1]. The verification score used was percent correct (PC). The same publications also contain Brier scores (B), skill scores (S), and the relative frequency of precipitation (RF). In addition, 4 more years of scores have now been published (Polger, 1983). This paper reports on a study undertaken to better understand Ramage's conclusions and to see whether these conclusions would hold over the longer period of record.

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[1]These data are contained in: Roberts, et al. (1967 and 1969), Derouin and Cobb (1970, 1971, and 1972), Sadowski and Cobb (1973 and 1974), and Cooley, et al. (1981).

2. THE DATA

The published data are not completely homogeneous, as changes have occurred in the NWS verification program over the years. However, there is certainly enough consistency to make a study of trends meaningful. Some of the characteristics of the data worth noting are discussed here.

For the first year--the 1966 summer and the 1966-67 winter--the data are for forecasts made in the early morning. Because 0600 GMT surface data were available to the forecaster in preparing these forecasts, they have been termed "06Z cycle" forecasts. For all other years, data for forecasts made in the late afternoon are also included in the publications; these forecasts are called "18Z cycle" forecasts. In studying trends, the scores for these two cycles may be averaged. The question then arises as to whether or not the year for which only 06Z forecasts were verified should be included in the study. The 15-yr sample for which both cycles of data are available can be used to judge whether or not there is a difference in scores for the two cycles. The Appendix details a study of the cycle differences. The conclusion reached is that the first year should not be included.

For PoP verification, the summer (winter) season is usually defined as the 6-mo period April through September (October through March). However, for 2 years of record, between May 1970 and April 1972, summer (winter) was defined as May through October (November through April). Although this change in definition undoubtedly has some effect on the scores by season, the 2 years with the different season definitions were included in Ramage's study and also in this study.

During the early years, up to and including April 1971, three sets of forecasts were verified--local, FP, and NMC. The FP's were prepared by Area Forecast (FP) Centers; each center forecast for its location and about five other stations. There were 21 FP centers in 1966; data from 100 stations were included in the FP verification program initially. These FP forecasts were used as guidance by local offices to produce the final product issued to the public. The number of stations in the local verification program varied considerably over the years, and the published reports do not contain verification of local forecasts beyond the 1970-71 winter season except for the 1-yr period April 1972 to March 1973. The "FP" terminology has remained, but in later years the corresponding forecasts have been produced by the approximately 48 Weather Service Forecast Offices (WSFO's). NMC guidance forecasts have been verified throughout the period. Although the local forecasts generally verified slightly better than the corresponding FP guidance, the forecasts used in this study of trends were all FP's. This results in a more homogeneous database than one containing both locals and FP's.

PoP forecasts are made and verified for three 12-h periods. These periods are 12-24, 24-36, and 36-48 hours after numerical model run times based on 0000 and 1200 GMT data and are called the first, second, and third periods, respectively. Thus, they are 6-18, 18-30, and 30-42 hours after the so-called 06Z cycle and 18Z forecasts. The actual time of preparation of these forecasts varies somewhat by station, but many times hourly data as late as 0800 and 2000 GMT are available for the 06Z and 18Z cycles, respectively.

Up through the 1970-71 winter season, the FP and NMC samples were of about equal size and were nearly "matching." The number of forecasts ranged from a low of 9,000 nationally (for each cycle and period) for the 1970 summer and 1970-71 winter seasons to 18,000 to 23,000 in the other years. For the 1971 summer and the 1971-72 winter seasons, the FP and NMC samples were matching and consisted of about 28,000 forecasts. In all the following years, two sets of verification data were presented--one set for matching FP-NMC forecasts, and one slightly larger set of all FP forecasts. During these years, the matched samples ranged in size from 9,000 to 31,000 forecasts nationally. In this study, the FP forecasts which matched with the NMC forecasts were used.

The precipitation forecasts verified were for <u>probability</u> of precipitation, and Brier scores and skill scores were computed. The scores are defined:

$$B = \frac{1}{N}\sum_{i=1}^{N} (P_i - O_i)^2, \text{ and}$$

$$S = \frac{BC - B}{BC}$$

where P_i = the probability forecasts; O_i = the verifying observations which take the value of 1 or 0 for occurrence and non-occurrence, respectively; N is the sample size; and BC is the Brier score of climatic forecasts defined by the long-term climatic relative frequency by station and month. Note that B (and correspondingly BC) is one-half the score originally defined by Brier (1950). In addition, the percents correct were computed, where PoP's of 50% and greater were taken to be precipitation forecasts.

Data are available by NWS region--Eastern, Central, Southern, and Western. For some years, data from Alaska were available; these were not included in this study.

We used data directly from the published reports rather than from magnetic tapes containing the basic data; we wanted this study to be based on exactly what is available in published form.[2] In transferring data from the reports to machine-readable form, PC was tabulated in tenths of percent, S to tenths, and RF and B to thousandths--three significant places for each variable. However, this degree of significance was not available for some variables in some reports. PC was listed in whole percent for the 1967-69 summers and following winters, and S was listed in whole percent for the 1967 and 1969 summers and following winters.

It was discovered in the course of this work that some scores are incorrect in the last two published reports (Cooley, et al., 1981, and Polger, 1983). Specifically, the FP S and NMC BS (the so-called sample Brier score) values are incorrect for the second period, 18Z cycle, matching FP and NMC tabulations. The S values can be calculated from the listed B and BC (which are correct), and that was done for this study.[3]

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[2] A better, machine-readable database is being prepared jointly by the Techniques Development Laboratory and the Office of Meteorology.

[3] For instance, on p. 30 of Cooley et al. (1981), the national 18Z FP S should be (.1508-.1179)/.1508 = 21.8 instead of 11.2. (Also, BS = .1354 is incorrect. Since these are matching samples, the NMC value should be the same as the (correct) FP value of .1416. These values were not needed in this study.)

3. DESIGN OF THE EXPERIMENTS

The scores PC, B, and S are published for each NWS region and also for all regions combined. For the national computations, PC, B, and BC were weighted by the regional sample sizes and averaged[4]; S was then computed from the national B and BC. It was felt the primary conclusions should be drawn from national scores, but regional trends were also computed.

B, being a measure of accuracy of probability forecasts, should be a good score to use in trend studies of such forecasts. However, it is strongly related to relative frequency of the event in the sample. In order for the analysis to be sensitive to trends, the major effect of RF must be removed. Glahn and Jorgensen (1970) and others have shown the relationship to be quadratic, especially when station scores over a season are studied and the RF varies widely. However, over the range of RF associated with regional and especially national scores, a linear relationship is adequate. Fig. 1 shows an example of national Brier scores, averaged over the two cycles, as a function of relative frequency.

The skill score, S, effectively removes most of the dependence on RF. Therefore, S, based on B and BC, should also be a good score to use in trend studies as RF does not have to be considered.

The percent correct, PC, is probably a less appropriate score for trend analysis than B or S. It is sensitive to not only RF (as is B) but also to the threshold used for transforming the probability forecasts to categorical forecasts in order to compute it. For the published data, a forecast of $\geq$ 50% was counted as a precipitation forecast. As stated earlier, PC was listed only in whole percent for 3 of the years. Taken over a 15-yr period, this loss of significance would not likely effect major conclusions. However, three-place accuracy is desirable, especially because the variation in PC is only a few percent. Although the variation of PC with RF is also likely quadratic as suggested by Reed (1983), a linear relationship as used by Ramage is quite adequate over the range of RF of these data. Fig. 2 shows an example of national percents correct, averaged over the two cycles, as a function of relative frequency.

Both 06Z and 18Z forecasts could be used in a trend analysis, making a sample of 2N over N years. However, because of the close relationship between 06Z and 18Z scores for a particular year, the number of degrees of freedom associated with significance tests would be considerably less than 2N-1 and might approach N-1. At any rate, the number would be unknown, and a better plan is to average the 06Z and 18Z scores for the analysis. This average was used by Ramage and also in this study.

Two basic periods of record were studied--the 12-yr period used by Ramage and the 16-yr period composed of those same years plus the 4-yr period subsequently published. However, as suggested in the previous section and supported in the Appendix, the first year was omitted for all comparisons except one. In order to compare more closely with Ramage, the trend of PC was computed for the complete 12-yr period. Other trends computed were for PC for the 15-yr period, and for B and S for both 11- and 15-yr periods.

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[4]Or, equivalently, the basic station data were used to compute PC, B, and BC.

Trends were studied for each of the three forecast periods (projections) separately. This is considered quite important, because trends, if there indeed are any, may vary considerably between the first and third periods. In addition, overall trends were computed for the three periods combined.

4. TRENDS IN PERCENT CORRECT

Tables 1 through 4 present the results of the study of trends in PC. Results for the 12-yr sample used by Ramage are shown in Tables 1 (summer) and 2 (winter). Results for the 15-yr sample (the first year omitted) are shown in Tables 3 and 4. For each of the four samples, for each of the four regions and for the national average, and for each of the three periods and for the periods combined, a regression equation was fit of the form

$$PC = a + b(RF) + c(YEAR)$$

where RF is in fractional form (not percent) and YEAR is the actual year (e.g., 1967). Tables 1 through 4 list the fitted coefficients a, b, and c along with the reduction of variance (RV) afforded by RF, the additional RF given by YEAR, the probability levels (PR) associated with the RF and YEAR terms, and the total RV associated with the equation. (This latter RV is merely a sum of the other two.) The probability level was found from the computed F-statistic, where the error variance of the total equation was used as an estimate of the error variance for each term. A PR = .05 is interpreted as the probability that an F as large or larger than that computed would occur by chance only 5% of the time under the null hypothesis of a zero coefficient. The SAS package (SAS Institute, 1979) used in this study gave values as small as .0001 for PR.

All results for PC confirm the very high relationship of that variable to RF. The higher the RF, the lower PC.

Summer 12-yr Record - Overall, the results do not support a significant trend for any of the three periods, although 11 of the 12 coefficients of YEAR for individual regions and periods are positive.

Summer 15-yr Record - Overall, the results do support a significant positive trend for all three periods, although not every one of the trends computed is judged significant by itself. Nationally, a trend of .10 per year (1.0% per 10 years) is indicated for the first period, .12 per year (1.2% per 10 years) for the second period, and .06 per year (.6% per 10 years) for the third period. The first two show significance below the .5% level (or, stated alternatively, above the 99.5% level) and the latter below the 10% level.

Winter 12-yr Record - Eight of the 12 computed regional trends by period are significant below the 10% level. Each national trend is signficant below the .5% level. The national trends range from .11 to .21 per year (1.1% to 2.1% per 10 years) for the first and third periods, respectively.

Winter 15-yr Record - Here, nine of the 12 computed regional trends by period are significant below the 10% level. Again, each national trend is significant below the .5% level. The trends range from .10 to .21 per year (1.0 to 2.1% per 10 years) for the first and third periods, respectively.

While 1% to 2% increase over 10 years may seem small, it must be remembered that the PC was already in the low to mid 80's in 1967. (The national PC was 87 in the first period winters of 1967-68 through 1970-71.) Therefore, since categorical forecasts of $\geq$ .01 in of precipitation can never be 100% correct over substantial periods of record because of the random component in the observations (see Smith, 1979), a 1% increase in 10 years may be a substantial scientific gain.

The conclusions reached here from the 12-yr sample are somewhat at variance with those of Ramage. The data in his Table 3 and in our Tables 1 and 3 do not match closely. The full reason for this is not known. However, two rather major differences existed in the two studies. We kept the periods separate (Ramage did not), and we computed national as well as regional trends (Ramage did not).

The addition of 4 years to the sample made the existence of positive national trends nearly unquestionable, especially in winter. The summer third period is most in question, the significance level being about 7%.

Figs. 3 and 4 summarize the national data and trends for summer and winter, respectively. The trends are plotted at the average RF, and the data points have had the effect of RF removed. That is, they are deviations from a linear relationship of PC to RF. These national data by period correspond to Ramage's Figs. 5 and 6 for combined period regional data. The trends seem obvious.

5. TRENDS IN BRIER SCORE

Tables 5 through 8 contain the results of the study of trend in B. These tables are quite similar to Tables 1 through 4, respectively. The equation is of the same form as the one for PC. All results confirm the very significant relationship of B to RF. The higher the RF, the higher (worse) B.

Summer 11-yr Record - The conclusions are in agreement with those for the 12-yr PC sample--there was no significant trend in B over the 11-yr period.

Summer 15-yr Record - Overall, the results support a significant trend for all three periods. Eight of the 12 computed regional trends by period are significant below the 10% level. Each national trend is significant at or below the 1% level. Nationally, an improvement of .006, .008, and .008 per 10 years is indicated for the first through the third periods, respectively. Starting from a base of B $\approx$.12 in 1967, these are changes in B of about 6%.

Winter 11-yr Record - Nine of the 12 computed regional trends by period are signficant below the 10% level. Each national trend is significant at or below the .5% level. The national improvements range from .007 to .014 per 10 yr period.

Winter 15-yr Record - Ten of the 12 computed regional trends are significant below the 5% level. Each national trend is significant below the .3% level. National improvements per 10-yr period range from .006 to .013, for changes in B amounting to 6 to 10%.

6. TRENDS IN SKILL

Tables 9 through 12 show the results of the study of trend in S. These tables are similar to previous tables, except that the equation for trend is of the form

$$S = A + B(\text{YEAR}).$$

Another equation was computed for each comparison of the form

$$S = a + b(\text{RF}).$$

For this latter equation, only the coefficients of RF are shown in Tables 9-12. These equations relating S to RF were computed to show that S is not well related to RF. In fact, the values of PR associated with these equations are what one might expect from sets of paired random numbers. Also, of the 60 RF coefficients, 28 are positive and 32 are negative.

Summer 11-yr Record - Viewed overall, there is some evidence that computed improvements in S are real; two of the three national trends are significant below the 10% level, as is the national trend for the three periods combined.

Summer 15-yr Record - Ten of the 12 computed regional trends by period are significant below the 10% level. Each national trend is significant below the 1% level. The improvements range from 3.9 to 6.0 per 10-yr period. These represent changes in S of about 15% and 60%, respectively.

Winter 11-yr Period - Ten of the 12 computed regional trends by period are significant below the 10% level. Each national trend is significant at or below the 2% level. The national improvements range from 5.7 to 11.2 per 10-yr period.

Winter 15-yr Period - All but one of the 12 computed regional trends are signficant at or below the 5% level. Each national trend is significant below the .3% level. The national improvements range from 4.6 to 10.3 per 10-yr period. These represent changes in skill of about 12% to 70%. The third-period skill in the 1981-82 winter is estimated to be nearly double what it was for the 1967-68 winter.

Figs. 5 and 6 summarize the national data and trends for summer and winter, respectively. These trends do not involve RF, and the data points plotted are the actual values.

7. SUMMARY AND CONCLUSIONS

Trends in skill and accuracy of NWS PoP forecasts have been computed for two periods of record: (1) the April 1966-March 1978 period analyzed by Ramage, and (2) the April 1966-March 1982 period for which published data are available in the NOAA Technical Memorandum NWS FCST series. Three published scores were analyzed--percent correct, Brier score, and skill score. To be consistent with Ramage, the complete 12-yr record was used for percent correct, the (only) variable he used. However, because scores were available for only the 06Z cycle for the first year, that first year was omitted for all other comparisons; it is shown in the Appendix that there were significant differences in the scores for the 06Z and 18Z cycles for the 15-yr April 1967-March 1982 period.

Trends were computed for the average of 06Z and 18Z scores for each season (summer and winter), for each forecast period (first, second, and third), and for each conterminous NWS region (Eastern, Southern, Central, and Western) as well as for all regions combined and for all periods combined. The effect of precipitation relative frequency was removed for percent correct and Brier score; this was not necessary for skill score. Although results by NWS region are shown, these are not discussed in detail, and conclusions are based mainly on the national results.

The major conclusions are as follows:

- In general agreement with Ramage, the 12-yr summer record <u>does not</u> support a firm conclusion of a positive trend in percent correct, although all computed national trends were positive and 11 of the 12 regional trends were positive. However, the 12-yr winter record <u>does</u> indicate a positive trend; the national trend for each forecast period is significant below the .5% level (or stated alternatively, above the 99.5% level). Ramage computed regional trends but not a national trend and he averaged scores for all forecast periods.

- The 11-yr summer record of Brier scores also does not show strong evidence of an improving trend. The skill scores for the same period are more indicative of an improving trend than are percents correct or Brier scores, the second and third period national trends being significant well below the 10% level. The 11-yr winter record indicates improvement in both Brier score and skill score; each national trend of Brier score (skill score) is significant at or below the .5% (2%) level.

- All 15-yr national records, for percent correct, Brier score, and skill score, for both summer and winter, and for all three periods show improving trends at or below the 10% level, with all but one at or below the 1% level. Percent correct improved at a rate of .6 to 2.1% per 10 years. While these improvements are not large, it must be remembered that the percent correct was already in the low to mid 80's in 1967. When problems associated with verifying $\geq$ .01 in of rainfall at single gauges are considered, the improvement in percent correct may be a substantial scientific gain.

- The 15-yr improvements in skill score for the summer (winter) period ranged from 3.9 to 6.0 (4.6 to 10.3) per 10-yr period. The 10-yr <u>change</u> in first period skill was 12 to 15% and in third period skill was 60 to 70%. Both summer and winter third period skill in 1981-82 is estimated by the linear trend to be nearly double what it was for 1967-68 (see Figs. 3 and 4).

- The computed 15-yr winter trends were not greatly different from the 11- or 12-yr trends. However, as shown in summary Table 13, the computed 15-yr summer trends were substantially greater than the 11- or 12-yr trends. Also, the longer sample, and possibly the omission of the first year for which only 06Z scores are available, allows one to place a high trust in the hypothesis that the improvement has not been due to chance. The <u>amount</u> of improvement is, of course, open to more question.

- o It is apparent that the skill score does not systematically depend on relative frequency, at least when aggregation of data is on a regional or national basis. In fact, of the 60 correlations computed between S and RF (one for each season, each period, each sample size, and each region and nationally) 28 are positive and 32 negative. Also, the sign was many times different for the 15-yr samples and the corresponding 11-yr samples.

- o In general, the 06Z forecasts seem to be better than the 18Z forecasts. In terms of skill S, the difference is estimated to be about 1.0. This equates to about a 2-yr improvement over the period studied.

- o In conclusion, there seems very little doubt that PoP forecasts and the categorical forecasts derived from them have improved over the 1967-1982 period. This does not imply the trend will continue, nor would a possible decrease in accuracy or skill after 1982 invalidate the 1967-1982 trend.

The skill score appears to be more sensitive to improvements than percent correct or Brier score. This is reasonable, because the skill scores are computed by removing the effect of monthly, long-term RF at the station level, while only the effect of seasonal sample RF on PC and B has been removed at the regional or national level in this study. (This is all the published data allow.) That is, the summations involved in computing BC (as well as B) are performed by station, so that the effect of station RF (albeit, the long-term RF) is removed. However, once B is computed for a region, only the effect of RF for that region can be removed. This aspect of verification needs more study. It may well be that a regional S should be computed as an average of station S, rather than from a regional summation of B and BC. Also, the pros and cons of using long-term RF as opposed to sample RF need to be investigated.

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APPENDIX

Differences of Scores by Cycle

The PoP verification data for the 1966 summer (April-September) and the 1966-67 winter (October-March) published by Roberts, et al. (1967) are for the forecasts made in the early morning. Because 0600 GMT surface data were available to the forecaster in making these forecasts, they have been termed "06Z cycle" forecasts. Later publications (e.g., Roberts, et al., 1969) also include verification of forecasts made in the afternoon which are called "18Z cycle" forecasts. In studying trends in skill or accuracy of PoP forecasts, the scores for the two cycles may be combined. The question then arises as to whether the year for which only 06Z forecasts were verified should be included in the study.

The published data for the period April 1967 through March 1981 contain forecasts for both cycles and can be used to judge whether or not there is a significant difference in the scores for the two cycles. Paired t-tests for summer and winter separately and for the three forecast projections (6 tests) showed many highly significant differences for PC, B, and S (see Table 14). However, similar tests also showed the cycle differences in RF to be highly significant. Since PC and B (and to a much lesser extent, S) are related to RF, it might be that the cycle differences in PC and B are due to the differences in RF. To test this possibility, the SAS GLM (SAS Institute, 1979) procedure was used to perform analyses of covariance for two different models. For comparison, two analysis of variance models were also used.

Tables 15, 16, and 17 detail the results for testing the significance of the difference of cycle means of PC, B, and S, respectively. Each table shows the results of four models for each season and each projection (or forecast period) for <u>national</u> scores.

We'll use Table 15 for illustration; entries in Tables 16 and 17 have similar explanations. Analysis of variance Model 1 relates the dependent variable, percent correct (PC), to one independent variable, cycle (CYC). For the summer season, period 1, CYC explains only 2.5 of the 27.9 total sums of squares (SS), leaving 25.5 for the error term (rounding may occasionally cause an apparent discrepancy in the last digit). With 1 degree of freedom (df) for CYC and 28 for the error term, the computed F to be compared to the tabled values of the F-distribution is 2.71. SAS gives this a probability level of .11. This is interpreted that there is a 11% probability that a difference as great as that observed in the 06Z and 18Z cycle means would have occurred by chance. The last two columns in Table 15 show the 06Z cycle mean to be 84.77 and the 18Z cycle mean to be 85.34. Although 11% is not usually considered "significant," it <u>is</u> a fairly low value and is associated with the 18Z cycle having the better score (higher PC) by 0.57. This test is equivalent to using a t-test to test the difference of the two means.

Analysis of variance Model 2 relates PC to CYC and year (YEAR). Since much of the variance (or SS) is due to differences between years, the test of the difference of cycle means by Model 1 is not very discriminating. Model 2, for summer period 1, shows YEAR accounts for 21.6 SS. For this analysis of variance design, the SS explained by CYC is the same for Models 1 and 2. This test, equivalent to a paired (by year) t-test, is much more discriminating than Model 1 and gives a computed F of 8.91. With 1 and 14 degrees of freedom, the significance level is about 1%, indicating the 18Z cycle PC is significantly larger than the 06Z cycle PC. Note that the PC cycle difference of .57 and the paired t-test significance are the same in Tables 14 and 15.

Models 3 and 4 involve the noncategorical covariate RF and are, therefore, analysis of covariance models. The idea here is to determine the difference of the cycle means of PC after the (linear, in this application) effect of RF is removed, and to test the significance of that difference. We know from Table 14 that RF tends to be significantly different for the two cycles (although the actual differences are not large), so the difference of the cycle means may decrease or even change sign when the RF effect is removed. Model 3 relates PC to RF and CYC. Table 15 shows that RF accounts for 16.5 SS (which is highly significant) and CYC now accounts for only .1 additional SS.[5] Even more importantly, the sign of the difference has reversed. That is, given a constant RF, the 06Z cycle PC is larger than the 18Z cycle PC. The values in the table (85.12 and 84.99) are those with RF set to its mean (of both cycles) value of 0.180.

Fig. 7 illustrates, following Neter and Wasserman (1974), what is happening with Model 3. Summer, period 1 data for each cycle are plotted along with the regression line for each. Note that the regression lines for this model have the same slope, and differ by an amount PC = .13--the difference of the cycle means. The 06Z mean occurs at PC = 84.77 and RF = .186 and the 18Z mean at PC = 85.34 and RF = .174, so the 06Z mean PC is less by .57, but if the regression lines are followed to the overall mean RF = 0.180, it can be seen the 06Z mean is greater by .13.

Model 4 is somewhat analogous to doing a paired t-test on the difference of the cycle means after the effect of RF is removed. Since the RF is used "first" in the model, its explained SS is the same as in Model 3. However, the calculated F is much larger because inclusion of YEAR has reduced the error SS dramatically (from 11.4 to 2.3) and the error mean square used in the denominator in computing F is smaller for Model 4 (2.3/13) than for Model 3 (11.4/27). YEAR, with the effect of RF removed, accounts for 9.0 SS and is still significant at about the 1% level. The CYC SS is still only about 0.1 and is not significant. The mean PC for the 06Z (18Z) cycle with the RF set to its mean value of 0.180 is 85.20 (84.91). Therefore, one is led to conclude that although the 06Z cycle PC mean is larger than the 18Z cycle PC by 0.29 when the effects of RF and YEAR are removed, this difference is not statistically significant.

Since the cycle scores (by period) are quite similar by year[6], Models 2 and 4 are much superior to Models 1 and 3. Previous studies have shown PC and B to be highly related to RF, so for PC and B Model 4 is to be preferred to Model 2. This does not mean Model 4 will tend to show more (or less) significance than Model 2 for the cycle differences. The SS explained by RF

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[5]The order of the variables is important here. The variation of CYC after the RF effect is removed is being tested. For the analysis of variance Models 1 and 2, order is not important.

[6]Note that the "paired" aspect of the tests does not involve any assumption concerning trend (linear or otherwise) by year.

will tend to lower the error SS and, even though the degrees of freedom are reduced by 1, lower the error mean square (MS). This lower error MS will tend to produce a larger F. However, the SS explained by RF may reduce the SS explained by the cycle and cause a lower F.

On the other hand, S is not well related to RF,[7] and, therefore, Model 2 is probably a better model to use for S than Model 4. One would hope, however, that the overall conclusions reached from using models 2 and 4 for S would be the same.

Looking at Table 15, we can note the following:

- Of the six samples (two seasons, three periods each), 06Z PC is larger (better) than 18Z PC in three. None of the differences is significant at the 10% level by Model 1. Model 2, however, shows all three differences significant, the levels ranging from 4% to .07%.

- Of the three samples with PC18 larger than PC06, Model 1 shows one to be significant (summer, period 3, at the 2% level), and Model 2 shows two to be significant at or below the 1% level.

- The removal of the (linear) RF effect by Model 3 reverses the sign of the cycle difference in four of the six samples! This results in three of the six samples indicating PC06 larger than PC18, but none of the six Model 3 tests shows significance.

- The removal of the RF effect by Model 4 results in four of the six samples indicating PC06 greater than PC18. Of the six Model 4 tests, only one shows significance (at the 2% level) and indicates PC06 larger than PC18.

From Table 16, we note:

- Of the six samples, 06Z B is smaller (better) than 18Z B in three. For both PC and B, the better scores are indicated for the second period summer and the first and third period winters. Also, for those season-period combinations that show better (worse) scores at 06Z, the RF is less (greater) at 06Z (Table 14). None of the three differences is significant at the 10% level by Model 1. Model 2 shows all three differences significant at or below .2%.

- Of the three samples with B18 better than B06, Model 1 shows none to be significant, and Model 2 shows two to be significant at or below the 6% level. These are the same two that show significance for PC18 better than PC06.

- The removal of the RF effect by Model 3 reverses the sign of the cycle difference in four of the six samples. This results in five of the six samples indicating B06 better than B18, but only one of the Model 3 tests shows significance below the 10% level.

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[7]In fact, S was designed to eliminate the effect of RF on B. While this aspect of S has not been studied extensively, the analysis shown earlier in this report strongly suggests that there is no systematic relationship between S and RF, at least for the aggregation of data over areas as large as NWS regions.

o The removal of the RF effect by Model 4 results in five of the six samples indicating B06 better than B18. Of those five, four show significance at or below 5%. Conversely, the period 2 summer B18 is indicated to be better than B06 at the 5% level.

Similarly, from Table 17:

o Of the six samples, 06Z S is larger (better) than 18Z S in five. None of the five differences is significant at the 10% level by Model 1. Model 2 shows all five to be significant at the 3% level or below.

o The one sample with 18Z S better than 06Z S does not indicate a significant difference by Models 1 or 2.

o The removal of the RF effect by Model 3 does not reverse the sign of any of the differences. Also, only three of the tests show RF to be significant at the 10% level. None of the six cycle differences is significant at the 10% level.

o The removal of the RF effect by Model 4 does not reverse any of the sign differences. Because of the large reduction in the error term by YEAR, RF shows more significance with Model 4 than Model 3 for some of the comparisons. However, this is misleading, because including RF as the "first" variable in the model allows it to explain some of the variance that can be accounted for by YEAR. For instance, for the winter period 3, RF and YEAR together account for 707.8 SS. But YEAR alone (by Model 2) accounts for 707.7 SS. Therefore, if YEAR were the "first" variable, RF would be worthless. Of the five tests showing S06 to be better than S18, four are significant at or below the 10% level.

o The poor relationship between S and RF (RF of little use in explaining the variance of S) is indicated by the results for Models 2 and 4. RF did not reverse the sign of any of the differences, and the conclusions one would reach from Models 2 and 4 are similar.

The conclusions about cycle differences of scores are stronger for S than for PC and B. Five of the six comparisons showed the 06Z S to be greater than the 18Z S by .95 to 1.73, all differences being significant at or below the 3% level by Model 2. The other comparison shows the 18Z S to be better than the 06Z S by .38, but is not significant even at the 20% level. Therefore, the year with only 06Z scores should not be used in the analysis.

Cycle differences of B and PC generally support the conclusion that 06Z scores are better than 18Z scores <u>after the effect of RF is removed</u>. The same five comparisons that show 06Z S better than 18Z S also show 06Z B better than 18Z B and four of these are significant at or below the 5% level by Model 4. For PC, only four of the six comparisons show 06Z better than 18Z after the RF effect is removed, and only one of these is significant. Since S and B results agree rather well, the weak support by PC probably indicates PC is a less desirable statistic than S and B.

Table 1. Trend statistics for percent correct (PC) for summer, 12-yr sample. For each period (1, 2, and 3) and for all periods combined (All) results are shown for each NWS region (E = Eastern, S = Southern, C = Central, and W = Western) and for all regions combined (N = National). Coefficients are given for the equations PC = a + b(RF) + c(YEAR), where RF = the precipitation relative frequency for that sample by year (YEAR). The reduction of variance (RV) is given in percent for the RF term, the additional RV for the YEAR, and the total. The chance of that high an RV occurring when no real relationship exists is given in the column headed PR for RF and YEAR.

Period	Region	a	RF			YEAR			Total
			b	RV	PR	c	RV	PR	RV
1	E	46.3	-44.1	70.5	.0026	.0234	.6	.6762	71.1
	S	-122.6	-58.7	83.4	.0001	.1099	10.5	.0034	93.9
	C	-4.7	-58.3	74.5	.0005	.0506	1.3	.4966	75.8
	W	-80.4	-67.1	75.4	.0001	.0903	9.3	.0449	84.7
	N	-28.5	-46.5	61.0	.0020	.0617	10.5	.1034	71.5
2	E	-29.1	-52.0	69.5	.0019	.0612	3.4	.3148	72.9
	S	-84.2	-73.1	75.9	.0001	.0911	8.9	.0478	84.8
	C	-58.9	-75.1	82.1	.0001	.0787	2.3	.2794	84.4
	W	-17.0	-75.2	78.7	.0002	.0580	3.2	.2415	81.9
	N	-12.2	-66.3	76.2	.0002	.0543	4.4	.1913	80.6
3	E	-153.6	-64.6	77.3	.0002	.1249	9.4	.0329	86.7
	S	32.3	-92.6	94.5	.0001	.0333	.6	.3167	95.1
	C	61.3	-85.3	92.7	.0001	.0183	.1	.7368	92.8
	W	138.0	-86.0	91.5	.0001	-.0202	.3	.5621	91.8
	N	82.7	-83.2	89.2	.0001	.0073	.1	.8127	89.3
All	E	-43.1	-53.5	77.8	.0005	.0686	4.2	.1818	82.0
	S	-66.9	-72.0	86.8	.0001	.0823	7.8	.0057	94.6
	C	.2	-73.1	86.6	.0001	.0487	1.0	.4332	87.6
	W	12.7	-76.4	86.8	.0001	.0432	1.9	.2554	88.7
	N	16.5	-64.0	81.2	.0001	.0397	3.1	.2158	84.3

Table 2. Same as Table 1, except for 15-yr summer sample.

Period	Region	a	RF b	RF RV	RF PR	YEAR c	YEAR RV	YEAR PR	Total RV
1	E	-145.3	-40.7	62.6	.0007	.1202	16.6	.0093	79.2
	S	127.7	-71.9	83.3	.0001	.1137	5.3	.0351	88.6
	C	-46.9	-56.8	67.5	.0002	.0720	5.0	.1650	72.5
	W	26.7	-69.7	84.2	.0001	.0362	2.1	.1976	86.3
	N	-93.9	-48.6	58.4	.0003	.0951	22.3	.0029	80.7
2	E	-268.8	-53.2	61.6	.0006	.1829	20.9	.0025	82.5
	S	-159.6	-77.0	85.1	.0001	.1297	6.2	.0127	91.3
	C	-166.5	-75.8	74.9	.0001	.1334	10.3	.0137	85.2
	W	-12.7	-75.4	82.4	.0001	.0559	4.2	.0771	86.6
	N	-145.4	-68.6	64.2	.0001	.1221	20.4	.0018	84.6
3	E	-322.3	-64.3	63.8	.0002	.2104	22.1	.0010	85.9
	S	5.2	-93.3	93.2	.0001	.0472	.8	.2296	94.0
	C	21.5	-90.5	92.0	.0001	.0391	.8	.2838	92.8
	W	54.3	-84.7	90.1	.0001	.0222	.6	.4042	90.7
	N	-10.0	-89.9	85.3	.0001	.0550	3.7	.0669	89.0
All	E	-245.7	-52.5	64.0	.0002	.1713	20.9	.0016	84.9
	S	-96.2	-80.4	89.2	.0001	.0979	3.7	.0271	92.9
	C	-64.9	-74.3	82.6	.0001	.0819	4.5	.0629	87.1
	W	22.3	-76.9	89.3	.0001	.0383	2.1	.1150	91.4
	N	-83.6	-69.1	72.5	.0001	.0910	13.5	.0053	86.0

Table 3. Same as Table 1, except for 12-yr winter sample.

Period	Region	a	RF b	RF RV	RF PR	YEAR c	YEAR RV	YEAR PR	Total RV
1	E	-1.0	-34.7	53.0	.0091	.0482	2.2	.5251	55.2
	S	-24.5	-37.1	61.2	.0032	.0606	4.6	.2990	65.8
	C	-286.4	-44.6	57.4	.0001	.1938	27.3	.0031	84.7
	W	-73.7	-51.3	86.2	.0001	.0866	1.8	.2776	88.0
	N	-119.8	-35.9	66.4	.0001	.1086	21.6	.0030	88.0
2	E	-222.3	-44.9	50.0	.0045	.1603	16.1	.0691	66.1
	S	-232.0	-69.1	80.2	.0001	.1671	12.4	.0036	92.6
	C	-157.5	-60.9	77.5	.0001	.1286	7.6	.0607	85.1
	W	-220.7	-67.4	87.4	.0001	.1612	3.5	.0955	90.9
	N	-252.7	-62.0	74.1	.0001	.1772	21.0	.0002	95.1
3	E	-410.1	-53.6	44.3	.0026	.2552	26.3	.0193	70.6
	S	-174.9	-79.6	87.3	.0001	.1383	6.8	.0108	94.1
	C	-239.3	-77.8	86.3	.0001	.1708	8.9	.0027	95.2
	W	-183.2	-70.8	86.3	.0001	.1417	2.5	.1925	88.8
	N	-316.2	-72.9	74.0	.0001	.2096	21.0	.0002	95.0
All	E	-208.8	-44.8	52.6	.0029	.1534	15.3	.0682	67.9
	S	-143.5	-62.3	82.1	.0001	.1219	8.4	.0200	90.5
	C	-227.0	-61.3	79.8	.0001	.1641	12.9	.0032	92.7
	W	-156.6	-63.3	87.7	.0001	.1285	2.6	.1566	90.3
	N	-228.0	-57.1	73.7	.0001	.1644	21.2	.0002	94.9

Table 4. Same as Table 1, except for 15-yr winter sample.

Period	Region	a	RF			YEAR			Total
			b	RV	PR	c	RV	PR	RV
1	E	33.2	-38.8	70.4	.0011	.0315	.8	.5725	71.2
	S	30.2	-43.7	62.2	.0032	.0333	1.3	.5277	63.5
	C	-140.8	-45.6	72.6	.0001	.1201	11.7	.0114	84.3
	W	-207.8	-49.2	85.7	.0001	.1544	6.8	.0063	92.5
	N	-93.1	-38.6	79.4	.0001	.0953	10.9	.0032	90.3
2	E	-297.0	-42.0	63.0	.0037	.1978	14.8	.0150	77.8
	S	-64.5	-72.2	81.1	.0001	.0824	3.3	.1372	84.4
	C	-197.0	-59.3	76.9	.0001	.1485	10.9	.0067	87.8
	W	-310.6	-65.6	86.7	.0001	.2066	7.0	.0033	93.7
	N	-240.8	-57.5	80.0	.0001	.1707	14.9	.0001	94.9
3	E	-390.4	-55.9	66.7	.0014	.2456	14.8	.0093	81.5
	S	-85.6	-82.1	88.4	.0001	.0933	3.7	.0363	92.1
	C	-184.9	-76.4	86.6	.0001	.1431	7.1	.0032	93.7
	W	-427.7	-67.2	84.6	.0001	.2652	9.9	.0006	94.5
	N	-316.3	-66.4	78.2	.0001	.2089	16.6	.0001	94.8
All	E	-218.5	-45.3	69.2	.0013	.1585	10.5	.0288	79.7
	S	-35.4	-66.9	83.2	.0001	.0674	2.8	.1477	86.0
	C	-171.5	-60.8	81.5	.0001	.1359	9.4	.0040	90.9
	W	-315.6	-60.6	86.3	.0001	.2088	8.1	.0013	94.4
	N	-213.6	-54.6	80.5	.0001	.1567	14.4	.0001	94.9

Table 5. Same as Table 1, except for Brier score (B), 11-yr summer sample.

Period	Region	a	RF			YEAR			Total
			b	RV	PR	c	RV	PR	RV
1	E	1.2635	.249	66.4	.0092	-.000607	6.9	.1875	73.3
	S	.8087	.362	76.8	.0008	-.000385	5.1	.1700	81.9
	C	-.3184	.401	79.5	.0005	.000180	.3	.7243	79.8
	W	-.6451	.596	68.8	.0028	.000329	1.5	.5518	70.3
	N	.5385	.305	62.0	.0068	-.000247	2.9	.4337	64.9
2	E	1.9256	.318	70.1	.0021	-.000943	12.6	.0416	82.7
	S	.9482	.453	82.5	.0002	-.000459	5.6	.0893	88.1
	C	.4474	.470	86.8	.0001	-.000207	.3	.6565	87.1
	W	.5876	.545	87.5	.0001	-.000289	1.4	.3484	88.9
	N	.8758	.443	75.0	.0007	-.000424	5.0	.1831	80.0
3	E	2.1698	.401	79.7	.0001	-.001071	13.6	.0038	93.3
	S	.6143	.568	91.5	.0001	-.000296	1.6	.2070	93.1
	C	.1265	.554	92.3	.0001	-.000048	.1	.9040	92.4
	W	-.0483	.635	93.2	.0001	.000031	.0	.9056	93.2
	N	.6653	.553	91.3	.0001	-.000323	2.4	.1126	93.7
All	E	1.7401	.325	76.1	.0007	-.000851	10.9	.0328	87.0
	S	.7881	.461	87.3	.0001	-.000379	3.8	.1036	91.1
	C	.0782	.474	88.1	.0001	-.000022	.0	.9609	88.1
	W	-.0403	.596	88.1	.0001	-.000026	.0	.9360	88.1
	N	.6737	.435	80.2	.0003	-.000321	3.4	.2336	83.6

Table 6. Same as Table 5, except for 15-yr summer sample.

Period	Region	a	RF b	RF RV	RF PR	YEAR c	YEAR RV	YEAR PR	Total RV
1	E	1.9209	.238	54.1	.0027	-.000940	22.7	.0051	76.8
	S	1.1385	.434	85.2	.0001	-.000559	3.9	.0614	89.1
	C	.7972	.370	70.1	.0001	.000383	3.4	-.2341	73.5
	W	-.0054	.474	72.1	.0001	.000011	.0	.9677	72.1
	N	1.1462	.306	56.3	.0008	-.000555	18.9	.0105	75.2
2	E	2.7081	.314	58.1	.0005	-.001340	27.3	.0005	85.4
	S	1.6032	.486	88.0	.0001	-.000794	6.1	.0041	94.1
	C	1.5299	.457	75.8	.0001	-.000755	9.1	.0194	84.9
	W	.4450	.520	90.4	.0001	-.000216	1.4	.1733	91.8
	N	1.5970	.447	64.7	.0001	-.000790	20.3	.0017	85.0
3	E	3.2001	.358	58.7	.0001	-.001589	32.1	.0001	90.8
	S	1.2967	.582	91.9	.0001	-.000643	3.2	.0160	95.1
	C	1.1601	.528	83.6	.0001	-.000570	4.3	.0614	87.9
	W	.4206	.572	92.3	.0001	-.000203	1.1	.1847	93.4
	N	1.5275	.525	74.2	.0001	-.000758	15.8	.0009	90.0
All	E	2.6107	.302	58.2	.0003	-.001290	28.5	.0003	86.7
	S	1.3579	.499	89.5	.0001	-.000671	4.4	.0120	93.9
	C	1.1667	.452	78.4	.0001	-.000572	5.6	.0621	84.0
	W	.2894	.523	89.2	.0001	-.000137	.5	.4283	89.7
	N	1.4240	.428	67.1	.0001	-.000702	18.4	.0021	85.5

Table 7. Same as Table 5, except for 11-yr winter sample.

Period	Region	a	RF			YEAR			Total
			b	RV	PR	c	RV	PR	RV
1	E	1.3000	.281	63.4	.0046	-.000643	5.8	.2564	69.2
	S	.7392	.270	78.5	.0010	-.000357	3.0	.2878	81.5
	C	1.9271	.283	72.7	.0001	-.000958	15.3	.0127	88.0
	W	1.7710	.330	87.0	.0001	-.000885	3.4	.1341	90.4
	N	1.4367	.264	77.7	.0001	-.000709	14.3	.0054	92.0
2	E	3.1721	.329	57.3	.0017	-.001588	23.3	.0146	80.6
	S	2.0953	.465	82.6	.0001	-.001051	8.2	.0277	90.8
	C	2.3549	.371	72.8	.0002	-.001173	12.8	.0287	85.6
	W	2.6167	.401	87.1	.0001	-.001311	4.7	.0643	91.8
	N	2.8007	.380	72.4	.0001	-.001403	23.2	.0002	95.6
3	E	3.5344	.400	60.8	.0009	-.001773	22.8	.0103	83.6
	S	1.7543	.554	89.4	.0001	-.000879	4.3	.0466	93.7
	C	2.4509	.482	82.6	.0001	-.001226	9.4	.0152	92.0
	W	3.0322	.432	84.7	.0001	-.001519	5.3	.0716	90.0
	N	2.8476	.456	76.6	.0001	-.001428	18.4	.0006	95.0
All	E	2.6723	.331	62.1	.0015	-.001335	18.2	.0261	80.3
	S	1.5329	.432	85.8	.0001	-.000764	5.4	.0571	91.2
	C	2.2351	.380	78.1	.0001	-.001115	12.1	.0139	90.2
	W	2.4638	.388	87.0	.0001	-.001234	4.5	.0721	91.5
	N	2.3582	.366	76.5	.0001	-.001178	19.4	.0003	95.9

Table 8. Same as Table 5, except for 15-yr winter sample.

Period	Region	a	RF b	RF RV	RF PR	YEAR c	YEAR RV	YEAR PR	Total RV
1	E	1.0547	.251	71.2	.0012	-.000514	4.3	.1721	75.5
	S	.3325	.324	75.7	.0002	-.000155	.6	.5768	76.3
	C	1.6441	.284	73.3	.0001	-.000815	13.6	.0041	86.9
	W	2.1288	.312	83.8	.0001	-.001065	7.6	.0067	91.4
	N	1.1874	.279	83.8	.0001	-.000584	8.8	.0026	92.6
2	E	2.8823	.286	67.0	.0010	-.001436	17.2	.0034	84.2
	S	1.3041	.480	84.9	.0001	-.000651	4.7	.0380	89.6
	C	2.3507	.386	74.0	.0001	-.001173	14.8	.0018	88.8
	W	2.5856	.385	85.6	.0001	-.001294	7.7	.0029	93.3
	N	2.3184	.367	79.2	.0001	-.001157	16.2	.0001	95.4
3	E	3.6829	.360	69.2	.0003	-.001843	19.1	.0008	88.3
	S	1.5328	.544	87.5	.0001	-.000766	5.4	.0111	92.9
	C	2.2896	.469	81.3	.0001	-.001143	10.8	.0016	92.1
	W	2.9415	.424	84.9	.0001	-.001473	8.0	.0030	92.9
	N	2.6530	.433	79.4	.0001	-.001327	16.1	.0001	95.5
All	E	2.5545	.296	70.8	.0005	-.001271	14.6	.0048	85.4
	S	1.0303	.454	86.6	.0001	-.000511	3.5	.0601	90.1
	C	2.0778	.382	77.8	.0001	-.001035	12.8	.0017	90.6
	W	2.5507	.374	85.6	.0001	-.001276	7.9	.0025	93.5
	N	2.0387	.361	81.7	.0001	-.001015	14.1	.0001	95.8

Table 9. Trend statistics for skill score (S) for summer, 11-yr sample. The coefficients are given for the RF term in equations S = a + b(RF), along with the RV and PR associated with each equation. Coefficients are also given for the equations S = A + B(YEAR).

Period	Region	RF Alone			Year Without RF			
		b	RV	PR	A	B	RV	PR
1	E	38.1	9.5	.3575	-459.5	.2482	12.0	.2956
	S	60.4	10.3	.3357	-383.5	.2041	8.8	.3757
	C	29.7	4.5	.5289	66.6	-.0205	.0	.9505
	W	-4.8	.0	.9534	-915.0	.4773	27.6	.0972
	N	90.3	20.6	.1610	-474.0	.2532	12.8	.2793
2	E	12.0	.6	.8184	-1141.6	.5895	50.1	.0148
	S	19.8	1.0	.7697	-566.2	.2932	18.1	.1922
	C	20.8	2.3	.6566	-423.0	.2227	5.3	.4948
	W	28.1	1.2	.7454	-962.9	.4968	26.7	.1038
	N	37.4	3.5	.5815	-805.4	.4168	35.1	.0546
3	E	-14.6	.9	.7817	-1323.6	.6786	72.6	.0009
	S	-25.7	3.1	.6057	-482.3	.2477	21.6	.1496
	C	-8.7	.6	.8284	-212.7	.1132	2.0	.6815
	W	9.5	.3	.8781	-416.7	.2164	9.2	.3637
	N	.8	.0	.9878	-735.2	.3782	50.1	.0148
All	E	8.5	.4	.8502	-974.9	.5055	50.7	.0139
	S	18.2	1.2	.7446	-477.3	.2483	17.9	.1948
	C	14.2	1.3	.7425	-189.7	.1052	1.4	.7247
	W	10.1	.2	.8920	-764.9	.3968	23.1	.1350
	N	41.7	5.7	.4786	-671.6	.3494	32.5	.0670

Table 10. Same as Table 9, except for 15-yr summer sample.

Period	Region	RF Alone			Year Without RF			
		b	RV	PR	A	B	RV	PR
1	E	28.9	2.9	.5412	-861.3	.4521	38.0	.0144
	S	-37.0	4.7	.4372	-703.1	.3663	26.5	.0494
	C	48.8	9.0	.2780	-472.3	.2530	11.2	.2237
	W	24.8	1.8	.6345	-198.6	.1138	3.5	.5017
	N	62.1	7.3	.3311	-749.9	.3932	41.1	.0100
2	E	-12.2	.3	.8419	-1429.6	.7357	65.5	.0003
	S	-70.2	14.0	.1692	-1107.2	.5677	54.0	.0018
	C	26.3	2.4	.5835	-913.0	.4714	33.8	.0229
	W	23.9	1.6	.6563	-536.6	.2805	20.1	.0937
	N	-4.8	.0	.9505	-1156.1	.5948	65.1	.0003
3	E	-25.7	1.1	.7113	-1687.2	.8632	75.7	.0001
	S	-103.3	32.5	.0266	-1090.3	.5563	56.9	.0012
	C	4.4	.1	.9151	-638.5	.3293	22.5	.0742
	W	5.7	.1	.9017	-508.2	.2629	24.8	.0590
	N	-32.7	1.6	.6538	-1164.2	.5959	71.5	.0001
All	E	-3.9	.0	.9461	-1326.0	.6837	64.8	.0003
	S	-69.9	16.3	.1350	-966.8	.4967	48.9	.0037
	C	26.6	3.0	.5397	-674.6	.3513	23.3	.0685
	W	17.8	1.2	.7023	-414.5	.2190	16.6	.1318
	N	7.4	.1	.9153	-1023.4	.5280	62.9	.0004

Table 11. Same as Table 9, except for 11-yr winter sample.

Period	Region	RF Alone			Year Without RF			
		b	RV	PR	A	B	RV	PR
1	E	-.5	.0	.9933	-1289.2	.6755	26.4	.1057
	S	105.8	39.1	.0397	-226.4	.1345	1.9	.6893
	C	75.7	29.0	.0873	-1181.9	.6186	35.9	.0513
	W	-60.9	37.8	.0440	-1766.3	.9145	65.9	.0024
	N	26.9	3.4	.5878	-1082.5	.5691	46.9	.0200
2	E	-11.5	.4	.8583	-2061.1	1.0618	61.4	.0043
	S	.5	.0	.9941	-1682.4	.8664	50.3	.0145
	C	78.5	20.6	.1606	-1512.4	.7795	36.5	.0491
	W	-84.9	45.2	.0234	-2556.3	1.3086	81.2	.0002
	N	-19.3	.9	.7866	-2146.1	1.1023	83.1	.0001
3	E	-31.7	1.9	.6824	-2297.2	1.1768	58.5	.0061
	S	-7.8	.2	.8981	-1497.6	.7682	49.8	.0153
	C	43.6	7.8	.4063	-1686.6	.8636	53.6	.0105
	W	-84.4	32.9	.0651	-2884.3	1.4709	75.6	.0005
	N	-38.4	3.3	.5923	-2193.3	1.1218	84.4	.0001
All	E	-11.8	.4	.8569	-1882.5	.9714	52.0	.0122
	S	32.2	3.6	.5780	-1135.4	.5897	33.8	.0607
	C	65.7	18.7	.1846	-1460.3	.7539	44.3	.0253
	W	-77.1	40.7	.0346	-2402.3	1.2314	79.3	.0002
	N	-10.2	.3	.8701	-1807.3	.9311	78.6	.0003

Table 12. Same as Table 9, except for 15-yr winter sample.

Period	Region	RF Alone			Year Without RF			
		b	RV	PR	A	B	RV	PR
1	E	-19.1	1.6	.6538	-865.9	.4607	26.1	.0516
	S	53.1	8.4	.2960	-133.6	.0875	1.2	.6946
	C	33.8	5.2	.4132	-1010.3	.5316	41.9	.0091
	W	-75.2	35.8	.0185	-1804.5	.9339	82.3	.0001
	N	-22.0	2.5	.5748	-861.8	.4571	50.7	.0029
2	E	-55.1	8.6	.2892	-1675.8	.8664	59.7	.0007
	S	-40.6	3.8	.4886	-1128.5	.5854	39.9	.0116
	C	12.8	.4	.8160	-1628.2	.8384	56.6	.0012
	W	-98.2	41.6	.0094	-2200.0	1.1279	83.0	.0001
	N	-74.4	12.1	.2042	-1753.7	.9032	80.9	.0001
3	E	-94.8	15.8	.1426	-2254.4	1.1552	68.8	.0001
	S	-44.1	4.5	.4494	-1347.6	.6921	53.2	.0020
	C	-3.4	.0	.9462	-1665.9	.8532	64.4	.0003
	W	-109.2	38.0	.0144	-2577.6	1.3154	82.4	.0001
	N	-92.8	15.3	.1498	-2021.3	1.0346	84.7	.0001
All	E	-55.7	9.0	.2763	-1598.7	.8274	57.3	.0011
	S	-13.3	.5	.8001	-869.9	.4550	30.9	.0315
	C	13.6	.6	.7778	-1434.8	.7411	57.7	.0010
	W	-94.2	40.2	.0111	-2194.0	1.1257	86.1	.0001
	N	-64.5	11.2	.2228	-1545.6	.7983	78.6	.0001

Table 13. The national 10-yr trends of PC, B, and S computed from 11- or 12-yr samples and 15-yr samples.

Season	Period	PC 12-yr	PC 15-yr	B 11-yr	B 15-yr	S 11-yr	S 15-yr
Summer	1	.06	.10	-.00025	-.00056	.25	.39
	2	.05	.12	-.00042	-.00079	.42	.59
	3	.01	.05	-.00032	-.00076	.38	.60
Winter	1	.11	.10	-.00071	-.00058	.57	.46
	2	.18	.17	-.00140	-.00116	1.10	.90
	3	.21	.21	-.00143	-.00133	1.12	1.03

Table 14. Paired t-tests for 06Z minus 18Z cycle means of PC, B, S, and RF for national scores. The first column for each variable (Diff) gives the actual difference, and the second column (Sig), the probability level associated with it. Equal variances of the 06Z and 18Z scores were assumed in computing each t-statistic and probability level.

Season	Period	PC Diff	PC Sig	B Diff	B Sig	S Diff	S Sig	RF Diff	RF Sig
Summer	1	-.57	.0098	.0021	.0568	1.73	.0005	.012	.0001
	2	.74	.0042	-.0040	.0018	-.37	.2476	-.011	.0001
	3	-1.23	.0001	.0038	.0084	1.01	.0221	.013	.0001
Winter	1	.43	.0007	-.0028	.0005	1.09	.0083	-.003	.0132
	2	-.01	.9450	.0004	.6158	.95	.0206	.005	.0052
	3	.33	.0361	-.0033	.0012	1.03	.0344	-.004	.0142

Table 15. Tests on cycle differences of PC for two seasons, summer (S) and winter (W), and three periods for national data. For each sample, the total sum of squares of PC is shown. For each model component (RF = relative frequency, YEAR = year, CYC = cycle), the sum of squares, computed F, and significance level associated with it are shown. There are 1, 15, and 1 degrees of freedom of the total of 29 associated with RF, YEAR, and CYC, respectively. For the four models, PC is related to: CYC (Model 1); YEAR and CYC (Model 2); RF and CYC (Model 3); and RF, YEAR, and CYC (Model 4). The order of inclusion of variables in each model (except Model 1) is important and is in the order stated. For each test, the error SS and its associated degrees of freedom is used in computing F. The 06Z and 18Z means (PC06 and PC18, respectively) are computed directly by CYC for Models 1 and 2, and are computed with RF set to its overall mean value for Models 3 and 4. The better mean of each pair is underlined.

Season	Period	Total SS	Model	RF			YEAR			CYC			ERROR		PC06	PC18
				SS	F	PR	SS	F	PR	SS	F	PR	SS	df		
S	1	27.9	1							2.5	2.71	.11	25.5	28	84.77	85.34
			2				21.6	5.57	.0014	2.5	8.91	.01	3.9	14	84.77	85.34
			3	16.5	39.18	.0001				.1	.24	.63	11.4	27	85.12	84.99
			4	16.5	92.83	.0001	9.0	3.63	.0130	.1	.77	.40	2.3	13	85.20	84.91
	2	48.2	1							4.1	2.61	.12	44.1	28	83.71	82.97
			2				39.2	7.95	.0002	4.1	11.67	.004	4.9	14	83.71	82.97
			3	31.7	52.12	.0001				.1	.24	.63	16.4	27	83.27	83.42
			4	31.7	176.88	.0001	14.0	5.61	.002	.2	.98	.34	2.3	13	83.19	83.50
	3	59.0	1							11.3	6.62	.02	47.7	28	81.72	82.95
			2				43.3	9.69	.0001	11.3	35.39	.0001	4.5	14	81.72	82.95
			3	50.7	165.53	.0001				.009	.03	.86	8.3	27	82.31	82.35
			4	50.7	343.95	.0001	6.4	3.08	.025	.012	.08	.78	1.9	13	82.29	82.38
W	1	38.0	1							1.4	1.08	.31	36.6	28	87.81	87.37
			2				35.5	33.29	.0001	1.4	18.48	.0007	1.1	14	87.81	87.37
			3	29.2	95.06	.0001				.5	1.75	.20	8.3	27	87.72	87.46
			4	29.2	414.88	.0001	7.4	7.52	.0004	.5	7.16	.02	.9	13	87.75	87.43
	2	86.5	1							.0003	.00	.99	86.5	28	84.927	84.933
			2				85.6	90.57	.0001	.0003	.00	.94	.9	14	84.927	84.933
			3	67.3	99.10	.0001				.9	1.35	.26	18.3	27	85.11	84.75
			4	67.3	1156.61	.0001	18.4	22.61	.0001	.07	1.29	.28	.8	13	85.00	84.86
	3	121.3	1							.8	.19	.67	120.5	28	83.28	82.95
			2				118.4	56.79	.0001	.8	5.37	.04	2.1	14	83.28	82.95
			3	92.7	87.46	.0001				.0004	.00	.99	28.6	27	83.11	83.12
			4	92.7	607.13	.0001	26.3	12.33	.0001	.3	1.82	.20	2.0	13	83.24	83.00

Table 16. Same as Table 15, except for B.

Season	Period	Total SS	Model	RF SS	RF F	RF PR	YEAR SS	YEAR F	YEAR PR	CYC SS	CYC F	CYC PR	ERROR SS	ERROR df	B06	B18
S	1	.00101	1							.000034	.98	.33	.00098	28	.1062	.1041
			2				.00087	7.83	.0002	.000034	4.31	.06	.00011	14	.1062	.1041
			3	.00056	35.75	.0001				.000031	1.99	.17	.00042	27	.1040	.1063
			4	.00056	189.75	.0001	.00039	9.51	.0001	.000023	7.76	.02	.00004	13	.1033	.1070
	2	.00188	1							.000120	1.91	.18	.00176	28	.1153	.1193
			2				.00165	14.45	.0001	.000120	14.74	.002	.00011	14	.1153	.1193
			3	.00126	55.96	.0001				.000019	.87	.36	.00061	27	.1182	.1164
			4	.00126	676.72	.0001	.00059	22.81	.0001	.000009	4.62	.05	.00002	13	.1184	.1162
	3	.00220	1							.000108	1.45	.24	.00209	28	.1275	.1237
			2				.00193	11.96	.0001	.000108	9.41	.01	.00016	14	.1275	.1237
			3	.00158	78.89	.0001				.000078	3.91	.06	.00054	27	.1238	.1275
			4	.00158	483.10	.0001	.00055	12.05	.0001	.000025	7.53	.02	.00004	13	.1236	.1276
W	1	.00174	1							.000059	.98	.33	.00169	28	.0874	.0902
			2				.00164	39.92	.0001	.000059	19.98	.0005	.00004	14	.0874	.0902
			3	.00142	128.17	.0001				.000020	1.82	.19	.00030	27	.0880	.0896
			4	.00142	577.40	.0001	.00027	7.81	.0003	.000018	7.44	.02	.00003	13	.0878	.0898
	2	.00368	1							.000001	.01	.92	.00368	28	.1063	.1059
			2				.00362	56.72	.0001	.000001	.26	.62	.00006	14	.1063	.1059
			3	.00286	97.63	.0001				.000028	.94	.34	.00079	27	.1052	.1071
			4	.00286	10040.41	.0001	.00077	20.15	.0001	.000007	2.61	.13	.00004	13	.1055	.1068
	3	.00507	1							.000083	.47	.50	.00498	28	.1171	.1204
			2				.00491	68.52	.0001	.000083	16.28	.0012	.00007	14	.1171	.1204
			3	.00397	99.10	.0001				.000010	.25	.62	.00108	27	.1182	.1193
			4	.00397	937.84	.0001	.00101	17.09	.0001	.000024	5.60	.03	.00006	13	.1176	.1198

Table 17. Same as Table 15, except for S.

Season	Period	Total SS	Model	RF SS	RF F	RF PR	YEAR SS	YEAR F	YEAR PR	CYC SS	CYC F	CYC PR	ERROR SS	ERROR df	B06	B18
S	1	248.7	1				210.6	13.35	.0001	22.4	2.77	.11	226.3	28	27.16	25.43
			2							22.4	19.84	.0005	15.8	14	27.16	25.43
			3	28.3	3.57	.07	196.8	12.07	.0001	6.7	.84	.37	213.7	27	26.83	25.77
			4	28.3	24.26	.0003				8.5	7.32	.02	15.1	13	27.43	25.16
	2	315.6	1				304.5	30.28	.0001	1.0	.09	.76	314.5	28	17.85	18.23
			2							1.0	1.46	.25	10.1	14	17.85	18.23
			3	.0	.00	.98	304.6	31.30	.0001	1.4	.12	.74	314.2	27	17.81	18.27
			4	.0	.01	.93				1.9	2.74	.12	9.0	13	17.52	18.56
	3	301.7	1				278.0	17.30	.0001	7.6	.72	.40	294.1	28	12.61	11.60
			2							7.6	6.62	.02	16.1	14	12.61	11.60
			3	.5	.05	.83	281.9	16.94	.0001	12.1	1.13	.30	289.1	27	12.82	11.39
			4	.5	.44	.52				3.8	3.23	.10	15.5	13	12.89	11.32
W	1	252.9	1				230.9	17.56	.0001	8.9	1.02	.32	244.1	28	41.19	40.11
			2							8.9	9.43	.01	13.1	14	41.19	40.11
			3	6.3	.72	.40	225.7	17.10	.0001	7.7	.87	.36	238.9	27	41.16	40.14
			4	6.3	6.72	.02				8.7	9.19	.01	12.3	13	41.32	39.98
	2	585.7	1				564.9	40.33	.0001	6.8	.33	.57	578.9	28	29.71	28.76
			2							6.8	6.81	.02	14.0	14	29.71	28.76
			3	59.2	3.11	.09	511.6	36.18	.0001	12.6	.66	.42	514.0	27	29.89	28.58
			4	59.2	58.65	.0001				1.8	1.77	.21	13.1	13	29.56	28.91
	3	736.2	1				707.7	34.68	.0001	8.0	.31	.58	728.1	28	21.56	20.53
			2							8.0	5.49	.03	20.4	14	21.56	20.53
			3	105.8	4.56	.04	602.0	33.75	.0001	3.5	.15	.70	626.9	27	21.38	20.70
			4	105.8	83.02	.0001				11.8	9.29	.01	16.6	13	21.83	20.26

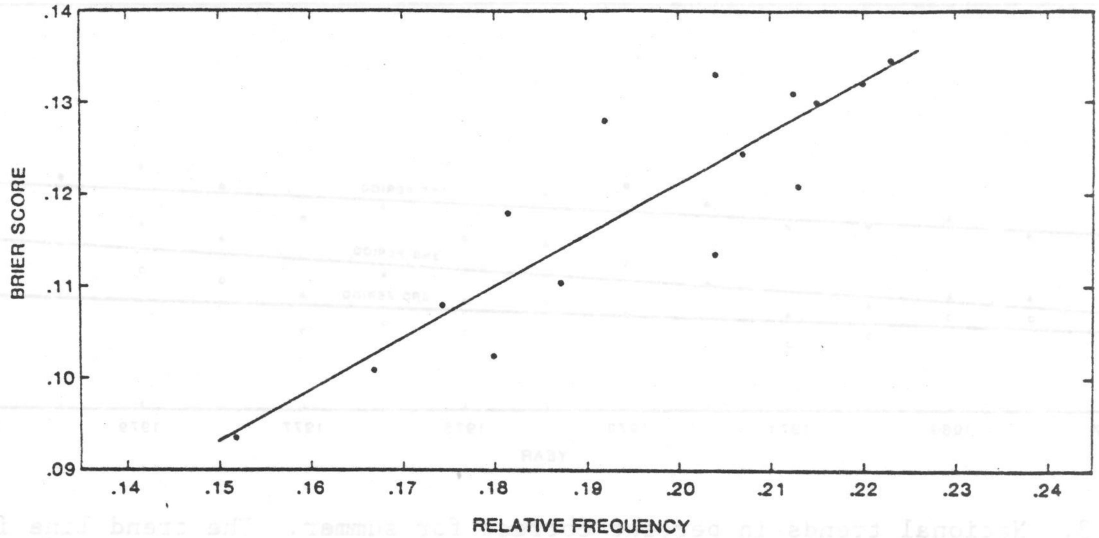

Figure 1. National Brier scores for the third period winter as a function of relative frequency.

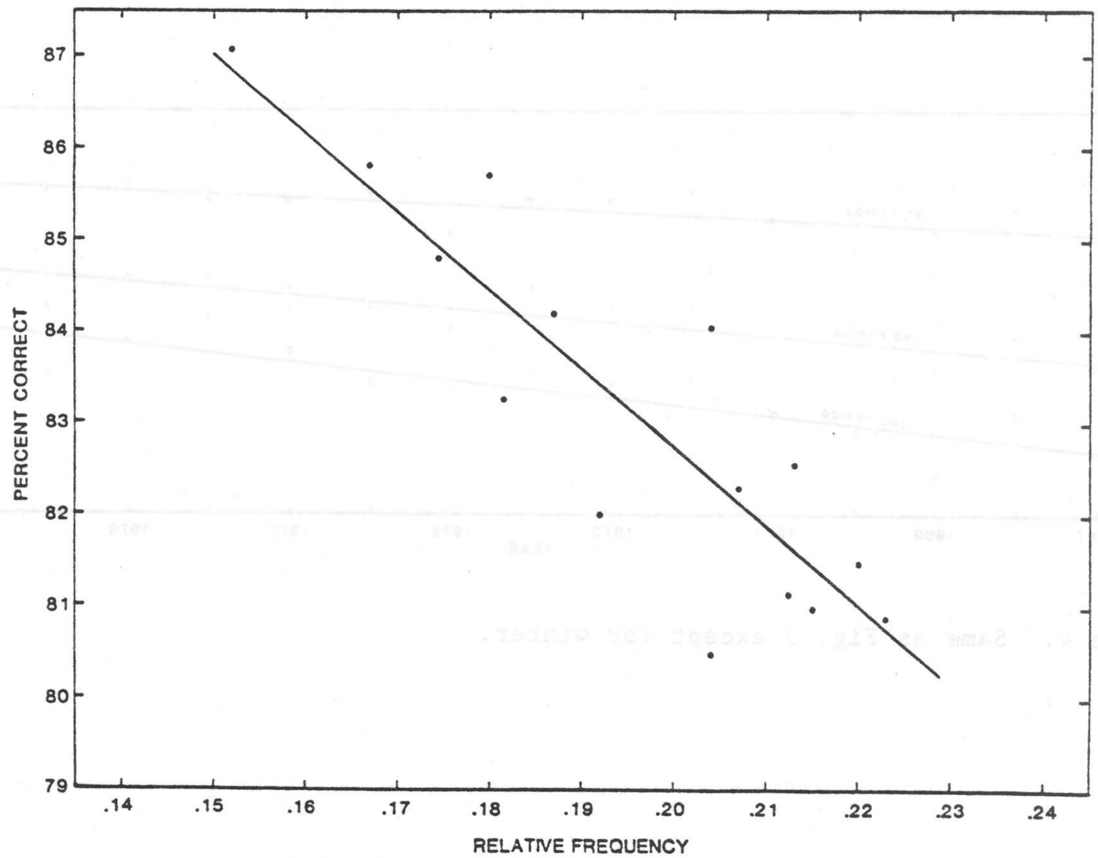

Figure 2. National percents correct for the third period winter as a function of relative frequency.

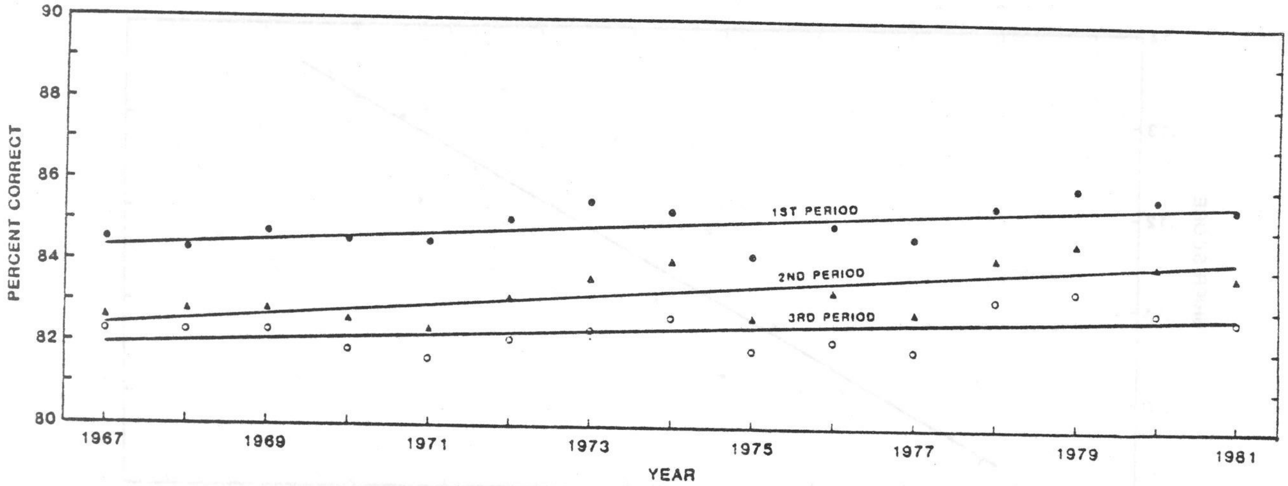

Figure 3. National trends in percent correct for summer. The trend line is plotted at the average relative frequency. The data points are deviations from a linear fit of percent correct to relative frequency.

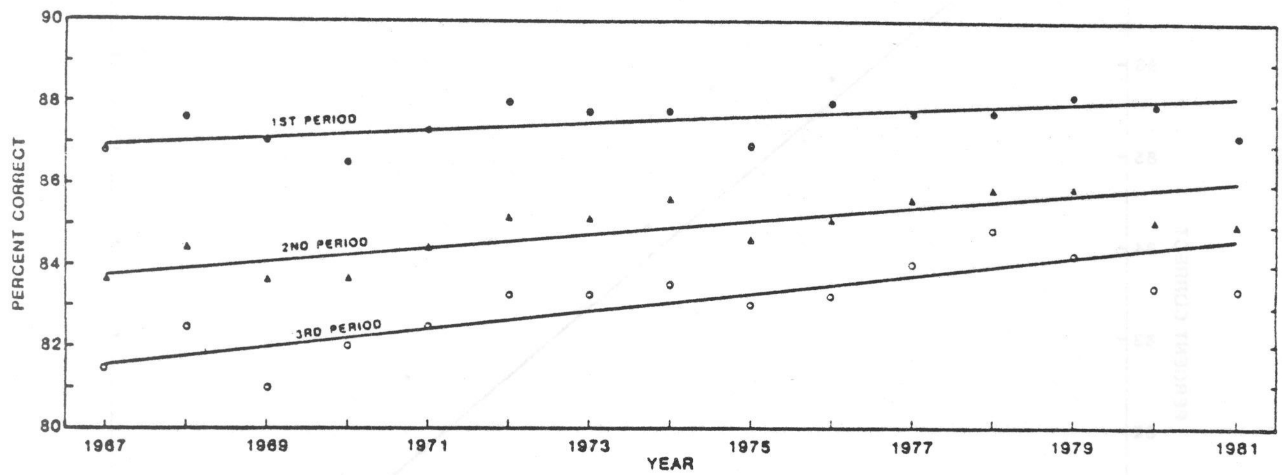

Figure 4. Same as Fig. 3 except for winter.

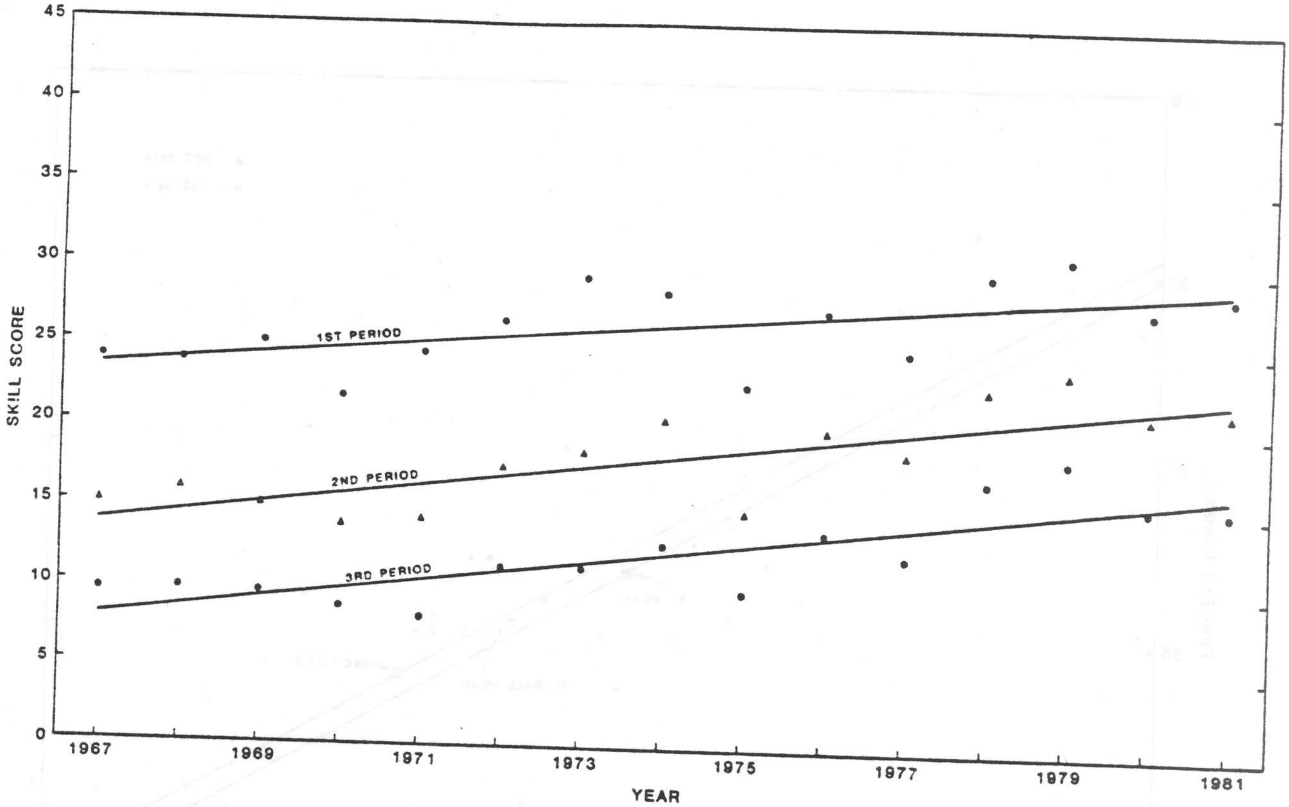

Figure 5. National trends in skill for summer.

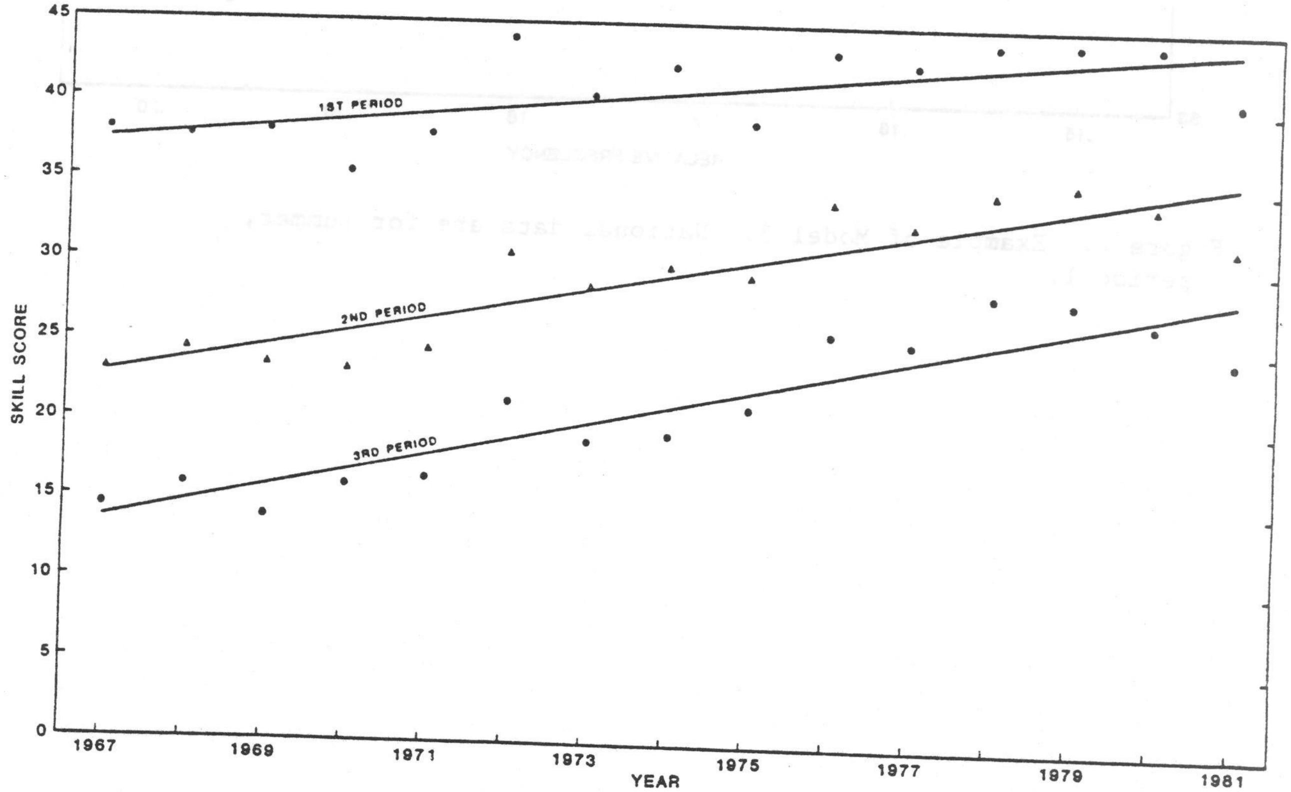

Figure 6. Same as Fig. 5 except for winter.

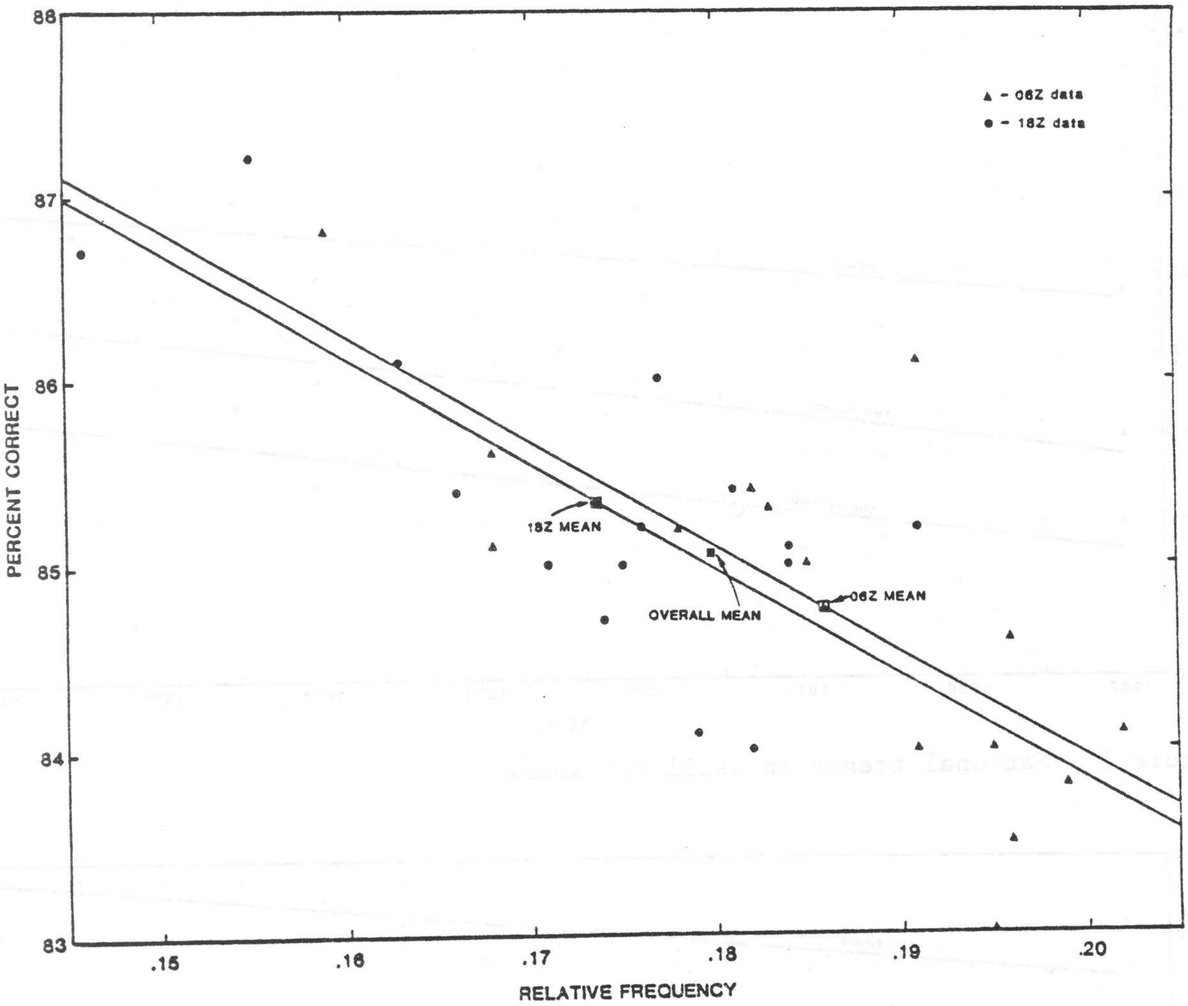

Figure 7. Example of Model 3. National data are for summer, period 1.

(Continued from inside front cover)

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NWS TDL 39 Computer Prediction of Precipitation Probability for 108 Cities in the United States. William H. Klein, February 1971, 32 pp. (COM-71-00249)

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