Specification of United States Seasonal Precipitation[1]

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ABSTRACT

Seasonal precipitation is specified for the United States by matching various area-averaged precipitation statistics as predictands with three different predictors in turn: 700 mb heights, North Pacific SST and North Atlantic SST. Predictors are in the form of empirical orthogonal function (EOF) amplitude time series. The predictands used in trials include total precipitation and precipitation frequencies derived using three different critical values: 2.5, 12.7 and 25.4 mm. Screening multiple linear regression is used to relate predictands to predictors for samples ranging from 24 to 35 years in length; initially trials are compared in terms of area-averaged true skill and percent area of local significance. In order to assess specification skill on an independent sample, additional tests are made using a jackknife regression approach.

Results suggest that skillful seasonal precipitation *prediction* will continue to be very difficult using predictors and methods presently in common use based on the use of specification equations on an independent sample. Generally, area-averaged explained variances are less than 10% and the area of significant local skill is less than 50%. Based on the low level of specification skill, predictive skill for precipitation using specification equations with imprecisely known specifier fields (like 700 mb heights) as input would be effectively zero.

Other conclusions are:

1) 700 mb heights specify seasonal precipitation about equally well in winter, spring and summer, but worse in fall.

2) Among the three predictor types employed, 700 mb heights are best for all seasons but fall, when Pacific SST does best. Specification using Atlantic SST is poor in all instances and inferior to the use of the other predictor fields.

3) Overall among the four precipitation statistics used as predictands, the frequency statistics have a slightly better relationship with 700 mb heights or Pacific SST than do precipitation totals.

1. Introduction

The purposes of this paper are two-fold. The first is to correct some of the findings of Lanzante and Harnack (1982) on specification of United States summer season precipitation, and the second is to extend this earlier work to the other seasons. The original intent of this study pertained only to the second purpose, but in preparing the seasonal precipitation data for use, as obtained on magnetic tapes from the National Climatic Data Center (NCDC), discrepancies were found between values on the tapes and those on the tapes employed earlier. After discussions with NCDC personnel, it was discovered that critical values for precipitation frequency counts were changed in the early 1950s. This was not documented for any of the tapes. Prior to 1954 the lowest critical value in the monthly summaries was 0.2 mm (0.01 inches); from 1954 to the present the critical value has been 2.5 mm (0.1 inches). The second critical value was changed from 6.4 mm (0.25 inches) to 12.7 mm (0.5 inches) in 1951, while the highest critical value has remained unchanged at 25.4 mm (1.0 inches). New calculations performed using the original data tape revealed that a substantial part of the good relationship reported earlier between summer precipitation frequency, especially using a critical value of 2.5 mm, and 700 mb heights came from the first seven years of the sample when the critical value used by NCDC was actually 0.2 mm. Therefore, the greater part of the earlier work has been repeated and the work extended in like manner to all seasons.

Previous specification studies were summarized in our earlier paper, and from this the important justifications for this study are revealed: 1) The seasonal time scale has been neglected with regard to specification relationships; 2) precipitation has received much less attention than temperature for the time scales of a month or longer; and 3) in some operational long range forecasting, temperature and precipitation are specified statistically from a forecast of the mean circulation (e.g., 700 mb height field).

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The large degree of discontinuity of precipitation in both space and time makes finding even a good concurrent relationship between precipitation and circulation difficult. This realization led to the idea of using precipitation frequency, as well as precipitation amount, to define predictands. The reader will find much of the specification work for the earlier period summarized in Klein (1965); recent work includes that of Walsh and Mostek (1980), who correlated monthly precipitation and empirical orthogonal functions (EOFs) of sea level pressure, and Klein (1983), who presented a specification of winter-month station temperatures using 700 mb heights.

In Lanzante and Harnack (1982), it was found that the strongest relationship between total summer precipitation and various predictors occurred using 700 mb heights ($R^2 \sim 0.24$), followed by Pacific sea surface temperature (SST) ($R^2 \sim 0.21$) and sea-level pressure ($R^2 \sim 0.12$). The use of large area averages ($\sim 10^5$ km^2) for the predictand produced slightly greater R^2 values for individual climatic divisions. In addition, the use of various transformations applied to precipitation amount (in order to account for precipitation skewness) did not appreciably improve the relationships, but use of precipitation frequency (especially using a critical value of 2.5 mm) gave an almost doubling of explained variance when 700 mb heights were the specifier field. The last conclusion was called into question when the aforementioned data problem was discovered. This problem and the seasonal dependency question are addressed in the following.

2. Procedure

a. Predictands

The predictands consisted of seasonal-mean area-averaged total precipitation, using 20 subareas of the United States, and area-averaged precipitation frequency using critical values of 2.5, 12.7 and 25.4 mm (hereafter referred to as P1, P2 and P3, respectively). The data for total precipitation as well as for frequencies were obtained on magnetic tapes for NCDC in the form of monthly station values. All stations within a state climatic division (CD) were averaged to form a CD value. The monthly CD values were summed to form a seasonal total for each CD. The seasonal precipitation value for each subarea was computed from the weighted mean (by area) of all CDs located within the given subarea. Subarea boundaries were formed by subdividing the ten "climatologically homogeneous" areas used by Namias (1978) (Fig. 1).

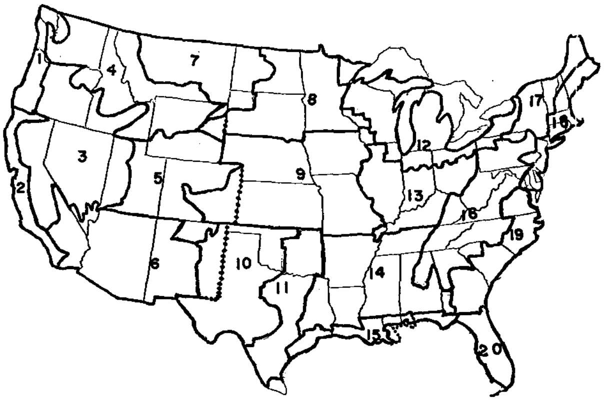

FIG. 1. Subareas used to define area-averaged precipitation statistics.

Based on availability, the precipitation data periods were 1947–81 (total precipitation), 1954–81 (P1), 1951–81 (P2) and 1947–81 (P3). Together with the data period of the predictor (specifier) fields, these determined the period used for building regression models describing the specification relationships.

b. Predictors

Data for three predictor fields were obtained on magnetic tape in the form of monthly mean gridded values and were time-averaged to form seasonal means. The predictor types and data sources were: 700 mb heights (Climate Analysis Center), and North Pacific and North Atlantic SSTs (Scripps Institute of Oceanography).

The spatial domain used for the 700 mb heights was 20–80°N and 120°E eastward to 40°E, with 10° latitude by 20° longitude resolution (105 grid points). For North Pacfic SST, 50 grid points between 25 and 55°N and 160°E and 125°W (on a staggered 5 × 5° grid) were used. For North Atlantic SST, 50 grid points in the latitude zone 25–65°N, with a staggered 5 × 10° latitude–longitude resolution, were used. The periods for the predictor data were 1947–77 for Pacific SST, 1949–78 for Atlantic SST, and 1947–81 for 700 mb heights.

To reduce the number of variables and to extract the major portion of the climatic signal, EOF analysis was performed onthe correlation matrix for each data set and season. EOF analysis was chosen to produce predictors in place of point variables because it was believed that the resulting specification equations would perform better in a situation where the predictor field itself must be first predicted. One drawback in using EOF analysis to define predictor variables is that smaller spatial scales may be lost; however, its use helps to limit artificial predictability (by reducing the size of the predictor pool), while still allowing for an objective comparison of various specification relationships. Predictors were then in the form of EOF time series: six for 700 mb heights, and five each for Pacific and Atlantic SST. Monte Carlo testing, as described by Overland and Preisendorfer (1982), was used as an aid to determine this number, along with the constraint that the sizes of the predictor pools were kept constant for each season. While the number of EOFs truncated by this method will undoubtedly eliminate some important information, its objectivity and its superiority as a cutoff method in unpublished experiments justify its use.[2] The height EOFs cumulatively explained between 56 and 69% of the height field variance, while Pacific and Atlantic EOFs explained between 77 and 83%, and 75 and 82% of the variance, respectively.

c. *Specification methodology*

Screening multiple linear regression was used to specify each of the four types of precipitation statistics (totals plus P1, P2 and P3 frequencies) for each subarea and season from each of the three predictor fields. The STEPWISE procedure of the statistical analysis system (SAS) with the maximum explained variance improvement (MAXR) technique was used to perform the regression analyses (Helwig and Council, 1979). Based on the rapidly diminishing amount of explained variance after three predictors were screened from the predictor pool of five or six, all results and significance tests pertain to three predictor models. This condition was relaxed for additional experimentation which is described in Section 3c. The period used for the regression analyses was determined by the common period of data availability between predictand and predictor. Sample sizes ranged from 24 years (P1 using Pacific SST) to 35 years (total precipitation using 700 mb heights).

d. *Assessment of model skill and significance*

As in the earlier study, model regression skill was initially assessed through the computation of true skill S using

$$S = S_H - S_A, \tag{1}$$

where S_H is the raw explained variance for the model and S_A is the artificial skill resulting from imperfect estimates of the statistics. The Davis (1976) formula for S_A was used:

$$S_A = \sum_{p=1}^{M} \tau_p / N\Delta t, \tag{2}$$

where M is the number of predictors in the pool (i.e., 5 or 6), N the sample size, Δt the time between observations (one year), and τ_p is the integral time scale for predictor p with respect to the predictand. The integral time scale was estimated using a formula presented by Sciremammano (1979):

$$\tau = \sum_{i=-100}^{+\infty} C_{xx}(i\Delta t) C_{yy}(i\Delta t)\Delta t, \tag{3}$$

where C_{xx} and C_{yy} are the autocorrelation functions of the two time series used (i.e., predictor and predictand). The summation was carried out for values $i = \pm L$, where L is large compared to the lag at which the autocorrelation functions become statistically indistinguishable from zero. The estimates of C_{xx} and C_{yy} were damped $\{$multiplied by $[1 - (i/N)]\}$ to account for error growth as $!i!$ increases.

Local significance was assessed using a two-step process:

1) Effective sample size N^* was computed based on a formulation of Davis (1976):

$$\tau = N\Delta t / N^*, \tag{4}$$

where N, Δt and τ are as before.

2) Next, randomly generated predictands and predictors were used in screening regression trials as in the actual analyses except that the effective sample size was used. The distribution of explained variance values from 1000 trials were used to find the 5% critical values of explained variance to assess local significance for each regression model.

Map (field) significance was determined by applying a Monte Carlo approach as suggested by Livezey and Chen (1983) to give the critical percent area needed to claim field significance. This procedure accounts for both the finiteness of the sample as well as the spatial dependence of the variables. Each predictand field was correlated to a normally distributed series of random numbers, and the percent area having a correlation coefficient significant at the 5% level was noted. This was repeated 2500 times in order to construct a frequency distribution of area from which the critical percent area was found by noting the area value which is greater than 95% of all area values. A map must have more than this percentage of its area deemed significant in order for field significance to be claimed. This simulation was done separately for each of the four seasons and four precipitation variable types as well as separately for the whole United States, and its eastern (subareas 8–12) and western (1–7) portions. The critical values for the whole United States range from 17.6 to 29.5%, depending on season and precipitation statistic.

3. Specification results

The results are summarized in Tables 1–3, which give area-averaged raw explained variances R^2, true skill S, and percent map area having significant local skill, %A, for all season–predictor–predictand combinations over the whole United States.

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[2] This method of determining the cutoff for EOFs is justified by unpublished work communicated to the authors by Michael Richman of the Illinois State Water Survey, in which several methods were compared for their ability to select the number of components from a data field having a predetermined number. The Monte Carlo approach was the superior method.

TABLE 1. Area-averaged explained variance $\bar{R}^2$, area-averaged true skill $\bar{S}$, and percentage area of local significance, %A, for all season–predictand combinations using 700 mb height EOFs as the predictors in seasonal precipitation specification.

Season	Predictand (precipitation)	$\bar{R}^2$	$\bar{S}$	%A*
Winter	Total	28.7	11.6	**39.4**
	P1	28.5	11.3	**37.2**
	P2	28.1	11.8	**32.8**
	P3	25.3	8.2	9.2
Spring	Total	25.6	8.8	16.3
	P1	26.9	10.5	**30.6**
	P2	26.1	9.4	18.5
	P3	23.3	6.9	14.5
Summer	Total	25.2	8.5	**36.7**
	P1	30.5	13.8	**30.6**
	P2	27.8	10.8	20.0
	P3	22.4	5.4	13.9
Fall	Total	23.6	7.0	18.6
	P1	26.8	10.7	25.1
	P2	23.2	7.0	9.2
	P3	21.9	5.6	13.6

* Boldface numbers are statistically significant at the 95% confidence level.

a. Comparison by predictor type

The predictors used in separate specification trials included 700 mb heights, North Pacific SST and North Atlantic SST. The latter did very poorly, regardless of season or type of precipitation statistic used. True skill was less than 7% in all cases and there was no instance of map significance. Depending on season and precipitation statistic, 700 mb heights or Pacific SST did best, with map significance occurring in many instances. With Pacific SST, field significance was seen in all seasons for at least one of the predictands, while with 700 mb heights field significance was seen in all seasons except fall.

TABLE 2. As for Table 1 except using Pacific SST EOFs as the predictors.

Season	Predictand (precipitation)	$\bar{R}^2$	$\bar{S}$	%A*
Winter	Total	28.0	12.0	16.6
	P1	22.9	6.6	21.1
	P2	27.6	11.4	**26.0**
	P3	29.1	12.6	**23.0**
Spring	Total	22.2	5.6	15.9
	P1	28.4	12.3	**38.2**
	P2	24.7	8.5	10.9
	P3	20.5	4.6	17.1
Summer	Total	22.4	6.7	**18.6**
	P1	24.2	8.1	**28.0**
	P2	23.8	7.8	16.6
	P3	23.1	6.8	18.3
Fall	Total	29.4	12.9	**43.1**
	P1	31.5	14.9	**41.3**
	P2	33.0	16.9	**42.2**
	P3	24.3	8.0	16.7

* Boldface numbers are statistically significant at the 95% confidence level.

TABLE 3. As for Table 1 except using Atlantic SST EOFs as the predictors.

Season	Predictand (precipitation)	$\bar{R}^2$	$\bar{S}$	%A
Winter	Total	24.4	6.7	1.2
	P1	24.4	6.8	8.9
	P2	22.3	3.1	0
	P3	22.0	3.8	1.2
Spring	Total	15.8	−1.7	0
	P1	18.8	1.6	9.9
	P2	20.6	3.2	0
	P3	19.6	2.0	0
Summer	Total	16.5	0.3	0
	P1	17.4	0.7	0
	P2	16.2	−0.2	1.8
	P3	14.9	−1.8	1.2
Fall	Total	21.9	4.6	7.3
	P1	20.4	3.0	0
	P2	23.5	6.6	10.0
	P3	20.5	3.7	8.8

When seasonal precipitation totals were the predictand, 700 mb heights were clearly best for spring and summer, although field significance was lacking for spring, but Pacific SST was clearly best for fall. For winter the results were somewhat similar in terms of true skill (12.0 versus 11.6), but percent area of significance was much larger for 700 mb heights (39.4 versus 16.6). Seasonal comparisons using precipitation totals as the predictand and 700 mb heights as the predictor revealed that winter specification was best followed by summer, spring and fall specification. The last two did not have field significance.

When precipitation frequency was the predictand, 700 mb heights clearly did best overall for winter and summer, but Pacific SST did much better for fall. Differences were slight in spring. Field significance was claimed in many cases, especially for frequency type P1. The overall best specification was for the fall season using Pacific SST as the predictor.

b. Comparison by predictand type

Among the four precipitation statistics, the P1 frequency type had the best relationship with 700 mb heights or Pacific SST. With 700 mb heights as the predictor, P1 was the best predictand for spring, summer and fall (though there was no field significance for fall); total precipitation, P1 and P2 had similar (and significant) specification skill for winter. With Pacific SST as the predictor, P1 was the best specified predictand for spring and summer, while none were clearly best for fall and winter. It must be added that despite the comparative results, the largest portion of the United States has poor (and not significant) seasonal precipitation and specification using this method, regardless of precipitation statistic or predictor field used.

While it still may be concluded that the use of summer precipitation frequency P1 in place of precipitation totals results in an increase of explained variance, when the predictor field is 700 mb heights, the difference is not as great as reported by Lanzante and Harnack (1982) who used the eastern United States only. The increase in area-averaged true skill for the whole United States when using P1 in place of total precipitation for summer specification is 62%. It should be noted that the best summer precipitation specification in terms of area-averaged true skill using 700 mb heights as the predictor was for P1 ($S = 13.8$). This shows that the greater portion of seasonal precipitation variation is unexplained by contemporaneous circulation or SST (at least 69.5% for summer using R^2 statistics).

These results are somewhat dependent on the methodology used here, such as the use of EOF analysis to define predictors, limiting the predictor pool to five or six, and designating the regression model size to be constant at three. It should also be noted that, according to Davis (1976), estimated skill on an independent sample is $R^2 - 2S_A$. Given the R^2 and S_A values obtained here, the estimate of specification skill on *independent* data is effectively zero in most cases. In order to check this apparent conclusion and also to determine if regression model size was critical, part of the study was redone using a jackknife regression approach.

c. Further specification trials using a "jackknife" regression approach

The jackknife regression procedure allows for essentially independent testing on the entire data sample available (Mosteller and Tukey, 1977). Skill is measured via the use of a set of regression equations derived for each subarea. The number of equations in the set, N, is the same as the sample size for the particular trial. Each of the equations is derived from $N - 1$ cases and tested on the single remaining case. Given N possible combinations of $N - 1$ leave out one, N forecasts, from which estimates of skill were determined, were made for each subarea. The verification statistics used for this portion of the study were area-averaged explained variance, R^2, area-averaged mean percent correct, and percent map area having significant local skill (%A). Local skill was computed as percent correct. All of the foregoing statistics were determined from the use of regression equations on the relevant independent case in turn. Percent correct statistics were determined by verifying equations against the observed precipitation in categorical format. All precipitation time series were ranked and divided into terciles for this purpose.

Regression equations were formulated separately for Pacific SST and 700 mb height EOF amplitude predictor sets having the same pool size as before, namely five and six, respectively. In this series of trials the regression equations applied to the independent cases were not constrained to have exactly three predictors. Instead, the highest-order model which was deemed significant at the 90% confidence level, using a Monte Carlo approach as outlined by Lanzante (1984), was retained and used.

Field significance was determined as before after finding the percent area having significant local skill and comparing it to a critical value obtained from Monte Carlo simulation. Local skill in this part of the study was the percent correct for subarea category forecasts. Local skill significance was found by comparing local skill to a critical value which was found using the binomial distribution in a cumulative way such that the probability of achieving a greater skill than the critical value was 5%. The number of temporal degrees of freedom was set at the sample size, a reasonable assumption for seasonally stratified samples.

Tables 4 and 5 give the verification statistics obtained by application of equations to independent cases for all jackknife regression (specification) trials. Examination of these tables suggests the following:

1) Mean explained variance R^2 is rather small regardless of the predictand–predictor–season combination. In general, values are less than 10%. This implies that precipitation specification equations like those described here are not useful in an operational environment as an aid in seasonal precipitation prediction.

2) Generally, area-averaged percent correct is better than chance expectation (i.e., 33%), and is statistically significant. However, most trials had less than 45% correct.

3) The percent area of the United States having significant local skill (%A) is less than 40% in most cases. Map significance was achieved in less than half the trials, but all of these were for trials involving precipitation frequency as the predictand.

4) The best specified predictand, among the four employed, is a function of season and verification statistic, but in terms of percent correct and %A statistics, one of the precipitation frequency type predictands is best for each season and predictor. The difference among predictands is not great, however, and so no obviously best individual predictand is suggested by this work. This is true even in summer where the earlier work of Lanzante and Harnack (1982) using dependent sample statistics suggested that it would be much better to use precipitation frequency P1 instead of the traditional precipitation totals.

TABLE 4. Area-averaged explained variance $\bar{R}^2$, area-averaged percent correct, %COR, and percent area having significant local skill, %A, for each predictand–season combination using 700 mb height EOFs as predictors (specifiers). Predictands are total precipitation, and P1, P2 and P3 precipitation frequencies. See text for details. Results are for independent cases (using jackknife procedure) and all subareas combined. Boldface numbers in the %COR and %A columns are statistically significant at the 95% confidence level assuming ten spatial degrees of freedom, and temporal degrees of freedom equal to the sample size.

Season	Predictand	$\bar{R}^2$	%COR	%A
Winter	Total	04	**41**	20.2
	P1	08	**43**	**41.6**
	P2	05	**43**	**26.3**
	P3	13	**42**	18.6
Spring	Total	03	**38**	6.7
	P1	03	**37**	4.7
	P2	04	**43**	**46.0**
	P3	04	34	0
Summer	Total	10	**40**	21.0
	P1	05	**38**	16.5
	P2	04	**42**	**34.2**
	P3	05	**39**	17.9
Fall	Total	03	36	8.5
	P1	−08	36	10.0
	P2	−04	**43**	**28.2**
	P3	0	37	14.4

5) There is no obvious particular season superiority, but specification is especially poor in fall using 700 mb heights.

6) 700 mb heights are a better specifier, in general, than Pacific SST. The clear exception is for the fall season.

7) The results of Lanzante and Harnack (1982), in which summer precipitation frequency was specified much better than precipitation totals in the eastern United States, were not confirmed in this portion of the study.

8) Results that were stratified as east versus west (not shown), showed only small differences.

9) Based on the jackknife regression results, skill on an independent sample is better than $R^2 - 2S_A$ given by Davis (1976). These results suggest that the multiplier factor is closer to 1 than to 2. We suggest two reasons for this: 1) the estimated S_A are too large, and 2) there is some year-to-year autocorrelation in the home series used.

4. Conclusions

We have reported results from a study of seasonal precipitation specification for the United States in which various area-averaged precipitation statistics were matched as predictands with three different predictors in turn: 700 mb heights, North Pacific SST, and North Atlantic SST. Predictors were in the form of EOF amplitude time series. The predictands used in trials included total precipitation and precipitation frequencies derived using three different critical values: 2.5, 12.7 and 25.4 mm. Screening multiple linear regression was used to relate predictands to predictors for samples ranging from 24 to 35 years in length; initially, trials were compared in terms of area-averaged true skill and percent area of local significance. Assessments of model skill and significance carefully considered the effects of sampling variability, dependence in the data fields, and screening of predictors from a larger predictor pool. In order to assess specification skill on an independent sample, new trials were made using a jackknife regression approach.

It is estimated that the overall explained variance for seasonal precipitation is less than half that for temperature. This assessment is based on the fact that in this study raw explained variances using three predictors were mostly between 20 and 30%, compared to an overall 67% explained variance for winter-month temperature using three 700 mb heights as predictors (Klein, 1983). Of course, the results are not directly comparable due to a number of differences in the experiments, but this suggests that skillful seasonal precipitation *prediction* using predictors and methods presently in common use will continue to be very difficult. This was confirmed by the use of specification equations on an independent sample, as done using the jackknife approach which generally gave area-averaged explained variances of less than 10% and an area of significant local skill of less than 40%, regardless of the predictand–predictor–season combination used. Based on this low level of specification skill, predictive skill for precipitation using specification equations with imprecisely-known specifier fields (like 700 mb heights) as input would be effectively zero. It is certainly possible that specification skill could be raised by using a different meth-

TABLE 5. As for Table 4 except predictors are North Pacific SST EOFs.

Season	Predictand	$\bar{R}^2$	%COR	%A
Winter	Total	−07	33	0
	P1	03	37	**26.0**
	P2	08	**44**	**35.8**
	P3	09	36	12.9
Spring	Total	02	35	13.1
	P1	0	33	8.0
	P2	01	**43**	**37.4**
	P3	04	37	15.9
Summer	Total	0	32	2.3
	P1	0	**39**	22.8
	P2	07	**44**	**44.6**
	P3	03	**39**	10.6
Fall	Total	05	**38**	7.1
	P1	11	**45**	**47.0**
	P2	02	**42**	19.1
	P3	07	**42**	**37.7**

odology than that employed here. Perhaps the screening of predictors from point values of 700 mb height instead of the use of EOFs could improve matters; however, the predictor pool and therefore artificial predictability would grow significantly.

On a comparative basis, the results reported here, including both dependent and independent assessments, support the following conclusions:

1) 700 mb heights specified seasonal precipitation about equally well in winter, spring and summer, but worse in fall.

2) Among the three predictor types employed, 700 mb heights were best for all seasons except fall, when Pacific SST did best. Specification using Atlantic SST was poor in all instances and inferior to the use of the other predictor fields.

3) Overall among the four precipitation statistics used as predictands, the frequency statistics had a slightly better relationship with 700 mb heights or Pacific SST than did precipitation totals.

4) In redoing the earlier work of Lanzante and Harnack (1982) on summer season precipitation specification for the eastern portion of the United States, it was found that the use of precipitation frequency in place of precipitation totals did not improve specification. In an overall sense it appears that using precipitation frequencies in place of the traditional precipitation totals results in a small improvement in precipitation specification. In light of this, more consideration should be given to using precipitation frequency as the predictand for experimental seasonal forecasts. Perhaps the use of 2.5 mm as the critical value would improve circulation–precipitation relationships even more. This is suggested by specification results obtained by using seven years of precipitation frequency for a critical value greater than 2.5 mm. A larger sample for use with the kind of predictors employed here has not been archived, so considerably more effort and expense would be needed to test this idea. One thing seems certain: the large spatial and temporal discontinuities of seasonal precipitation will continue to make it difficult to find even a good concurrent relationship between precipitation and circulation.

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