AN ATTEMPT TO PROJECT WINTER TEMPERATURE DEPARTURES FOR THE EASTERN UNITED STATES

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Abstract

The temperatures of the winter season (December through March) in the eastern two-thirds of the United States were related to sea surface temperature anomalies and tropical precipitation data through a forward step-wise regression technique to arrive at a predictive set of equations. Physical reasoning led to a selection of predictors which were tested against five years of independent data. A forecast for the 1978-1979 winter season was included.

The independent tests gave sound evidence that sea surface temperature anomalies and tropical precipitation were useful as predictors for eastern U.S., winter season temperature departures from average values. Problems exist with gradient area resolution, positioning of maxima, and with different display methods. But in spite of some difficulties, meaningful and rather useful predictive results were obtained.

Editor's Note: A verification of the Author's winter's forecast will appear in the May issue of the Digest.

1. INTRODUCTION

The influence of the oceans should be considered when studying and forecasting long term weather anomalies. Pioneering work on the ocean-atmosphere interdependency was done for the North Atlantic by Helland-Hansen and Nansen (1920) and for the Pacific by Namias (1959). These studies established a mutual adjustment between the two but not a cause-and-effect relationship. Later work by Bjerknes (1963) and Namias (1964) found distinct surface patterns, quite often associated with sea surface temperature gradients in the North Atlantic. In the Pacific sector, extensive diagnostic studies by Namias in the 1960's demonstrated strong associations between sea surface temperature anomalies and circulation anomalies. Namias (1972) also showed a major reversal in the prevailing winter oceanic and atmospheric anomalies in the late 1950's lasting through the 1960's.

With the advent of numerical modelling of the atmosphere a new approach was attempted. "Blocking" of atmospheric flow in the North Atlantic was shown in an excellent paper by Ratcliffe and Murray (1970) to be statistically associated with abnormally cold waters off Newfoundland. Houghton (1974) attempted to simulate numerically these effects by the NCAR six-layer model and was partially successful. Spar (1972) numerically tested the possible effects of Pacific sea surface temperature anomalies on atmospheric circulations obtaining partial and controversial success.

The importance of equatorial waters on atmospheric circulation was examined by Bjerknes. Bjerknes (1966), by statistical methods, suggested that significant atmospheric changes follow warming of the Eastern and Central Equatorial Pacific. Rountree (1972) gave strong numerical support for this Bjerknes hypothesis. Two different tests of warm vs. cold equatorial waters under different initialization procedure produced forced convective tropical rains, northward ageostrophic flow, and a deepening of the quasi-stationary Aleutian low.

The possible effects of sea surface anomalies are as follows: enhanced baroclinicity in the overlying atmosphere to increase cyclonic activity, positive feedback mechanism between sea and air resulting in a long-lasting coupled system, a spatial scale that is often complementary with one half a planetary wave length, enhanced cyclogenesis by increased diabatic heating and differential destabilization of the lower atmosphere, and an apparent forcing of mid-latitude flow by a warming of the tropical east Pacific waters.
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The objective of the study is to obtain a meteorologically sound statistical model using sea surface temperature anomalies capable of predicting seasonal departures of surface temperature from average values. Following a feasibility study by Harnack and Henricksen (1973), a stepwise linear regression procedure for eighteen points in the eastern two-thirds of the United States was used.

2. PROCEDURE
Initially, a pilot study was carried out by Harnack and Henricksen (1973) to examine the feasibility of using sea surface temperatures as predictors for a single station predictant, the temperatures at Washington, D.C. The data sample was restricted to twenty-three years, after examining both Pacific and Atlantic data availability. The scarcity of data prior to 1950 in both oceans limited the population sample. A month-to-month predictive technique was tried using a statistical lag relationship of one month's sea surface temperature pattern to the next month's surface temperature departure from normal at Washington, D.C. The best month-to-month lag correlation was found to be November to December, but even that was rather weakly correlated. By expanding the time period for prediction to the overall cold season of December through March, the short wave fluctuations within one month were smoothed to a four-month mean. This would reflect the long wave condition in the mean departure from average. The encouraging results of this pilot study and the relatively large data base prompted further research.

As was the case in the pilot study, the BMD02R* forward stepwise regression program was used on the University of Maryland's UNIVAC 1108 computer. This program computes multiple linear regression equations with one variable added at each step in a forward manner yielding the greatest reduction in the error sum of squares. An F ratio for inclusion at the .01 level is applied as each variable is included as is an F ratio for exclusion at the .005 level. The F ratio values of exclusion and inclusion plus the standard error of estimate are printed out at each inclusion step of a variable. A multiple correlation ratio and variance are printed out at each step as well as in a summary table. The means and standard deviations are printed for each variable read into the program. The program is limited to a total of 80 variables.

Through the results of the pilot study and the reasoning given in the introductory remarks, ample physical evidence is available regarding use of sea surface temperatures as a basis for predictors. The sea surface temperature (departure from average data for November) in the Pacific was entered in a staggered ten degree latitude by five degree longitude grid system with gradients as shown in Figure 1. The data from 1951 through 1975 was supplied by the Long Range Prediction Group with special permission from Mr. Jerome Namias. The Atlantic data were restricted to the sea surface temperatures at the ocean weather ships for November 1951 through 1973. The entire 1950's had sketchy non-homogeneous data sources outside of the ocean weather ships. These were obtained from the Monthly Climatic Data for the World and from Deutscher Wetterdienst (1951-1960). Data prior to 1951 in the Atlantic are very sketchy over the high seas and available mainly along the shipping routes in non-compatible groupings. Gradients were also taken and entered between ocean weather ships along the mean cyclone tracks for winter. Detail as to location of these ships and gradients is shown in Figure 2. Six tropical points were entered into the statistical model. October values (used rather than November because of operationally slow transmission of data) for sea surface temperature departures from average were used for Puerto Citricana, Peru (7.6S 79.5W) and Canton Island (2.5S 171.4W) for 1951 through 1975 and were obtained from a paper by Rountree (1972). Tropical precipitation amounts were used based upon their high correlation with sea surface temperature anomalies in the tropics. The points were obtained from the Monthly Climatic Data for the World, Australian Weather Service Records, National Weather Service and Environmental Data Service. The points entered in millimeters of precipitation were Tarawa (1.2N 172.6E), Fanning Island (3.5N 159.2W), and Arorae Island (2.4S 176.5E) in the Pacific and Sao Tome (0.2N 6.4E) in the Atlantic. As a physical basis, the statistical model considers the influence of the Tropics, Atlantic, and Pacific oceans on the mean circulation.

Nineteen years of dependent data with five independent test years were used. The question of validity of whether or not the sample population is representative of the universe can in part be answered by independent testing and in part by test statistics. Due to the relatively small sample size a t-test for statistical significance was applied to the first predictors' single correlation at the five per cent level. If it did not meet this test the equation was rejected. Also an F test for significance with the inclusion of multiple variables was applied and if it failed caused rejection of the equation. In addition, the standard error of estimate was used with a t-distribution to obtain confidence intervals. At the risk of overfitting the data, a limit of seven predictors was chosen but closely checked against a choice of only three predictors.

Figure 1. Grid points of Pacific dependent data with gradient areas denoted by arrows.

Figure 2. Grid points of Atlantic dependent data of Ocean Weather Ships. Gradient areas denoted by arrows.

The predictands were divided into eighteen grid points in a staggered array across the eastern two-thirds of the United States. The grid system as seen in Figure 3, was chosen after noting a considerable amount of noise in the departure from average at many observing sites, even over a four-month period. Twenty-four years of departure from average (1931-1960) "normal" charts for the four-month period were constructed to obtain grid point data.
3. RESULTS

a. The Predictors.

Two equations, numbers 10 and 16 (see Table 1) were finally eliminated from the original set of eighteen because they failed to pass either the t-test or the F ratio test for statistical significance. These two tests were applied to all equations before their inclusion in the predictive set. The equation for the tenth grid point (just north of the Great Lakes) was eliminated because the F ratio for the second predictor in the regression equation was not significant at the one per cent level of confidence. For sixteen degrees of freedom for the lesser mean square and two degrees of freedom for the greater mean square the F ratio for that predictor was found to be less than 3.63. This test was added to the computer-generated inclusion and exclusion test applied at each predictor addition step. It acts as a double check with the ratio test having a more rigid standard for inclusion. The equation for the sixteenth grid point (northeastern Great Lakes) was eliminated because its single correlation was judged not significant by a t-test and also since the F ratio for the first predictor in the regression equation was not significant at the one per cent level of confidence. To be significant with a t-test at five per cent tolerance the single correlation with N equals 19 had to be equal to or greater than .43. This criterion was met or exceeded in all equations except the equation for grid point sixteen.

Table 1. List of predictive equations for eastern two-thirds of the United States.

<table>
<thead>
<tr>
<th>Grid Point</th>
<th>Equation</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>$-3.50 + 1.70x^1 + 0.94x^2 - 1.93x^3 + 3.7x^4 + 46.25/160$</td>
</tr>
<tr>
<td>2</td>
<td>$-0.19 + 1.06x^1 + 45/160 + 0.85/160 + 1.19x^2 + 2.17 + 0.25/160$</td>
</tr>
<tr>
<td>3</td>
<td>$-3.5/40^1 + 1.31x^2 + 3.60/165 + 1.530/157 + 3.11/172$</td>
</tr>
<tr>
<td>4</td>
<td>$-0.19 + 0.99x^1 + 0.70x^2 + 0.19x^2 + 45/150 + 1.19/170$</td>
</tr>
<tr>
<td>5</td>
<td>$-0.11/140 + 0.66/160$</td>
</tr>
<tr>
<td>6</td>
<td>$-1.75 + 3.0x^1 - 0.17x^2 - 0.70x^3 - 0.770/165 + 1.120/135 + 1.60/170$</td>
</tr>
<tr>
<td>7</td>
<td>$-0.40/140 - 0.019/160$</td>
</tr>
<tr>
<td>8</td>
<td>$-0.20/150 + 0.40/170$</td>
</tr>
<tr>
<td>9</td>
<td>$-0.14/150 - 0.280/170 + 0.107/165$</td>
</tr>
<tr>
<td>10</td>
<td>$-0.60/165 - 0.59/170 + 0.106/110$</td>
</tr>
<tr>
<td>11</td>
<td>$-0.10/170 + 0.170/150$</td>
</tr>
<tr>
<td>12</td>
<td>$-0.14/150 - 0.250/170$</td>
</tr>
<tr>
<td>13</td>
<td>$-0.20/165 + 0.80/150 + 0.150/170 - 0.770/135$</td>
</tr>
<tr>
<td>14</td>
<td>$-0.20/165 + 0.80/150 + 0.150/170 - 0.770/135$</td>
</tr>
<tr>
<td>15</td>
<td>$-0.10/170 + 0.170/150$</td>
</tr>
<tr>
<td>16</td>
<td>$-0.010/100 + 0.100/170 + 0.100/150 + 0.100/170 + 0.100/150$</td>
</tr>
<tr>
<td>17</td>
<td>$-0.10/170 + 0.170/150$</td>
</tr>
<tr>
<td>18</td>
<td>$-0.10/170 + 0.170/150$</td>
</tr>
</tbody>
</table>
To be physically feasible the predictors chosen should show some cohesiveness in choice from grid point to grid point. Thus in forecasting a mean long-wave pattern, the predictors of that broad scale feature should not vary strongly from one grid point to any adjacent grid point. The cohesiveness of the predictors together with the statistical test techniques used help to dispel the possibility that these predictors were chosen by mere random chance and do not represent a good sample of the universe. However, the predictors' value as a forecasting tool rests with how representative they are of the dependent sample. To assume that nineteen years of dependent data explain all possible mean atmospheric circulations is foolish. Figure 4 shows some encouraging results when one examines the first three predictors chosen for all eighteen grid points by the regression technique. The variance explained by these first three predictors was around sixty percent.

Figure 4. Top three predictors picked at all grid points.

Ocean weather ship "C" was very prominent as a first or second predictor in grid point equations from New England through the Mid-Atlantic States and into the deep South. Ship "C" was picked as a first or second predictor in eleven out of the final sixteen equations. All predictive equations using ship "C" had it as a positive correlation with single correlation ratios from .50 to .63, well within the significant range for a t-test. The physical implication of such a high positive correlation is difficult to explain, but it may be a measure of the position of the troughs in the polar westerlies or the position of the climatological "blocking high" with reference to the semi-permanent Icelandic low, or both. The positioning of a "blocking high" through anomalously warm sea surface temperatures is very difficult in high latitudes especially when over a period of months these highs both retrograde and progress in the flow pattern. Namias (1974) examined this complex relationship by following the progression of warm and cold anomalies of sea surface temperature through a period of about one year but illustrated the relationship of these anomalies to the 700 millibar flow and not to a blocking pattern. Warm anomalies were located about five to fifteen degrees downstream of the monthly mean 700 millibar troughs in the winter and cold anomalies were not very precisely located 20 to 30 degrees upstream of the mean 700 millibar trough. Applying this relationship to the positive correlation of ocean weather ship "C", would place the mean trough along about 50° west longitude for a warm anomaly and along about 15° west longitude for a cold anomaly. Examining Atmospheric Teleconnections of Mean Circulation Anomalies at 700 Millibars (1969), negative 700 millibar height anomalies along 50° west yield positive height anomalies over the Mid-Atlantic coast and deep South for winter. This would in most cases result in warmer than normal winter temperatures, hence the positive correlation with warm sea surface temperature anomalies. With the trough along about 15° west longitude the teleconnection is poorer, but a weak tendency for a negative height anomaly is noted over the southern United States. It is interesting to note that the positive correlation of ship "C" is located downwind in the atmospheric circulation pattern from the Eastern United States, illustrating the importance of Mid-Atlantic forcing on the upwind long wave pattern.

Upwind, a positive correlation was picked in the Pacific for most of the same points except over the southeastern United States where ship "C" was picked earlier. A strong positive correlation near 50° north latitude and 135° west longitude existed for eight grid points out of the final sixteen equations selected. Using previous reasoning this location would place a trough along about 140° west longitude for warm sea surface temperature anomalies and along the lee of the Rocky Mountains (admitting the complexities of the Rocky Mountains influence which may make trough placement difficult) for cold sea surface temperature anomalies. Examining teleconnections again, negative 700 millibar height anomalies along 140° west longitude would yield positive height anomalies along the central and northern portion of the Eastern United States excluding the southeast. This would in most cases result in warmer than normal winter temperatures, hence the positive correlation. Negative 700 millibar height anomalies along the lee of the Rocky Mountains tend to extend northeast and east through all but the southeastern United States, but this is a rather weak teleconnection. The tendency for colder than normal winter temperatures could be inferred from this, but with weak physical reasoning.

It appears that the placement of warm anomalies in sea surface temperatures are much more apt to enable prediction downwind or upwind trough positions than cold anomalies. However, the positioning of cold anomalies to the rear of troughs are much more difficult and complex than the positioning of warm anomalies in advance of
area effect for winter months is being discussed.

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equator. Thus with the exception of one predictor, warmer waters than normal or higher precipitation than normal in the equatorial zone results in a cooling contribution to the winter season temperature in mid latitudes. Similarly cooler waters than normal or less precipitation than normal in the equatorial zone results in a warming contribution to winter season temperatures. The physical reasoning for selection is not clear, especially when considering the selection of Puerto Chicama as a positive correlation, but just being included as predictors of a weather feature thousands of miles away is intriguing and thought provoking as to the probable influence of the Hadley Cell on the mid-latitude circulation.

b. Independent Testing

After establishing a physical basis for some of the predictors and applying some statistical test techniques on those predictors, five years of independent data were used to test the dependent data. It was found that it is essential to smooth the dependent data through a grid network to obtain a noise-free dependent analysis. In testing the dependent set of equations, value was seen between using actual station point dependent data versus grid point dependent data. Figure 5 shows isolated minima and maxima generated by noise of single-station data compared with the relatively smoother analysis generated by grid point data shown in Figure 6. All test data were based on the grid system and verified against charts of departure from "normal" constructed with the grid using 1931 through 1960 means.

When predicting anomaly patterns the results of three predictors versus seven predictors were compared. Differences in resolution and value did occur, but no sharp sign changes or rapidly varying numerical values occurred. A statistical F ratio test was applied to evaluate the significance of each variable added after the third variable was included in an equation. The lack of very significant value deviations from the use of three predictors versus seven in addition to the decrease in the standard error of estimate from three predictors to seven prompted the use of seven variable equations to test the five independent years.

Figure 5 through Figure 15 illustrate the predictions and verification of independent data for five winter seasons 1970-1971 through 1974-1975. The last two winter test years used hand calculated ocean weather ship data obtained from passing ships near the old points of observation inasmuch as ocean weather ship observations were unfortunately discontinued in the fall of 1973. Otherwise verification data as well as predictive data were supplied by the National Climatic Center and by Scripps Institution of Oceanography. All predictions and verifications are in degrees Fahrenheit departure for the 1931-1960 mean.

The winter of December 1970 through March 1971 was predicted rather well by the sixteen equations. The areas of minima were quite well predicted across the Great Lakes and New England as can be seen in comparing Figure 6 to Figure 7. Also the minimum area across the mid-Mississippi Valley through the Tennessee Valley was handled well except for an incorrect maximum predicted in the Ohio Valley. The predicted and observed inferred atmospheric pattern was rather meridional in nature. Errors occurred in predicting the strong gradient along the mid-Atlantic coast and an incorrect orientation of the maximum center over the southwestern plains states. The prediction for the gradient area in the northern plains turned out to be too warm. Predictions in the lower Mississippi Valley, mid-Atlantic coast, and the northern plains had the largest errors of 1.5 to 2.0 degrees Fahrenheit, even though the overall pattern predicted showed a good fit to the verified temperature anomaly pattern. No strong positive or negative bias was noted.
Examining Figures 8 and 9, it is apparent that the winter of December 1971 through March 1972 was forecast very well by the equations except in strong gradient areas. The positions of the minima and maxima were very accurate and very close on their actual verified values. The predicted pattern was rather meridional in inferred atmospheric pattern, but the observed pattern was more zonal in nature. Large errors did occur over New England. As in the prior year's predic-
tion, gradient areas were incorrectly placed and spaced. However, comparing Figure 7 to Figure 9 illustrates a marked change from one winter's observed pattern to the next. Even with such a marked change, the predictive equations were able to ascertain the change in patterns as dictated by sea surface temperatures anomalies and tropical predictors from one November to the next. The largest errors were in New England, and the Ohio Valley and amounted to 2 to 3 degrees Fahrenheit. There was a slight positive bias overall.

Figures 10 and 11 illustrate a good pattern fit, but a rather poor numerical resolution in some cases. The winter of December 1972 through March 1973 was markedly different across the northern portion of the United States from the previous year. The predicted pattern of Figure 10 is meridional in inferred circulation pattern as is the observed pattern in Figure 11. The maximum value was very well predicted, whereas the minimum area was poorly positioned and incorrect in value. The "trough" of maximum values through the southeast was very well handled, but the gradient areas in the southwestern and northern plains was poorly resolved. Largest errors were in the southwestern plains and northern plains and ranged from 1.5 to 2.5 degrees Fahrenheit. No discernable bias was present.
Examining Figure 12 and Figure 13 for the predicted versus observed winter of December 1973 through March 1974, shows marked errors over the mid-Atlantic states. The predicted and observed inferred atmospheric pattern was strongly meridional. Once again the gradient areas were not predicted very well, but the position and magnitude of the minimum area over the northern plains was well placed. The maximum over the south was placed too far southwest and the "ridge" of warm temperatures was poorly predicted. A weak minimum over the Ohio Valley did verify, but further to the north into New England. The largest error was over the mid-Atlantic states and amounted to 2.5 to 3.5 degrees Fahrenheit, by far the worst of the years tested. The bias in most cases was negative.

The final independent test of the winter season December 1974 through March 1975 yielded different results from previous test years. Both the predicted and observed inferred atmospheric pattern was zonal in nature, with a maximum across the northern plains and Great Lakes and a
minimum across the south central states. The maximum center was quite accurately placed, but the minimum center was poorly positioned. Similarly the gradient areas through the Mississippi Valley and the south were incorrectly positioned. The extension of a minimum into the central Appalachians was correctly forecast, but the observed minimum in the central plains was missed. The largest errors occurred over the southern Mississippi Valley and the Tennessee Valley and amounted to 2.5 to 3 degrees Fahrenheit. There was a negative bias throughout most of the forecast points.

Figure 16. RMS error for five independent test years/standard deviation for nineteen dependent years.

No trend was seen in any of the sixteen equations to be either negatively or positively biased throughout the five test years. A root mean square error was computed for each grid point for the five winter seasons of independent tests. Figure 16 illustrates the root mean square error for all stations as compared to the standard deviation for the dependent year's data (N equals 19). In all cases the root mean square error for the five winter seasons were equal to or less than the standard deviation. In most cases the root mean square error was considerably less than the standard deviation. The envelope root mean square error for all sixteen stations was 1.63 degrees Fahrenheit with the envelope standard deviation of about 2.5 degrees Fahrenheit. Grid points that had large root mean square errors should not be considered less reliable for future use than grid points that had small root mean square errors. The future performance of all equations is subject to complex influences not covered in a mere five years of testing. However, the root mean square error can be used with the standard deviation and statistical methods to arrive at a less sensitive forecast product, especially in gradient areas which are difficult to predict.

Figure 17. Standard error of estimate dependent years/confidence interval at t95% dependent years.

Two examples following this thinking were drawn for the winters of 1971 through 1972 and of 1973 through 1974. The departures from normal values plotted on the maps were arrived at by applying a +1.5 degrees Fahrenheit correction to the independent data and then examining each grid point to see if the corrected data fell within a certain departure from the standard deviation for both sides of the corrected interval. One half a standard deviation was considered a significant departure to deem the corrected value either above or below normal. No criterion was established for categories "much above" and "much below" normal. Results can be seen in Figures 18

Figure 18. Forecasted departure from "NORMAL" map with three classifications for winter December 1971 through March 1972.
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through 21. The net effect of this technique was to broaden the area of "near normal" values and to isolate "below normal" and "above normal" values on the predicted pattern. This, in effect, smooths out the gradient areas which gave problems previously. Though this weakened the numerical value of the product, it prevented the forecast from being off by more than one category in any one locale. Still the errors made were

obvious. The "near normal" region was poorly delineated on Figure 18 as well as Figure 20. Although the patterns were well handled by this method, compared with the verification, there is doubt about the usefulness of this approach for prospective consumers. The numerical method, though prone to localized large errors, would perhaps be much easier to use in conversion to degree days and for physical planning techniques.

Figure 19. Observed departure from "NORMAL" map with three classifications winter December 1971 through March 1972.

Figure 22. Forecasted departure from "NORMAL" map with three classifications winter December 1978 through March 1979.

Figure 20. Forecasted departure from "NORMAL" map with three classifications winter December 1973 through March 1974.

Figure 23. Forecasted departure from "NORMAL" map with three classifications winter December 1978 through March 1979.

Figures 22 and 23 give the forecast for the upcoming winter season of December 1978 through March 1979 prepared on December 5, 1978. Limitations noted in the previous independent test years should be applied to this forecast.

4. CONCLUSIONS

Viewing the five independent test winter seasons presented here as a whole the results are very encouraging. Pattern recognition was high even though numerical point values were often in error. The usefulness of sea surface temperature anomalies and tropical precipitation as predictors of winter season temperature patterns cannot be dismissed as mere happenstance. The physical reasoning and test results show these predictors
to be a powerful long range forecasting tool. The usefulness of the predictors varies from year to year and location to location, but overall the error is not too high considering what is being forecast.

A basic question still lingers when one relates sea surface temperatures and tropical precipitation to winter season temperature anomalies was the atmospheric condition already established and hence just reflected in the two types of predictors or did they force the establishment of a future atmospheric circulation? This question is not a simple one to resolve, but examining the forecast results in terms of general circulation, the predictors seem to force the establishment of an atmospheric circulation in most cases.

Therefore, on the basis of the independent tests, physical reasoning, and statistical tests it appears likely that a meteorologically sound statistical model capable of predicting winter seasonal departures of surface temperature for the Eastern U.S. from average values has been made plausible.

5. SUGGESTIONS FOR FUTURE RESEARCH

Considering that this predictive study is a first of its kind, there is much room for future expansion of its initial idea. The problems inherent in such a study opens vistas for future research. The existing computer program was limited in capacity for handling variables. It could be readily expanded to handle a much larger variable load. Also different predictive techniques rather than the forward stepwise regression technique employed could be used. Data were the largest problem not only as constraints for the computer program, but in particular as regards availability of data. Certainly a much better data coverage of the Atlantic Ocean is desirable. Also a search back through the 1940's to expand the population sample size would be very important. However, this type of statistical study will probably always be plagued by an insufficient population sample.

This study focused upon only two effects on winter season temperature patterns: sea surface temperature anomalies and tropical rainfall amounts. Future studies should, if possible, examine the influences of global precipitation, snow cover, Arctic ice, height anomaly lags, and circulation indices. But care should be taken as these types of data sources tend to be noise-prone and non-conservative in nature. The program could also focus on a wider geographical area with a tighter or looser grid network.

BIBLIOGRAPHY


