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**STATISTICAL EXAMINATION OF CLIMATOLOGICAL DATA
RELEVANT TO GLOBAL TEMPERATURE VARIATION**

Final Report

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INTRODUCTION

Since the writing of the original proposal, debate within the scientific community continues concerning the existence of a global "warming trend" due to the build-up of CO₂ and other greenhouse gases. Thus sound statistical analysis of the pertinent data continues to be a critical need. As indicated in the original proposal, the goals of this project are to critically examine the quality of existing data sets upon which conclusions are being drawn as well as to use state-of-the-art statistical techniques to model appropriate data for purposes of assessing whether a warming trend exists and identifying and understanding the explanatory variables. In this report the progress which has been made is discussed.

1. MAJOR ACCOMPLISHMENTS

(a) Testing for Trend in the Global Temperature Data

Global temperature anomaly series such as that obtained by Hansen and Lebedeff (H&L) (1987, 1988) have been obtained for the past 100-130 years, and these data have shown a tendency for the temperatures to increase over this time period. The series have been analyzed, (see Bloomfield and Nychka (1992), Bloomfield (1992)) by testing for a deterministic trend assuming the model

Model 1:
$$X_t = a + bt + Z_t$$

where X_t is the temperature anomaly series, t is time in years, a and b are real constants and Z_t is a stationary, fixed mean process. These authors used regression-type tests for the significance of the least squares estimate of slope, adjusting for the correlation in the residual series. Using this approach, a significant deterministic trend is found in these temperature series. It is important to note that if such a model is fit to the data, there is a tacit implication that the trend is of the type which would be forecast to continue should conditions not change, e.g. through some event effecting global temperatures such as the recent Mt. Pinatubo volcano. In fact when a significant trend is found in such data, best forecasts using Model 1 roughly follow the fitted trend

line.

Another class of models which are very reasonable models for the temperature series are the ARIMA models popularized by Box and Jenkins (1976). Specifically, these models are of the form

Model 2:
$$\phi(B)(X_t - \mu) = \theta(B)a_t$$

where

$$\phi(B) = 1 - \phi_1 B - \dots - \phi_K B^K$$

$$\theta(B) = 1 - \theta_1 B - \dots - \theta_q B^q,$$

a_t is white noise and B^j is the backward shift operator defined by $B^j X_t = X_{t-j}$. When the roots of the characteristic equation $\phi(r) = 1 - \phi_1 r - \dots - \phi_K r^K = 0$ lie outside the unit circle, X_t is stationary. Whenever there are roots of the characteristic equation on or inside the unit circle, the process is nonstationary. Woodward and Gray (1992a) fit these models to the temperature series and found that the optimal models of this type had a single unit root. It is shown that the correlation structure for these models is not nearly strong enough for the ARIMA-based forecasts to predict any continued increase. Thus, the distinction between these two models is dramatic: Model 1 forecasts a trend to continue while Model 2 does not.

Research conducted on this project related to the choice of models has concentrated on two problems. First, an investigation has been completed on the tests for trend suggested by authors such as Bloomfield and Nychka (1992) applied to realizations from ARIMA models. This first area of research demonstrates vividly that the finding of a significant trend in a realization does not indicate that forecasts should predict the trend to continue. However, this area of research does not directly address the issue of which model, Model 1 or Model 2, is more appropriate for the temperature series. The more recent research has focused on the extent to which one can determine whether a trend should be predicted on the basis of the data alone.

(i) *Examination of Tests for Trend*

While there are fundamental differences between the forecasts from Models 1 and 2, realizations from both types of models can display trending behavior such as that seen in the temperature series. Realizations from the ARIMA models fit to the temperature series tend to have random trends which can go either up or down and are of varying lengths. These random trends cause the tests for trend to detect a significant deterministic trend in a high percentage of the realizations. Specifically, the test given by Bloomfield and Nychka(1992) found a significant deterministic trend in over 50% of the realizations from the ARIMA models which Woodward and Gray fit to the H&L series. Thus, these tests of the hypothesis $H_0: b = 0$ have little or no ability to distinguish between realizations from ARIMA models with a high correlation between successive values and realizations from linear trend models.

To further emphasize these points, analyses have been conducted on the yearly average Zurich sunspot numbers for the 108 years spanned by the Hansen and Lebedeff temperature series, i.e. 1880-1987 (see Waldmeier, 1961 and NOAA, 1990). These data have a pseudoperiodic behavior with a period of about 11 years along with a general tendency for the amplitudes of the oscillations to increase over this time span. The tests for trend were applied to this series and it was noted that these tests conclude that there is a significant deterministic linear trend in the sunspot data for the past 108 years. Hence forecasts from this linear trend model predict a continued trend in sunspots. This is of course a finding which would not be viewed as reasonable by the scientific community, and little credence is placed in the belief that the increasing trend observed over the last 108 years will continue over any extended period of time. On the contrary, since there is a long history of sunspot data, it is known that the behavior observed over the last 108 years is simply a part of the natural cycle of sunspot behavior. In particular, for the 239 years from 1749-1987, there have been several periods of increasing and of decreasing amplitudes. Thus, the conclusion is that trend tests based on Model 1 for purposes of forecasting future behavior should be used with caution.

A paper written by Woodward and Gray discussing these results has been accepted to appear in the *Journal of Climate*. A shortened version of the paper appeared as a DOE Research Summary.

(ii) *Distinguishing Between Models 1 and 2*

In the previous work Woodward and Gray (1992a,b) made no claims concerning which of the two model types were preferable for modeling the temperature series and consequently did not come to a conclusion concerning whether a trend should be forecast to continue based on the temperature series. This, however, is a problem of considerable interest and was the focus of recent research. Specifically, techniques for ascertaining whether the temperature data show characteristics of realizations from Model 1 or Model 2 have been examined, and a summary of these findings are given here.

We have considered the use of unit root tests which are popular in the econometrics literature (see Dickey and Fuller(1979, 1981) and Dickey, Bell, and Fuller(1986)) for distinguishing between realizations for which a trend would be forecast to continue and those for which best forecasts do not predict continued trends. Simulations show that these tests do not distinguish between the two cases for data of the nature of the global temperature series.

As an alternative approach, current work focuses on a bootstrap procedure for choosing between Models 1 and 2. This procedure essentially determines whether temperature realizations "look more" like realizations from Model 1 or Model 2. The procedure involves first modeling the temperature series using each of the models. Model 1 was obtained as a linear trend line with AR(8) errors while the optimal model of type 2 had one unit root and was identified as an ARIMA(9,1,0) model. The procedure uses the test statistic which Bloomfield and Nychka(1992) suggested for testing the significance of $\hat{b}$. For the H&L data this test statistic is 4.70 which is highly significant. As mentioned previously, this does not automatically imply that a linear trend model is appropriate for these data. The pertinent question seems to be whether this test statistic is more similar to those which would be found from realizations from Model 1 or from Model 2. Next, 50 bootstrap realizations of length $n = 100$ from each of the two fitted models are obtained. These are treated as training samples of size 50 from the populations of test statistics from the two models. The goal is to classify $\hat{b}$ (obtained from the actual temperature series) into one of the two populations based on the information in the "bootstrap" training samples. Fisher's linear discriminant

function (Fisher, 1938) is used for classification purposes. In the current setting the test statistic means are $\bar{b}_1 = 9.80$ and $\bar{b}_2 = 3.29$, and the classification procedure picks the ARIMA as the more plausible model. That is, the test statistic for the actual H&L temperature realization, $\hat{b} = 4.70$, appears to be more like that obtained from realizations from the ARIMA model than from the linear trend model fit to the temperature series. Thus, using this procedure, the trend would not be forecast to continue.

A simulation study was designed to examine the effectiveness of the bootstrap procedure. First 100 realizations of length $n = 100$ are generated from the linear trend model previously fit to the H&L data. Each of these realizations is classified as resembling Model 1 or 2 using the bootstrap procedure. If the test statistic is not significant, in this implementation if $|\hat{b}/SE(\hat{b})| \leq 2$, the realization is declared to be from a fixed-mean ARIMA model. However, if the k th realization has a "significant" test statistic it is fit using a linear trend model and again with a ARIMA(9,1,0) fixed mean model. Then 50 bootstrap realizations are obtained from each of these fitted models and Fisher's linear discriminant function is used to classify the k th realization as being from Model 1 or Model 2. One hundred realizations were also generated from the ARIMA(9,1,0) model fit to the H&L series. The procedure described above was used to classify each of these realizations as being from Model 1 or 2. The results of this classification procedure are that 79% of realizations from Model 1 and 57% of the realizations from Model 2 were correctly classified. These results are encouraging.

Intuitively, one reason for the uncertainty concerning whether the upward trend in the temperature series should be forecast to continue on the basis of the data alone is due to the relatively short length of these series. In order to investigate the effect of increased realization lengths, realizations of length $n = 200$ from Models 1 and 2 were simulated in order to determine if the decision concerning whether to forecast a trend is more clear-cut. Preliminary results based on 20 realizations from each model show that 70% of the realizations from Model 1 and 95% of the realizations from model 2 were correctly classified. These results indicate that increasing the realization length increases the ability to distinguish between the two models. The results of this latter study are very encouraging. The implication is that if 200 years of reliable temperature data were available, then a more definitive conclusion could be made concerning

whether the trend should be forecast to continue. Since it may be possible to extrapolate temperature into the past via tree ring, ice core, or other data, the possibility of obtaining meaningful longer temperature readings is non-negligible. The principal investigators are presently investigating this possibility. Even if accurate extrapolations do not prove to be reliable, the results here suggest that it will be possible to determine how long global temperature must be monitored in order to conclude with desired accuracy whether a trend should be forecast.

(b) Estimating Regional and Global Mean Temperature Anomalies

A second major effort on this project involves examining the quality of existing temperature series along with developing techniques for obtaining improved estimates of regional and global mean temperature anomalies. A number of important and currently unresolved spatial issues relevant to the statistical analysis and to the modeling of global temperature variation data have been identified and are under investigation.

(i) Defining and Estimating Global Mean Temperature Change

Initial efforts focused on the procedures that are currently advocated to estimate mean temperature anomalies over spatial regions. Literature reviews found little documentation that described the statistical rationale behind the computational methods that are widely used to estimate mean temperature anomalies. Subsequent theoretical and empirical work led to recommendations supporting some of the practices but not others. Use of unweighted averages was found to be more beneficial than distance-weighted averages in the calculation of grid-point values when the purpose of gridding is to estimate spatial anomaly means, as opposed to estimating the anomaly value at a specific location. In addition, gridding was found to be advantageous in reducing the bias that occurs from irregularly spaced station locations. The reuse of station anomalies in the estimation of spatial means for two or more neighboring grids was found to bias the gridded estimates and is not recommended. A paper by Gunst, Brunell, and Basu which discusses the findings in detail has been published in the *Journal of Climate*.

(ii) *Spatial Correlations in Station Temperature Anomalies*

Available station temperature data are irregularly spaced at stations in the northern and southern hemispheres, mostly over continental land masses (Folland et al. 1990). Little can be done to supplement these historical data, so emphasis must be placed on the statistical modeling of the available data. Statistical modeling of station temperature data can be considered crude at best, in part because no comprehensive accounting of spatial correlations in the station data has been included in the modeling of historical data or in the extensive general circulation models used to simulate the climatic effects of various types of natural and anthropometric forcings. The use of averages to estimate grid-point values assumes a de-facto statistical model that is entirely inappropriate for spatial data such as station temperature anomalies.

Use of ordinary averages of station temperature anomalies in a grid is appropriate if the temperature anomalies follow a statistical model that assumes (1) a constant mean throughout the grid, (2) a constant variance of the anomalies across stations in the grid, and (3) uncorrelated station temperature anomalies. Distance-weighted averages are appropriate if the variances of the anomalies increase with the distance from the center of the grid square. If the grid-size is sufficiently small, the first assumption may be a reasonable one. There is some support for the second assumption, that of constant variance (e.g., Solow 1988), but none has been found for increasing anomaly variances based on the distances of stations from the centers of grids. The third assumption is highly questionable.

Recent work on this project has been directed at understanding the spatial nature of station correlations and on developing more realistic statistical models for temperature anomaly data, models that include spatial correlations. Examination of station data for stations in the contiguous United States has shown the existence of the spatial correlations, and preliminary modeling efforts appear very promising. These results are reported in Gunst (1992), "Spatial Correlations in Station Temperature Anomalies".

The intent of the work in Gunst (1992) is to demonstrate the need for including spatial correlations in any modeling of temperature anomalies. The data base used for

this purpose contains 100 temperature stations for the contiguous United States in 1990, the year studied. These stations are located at distances of fewer than 100 km to over 4,000 km from one another. An isotropic Gaussian variogram model was fit to average squared anomaly differences using a lag of 100 km. From the Gaussian fit for January 1990, spatial correlations were estimated to be over 0.9 for stations within approximately 100 km of one another to 0.2 for stations about 1,000 km apart. For May 1990, the highest correlations were somewhat lower than for January, about 0.8 for stations within 100 km of one another, but they were higher for stations more distant, about 0.4 for stations approximately 1,000 km from one another. Use of ordinary averages or distance-weighted averages for estimating spatial mean temperature anomalies is thus suspect on the basis of this study.

(iii) Spatial Modeling

It is imperative that spatial correlations be included in models of temperature change in order to provide valid uncertainty limits for estimated mean temperature anomalies. Kriging is a spatial modeling technique that produces minimum variance unbiased predictions of spatial variates when either the spatial covariance matrix or the spatial variogram matrix is known. It also provides standard error estimates for the predicted anomalies. These standard error estimates can be used to set uncertainty limits on estimated mean temperature anomalies. Kriging has been applied primarily in the geosciences, notably in mining, and is yet to be applied to the estimation of global mean temperature anomalies.

Traditional applications of kriging are subjective, labor intensive, and require specialized computer software. A critical aspect of kriging applications is variogram modeling. If $a(s_1)$ and $a(s_2)$ represent station anomalies for two stations located at s_1 and s_2 , then the variogram is defined to be $\text{var}\{a(s_1) - a(s_2)\}$. For a variety of theoretical and practical reasons, the variogram itself is modeled as a function of the distances and the directions between pairs of stations. As with time series modeling, there is an assumption of spatial stationarity that is needed to model the anomaly values. In the present setting, the assumption would be that stations the same distance and direction apart will have a constant correlation between the station anomalies, regardless of where on the globe the respective stations are located. This assumption, of

course, awaits verification.

One major activity has been the writing of specialized computer software that would allow the fitting of spatial variogram models to the squared anomaly differences, $\{a(s_1) - a(s_2)\}^2$. A technical report by Brunell (1992), "An Automatic Procedure for Fitting Variograms by Cressie's Approximate Weighted Least Squared Criterion," describes the software that was written. This program, written in C for a SUN workstation, enables the user to fit any of ten variogram models to sample variograms. The sample variograms are constructed by binning the squared anomaly differences into lags that are multiples of a user-supplied distance and direction, each of which can be specified as a range of values. Method of moments and robust (e.g., Cressie and Hawkins 1980) sample variogram estimates can be calculated for each bin. Weighted least squares is used to find the best fitting model parameters once a model and a sample variogram have been selected.

(c) Analysis of the Effect of Initial Conditions on Autoregressive Models for Global Temperature Data

A common approach to studying the impact of greenhouse gases on climate is via computer simulation using general circulation models (GCMs) which integrate current understanding of the various factors influencing climate through a comprehensive mathematical model. There is much current debate over the degree of validity that can be attributed to the output from a GCM since understanding of the input factors which effect climate is far from perfect. In a recent article, Tsonis (1991) examines the sensitivity of GCMs to initial conditions. As stated by Tsonis, an obvious way to determine the effect of the initial conditions on predictions obtained from a GCM is to obtain a control realization (i.e. a sample over time), modify the initial conditions, obtain another realization, and compare the results. Since this could be excessively time consuming, Tsonis suggests modeling the global temperature series of Jones, et al. (1986a,b,c) and Jones (1988) by fitting a fourth order autoregressive process, AR(4), to the data and then using such a model to generate additional realizations with modified starting values. He assumes that the sensitivity of GCMs to initial conditions is similar to that of the AR model, and he then reasons that if slightly changing the initial values

in simulated realizations from the AR(4) model results in very dissimilar realizations, this provides evidence that the GCMs themselves are too sensitive to initial conditions to trust predictions made from simulations.

Tsonis is incorrect when he concludes that predictions from a stationary autoregressive model fitted to temperature data are sensitive to the starting values; on the contrary, the opposite is true. It is well known that for any stationary AR process, if the sample size is large relative to the order of the process, the initial values will have little effect on forecasts. Tsonis repeatedly generated different realizations from processes with slightly different starting values and attributed the dissimilarity after 30 and 50 years to the difference in the starting values. Gray and Woodward (1992) demonstrate that this dissimilarity is not due to initial values, but instead it is due to the correlation structure and noise sequence. In fact, they show that for the AR(4) model under consideration, realizations which have the same starting values but different noise sequences will show the same type of dissimilarity Tsonis observed. On the other hand, for this model, they show that realizations from dramatically different starting values but the same noise sequence (corresponding to the same random forces driving the weather) typically merge within 30 years, again illustrating the insensitivity of these realizations to the starting values.

Thus, the claim of Tsonis that the stationary autoregressive model fit to the global temperature data is overly sensitive to starting values is incorrect. The question still remains open, however, as to the sensitivity of the GCMs themselves to initial conditions. Further study of climate will involve a significant amount of simulation. The authors believe that statistical processes such as autoregressive models will play a fundamental role in such simulations. The Woodward and Gray (1992) paper contributes to a better understanding of the nature of these processes.

(d) Understanding Natural Temperature Variability

Through the interaction of statisticians on this project with researchers from the departments of Anthropology and Geological Sciences at Southern Methodist University analysis of climate data extending back beyond the 100-130 year time frame of the thermometer-based temperature series have been conducted.

(i) *Tree Ring Data*

A real need in the area of climate change research is for usable sequences of temperature proxy data which extend backward beyond the last 130 years or so for which thermometer-based readings are available. Other data sets such as the O^{18} readings found in ocean sediments provide indications of temperature in past climates. However, these series are usually on a long time scale with readings typically being approximately 2000 years apart. This time scale provides very little information concerning the types of natural climate variability which have occurred over 100 year periods in the past.

Temperature variation patterns in the Late Holocene can be studied using reconstructed temperature records from tree rings providing one can verify that known patterns observed with modern temperature records are retrievable from the tree ring record. A project has begun at Southern Methodist University using a series of dendroclimatological data sets that contain temperature reconstructions for the past four centuries (Fritts, 1991). To assess the validity of individual records, real temperature records have been compared with their dendrochronological analogs. A high degree of correlation exists for many of the tree-ring sites where as much as 60% of the total temperature signal can be reconstructed using tree-ring widths. At sites where such high correlation exists, it seems as though the modern record has repeated itself several times in the past four centuries (Hietala and Hill, 1992). However, individual records themselves are part of more general regional patterns which may or may not mirror global patterns, if such exist.

A series of 75 dendrochronological sites across the mid-latitudes of North America are currently being investigated. The preliminary results suggest that there are probably four or five major regional patterns associated with the east, midwest, west and south. In addition, the mountainous region of western North America seems to have a strong pattern associated with sites on the leeward side of the continental divide. These, in turn seem to be negatively associated with apparent patterns among some sites of the east. It is of some interest that exceptionally warm decades in the east may be associated with cooler than average decades on the leeward side of the mountains in the northwest. It is also of interest that a signature of the Little Ice Age (a stretch of extremely cold weather lasting roughly from 1450 to 1850) seems to manifest itself in

some but not all regional patterns.

The definitions of the regional patterns based on the tree-ring temperature reconstructions are currently being fine tuned. The next stage of the analysis is to verify the reconstructed regional patterns with their regional analogs based on the modern temperature record. This work was performed primarily by Hietala and Hill from Anthropology. A preliminary report of these findings was given by these authors at the 12th Biennial Meeting of the American Quaternary Association during 1992.

(ii) *Climate Studies in Saharan North Africa*

Another research effort concerning past climatic variation has been the study of Saharan North Africa. This is an arid continental region which is extremely sensitive to global-scale climatic change. The anthropologists involved in this research have studied the Bir Tarfawi region in southern Egypt extensively and find indication of several pluvial episodes between >140,000 and approximately 80-90,000 B.P. Pluvial episodes at Tarfawi were probably a response to monsoonal circulation patterns and serve as a test for climate models. The occurrence of pluvials around 140,000 B.P. seems to contradict models which rely on threshold insolation values to initiate monsoonal conditions. If the glacial-interglacial boundary occurred around 130,000 B.P., then North African monsoons from >140,000 B.P. might be associated with global dynamics of deglaciation. If pluvials do predate threshold insolation values, this may indicate that the primary causes of climatic variation recorded by Saharan lake deposits are internal oscillations not directly linked to high insolation. Results obtained in this area by Hill and Wendorf have been accepted to appear in *Quaternary Research*.

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2. GRADUATE STUDENTS TRAINED

This grant has provided partial funding for three statistics graduate students and one anthropology graduate student. Pat Gerard, Tommy Fu, and Sunho Hong have all been supported as research assistants on this grant. Gerard and Fu have assisted in the research efforts and provided computing support. Hong recently completed the requirements for the Ph.D. degree under direction of Dick Gunst. His dissertation research was on theoretical properties of kriging models. This work applied asymptotic properties of correlated regression models to spatial modeling. Initial results on the use of measurement-error modeling as an alternative to certain types of co-kriging were also obtained. Christopher Hill from the Department of Anthropology was supported on this grant as he completed his Ph.D. degree. He has been involved in the study of paleoclimate of North Africa and dendroclimatology.

3. BIBLIOGRAPHY AND OTHER SCHOLARLY ACTIVITIES

Listed below are the reports which have been either published or accepted for publication under the sponsorship of this grant. Also included are other activities such as presentations and technical reports which have at this point not yet been published. Several new results will be forthcoming in the near future.

1. *Reports Which Have Appeared or Have Been Accepted to Appear in Scientific Literature*

- (a) Gray, H.L. and Woodward, W.A. (1992) "The Effect of Initial Conditions on Autoregressive Models for Global Temperature Data," *EOS* 73, 267-268.
- (b) Woodward, Wayne A. and Gray, Henry L. (1992) "Testing for Trend in the Global Temperature Data," *DOE Research Summary*, No. 16, April 1992.

- (c) Woodward, W.A. and Gray, H.L. (1993) " 'Global Warming' and the Problem of Testing for Trend in Time Series Data," *Journal of Climate* 6, 953-962.
- (d) Gunst, R.F., Basu, S., and Brunell, R. (1993) "Defining and Estimating Mean Global Temperature Change," *Journal of Climate* 6, 1368-1374.
- (e) Gunst, R.F. (1991). "The Scientific Controversy Over Global Warming," *STATS: The Magazine for Students of Statistics*, 3-8.
- (f) Gray, H.L., Gunst, R.F. and Woodward, W.A. "Statistical Examination of Climatological Data Relevant to Global Temperature Variation," *Proceedings of the 5th International Meeting on Statistical Climatology*, 197-201.

2. *Unpublished Technical Reports*

Brunell, R.M. (1992). "An Automatic Procedure for Fitting Variograms by Cressie's Approximate Weighted Least Squared Criterion," Department of Statistical Science Technical Report No. SMU/DS/TR 259, Southern Methodist University.

Gunst, R.F. (1992). "Spatial Correlations in Station Temperature Anomalies," Department of Statistical Science Technical Report No. SMU/DS/TR 258, Southern Methodist University.

3. *Presentations*

Richard F. Gunst

- 1. "Statistical Issues in the Global Warming Controversy"
 - (i) Statistical Science Department Seminar, Southern Methodist University,

- (ii) Division of Mathematics Seminar, Computer Science and Statistics, University of Texas at San Antonio.
- 2. "Statistical Challenges in the Estimation of Global Mean Temperature Anomalies," Statistics Seminar Series, Texas A&M University.
- 3. "Estimating Global Mean Temperature Change," 1992 Annual Joint Meetings of the American Statistical Association and the Biometric Society, Boston.
- 4. "Assessing the Statistical Debate Over Global Warming," Mathematics Club, Sacred Heart University, April 28, 1993.
- 5. "Estimating Spatial Correlations," poster session at the 18th Annual Climate Diagnostics Workshop, Boulder, CO, November 1-5, 1993.
- 6. "Estimating Global Mean Temperature from Instrument Data," NSF/NCAR Conference on Applications of Statistics to Modeling the Earth's Climate System," National Center for Atmospheric Research, Boulder, CO, July 11, 1994.

H.L. Gray

- 1. "Warming Trend: Fact or Fiction?"
 - (i) Physics Department Seminar, Southern Methodist University
 - (ii) Freshman Seminar, Southern Methodist University
- 2. Served as a panelist at Texas Tech University in February 1991 in a panel discussion on global warming.

Wayne Woodward

- 1. "Global Warming and the Problem of Testing for Trend in Time Series Data,"
 - (i) Stephen F. Austin University, Mathematics Department Seminar
 - (ii) Southern Methodist University, Statistical Science Seminar

2. "Statistical Examination of Climatological Data Relevant to Global Temperature Variation," invited presentation at the 5th International Meeting on Statistical Climatology (5IMSC) held at the University of Toronto, June 22-26, 1992. (joint with Gray and Gunst)
3. "Distinguishing between Deterministic and Random Trends in Time Series Data," invited presentation at the 25th Symposium on the Interface between Computer Science and Statistics, San Diego, CA, April 14-17, 1993.

Paul Whitney

1. "Statistical Issues in Climatology: Looking for the Greenhouse Effect," Texas Academy of Science, Stephen F. Austin University, March 1, 1991.
2. "Temperature Trends During the Past Century," Texas Conference of Statisticians, Dallas, Texas, March 19, 1991.

Christopher Hill

1. "Global Climate Change and Pleistocene Pluvials in Saharan North Africa," Geological Society of America Meetings, 1991.

Harold Hietala

1. "An Analysis of Temperature Variation During the Late Holocene," American Quaternary Association meetings, 1992.

4. Refereeing

One indication of the reputation the research team at Southern Methodist University is developing in the area of statistical climatology, is that these investigators have been asked to referee the statistical aspects of several papers submitted to *Journal of Climate* and *Journal of Applied Meteorology*. This is important yet time consuming work.

5. *Interaction with Climatologists*

While the expertise of the Southern Methodist University research team is primarily statistical, the ability of this research group to make substantive contributions to the field of statistical climatology has been enhanced through interaction with climatologists. Tom Wigley from the Climate Research Unit in East Anglia has visited the research team on two separate occasions, and one of these visits was for a week's duration. These discussions have proved to be useful to all involved. Other contacts with climatologists at meetings have also been useful. Two such meetings have been the 5th International Meeting on Statistical Climatology held in Toronto in June 1992 and a week-long conference with climatologists and other statisticians working on temperature data modeling at the University of Minnesota in July 1992.