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Regional Climate Change Predictions from the Goddard Institute for Space Studies High Resolution GCM

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Abstract:

Model simulations of global climate change are seen as an essential component of any program aimed at understanding human impact on the global environment (National Academy of Sciences, 1986[1]). A major weakness of current General Circulation Models (GCMs), however, is their inability to predict reliably the regional consequences of a global scale change, and it is these regional scale predictions that are necessary for studies of human/environmental response.

This research is directed toward the development of a methodology for the validation of the synoptic scale climatology of GCMs. This is developed with regard to the Goddard Institute for Space Studies (GISS) GCM Model II, with the specific objective of using the synoptic circulation form a doubles CO_2 simulation to estimate regional climate change over North America, south of Hudson Bay.

This progress report is specifically concerned with validating the synoptic climatology of the GISS GCM, and developing the transfer function to derive grid-point temperatures from the synoptic circulation. Principal Components Analysis is used to characterize the primary modes of the spatial and temporal variability in the observed and simulated climate, and the model validation is based on correlations between component loadings, and power spectral analysis of the component scores. The results show that the high resolution GISS model does an excellent job of simulating the synoptic circulation over the U.S., and that grid-point temperatures can be predicted with reasonable accuracy from the circulation patterns.

[1] "Global Change in the Geosphere-Biosphere: Initial Priorities for an IGBP," National Academy Press, Washington, D.C., 1986.

List of Tables and Figures:

1. Introduction.

Human society has induced a variety of modifications to the Earth's atmosphere over the past century, a process that, setting aside much political rhetoric, shows little sign of abating over the next few decades. Recognizing this trend, considerable effort has focused on the global changes that may result from society's activities, and from the interactions of the human and physical environment. The most publicized of these issues is the portended global warming, or so called "greenhouse effect," and the consequent climate change that may result from the anthropogenic contribution to atmospheric CO_2. The Co_2 levels in the atmosphere have increased rapidly over the last few decades and the predictions are that they will reach double the pre-industrial levels sometime in the 21st century. We can anticipate that these increases will have some measurable influence on world climate; although current numerical models cannot predict with any degree of certainty the global distribution of the probable climate change.

Recent General Circulation Model (GCM) simulations for doubled atmospheric CO_2 show an approximate 2°C to 4.5°C increase in the global mean surface air temperature. This increase over present conditions is greater than any change estimated to have occurred over the recent geologic past (i.e., the last 8,000 years). All models agree that the consequences of an increase in atmospheric CO_2 will be an average global warming, but the regional details of such a warming show large inter-model variability (Figure 1). Despite the considerable effort expended on the problem, there is no general agreement on how a global warming of this magnitude will translate into a change in climate on a regional basis. This inability to provide accurate regional scale predictions becomes significant for any social or environmental planning on a decadal time scale. An estimate of global or zonal mean climate change is not sufficient. Regardless of whether planning is to be at a national, regional, or local level, it is necessary to know how climate will change within individual regions. A major problem thus

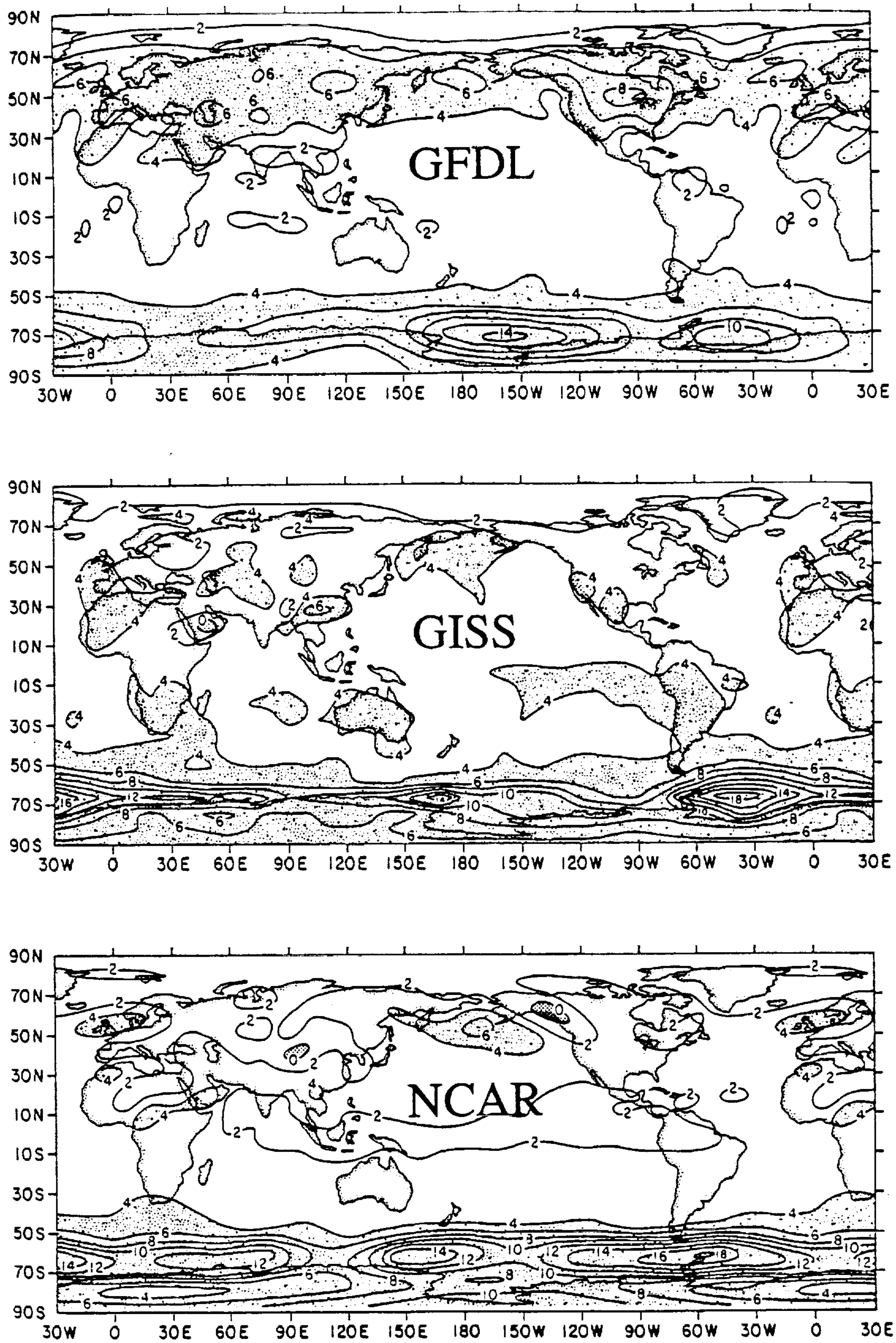

Figure 1. World Temperature Prediction Under a 2 x CO_2 Atmosphere From Three Models. (From Schlesinger & Mitchell, 1985)

exists in moving from the global scale at which current GCMs work best, to the regional and local scale at which climate change predictions are necessary for impact assessment.

The present work addresses this question of the representativeness of the GCM output at the regional scale. Specifically, it examines the synoptic scale atmospheric circulation simulated by the GISS GCM, and compares this to the observed circulation over North America, south of Hudson Bay. The ultimate objective is to use changes in the atmospheric circulation of a doubled CO_2 world to predict changes in regional temperature. The approach adopted is, in a sense, a combined modeling and analog technique. The GCM predicts the general state of the atmosphere with a doubling of CO_2, and the regional climate change prediction is derived from an analog with the present synoptic circulation. Such an approach makes several important assumptions. The first is that the model accurately simulates the synoptic scale atmospheric circulation over the U.S. Second, we assume that there is a strong relationship between the synoptic circulation and the surface air temperature. The third assumption is that the synoptic climatology of the doubled CO_2 world, and its consequences for regional climate, can be described in terms of the present synoptic climatology of the region. The present report deals with the first two assumptions, and demonstrates that the model does a very good job of simulating the synoptic circulation, and that we can use the synoptic circulation to make a reasonable prediction of daily temperatures over much of the United States.

2. The Synoptic Circulation.

Data Characteristics:

Daily (1200z) National Meteorological Center (NMC) gridded data, and 1200z grids from a control run of the 4° x 5° GISS GCM, are used to validate the simulated synoptic scale atmospheric circulation. Hansen et al. (1983) describe the structure, equations, and parameterizations of the GISS model, which is global in horizontal extent and has variable vertical resolution. The model run used here has 9 layers in the vertical with a distribution of two in the boundary layer, five in the rest of the troposphere, and two in the stratosphere. The top of the model atmosphere is fixed at 10mb. The model considers the radiative heating and the transfers of energy, mass, and momentum, both horizontally and vertically. The model includes sub-grid scale convection, and also includes large scale cloud processes, ground processes, and ground-atmosphere interactions through the surface air layer. Snowcover may occur over land or ice as dictated by the model, and surface-atmosphere interactions are dependent on surface type. The cloud cover is given as a fraction of each grid box for each layer, and the ocean ice cover and the sea surface temperatures are specified climatologically. The spatial coverage used bounds the continental United States from 125°W to 70°W, and from 26°N to 50°N, the limits being prescribed by the GISS supplied data. The analysis uses two years of the model control run with 1950's atmospheric CO_2 levels.

The NMC data were obtained from the National Center for Atmospheric Research (NCAR), and consist of sea level pressure measurements extrapolated to a grid of nominally equidistant points overlain on a polar stereographic projection (Jenne, 1975). The analysis uses daily data from 1960 to 1974, during a time period of predominantly meridional [redacted] flow in the upper atmosphere. The length of record is determined partly by computing constraints, and partly by the increased incidence of missing data that occurs in the latter 1970's. Palecki (1990) [redacted] shows that the GISS medium resolution model has a tendency toward more zonal flow over the U.S., but this appears to have only a minor effect on the results [redacted]. The NMC analysis methods employed during the 1960's and early 1970's underwent few changes, and are essentially those described by Cressman (1959). The changes that did occur involved the addition of new variables, some minor improvements to the algorithms, and the porting of the model to new computer systems. The observed errors are limited primarily to boundary problems, and to data sparse areas, neither of which affect the region used here. The areal coverage of the GISS output is matched by 126 data points from the NMC grid.

Data Pre-processing:

The data pre-processing consisted of filling in missing days in the NMC data, re-interpolating the GISS grid to the NMC grid, and removing the seasonal cycle from both data sets. The data gaps in the NMC record were of one day duration except for a single case with two missing days; consequently, linear interpolation between the previous and the following day's values are used to fill in missing grids. The GISS model operates on a longitude-latitude grid that results in a longitudinal difference of up to 30% in the distance between grid points from the southern to the northern boundaries of the region. This biases the data matrix to the northern part of the grid, and the GISS data are thus re-interpolated to the NMC grid prior to analysis. This has the further advantage of facilitating the comparison of the two data sets. The interpolation algorithm used is, in essence, an implementation of the equations presented by Willmott et al. (1985). The routine searches for N number of grid points within a pre-selected radius of the location of the interpolated point. The spherical distance to each point is calculated, and the points are weighted according to the inverse square of their distance from the point to be interpolated. Any directional bias is removed by adjusting the weights according to the angular separation between the points. A feature presented by Willmott et al. (1985) that allowed an interpolated point to be projected beyond the range of the data set was excluded in order to preserve a conservative approach to the study.

The objective of the study is to isolate the primary modes of the synoptic scale atmospheric circulation having temporal characteristics of days-to-weeks. Consequently, it is necessary to remove all components of the variance within the data set with time scales longer the synoptic events of interest. This was achieved using a simple moving average filter with a 13-day cutoff, centered on the day concerned. Each grid point is expressed as the difference from a mean value, where the mean is the average of all grid points over the 13 days. This procedure removes 6 days from the beginning and end of both data sets, which amounts to 0.2% of the NMC data and 1.6% of the model grids.

Map means (rather than the 13-day grid point means) are used in order to maintain the spatial gradients. The use of grid point means can distort, or even reverse, the actual pressure gradients where, for example, a weak low pressure system on a given day may appear as a positive departure for that time period. Using the 13-day map mean, however, does assume that all grid points are behaving synchronously to the same seasonal signal. While this is plainly not correct, it becomes a reasonable assumption when using a 13-day period since the seasonal leads and lags across the grid can be considered negligible in this time frame. The 13-day filter was selected based on autocorrelation (correlelograms) and power spectra of sea level pressure time series at a range of grid points. The power spectra indicate the spectral peaks, and the correlelogram shows the harmonics. The filter time period was then set at the period just prior to the first significant harmonic. In a final step, the data were sub-set into four overlapping regional sets covering each quadrant of the continental U.S. (Figure 2), and each set was further subdivided into four seasons, December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November(SON), resulting in 25 data sets for both the NMC data and the GISS model output.

Principal Components Analysis:

Principal Components Analysis (PCA) is an analytical technique that has been used in numerous studies to examine the spatial and temporal modes of atmospheric variability (Richman, 1986). It has also been used, with reasonable success, to carry out a simple comparison of observed Arctic sea level pressure patterns and GCM simulations (Crane and Barry, 1988). In the present case, the principal components (or eigenvectors) are extracted from the correlation matrix, and an orthogonal

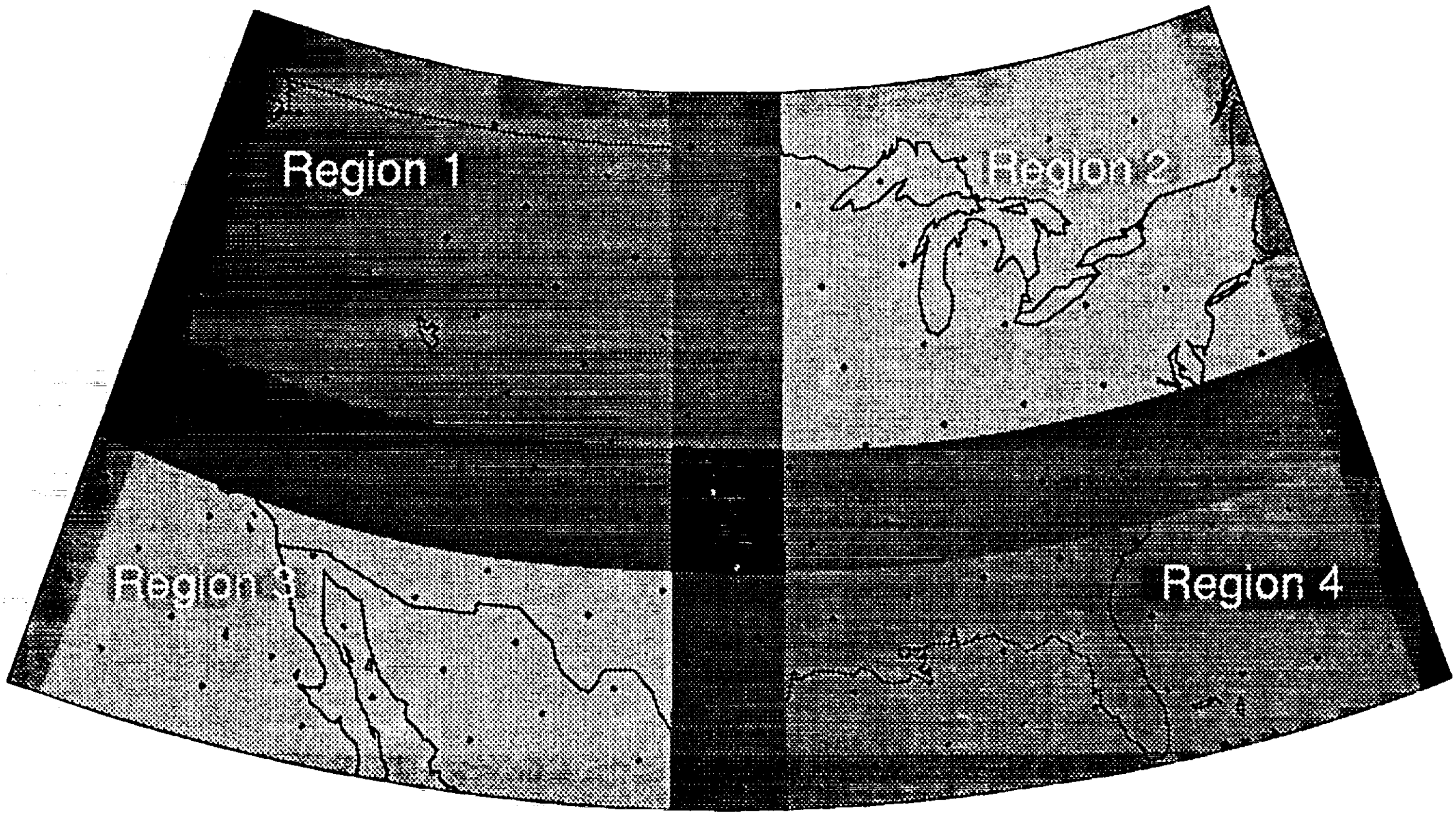

Figure 2. NMC Grid and Regional Boundaries.

rotation is employed to enhance the interpretability and to avoid the creation of Buell patterns (Buell, 1979). The number of components retained for rotation is based on a scree test, and, in all of the analyses, the retained components explained from 70% to over 90% of the variance. This was achieved using seven components for the continental scale analyses, and four components for each of the sub-regions. The component loadings for each grid point (which explain how each grid point loads on, or is related to, the component) are plotted as contour maps to provide a spatial representation of each component. Using these components, a time series of component scores for each day is generated, showing each component's contribution to any given days synoptic pattern. It is important to note, however, that PCA represents a *linear* filter, and that non-linearities in the data are not considered.

Comparison of Spatial Patterns:

Since the component loadings represent the fundamental modes of variance in the data set (i.e., those patterns that make up the primary synoptic circulation modes), the representativeness of the model circulation can be determined by correlating the observed and the modeled component patterns. Pairwise correlations of all combinations of the observed and the model components are calculated using Pearson's correlation coefficient to determine which, if any, of the NMC components are present in the model simulations. Three sets of correlations are computed, one using the actual grid point loadings, and the other two using the north-south and east-west gradients at each grid point. The measure of comparison then, becomes the average of the three correlation coefficients. Such a procedure is necessary because the Pearson's correlation coefficient does not distinguish gradient or amplitude differences between grids, leading to anomalously high coefficients when only the grid point loadings are used. All pairs are retained for which the average correlation is greater than 0.65[1]. The correlation coefficients for each pair of components in the "annual continental" analysis are shown in Table 1 and an example of two highly correlated patterns is shown in Figure 3.

The 0.65 cut-off results in seven pairs, with the lowest average r value being 0.87, and the highest being 0.94 (88% of the variance in common). Table 1 also shows that the matching patterns in the two data sets are very distinct. For example, NMC component 1 correlates with GISS component 1 with an average r value of 0.94. The next best correlation for NMC component 1 is with GISS component 4, with an average r value of only 0.23. In other words, there are no cases where a component in one set has a high correlation with more than a single component in the other. It is also interesting to note that the components have an almost one to one correspondence (eg. NMC 1 with GISS 1, 2 with 3, 3 with 2, etc.) indicating that not only do the patterns match, but they have similar ranks in their contribution to each data set's total variance. The matching components in the two sets also have similar levels of explained variance, although the GISS components tend to explain slightly less of the variance than does the corresponding NMC component. This is not surprising as the model can be expected to have more noise in its spatial representation of the circulation patterns due to the simplifications and parameterizations involved in the computations. This would lead to the variance being slightly less concentrated in the principal eigenvectors.

The results are similar for all analyses, with the exception of the summer season (all regions), the winter season for the North-East region, and fall in the South-West, where the results are less satisfactory (Figure 4). The poor performance in summer is probably due to the patterns being less persistent than in the other seasons. The summer patterns also tend to be less coherent and have

[1]Any correlation coefficient greater than .2 is significant at the 5% level and values greater than about .25 are significant at the 1% level. The cut-off at .65 is arbitrary, but represents a fairly conservative choice and ensures that at least 40% of the variance is common to the two patterns.

Table 1

Correlation results from correlating all combinations of components from annual continental data sets of NMC and GISS.

NMC Components	GISS Components	Average r	Grid Loadings	North-South Gradients	West-East Gradients
1	**1**	**0.94**	**0.97**	**0.91**	**0.93**
6	**5**	**0.91**	**0.97**	**0.84**	**0.92**
2	**3**	**0.91**	**0.95**	**0.85**	**0.92**
7	**4**	**0.91**	**0.97**	**0.87**	**0.87**
5	**7**	**0.90**	**0.96**	**0.87**	**0.86**
3	**2**	**0.89**	**0.96**	**0.81**	**0.91**
4	**6**	**0.87**	**0.94**	**0.75**	**0.90**
5	3	0.37	0.16	0.57	0.37
1	4	0.23	0.09	0.10	0.51
4	2	0.16	0.02	0.10	0.35
6	1	0.11	0.15	0.12	0.06
7	1	0.08	0.02	-0.20	0.41
3	7	0.06	0.31	-0.45	0.32
1	5	0.02	0.10	-0.01	-0.03
2	1	0.01	0.10	0.04	-0.11
3	6	-0.00	-0.01	-0.19	0.19
4	7	-0.01	-0.18	-0.30	0.43
1	3	-0.02	-0.00	0.12	-0.18
2	5	-0.03	0.07	-0.53	0.39
3	4	-0.04	-0.26	0.22	-0.07
2	7	-0.04	-0.19	0.21	-0.13
7	2	-0.05	-0.22	0.12	-0.05
7	3	-0.08	-0.36	0.17	-0.05
2	4	-0.11	-0.44	0.16	-0.05
5	2	-0.11	0.15	-0.62	0.12
4	1	-0.12	0.04	0.07	-0.48
4	5	-0.12	-0.40	0.36	-0.33
4	4	-0.13	0.07	-0.09	-0.35
6	6	-0.14	-0.42	0.33	-0.33
5	6	-0.15	-0.24	-0.43	0.22
6	3	-0.15	-0.01	-0.53	0.09
6	4	-0.15	0.05	-0.28	-0.23
7	5	-0.17	0.04	-0.28	-0.29
5	1	-0.18	-0.51	0.41	-0.45
5	4	-0.21	-0.33	-0.11	-0.20
3	3	-0.22	-0.08	-0.10	-0.49
1	7	-0.22	-0.51	0.28	-0.44
7	7	-0.23	-0.30	-0.23	-0.15
5	5	-0.25	-0.10	-0.20	-0.46
6	2	-0.26	-0.44	-0.06	-0.28
1	6	-0.26	-0.14	-0.13	-0.53
2	6	-0.33	-0.29	-0.48	-0.23
2	2	-0.34	-0.10	-0.41	-0.53
7	6	-0.35	-0.18	-0.36	-0.50
6	7	-0.36	-0.24	-0.14	-0.69
4	3	-0.39	-0.39	-0.64	-0.15
3	5	-0.39	-0.46	-0.29	-0.43
3	1	-0.43	-0.54	-0.35	-0.38
1	2	-0.51	-0.58	-0.50	-0.45

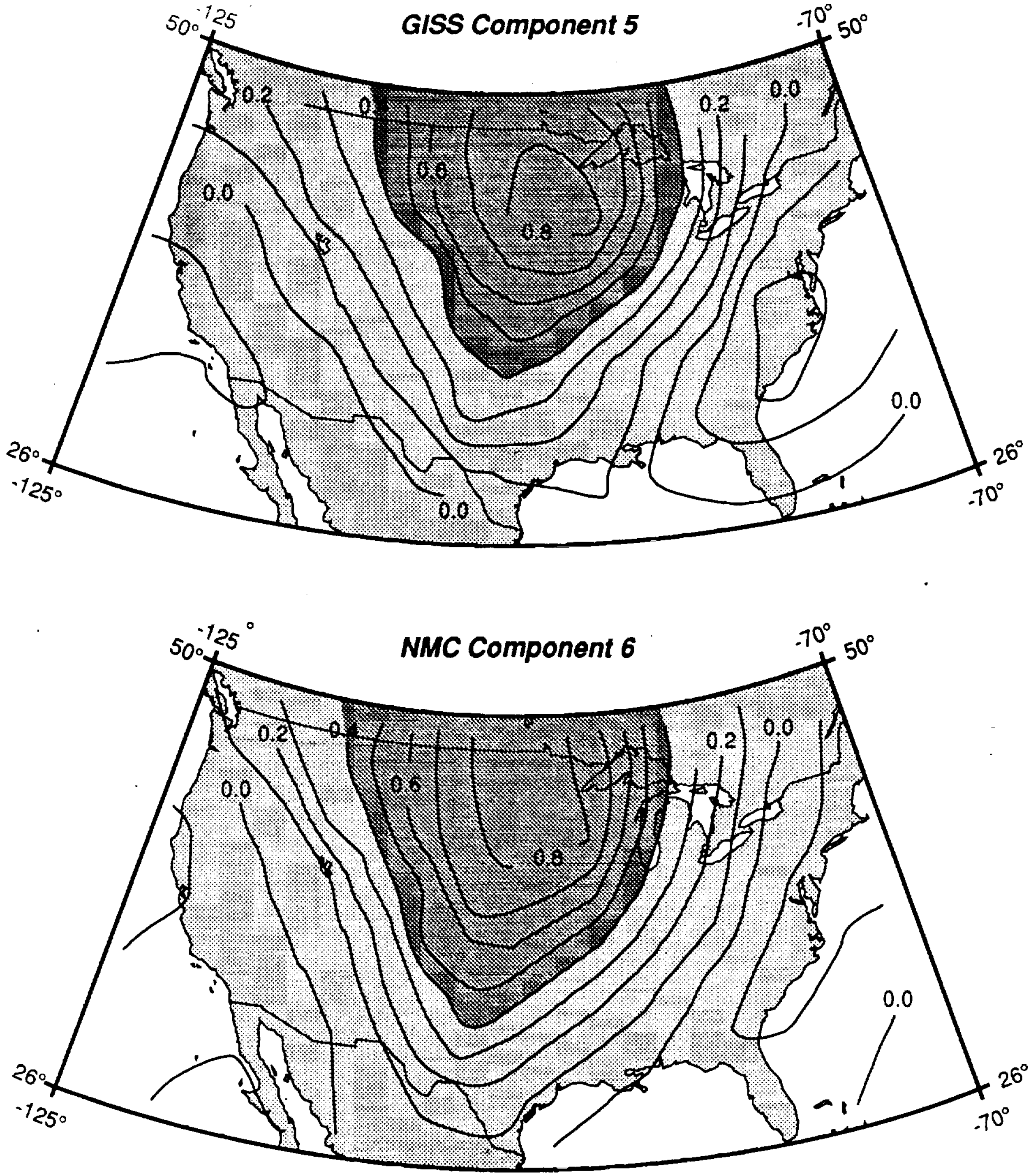

Figure 3. Examples of Patterns Having High Correlations Between the GISS and NMC Data.

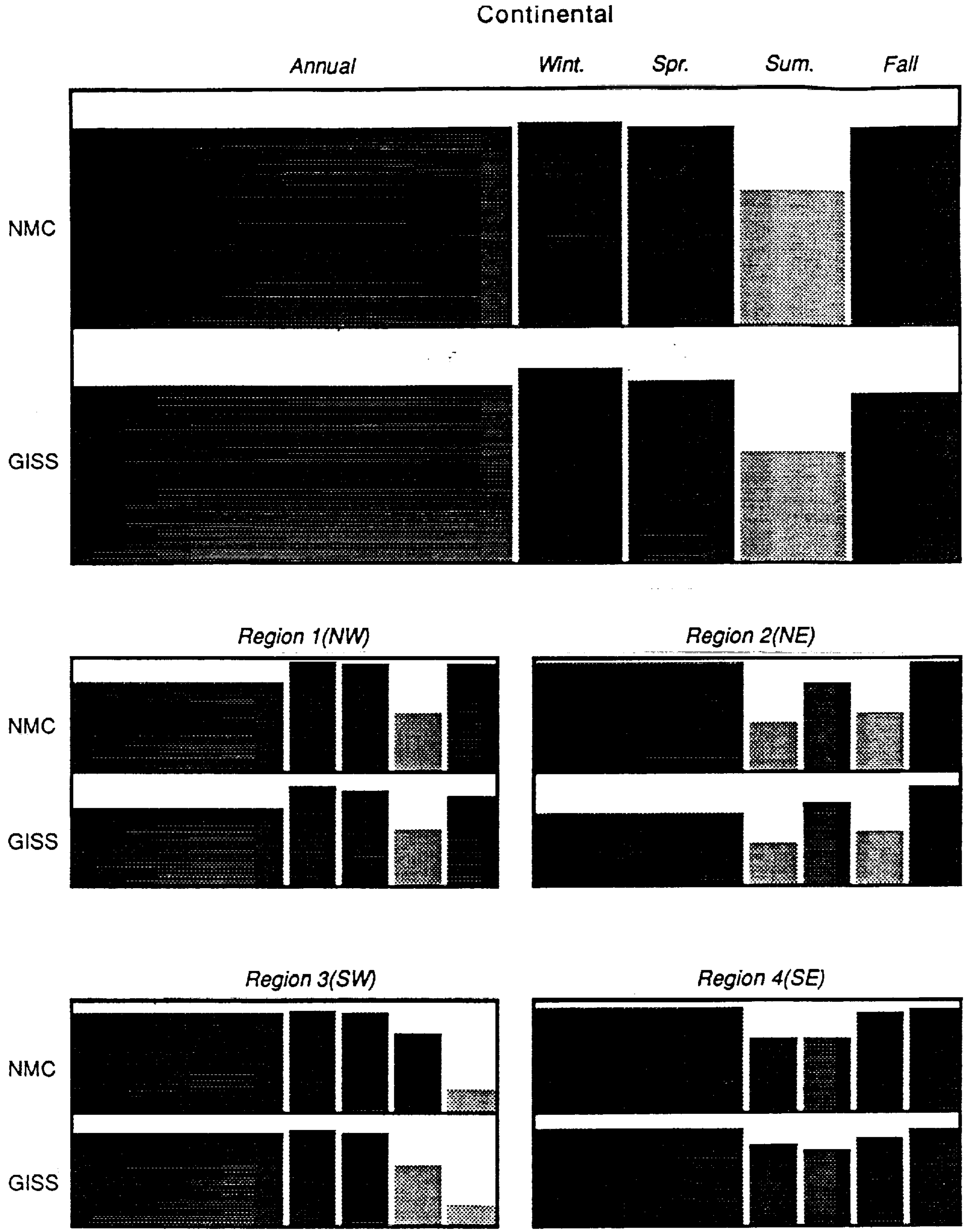

Figure 4. Total Percentage Variance Explained by Components That Correlate Spatially at all Seasons and Spatial Scales.

weaker gradients, making a good correlation more difficult. The poor winter correlation in the North-East is most likely due to that regions sensitivity to the upper atmosphere flow. As the model shows a slightly more zonal flow than the observed data at this time, it would lead to different surface patterns in the North-East. This would also tend to be most notable in winter when the jet stream is at its most southern extent.

The poorest of all of the spatial correlations are found in the fall season in the South-West. The reason for this is less clear, especially considering the very good correlations obtained during the rest of the year. The correlation coefficients show high correlations (> 0.7) for the component loadings, but very low correlations for the gradients. Most of the grid points in this region are at high elevations, and a possible explanation of the poor correlations may be found in the extrapolation to sea level values. Coupled with this is the fact that the fall represents the transition from the weak gradients of summer to the stronger winter patterns, which may provide a further explanation of the poor gradient matching.

Temporal Correlations:

The correlation of the component loadings shows that there is very good agreement between the model and the NMC data in terms of their spatial patterns. That is, both show the same synoptic scale atmospheric circulation features. The next test is to determine whether these synoptic scale features how similar temporal characteristics. The explained variance of each component shows how important it is to the overall variance in the data set, but it does not reveal how the component behaves with time (i.e., the frequency of observation or reoccurrence). The temporal patterns are, therefore, examined using Fourier analysis to show the dominant periods in their temporal occurrence. The power spectra of those components that have similar spatial patterns are correlated to determine whether they have similar spectral peaks. The spectra are correlated using Pearson's correlation coefficient over three band widths, from 2-12 days, 12-31 days, and 2-31 days. As the coefficients only demonstrate how well two variables co-vary, the total power for each bandwidth is also ratioed to give an index of how much power was contained in the NMC data with respect to the GISS data.

Unlike the spatial correlations, the temporal correlations were not quite as satisfactory (Table 2). The components that have high spatial correlations only have similar spectral peaks in the 2-12 day period, with the best correlations being found in the annual data. The seasonal data gave consistently poorer results. The power ratios within each bandwidth showed, as one might expect, that the NMC data tend to contain more power, thus indicating a greater coherence in the temporal behavior of the observed data[2]. Table 2 does serve to indicate, however, that the model is at least determining the broader, more fundamental, synoptic features with reasonable temporal accuracy. Component ~~1~~ 5, for example, which most likely represents the advance and retreat of the semi-permanent Canadian high pressure system (Figure ~~5~~ 3), is shown to have a good correlation with the models high pressure system in the short time frame. In other words, the model correctly determines the rate of advance and retreat of the high into the northern USA. That the correlation is poor at the longer time scales simply indicates that the pressure system dynamics on this time frame are more random in the model (i.e., the repetition period is not as regular). There is, however, near equivalence in the total power contained in the 2-31 day bandwidth for both spectra, showing that this feature explains a similar amount of variance in the model and the observed data on the monthly time scale.

[2]The annual data does not demonstrate this quite as clearly as all of the other analyses, where approximately 70% of the correlations showed the NMC data having the greater power within any bandwidth.

TABLE 2: Temporal correlations in three frequency bands for matching NMC and GISS component patterns in the "continental annual" data sets.

Components		2 to 31 days		2 to 12 days		10-31 days	
NMC	GISS	r	NMC/GISS ratio	r	NMC/GISS ratio	r	NMC/GISS ratio
1	1	0.26	-0.28	**0.80**	-0.11	0.12	-0.35
6	5	0.10	-0.43	**0.66**	-0.35	**0.60**	-0.16
2	3	0.49	-0.04	**0.77**	-0.28	0.45	0.17
7	4	0.36	-0.16	**0.60**	0.22	0.30	-0.07
5	7	0.28	-0.18	**0.80**	0.05	0.57	0.11
3	2	0.11	0.05	0.20	0.27	0.25	0.03
4	6	-0.12	0.31	**0.88**	0.23	**0.62**	0.49

Numbers in **bold** are those temporal correlations where $r > 0.6$

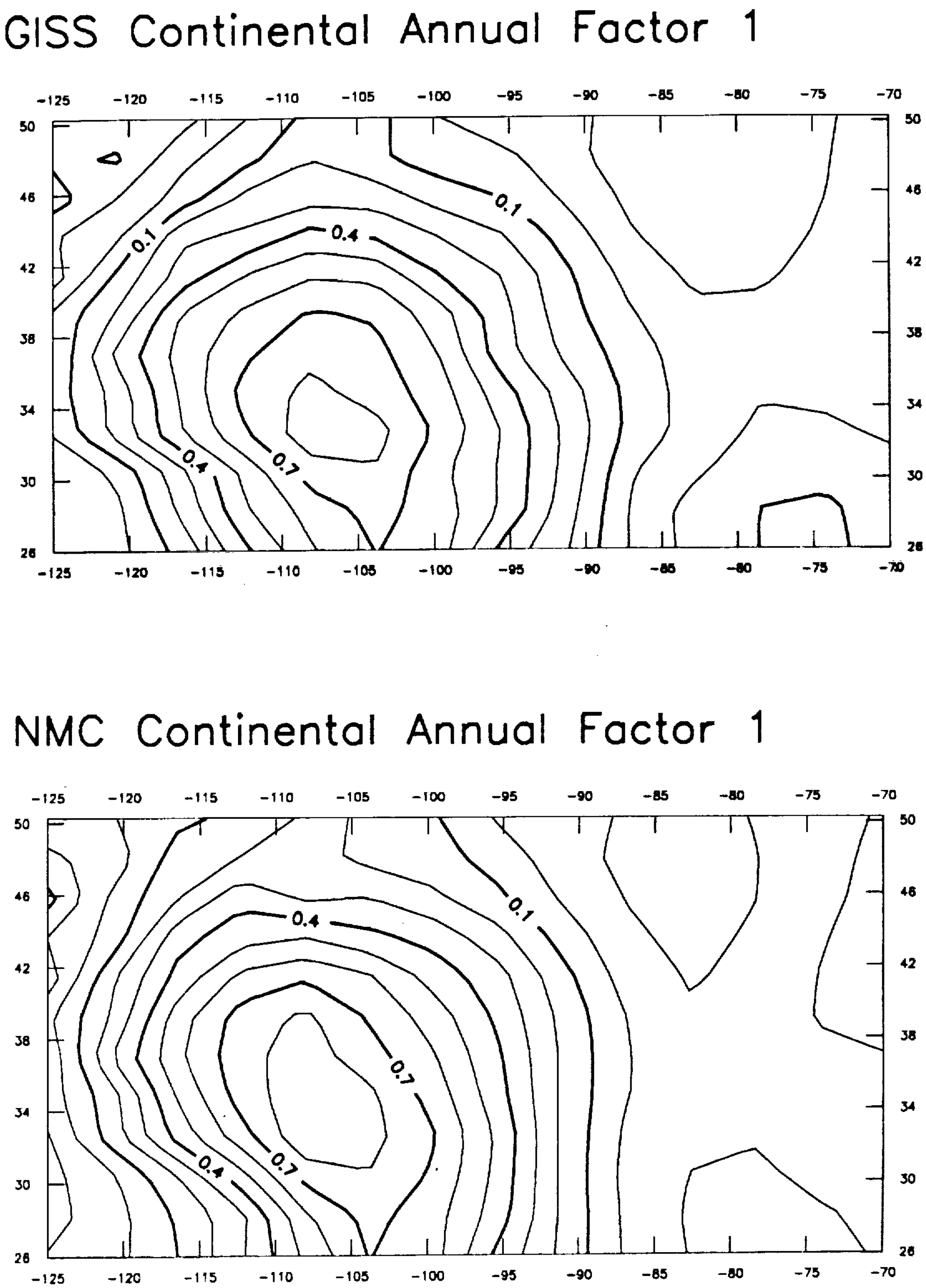

Figure 5. Spatial Distribution of NMC Component 1 and GISS Component 1.

3. Atmospheric Circulation and Grid-Point Temperature

The grid-point temperature predictions are made by matching a day's circulation to one of a pre-determined selection of representative pressure fields, and assigning it the temperature pattern for that group. This is a common technique in synoptic climatology (Barry and Perry, 1973), but it does have some limitations. A major objective in synoptic classification is to reduce a large number of circulation patterns into a small number (say 10-30) of synoptic "types" that represent a significant proportion of the original data set. There are a variety of approaches that have been attempted, but all of them result in synoptic "types" with relatively large within-group variance. This makes it difficult to predict specific climatic parameters from the synoptic circulation with any high degree of certainty. The present analysis, therefore, employs similar techniques, but does not limit the number of categories to a "convenient" few.

The Temperature Transfer Function:

Days in the NMC data set were categorized into like types using the time series of principal component scores (which represent the degree to which each day is influenced by each component). The scores for a single day are treated as a multidimensional vector, and the angle between any pair of vectors (days) is used as an indication of their similarity. A stringent threshold of $r \geq 0.95$ is used to assign vectors to groups, resulting in about 170 "types" for a single year of data. The size of the groups ranged between 1 and 10 days, and, for each group, a mean temperature map was created by averaging the temperature patterns for all of the days within each group. To predict the temperature for any given day, the PCA score for that day is correlated with each of the 170 "types" to obtain the closest match, and the mean temperature map for that type then becomes the predicted temperature distribution for that days pressure pattern.

Temperature Predictions:

The temperatures were predicted for a year of known data in order to test the transfer function. The time series of predicted temperatures at each grid were then correlated against the observed data, and a map of the grid point correlations was created. As can be seen in Figure 6, the prediction technique produces mixed results. The method predicts the northern and southern regions extremely well, with a zone of poorer correlations in between. The band of low correlations represents the polar front dividing the cooler polar air from the warmer sub-tropical air to the south. The correlation pattern is easily explained when considered from the viewpoint of the source regions affecting each area. Systems moving into the northern region of the U.S. are predominantly from the north and north-west. In contrast, the source for the South and the South-East is generally the Caribbean and the Atlantic, and for the South-West, the source becomes the Pacific. The Central U.S., however, is subject to air arriving from all regions. Similar circulation patterns over the Great Plains may have trajectories arriving from north or south, depending on the history of the system; two scenarios that would bring vastly different temperature characteristics to the region. To improve the temperature predictions over the central portion of the continent, therefore, requires that some degree of dynamics describing the movement of air masses be incorporated into the typing scheme.

4. Summary and Future Development

Current Status:

The analysis demonstrates that the GISS high resolution GCM effectively simulates the synoptic scale atmospheric circulation over the United States. The surface pressure patterns describing the atmospheric circulation of the model are comparable to those found in the observed data, and comparable patterns explain similar amounts of variance in their respective data sets. The frequency

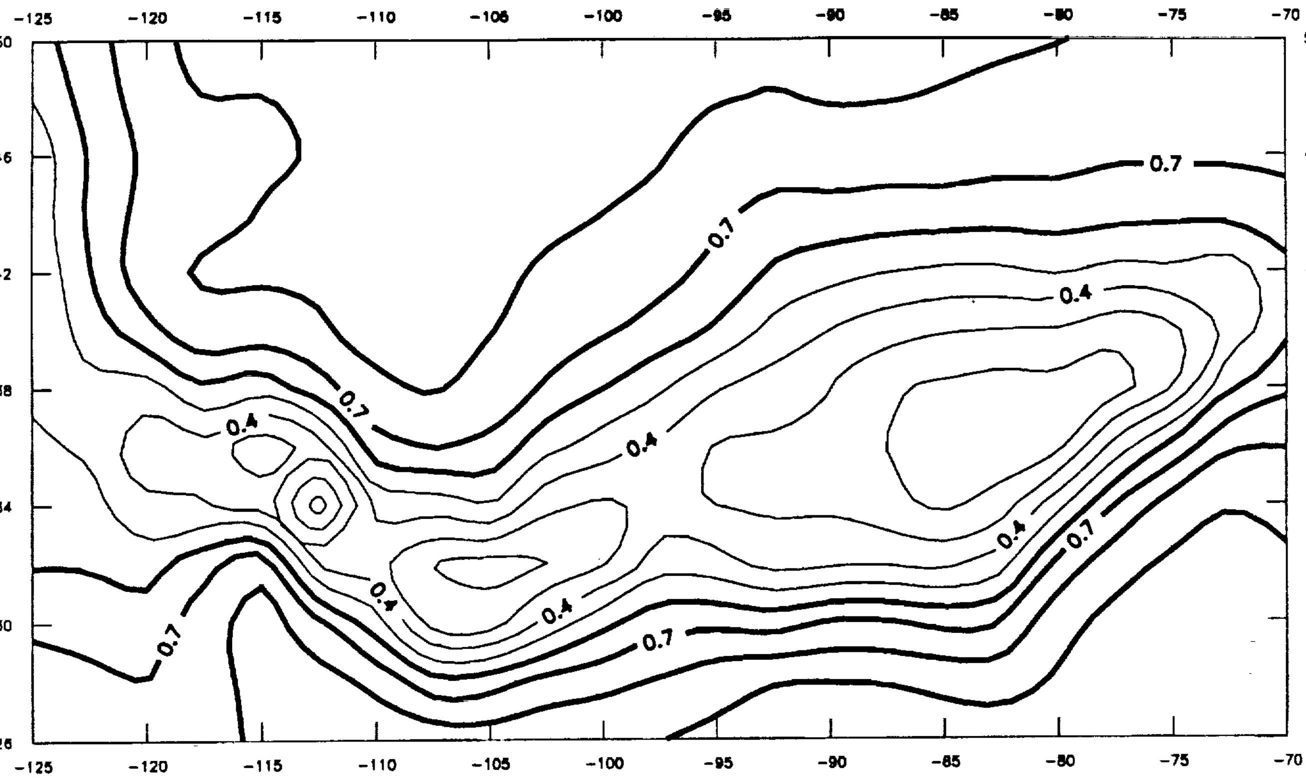

Figure 6. Correlations of Predicted vs Actual Temperatures for One Year Over the Continental USA.

of occurrence of these patterns on the synoptic time frame are also comparable, at least for the annual continental data sets. The first assumption outlined in the introduction (namely that the model accurately simulates the synoptic circulation) is , therefore, justified. One word of caution that should be noted is that the data are representative of only one portion of the northern hemisphere. This is also a region that lends itself to optimal results in that the controlling circulation factors of the upper atmospheric flow are strongly locked in place by the Rockies, and by the baroclinicity of the East Coast. Whether equally good results could be obtained for all extra-tropical regions remains to be tested.

With regard to the second assumption (that the temperature field is strongly related to the synoptic circulation), the results are mixed. The transfer function results in good temperature predictions for more than half of the country. These results are good enough that we could continue with the second phase of the study and examine the changes in the doubled CO_2 simulations. Before doing this, however, it is worth trying to improve on the temperature predictions for the central region by modifying the typing scheme to include some information on dynamics.

Current Work:

The plans for the remainder of Year 1 are to improve on the temperature transfer function. This will be achieved by calculating trajectories from grid points in the central U.S., and grouping those days that have a similar distribution of grid-point trajectories. The synoptic typing will then be a two step process. The initial typing will be performed on the PCA scores, and groups will then be subdivided in terms of the source regions affecting the central part of the continent.

Year Two:

The objectives for year two are to:

1) Continue the analysis of the regional and seasonal data sets.

2) Use the temperature transfer function to calculate the temperature fields for the model control run, and compare these to the model simulations of temperature on a daily and monthly basis.

3) Determine the changes in the synoptic scale circulation between the model control run and the doubled CO_2 climate.

4) Use the transfer function to calculate the change in the temperature field for a CO_2 doubling.

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Attachment I: Conference/Seminar Papers and Publications Supported Under NAG 5-1133.

Papers:

Crane, R.G. and Hewitson, B.: **Regional Climates in the GISS GCM.** Invited Seminar Paper, The Goddard Institute for Space Studies, New York, New York, March 1990.

Hewitson, B. and Crane, R.G.: **Validation of GCM Simulations of Synoptic Scale CIrculation.** Annual Meeting of the Association of American Geographers, Toronto, Canada, April 1990.

Publications (in preparation):

Hewitson, B. and Crane, R.G. Regional Climates in the GISS GCM: Synoptic Scale Circulation. To be submitted to ***Journal of Climate***.

Hewitson, B. Regional Climates in the GISS GCM: Grid-Point Temperature Patterns. To be submitted to ***Journal of Climate***.