The Journal of the Iowa Academy of Science: JIAS

Volume 98 | Number Article 3

1991

Iowa's Climate as Projected by the Global Climate Model of the Goddard Institute for Space Studies for a Doubling of Atmospheric Carbon Dioxide

E. S. Takle
Iowa State University

S. Zhong
Iowa State Universtiy

Jour. Iowa Acad. Sci. 98(4):153-158, 1991

Iowa's Climate as Projected by the Global Climate Model of the Goddard Institute for Space Studies for a Doubling of Atmospheric Carbon Dioxide[1]

E.S. TAKLE and S. ZHONG

Department of Agronomy, Department of Geological and Atmospheric Sciences,
3010 Agronomy Hall, Iowa State University, Ames, IA 50011 (515) 294-9871

Results of a global climate model that simulates climate under a doubling of atmospheric carbon dioxide (estimated to occur by the latter half of the twenty first century) have been interpolated to Iowa. Summer temperatures under such a doubling are projected to rise by 4 to 7°F (2.2 to 3.9°C) and winter temperatures by 10 to 11° (5.6 to 6.1°C). Estimates of space heating and cooling demands from these data suggest a 30 to 35% decrease in space heat demand and a 200 to 300% increase in space cooling demand. Temperature variability is projected to decrease. Precipitation estimates from global climate models are not considered very reliable. For the model used, total annual precipitation for Iowa increases by about 3% which is well within the natural year-to-year variability.
INDEX DESCRIPTORS: Climate change, Climate variability, Heating degree days, Cooling degree days.

We have analyzed the data produced by the global climate model of the Goddard Institute for Space Studies (GISS) for a doubling of atmospheric carbon dioxide and have interpolated these data to points in the state of Iowa. We present here some preliminary results of this analysis and an interpretation of some of the implications for the energy consumption and agricultural activities of the state.

We emphasize that these projections are not predictions of the climate at some point in the future. Rather, they represent global patterns of climatological conditions that are internally consistent with a doubling of atmospheric carbon dioxide and obey global conservation laws for energy, mass, and momentum at least to within the limits of the approximations employed. Although large discrepancies exist among models in projections for specific locations, some characteristics (e.g., larger warming at the poles than in the tropics, warming of continental interiors greater than the global mean) are common to all models. Inadequate characterization of the effects of clouds, oceans, and subgrid-scale processes are the major limitations of present models. As models are improved, regional details likely will be modified from present projections. The purpose of the present paper is to demonstrate what the implications of a particular pattern of global warming would mean for Iowa. If improved models show more or less warming than the present GISS model, the results herein presented should be comparably adjusted.

The most widely held opinion of climate modelers (the notable exception being the chief scientist of the GISS model program [Kerr, 1989]) is that there is too much uncertainty in the models to attribute the observed climate warming of the last century (Jones, et al., 1986) to the observed increase in CO_2 and other greenhouse gases. Climate models with observed concentrations of greenhouse gases produce a rise in surface temperature of about 1°C over the last century, whereas the climate data indicate a 0.5°C rise. These results suggest the models are accurate to about a factor of 2 in projecting temperature changes due to an increase in greenhouse gases (Schneider, 1990). Despite the intense debate over magnitudes, most modelers agree that the build-up of greenhouse gases ultimately will lead to global warming (Kerr, 1990). Because of this widespread scientific consensus, simulations of the earth's climate consistent with elevated concentrations of greenhouse gases (expressed as a CO_2-equivalent) have been used as a basis for global and regional studies of the impacts of such change. This brief report summarizes some characteristics of the Iowa climate as projected by the GISS model. Tables and figures included in this report have temperatures in degrees Fahrenheit and precipitation in inches for ease of comparison with National Weather Service observations and for comparison with other derived units (e.g., Heating Degree Days).

THE GISS MODEL

The GISS model (Hansen et al., 1983; Rind, 1988; and Hansen et al., 1988) represents the global atmosphere by meteorological variables at grid points separated by 7.83 degrees latitude, 10.0 degrees longitude, and nine levels in the vertical. The model represents the average intensity of the solar radiation at the outer edge of the atmosphere by the observed 1387 W/m^2. Control runs of the model use an atmospheric carbon dioxide level of 315 ppm, which corresponds to the 1958 average measured value. At the earth's surface, the model represents each grid box by fractional coverages of land (with no permanent ice), land ice, ocean or lake ice, and open water. The fractional coverages of ocean/lake ice and open water are allowed to vary in response to surface temperatures throughout the simulation. The GISS model simulates the diurnal cycle by allowing solar radiation to vary as observed over each day. The earth's surface is represented by two soil layers over land and a slab ocean that varies somewhat in depth with the seasonal cycle, but is never deeper than 65 m. The capability of the oceans to move heat towards the poles is crudely represented in the model. The top layer of soil can store 20 cm of water in rain forests, 3 cm in other forests and crops, and 1 cm in deserts. The second layer can hold about 30 to 45 cm of water for all forests, about 20 cm for grass and crops, and only 1 cm for deserts. Water cannot be extracted from the soil if the ground is frozen.

To simulate the present climate ($1xCO_2$) or the climate consistent with a doubling of atmospheric CO_2 ($2xCO_2$), the model has been run for a simulated time of 35 years, with the average of the last 10 years used to represent the mean climate.

The model predicts that the mean global surface temperature will increase by 4.2°C for a doubling of CO_2. About 30% of this increase is attributed directly to increased infrared absorption by water vapor (which is about 33% higher than present levels), 20% to decreased cloudiness and increased proportion of cirrus, and 10% to changes in surface reflectivity, mostly due to reduction of sea ice.

The GISS model has also been run in the "transient mode," in which the concentrations of greenhouse gases gradually change from their

[1]Journal Paper No. J-14226 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project No. 2779.

Table 1. Surface air temperature normals and air temperature computed for a doubled CO_2 climate (°F). 2-N = $2xCO_2$ - normal.

STATION	DES MOINES WSO			MASON CITY FAA			OTTUMWA FAA		
MON	NORMAL	2*CO2	2-N	NORMAL	2*CO2	2-N	NORMAL	2*CO2	2-N
JAN	18.6	29.8	11.2	12.5	23.8	11.3	19.9	31.0	11.1
FEB	24.5	34.3	9.8	18.6	28.8	10.2	25.9	35.6	9.7
MAR	35.1	45.2	10.1	29.4	39.2	9.8	36.1	46.1	10.0
APR	50.5	59.5	9.0	46.0	54.9	8.9	51.1	60.2	9.1
MAY	62.1	67.3	5.2	58.4	63.3	4.9	62.5	67.7	5.2
JUN	71.6	78.4	6.8	68.2	75.0	6.8	71.9	78.7	6.8
JUL	76.3	80.7	4.4	72.2	76.2	4.0	76.2	80.5	4.3
AUG	73.9	81.1	7.2	70.0	76.9	6.9	73.9	81.1	7.3
SEP	65.1	77.8	12.7	60.7	73.1	12.4	65.5	78.5	13.0
OCT	54.2	61.3	7.1	49.9	56.7	6.8	54.5	61.6	7.1
NOV	38.6	50.3	11.7	33.9	43.7	9.8	39.5	51.4	11.9
DEC	25.7	36.1	10.4	19.8	30.0	10.2	26.9	37.4	10.5
ANN	49.7	58.5	8.8	44.9	53.5	8.6	50.3	59.1	8.8

observed 1958 values at one of three rates representing strong, moderate, and weak growth. These simulations allow the ocean temperature to lag behind the atmospheric level (because of its greater thermal storage capacity). Model results from these simulations have been acquired from the National Center for Atmospheric Research (Jenne, 1988).

PRELIMINARY RESULTS FOR THE EQUILIBRIUM $2xCO_2$ SIMULATION

Mean temperature

The analysis of model-generated mean monthly surface-air temperature is given in Table 1. We have interpolated the GISS model values to three points (Des Moines, Mason City, and Ottumwa) representing central, northern, and southern latitude cities within the state. The use of three locations within a single GISS grid cell is a crude but simple way of demonstrating changes in the north-south gradient of temperature (which all models project to be altered) and the sensitivity of derived variables to this change. For each city, we give the mean temperature as listed in the tables of monthly normals for 1951-80 (NOAA, 1982b). Model simulations using the present atmospheric trace-gas concentrations differ from these normals, in the worst instances, by being 10°F (5.6°C) too warm in February and by being 12°F (6.7°C) too cold in June. The modeled amplitude of the seasonal cycle of the present climate (highest monthly mean minus lowest monthly mean) is 17°F (9.4°C) less than the observed value. Because the models are more reliable at simulating differences than absolute values, we have subtracted the projected temperatures for the $2xCO_2$ simulation from the $1xCO_2$ simulation and added this difference (third column under each city in Table 1) to the observed normals (first column under each city in Table 1) to obtain the estimated surface-air temperature under doubling of carbon dioxide (second column under each city in Table 1). The results show warming in all months, with largest values in September and November through March. Because of the coarse resolution of the model, the simulated temperature increases are uniform across the state. The annual mean increase is about 8.8°F (4.9°C), which is about 1.2°F (0.7°C) more than the global mean increase.

Mean Precipitation

It is widely acknowledged that precipitation simulations by climate models are very crude. Precipitation amounts vary widely over fairly small distances, particularly in the warm season, so models having such coarse resolution as the GISS model should not be expected to represent true spatial variability. Furthermore, the simplified manner in which precipitation, evaporation, soil moisture-retention and runoff are represented casts doubt upon the reliability of precipitation estimates. Nevertheless, these values have been used in other studies on agricultural impacts.

Table 2 lists the monthly normal precipitation for three Iowa cities for 1951-80. The model does not accurately reproduce the observed precipitation for the simulation of the present climate, so a ratio has been taken (column three under each city in Table 2) of the precipita-

Table 2. Precipitation normals and precipitation computed for a doubled CO_2 climate (inches). Ratio = $2xCO_2$/Normal.

STATION	DES MOINES WSO			MASON CITY FAA			OTTUMWA FAA		
MON	NORMAL	2*CO2	RATIO	NORMAL	2*CO2	RATIO	NORMAL	2*CO2	RATIO
JAN	1.01	1.16	1.15	0.82	0.85	1.04	1.15	1.31	1.14
FEB	1.12	1.15	1.03	0.86	0.88	1.02	0.99	1.03	1.04
MAR	2.20	2.82	1.28	1.85	2.48	1.34	2.41	3.01	1.25
APR	3.21	3.27	1.02	2.76	2.90	1.05	3.52	3.52	1.00
MAY	3.96	4.67	1.18	4.10	4.67	1.14	3.80	4.56	1.20
JUN	4.18	4.34	1.04	4.57	4.84	1.06	3.93	4.17	1.06
JUL	3.22	3.22	1.00	4.21	4.29	1.02	4.42	4.69	1.06
AUG	4.11	4.23	1.03	4.14	4.31	1.04	4.01	3.85	0.96
SEP	3.09	2.44	0.79	3.25	2.57	0.79	3.61	2.74	0.76
OCT	2.16	1.71	0.79	2.02	1.70	0.84	2.46	1.97	0.80
NOV	1.52	1.58	1.04	1.27	1.37	1.08	1.66	1.69	1.02
DEC	1.05	1.27	1.21	0.96	1.20	1.25	1.29	1.55	1.20
ANN	30.83	31.86	1.03	30.81	32.06	1.04	33.25	34.09	1.03

Table 3. Heating degree days (base 65°F) computed from monthly normal temperatures and for a doubled CO_2 climate.

STATION	DES MOINES WSO		MASON CITY FAA		OTTUMWA FAA	
MON	NORMAL	2*CO2	NORMAL	2*CO2	NORMAL	2*CO2
JAN	1438.4	1091.2	1627.5	1277.2	1398.1	1054.0
FEB	1134.0	859.6	1299.2	1013.6	1094.8	823.2
MAR	926.9	613.8	1103.6	799.8	895.8	585.9
APR	435.0	165.0	570.0	303.0	417.0	144.0
MAY	89.9	0	204.6	52.7	77.5	0
JUN	0	0	0	0	0	0
JUL	0	0	0	0	0	0
AUG	0	0	0	0	0	0
SEP	0	0	129.0	0	0	0
OCT	334.8	114.7	468.1	257.3	325.5	105.4
NOV	792.0	441.0	933.0	639.0	765.0	408.0
DEC	1218.3	895.9	1401.2	1085.0	1181.1	855.6
ANN	6369.3	4181.2	7736.2	5427.6	6154.8	3976.1

tion simulated for the $2xCO_2$ run to the precipitation simulated for the $1xCO_2$ run and the result multiplied by the 1951-80 normal value (column 1) to arrive at the estimated precipitation under doubling of CO_2 (column 2).

Annual precipitation simulated for the doubled CO_2 climate is increased by a few percentage points, with most of the increase occurring from December through May. Only September and October have reduced precipitation. Because of the higher winter temperatures, however, we would not necessarily expect higher snowfall totals. More cold season precipitation, together with a longer period of frost-free soil, suggests increased opportunity for winter recharge of subsoil moisture supplies under the climate of doubled CO_2.

Heating Degree Days

The heating degree day (HDD) is a crude measure used by the National Weather Service (NWS) to relate temperature to the need for space heating. The HDD is defined by the NWS as the difference between 65°F and the average daily temperature for mean daily temperatures below 65°F (Fahrenheit temperatures are the accepted units for HDD, so no Celsius equivalent will be given). The sum of all daily values for a month then gives the monthly total HDD. We have estimated the monthly total HDD for the model-simulated climate by subtracting the monthly mean temperature (column 2 of Table 1 for each city) from 65°F and multiplying the difference by the number of days in the month. Because we are interested in changes in HDD from the present amounts, we have used the same procedure to estimate monthly normals. This procedure underestimates the true value, which requires *daily* temperatures. As a result, the entries under normal in Table 3 differ from the 1951-80 climatological values based on daily temperatures by 1% or less for November through March, less than 10% for October and April, but 50% or more for May through September. The annual total is only 3% low, however.

Analysis of Table 3 reveals that the annual total HDD is reduced by 34% for Des Moines, 30% for Mason City, and 35% for Ottumwa under a doubling of CO_2. Heating demand during January under $2xCO_2$ is less than that during December under the present climate. Values for transitional months have large relative errors. For instance, September will probably have a few days with mean temperatures below 65° even though the monthly average is above 65°F.

Cooling Degree Days

A quantity that is used for estimating space cooling demand is the cooling degree day (CDD), which is defined by the NWS as the difference between the mean daily temperature and 65°F for days with mean daily temperatures above 65°F. The CDD is less reliable in estimating the need for space cooling than HDD is for heating because cooling is considered more of a comfort than a necessity. (A continuous temperature of 80°F [15 CDD] would be more acceptable than 50°F [15 HDD] for most people.) The sum of the daily values for a month is the monthly total. With the same approximations used for HDD, we have estimated monthly total CDD's by using both the mean monthly temperatures for the 1951-80 observations and the $2xCO_2$ temperatures of Table 1 (see Table 4). The monthly values underestimate totals computed by using mean daily temperatures by up to 10% for Des

Table 4. Cooling degree days (base 65°F) computed from monthly normal temperatures.

STATION	DES MOINES WSO		MASON CITY FAA		OTTUMWA FAA	
MON	NORMAL	2*CO2	NORMAL	2*CO2	NORMAL	2*CO2
JAN	0	0	0	0	0	0
FEB	0	0	0	0	0	0
MAR	0	0	0	0	0	0
APR	0	0	0	0	0	0
MAY	0	0	0	0	0	0
JUN	198.0	402.0	96.0	300.0	207.0	411.0
JUL	350.3	486.7	223.2	347.2	347.2	480.5
AUG	275.9	499.1	155.0	368.9	275.9	499.1
SEP	3.0	384.0	0	243.0	15.0	405.0
OCT	0	0	0	0	0	0
NOV	0	0	0	0	0	0
DEC	0	0	0	0	0	0
ANN	827.2	1771.8	474.2	1259.1	845.1	1795.6

Table 5. Observed interannual variability (standard deviation) of mean monthly temperatures (°F) and estimated interannual variability in a doubled CO_2 climate.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Observed	5.2	5.7	5.7	3.4	3.3	2.7	2.7	2.1	2.4	4.0	3.6	4.8
0.85xObs.	4.4	4.8	4.8	2.9	2.8	2.3	2.3	1.8	2.0	3.4	3.1	4.1

Moines for June, July, and August and by much larger percentages for April, May, September, and October; absolute magnitudes of these underestimates, however, are small. Annual totals are estimated to be about 20% low because monthly mean temperatures are used.

The annual totals show a doubling of CDD's for Des Moines and Ottumwa and a near tripling for Mason City. At all locations, June and September contribute much more significantly to the annual total. Peak values shift from July at present to August under doubling of CO_2, and magnitudes increase by 43 to 65%. As with HDD, the monthly values during transition months have large errors compared to the totals derived from daily values. October and May will probably have several days with mean daily temperatures above 65°F even though monthly means are less than 65°F.

Soil temperatures

Soil temperatures under a doubling of CO_2 are projected to rise by amounts equivalent to the surface-air temperature changes given in Table 1. These increases will substantially change the length of time the soil is frozen in winter.

Normally, central Iowa soil freezes in about the first week in December (although this can vary by at least half a month) and thaws during the middle to the end of March (also variable within a few weeks) thereby giving a frozen soil period of about 3 1/2 months. With winter temperature changes projected by the GISS model (about 10-11°F [5-6°C] warmer), this period is reduced to about 1 1/2 months and spans the beginning of January to mid-February. Some winters would not have frozen soils. Under the climate change projected by this model, precipitation during December and late February/early March would be available to recharge groundwater supplies and be less likely to contribute to runoff and early spring stream flow. There is additional uncertainty in these projections because of the influences of other factors such as increased evaporation and changes in surface insulation due to changes in snowfall amount.

The combined effects of reduced freeze period, increase in number of freeze/thaw cycles, and modified soil hydrology will probably have impacts on physical, chemical, and biological processes in the soil between growing seasons. The nature and magnitude of these impacts have yet to be determined.

Temperature variability

Variations in temperature, rather than mean temperatures, are frequently the limiting factors for biological systems. Killing frosts or "heat waves" can abruptly terminate biological processes in an otherwise "normal" year. When mean climate changes, those species at the outer boundaries of their optimum climatic zone are especially vulnerable.

We have not yet made studies of climate variability in Iowa under doubling of CO_2, but Rind et al. (1989) have used the GISS model to examine stations in the Great Lakes Region, the southern Great Plains, and two other areas of the US farther from Iowa. Temperature variability is considered on three scales: year-to-year varability, daily variability, and diurnal cyclical variability. The following statements on temperature variability for Iowa are based on the results of Rind et al. for nearby areas.

Rind et al. (1989) conclude that modeled values of temperature variability are in good agreement with observed values of the present climate, except in summer, when the model tends to overestimate variability. They attribute this deficiency to poor representation of the surface hydrology during the warm season. Their results show that interannual variability of temperature decreases with a doubling of CO_2, with larger reductions generally occurring at higher latitudes. Rind et al. provide physical evidence in support of this general trend. From their data, we estimate the interannual variability of temperatures for Iowa under doubling of CO_2 to be about 85% (± 25%) of the present observed values. On line 1 of Table 5, we give the interannual variation in mean monthly temperatures as determined from the 1951-80 data (National Oceanic and Atmospheric Administration, 1982a) for Des Moines. The largest variation from year to year is in February and March, and the minimum variation is in August. On line 2 of Table 5, we have taken 85% of the corresponding monthly value from line 1. The percentage change in temperature variation for $2xCO_2$, as determined by Rind et al., is not the same for each month but shows no clear seasonal trend, so we simply multiply the observed variability by 0.85 for all months.

The day-to-day variability computed by Rind et al. showed a 10-20% decrease roughly corresponding to the reduction in interannual variability, but the results were not statistically significant. No obvious change in persistence was observed for the warmer climate. Decreased variability in a warmer climate described by Table 1 means that January temperatures would hover nearer the freezing point than they do in the present climate. The frequency of prolonged cold periods or abnormally warm periods would be reduced.

Typical diurnal variations in temperature (daily maximum minus daily minimum) for Iowa are shown in Figure 1. Stations at a distance from major metropolitan areas were chosen to reduce commonly observed anomalous nighttime urban warming. All stations shown experience warm season variability 3° to 5°F (1.6° to 2.8°C) greater than in the cold season. Diurnal variability of the GISS model $2xCO_2$ climate is reduced by up to about 25% in summer in comparison with the present climate. Winter variability is also reduced, but by a smaller percentage. The model $2xCO_2$ climate has less nighttime cloud cover during winter, spring, and fall but about the same summer cloud cover when compared to the present climate, thereby allowing increased trace-gas concentrations to play a greater role during the cool seasons. The decreased cloudiness, however, allows for enhanced cooling, which offsets parts of the trace-gas warming.

A reduction in the diurnal range, coupled with increased mean temperatures, has significant implications for agriculture. If the nighttime minimum temperature is increased by trace-gas absorption, the likelihood of dew formation would be reduced. Diseases and insects thriving under the presence of dew would find this scenario less favorable. (The 1971 Southern Corn Leaf Blight epidemic was attributed in part to an extended period during which dew was continuously present). By contrast, if minimum nighttime temperatures increase because of the higher water-vapor content of the atmosphere, the likelihood of dew formation would increase.

The question of whether extreme high temperatures would occur more frequently under doubled CO_2 is difficult to answer. From Table 1, surface-air temperatures in summer are increased by about 6°F (3.3°C). The observed diurnal range in summer (Figure 1) is about 23.5°F (13.0°C), which according to Rind et al., would be reduced by about 20%, to 19°F (10.6°C). If this range is simply superimposed on the monthly mean, the mean daytime high temperature is about 4°F (2.2°C) higher than at present. Rind et al. also noted that the model was disposed to produce more extreme surface temperatures than are

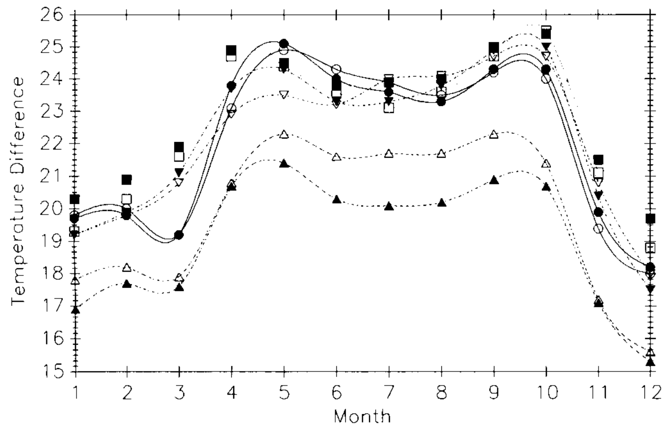

Fig. 1 Observed diurnal temperature range (difference between daily maximum and daily minimum) in °F at eight cities in Iowa, representing the following areas:

Northwest:	Milford (open circles) Sheldon (solid circles)
Northeast:	Cresco (open triangles, pointing up) Waukon (solid triangles, pointing up)
Southwest:	Shenandoah (open squares) Clarinda (solid squares)
Southeast:	Bloomfield (open triangles, pointing down) Keosauqua (solid triangles, pointing down)

observed. These factors taken together suggest that summer extreme high temperatures might not be expected to increase as much as the mean values in Table 1. This conclusion should be considered highly speculative, however.

Precipitation Variability

Daily precipitation amounts can be markedly different over distances of a few kilometers, so determining variability of precipitation over Iowa by interpolation from the very coarse grid of the GISS model is tenuous at best. Rind et al. conclude that when large geographic areas are considered, interannual precipitation variability increases in a doubled CO_2 climate. The GISS model produces an increase in mean annual global precipitation, so it is to be expected that variability increases as the mean increases.

PRELIMINARY RESULTS FROM TRANSIENT RUNS

The GISS model has also been run in a transient mode in which greenhouse gases gradually increase in concentration from their observed values in 1958. Three rates of increase have been used, representing rapid (transient A), moderate (transient B), and slow (transient C) growth rates. We will examine only the results for transient B, which most clearly represents the expected growth rate. The assumed rates of increase of trace gases (carbon dioxide, methane, and chlorinated fluorocarbon-12) for this scenario are given in Table 6 (Jenne, 1988). The base climate to which comparisons are made is for the period 1946-55.

Decadal Mean Temperature Change by Season

A plot of the decadal averages of seasonal changes in temperature from the base climate for Des Moines is shown in Fig. 2. All seasons are projected by the model to have temperature increases as CO_2 levels increase, with the most significant increase occurring in the cool season. The model produces considerable fluctuation from decade to decade, with some periods having temperature decreases from the base period.

Table 6. Atmospheric concentrations of trace gases changed in the GISS transient B run.

Year	CO_2(ppm)	CH_4(ppm)	CCl_2(ppt)
1958	315.0	1.40	0.025
1980	337.6	1.65	0.308
2000	370.5	2.10	0.700
2030	427.0	2.40	1.400
2050	465.0	2.70	1.800

For the decades of the 1970s and 1980s we have observations corresponding to the model projections. Mean values and standard deviations are given in Table 7, and mean values are plotted on Fig. 2 (standard deviations are not plotted, to avoid clutter). The values in Table 7 were determined from the Local Climatological Data and have not been corrected for effects of urbanization (which would tend to create higher temperatures in more recent decades). The standard deviations of the decadal departures range from 2.8 to 4.7°F (1.6 to 2.6°C). These large natural variabilities overwhelm the relatively small values computed by the model for the seasonal departures due to increased CO_2 and demonstrates the difficulty of using single-station data to detect evidence of climate change resulting from increased concentrations of radiatively active trace gases. It is very likely that if global warming occurs, there will be isolated stations that have long-term trends counter to the global mean.

Decadal Mean Precipitation Ratio by Season

In Fig. 3, the results of the GISS transient B ratios of decadal mean precipitation to precipitation for the base period are plotted. As previously discussed, precipitation projections by climate models are considered quite crude, so the results shown in Fig. 3 should be used with extreme caution. The model produces a somewhat drier late summer and fall and a slightly wetter winter and spring. This tendency seems characteristic of most decades simulated and is not dramatically influenced by increased CO_2, perhaps because of model deficiencies in representing soil moisture. The coarse resolution of the model constrasted with the high spatial and temporal variation of regional rainfall suggests that comparisons of modeled and observed regional precipitation are not very meaningful. The most we can conclude from Fig. 3 is that the model does not produce major (greater than 20%) changes in precipitation due to increases of trace gases over the next 40 years.

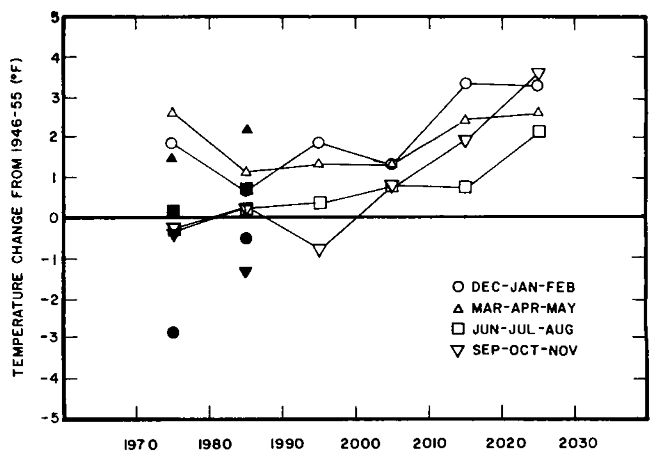

Fig. 2. Decadal mean seasonal temperature change from the 1946-55 mean for Des Moines as computed by the GISS model. Model results are shown as open symbols, and observed seasonal means for decades of the 1970s and 80s are shown as solid symbols.

Table 7. Observed seasonal mean (standard deviation) of decadal temperatures (°F) for Des Moines, IA for the base period, the 1970s, and the 1980s and the observed mean (standard deviation) of decadal departure temperatures from the 1945-56 base period.

Decade	DJF	MAM	JJA	SON
Temperatures (standard deviation) (°F)				
1946-55	24.7 (2.9)	48.9 (2.9)	74.1 (2.2)	53.1 (2.4)
1970-79	21.8 (3.6)	50.4 (2.9)	74.4 (1.2)	52.8 (2.4)
1980-89	24.2 (3.8)	51.2 (2.9)	74.8 (2.8)	51.8 (1.5)
Departure (standard deviation) (°F) from the base period.				
1970-79	-2.9 (4.6)	1.5 (4.1)	0.3 (2.5)	-0.3 (3.4)
1980-89	-0.5 (4.8)	2.3 (4.1)	0.7 (3.6)	-1.3 (2.8)

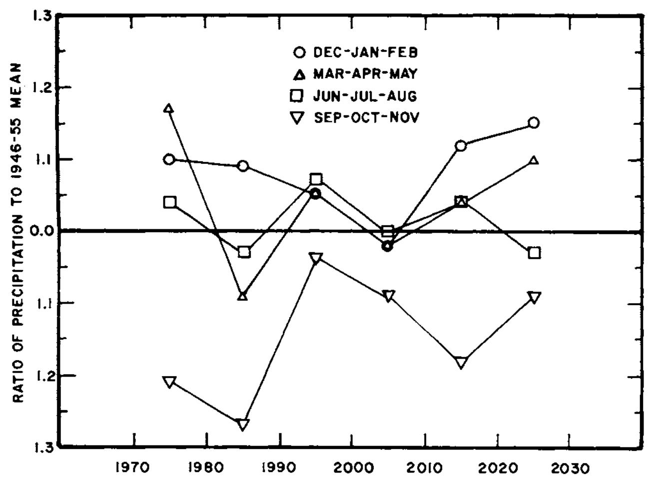

Fig. 3. Decadal mean seasonal ratio of precipitation to the 1946-55 mean for Des Moines as computed by the GISS model.

SUMMARY

We have presented a preliminary survey of Iowa's equilibrium climate as represented by the GISS global climate model under a doubling of CO_2 and of the changes in climate represented by this model under gradual increases of radiatively active trace gases. Because of uncertainties in model parameterizations of surface characteristics, the role of oceans, and the role of clouds, most modelers recommend that results of such models not be the sole basis for making policy decisions.

Perhaps the most prudent uses of such model results for Iowa are in identifying the areas of our economy — particularly agricultural practices and energy production and consumption — most sensitive to projected climate changes and in improving our understanding of their relation to natural climate fluctuations in the past. Then as climate models improve or seasonal forecasts gain additional credibility, state policy makers will be able to make more informed choices.

ACKNOWLEDGEMENT

This research was supported by the Iowa Department of Natural Resources and is based on climate model results supplied by Roy Jenne and Dennis Joseph of the National Center for Atmospheric Research, which is sponsored by the National Science Foundation.

LITERATURE CITED

HANSEN, J., I. FUNG, A. LACIS, D. RIND, S. LEBEDEFF, R. RUEDY, G. RUSSELL, and P. STONE. 1988. Global climate changes as forecast by Goddard Institute for Space Studies Three-Dimensional Model. *J. Geophys. Res.* 93:9341-9364.

HANSEN, J., G. RUSSELL, D. RIND, P. STONE, A. LACIS, S. LEBEDEFF, R. RUEDY, and L. TRAVIS. 1983. Efficient three-dimensional global models for climate studies: Models I and II *Mon. Wea. Rev.* 111:609-662.

JENNE, R.L. 1988. Data from climate models; the CO_2 warming. National Center for Atmospheric Research paper. 33 pp.

JONES, P.D., T.M.L. WIGLEY, and P.B. WRIGHT. 1986. Global temperature variations between 1861 and 1984. *Nature* 322:430-434.

KERR, R.A. 1989. Hansen vs. the world on the greenhouse threat. *Science* 244:1041-1043.

KERR, R.A. 1990. The greenhouse consensus. *Science* 249:481.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, 1982a: Local Climatological Data - 1981.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, 1982b: Monthly normals of temperature, precipitation, and heating and cooling degree days, 1951-80, Iowa, 18 pp.

RIND, D. 1988. Dependence of warm and cold climate depictions on climate model resolution. *J. Climate.* 1:965-997.

RIND, D., R. GOLDBERG, and R. RUEDY. 1989. Change in climate variability in the 21st century. *Climate Change* 13:5-37.

SCHNEIDER, S.H. 1990. The global warming debate heats up: An analysis and perspective. *Bull. Amer. Meteorol. Soc.* 71:1291-1304.