changeable Al were spectroscopically visible, as we suggest.

The ^{27}Al NMR data have shown that Al_{13} can occur in soils although it cannot be predicted when soil Al will be spectroscopically visible. Changes in the physical properties of the samples during the time to acquire the ^{27}Al spectra is a concern, but little change in the aqueous Al concentration and soil pH is expected (*15*). The presence of Al_{13} in acid soils will require a reevaluation of current thermodynamic models in which aluminum toxicity is attributed to mononuclear Al species.

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The Greenhouse Effect in Central North America: If Not Now, When?

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Climate models with enhanced greenhouse gas concentrations have projected temperature increases of 2° to 4°C, winter precipitation increases of up to 15 percent, and summer precipitation decreases of 5 to 10 percent in the central United States by the year 2030. An analysis of the climate record over the past 95 years for this region was undertaken in order to evaluate these projections. Results indicate that temperature has increased and precipitation decreased both during winter and summer, and that the ratio of winter-to-summer precipitation has decreased. The signs of some trends are consistent with the projections whereas others are not, but none of the changes is statistically significant except for maximum and minimum temperatures, which were not among the parameters predicted by the models. Statistical models indicate that the greenhouse winter and summer precipitation signal could have been masked by natural climate variability, whereas the increase in the ratio of winter-to-summer precipitation and the higher rates of temperature change probably should have already been detected. If the models are correct it will likely take at least another 40 years before statistically significant precipitation changes are detected and another decade or two to detect the projected changes of temperature.

Adequate supplies of water for crops and livestock are of primary importance to the central North America region (*1*). Severe droughts of the 20th century have affected both the biophysical and socioeconomic systems of the region (*2*). One of the more ominous scenarios that has been suggested on the basis of several climate model simulations in an enhanced greenhouse world is the decrease of summertime precipitation and an increase of temperature across central North America (*3*). The model predictions admittedly suffer from potentially significant limitations. For example, some regional phenomena such as the El Niño–Southern Oscillation (ENSO) are not adequately simulated by these models, but do appear to have linkages with regional surface temperature and precipitation variations in the United States (*4*). Nonetheless, if the projected climate occurs, it would certainly have a deleterious impact, and the region would have a difficult time adapting. In this report, we use observational records and purely statistical methods to review temperature and precipitation trends over the past century and assess the likelihood that climate projections will be verified by current climate monitoring techniques if contemporary climate model predictions are basically correct.

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Areally averaged seasonal mean temperature and precipitation over the IPCC Central region (Fig. 1A) bounded by the latitudes 35° to 50°N and longitudes 80° to 105°W (less a small part of land over the Canadian Provinces) were used to determine past changes (*5*). This is one of the regions where projections of temperature and precipitation change have been issued (*3*). The data are derived from the climate division averages of temperature and precipitation (*6*). A slightly different region referred to as "Central" (Fig. 1B) was used to examine past changes in the seasonal mean daily maximum and minimum temperatures (*7, 8*), for which projections were not made by the IPCC. The seasonal mean daily maximum and minimum temperatures are area averages over the period 1901 to 1987 derived from 147 stations (*8*).

We analyzed changes of seasonal mean temperature and precipitation over the IPCC Central region using tests of significance of linear trends, the nonparametric Wilcoxon sign-rank test, and the two-phase regression test described by Solow (*9*). The two-phase regression can be used to test for a change point in the linear trends. Use of the two-phase regression helps ensure against undetected nonlinear trends. Similar tests were also applied for changes of the seasonal mean daily maximum and minimum temperatures.

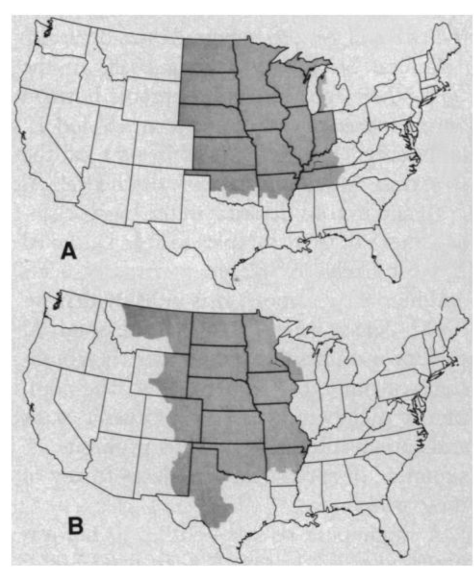

Fig. 1. (**A**) The "IPCC Central" North American region; (**B**) the "Central" United States region.

We developed autoregressive moving-average (ARMA) models using the seasonal time series of the precipitation and temperature records for the IPCC Central region. All data were transformed to standardized departures for temperature and precipitation by use of the normal and gamma statistical distributions, respectively. Five models were developed. Two were models for seasonal temperature (one for winter and one for summer) and two were for precipitation. The fifth model pertained to the ratio of winter to following summer precipitation. The models can be written as

$$Y_t = \sum_{i=1}^{p} \phi_i Y_{t-i} + \sum_{j=1}^{q} \theta_j a_{t-j} + a_t$$

where Y_t is the value of the time series at time t; ϕ_i is the ith autoregressive (AR) coefficient; θ_j is the jth moving average (MA) coefficient; and a_t is random noise (or a shock) at a time t. The order of the model is expressed as the sum of p and q and represented as ARMA (p, q). We assumed that a_t had a normal distribution with mean zero and standard deviation σ_a. Most stationary processes can be fitted by an ARMA model (*10*).

The Akaike information criterion (AIC) and the Bayesian information criterion (BIC) were both considered in the selection of the appropriate model order. Each model was tested up to order 12. After inspection of the residual mean squares of each of the models, a decision was made to use the AIC in the one instance where the two information criteria provided conflicting advice (the ratio of winter-to-summer precipitation). The AIC is known to somewhat overspecify a model (*11*), but in our analysis only one of the models had an order as high as two, and none of the models deviated greatly from white noise process. Four of the models are ARMA(0,1), whereas the ratio of winter-to-summer precipitation is an ARMA(1,1).

The time series generated from these models (if the models are perfectly specified) reproduce data that have all the characteristics of the observations. For each model, 1000 time series were generated of length 41 years (regarded as spanning the years 1990 to 2030) and 95 years (regarded as spanning the years 1895 to 1989). Linear trends (a convenient simplification used in the absence of any compelling reasons to suggest otherwise) were superimposed on the output from these models. The trends consisted of various percentages of the projected changes given in Table 1. The first year in which a significant trend could be detected was calculated by use of the empirically based 0.05 significance level. This statistical significance level was derived from the distribution of the slopes of the linear trends in 1000 simulations of the ARMA models without trends imposed.

No significant trends, even at the 0.10 significance level, could be found in the seasonal means of temperature, precipitation, or the ratio of winter-to-summer precipitation over the 1895 to 1989 time period. We looked for both linear trends and trends with one change point (*9*) (Table 2). No significant trends were observed even though substantial changes of temperature and precipitation over this region could have been anticipated on the basis of the model projections. For example, winter precipitation is expected to increase by as much as 15% (Table 1), but it has fallen at a rate slightly greater than 4% per century (Table 2). Summer precipitation has shown a slight decrease, but the magnitude is small, less than 1% per century (Table 2), despite projections of a decrease in precipitation by 5 to 10% by 2030. The ratio of winter-to-summer precipitation is projected to increase over this region, but it has decreased at a rate of nearly 4% per century. At least the direction of temperature change in both winter and summer is consistent with the projections, increasing by 0.23° and 0.43°C per century, respectively. None of the changes, however, are statistically significant. The hypothesis that all of the time series are stationary ARMA processes cannot be rejected, and thus ARMA models are appropriate tools for further analysis of these data.

We also considered the possibility that a greenhouse gas signal was masked by the natural climate variability in this region. To answer this question we imposed trends of various magnitudes on the 1000 simulations representing the years 1895 to 1989 for each of the five parameters of interest and calculated the probability that those trends would not be detected by our tests. The magnitudes of the trends imposed were 7, 14, and 28% of the total projected changes (Table 1). The rationale for these magnitudes is that global temperatures have risen by nearly 0.5°C since the 19th century (*3*), and this is 28% of the projected warming (1.8°C) expected by the year 2030 (*3*). The 7 and 14% changes correspond to potential undetectable greenhouse gas–induced changes that are only a fraction (0.25 and 0.50) of that corresponding to the 0.5°C global mean temperature increase. The IPCC concluded that the observed warming of nearly 0.5°C is already at the low end of the sensitivity of current climate models to greenhouse-induced warming.

For the projected rates of summer (three of three models) and winter (two of three models) warming, it is unlikely, but still possible (probability between 0.05 and 0.25, depending on the model used), that the changes projected would have been undetected if the rates of change in IPCC Central were proportional to the rate of global warming (28% of the value projected by the year 2030, Fig. 2A). Only for the winter projections from the GFDL (*3*) model (2°C warming by 2030) did we find it probable that changes could have been masked by natural variability. If climate model sensitivity were reduced by a factor of 2, we would likely (probability greater than 0.50) be unable to detect any of the greenhouse signals in the 95 years of thermometric records.

For winter and summer total precipitation (Fig. 2B), the natural variability of the climate record makes it unlikely that we would be able to detect the changes projected by the climate models, even if they were correct. In contrast, for the projected change in the ratio of winter-to-summer precipitation, at least for two of the models in which large changes in that ratio are projected, we should have already detected the changes. Once again, this conclusion is strictly valid

Table 1. Estimates of changes in areal means of surface air temperature (Temp) and precipitation (Precip) over central North America (35° to 50°N, 80° to 105°W) from preindustrial times to 2030, for the IPCC "business as usual" (*3*) emission scenario. These projections have been scaled to correspond to a global mean warming of 1.8°C by 2030. Model abbreviations are the Canadian Climate Center (CCC), Geophysics Fluid Dynamic Laboratory–USA NOAA (GFDL), and the United Kingdom Meteorological Office (UKMO) as provided by IPCC (*3*).

Parameter	Season	Model		
		CCC	GFDL	UKMO
Temp (°C)	Winter	4	2	4
Temp (°C)	Summer	2	2	3
Precip (%)	Winter	0	15	10
Precip (%)	Summer	−5	−5	−10
Precip (%) ratio	Winter/summer	5	21	22

Table 2. Observed trends of seasonal mean temperature (Temp) and total precipitation (Precip) from 1895 to 1989. No trends are statistically significant at the 0.10 level. Both a parametric test and a nonparametric test were used. Slopes are percent per 100 years for precipitation and degrees centigrade per 100 years for temperature.

Parameter	Season	Slope
Precip	Winter	−4.2
Precip	Summer	−0.7
Temp	Winter	0.23
Temp	Summer	0.43
Precip ratio	Winter/summer	−3.7

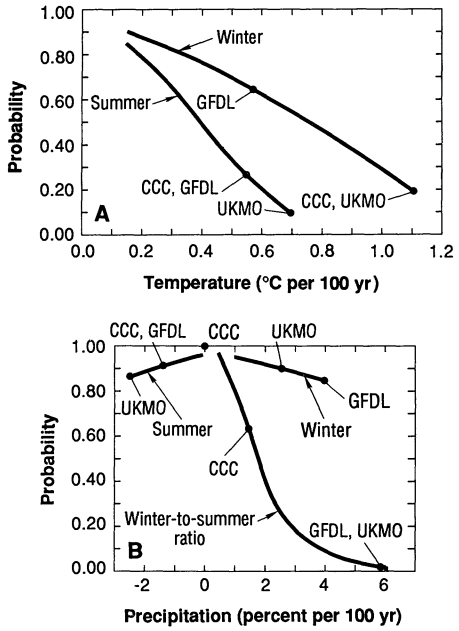

Fig. 2. Probability that trends of various magnitudes would have gone undetected over the IPCC Central North American region during the period 1895 to 1989: (**A**) temperature and (**B**) precipitation. Large dots indicate the trends that are consistent with projections from each of three climate models when these projections are reduced to the fraction of global warming already observed compared with that projected in the year 2030 (reduced, that is, to 28% of total projections). Abbreviations are defined in Table 1.

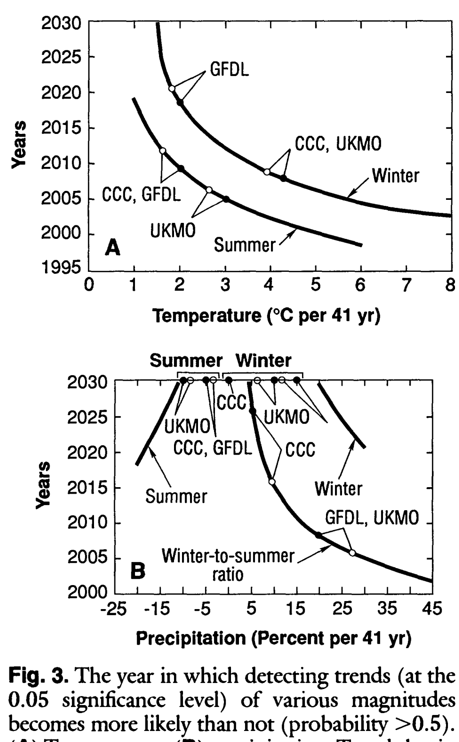

Fig. 3. The year in which detecting trends (at the 0.05 significance level) of various magnitudes becomes more likely than not (probability >0.5). (**A**) Temperature; (**B**) precipitation. Trends begin in the year 1990. The solid dots represent the magnitudes that would be equivalent to the projections of CCC, GFDL, and UKMO from the beginning of the industrial revolution to 2030 as given by the IPCC (*3*). The open circles represent similar magnitudes after consideration of the changes already observed since 1895.

only if the changes were proceeding at a rate in concert with the increase of global mean temperature (and if the increase of global mean temperature is indeed greenhouse-induced), that is, if we have experienced about 28% of the projected greenhouse-induced changes in temperature and precipitation as of 1990.

Assuming that all of the IPCC projections are correct and that the observed record to date is trend-free, we calculated when detection of the projected changes during the next 41 years would be likely. Another 15 to 20 years would be required for the detection of summer temperature changes (Fig. 3A). Between 15 and 30 years would be required for the detection of winter changes, depending on the projection and whether the warming that has already occurred is considered. Detection of the projected change for precipitation is less likely than for temperature during the next four decades (Fig. 3B) because of the large year-to-year variability. If the precipitation changes were about twice as large as those projected, we probably (probability >0.5) could detect the changes by about 2020. For the expected change in the ratio of winter-to-summer precipitation even though we should have already detected the larger rates of change projected by the GFDL and UKMO models during the past 95 years, it would not be until around 2005 that we would be able to detect the projected changes if they were to begin in 1990 and proceed at an approximately linear rate.

Although the general circulation model results we used do not project changes in the extremes of temperature, such extremes are useful diagnostic tools. Seasonal mean daily minimum temperature has increased in the central United States (Fig. 1B and Table 3) during all seasons and at a significant rate during spring and summer. The rise of the minimum is stronger than that of the maximum in all seasons. Differential changes in the seasonal mean maximum and minimum temperatures indicate that because of a focus on changes of seasonal mean temperature alone, many important aspects of climate change are being overlooked. Recent work (*12*) implies that the differential changes of maximum and minimum are related to increases of cloudiness.

These results suggest that it is difficult to dismiss outright many of the IPCC projections as inconsistent with the observations, except for the change in the ratio of winter-to-summer precipitation and the rates of summer temperature increase as projected by the UKMO model. If these latter projections were correct, we probably should have already detected some statistically significant changes. Furthermore, except for the expected change in the ratio of winter-to-summer precipitation, even if all the changes began to occur in 1990, it is unlikely that we will be able to detect these signals over the next few decades. Recently, Briffa *et al.* (*13*) have made similar conclusions for temperature changes in the Fennoscandia regions.

Table 3. Observed trends of the seasonal mean daily maximum and minimum temperatures over the central region of the United States for the period 1901 to 1987. Trends that are statistically significant at the 0.10 significance level are indicated by an asterisk (parametric test). None were significant according to the nonparametric test. The years of significant change points are listed along with the sign of the associated shift in the time rate of change.

Parameter	Season	Slope (°C/100 years)	Year of change point
Maximum	Winter	0.20	None
Minimum	Winter	0.59	None
Maximum	Spring	0.38	None
Minimum	Spring	*0.94	None
Maximum	Summer	0.45	1934(−)
Minimum	Summer	*0.98	1935(−)
Maximum	Fall	−0.55	None
Minimum	Fall	0.35	None

These analyses leave planners and policy makers in an unenviable position. They must decide to use or not use the IPCC projections without a clear rejection or acceptance of many of those projections and only a fuzzy notion that the projections may be overly sensitive to greenhouse increases when compared to the observed climate record in this region. To compound the dilemma, significant changes have now taken place with respect to increases of the seasonal mean daily minimum temperatures (which appear to be related to increased cloud cover), but we do not yet have a sound understanding of how these changes may or may not be related to the greenhouse effect.

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Evidence of Strong Earthquake Shaking in the Lower Wabash Valley from Prehistoric Liquefaction Features

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Earthquake-induced liquefaction features in Holocene sediments provide evidence of strong prehistoric shaking, magnitude m_b 6.2 to 6.7, in the Wabash Valley bordering Indiana and Illinois. The source of the one or more earthquakes responsible was almost certainly in or near the Wabash Valley. The largest event is interpreted to have occurred between 7500 and 1500 years ago on the basis of archeological, pedological, and stratigraphic relations.

Five slightly damaging earthquakes having body-wave magnitudes (m_b) of 5.0 to 5.8 and many smaller events have taken place in and near the lower Wabash River Valley of Indiana and Illinois during the 200 years of historic record (*1*). Because of this continuing seismicity and the numerous faults in the Wabash Valley seismic zone [as defined by Nuttli (*2*)] the tectonic setting (*3*) has long been suspected of having the capability to produce shaking much stronger than observed. Some of the faults may be related to faults associated with the great earthquakes of 1811 to 1812 near New Madrid, Missouri (Fig. 1). The northern limit of the 150-km-long causative fault of the four largest of these earthquakes (m_b 7.0 to 7.4) (*4*) lies just south of Illinois and strikes northeastward toward the Wabash Valley seismic zone.

To determine whether the lower Wabash Valley has sustained strong earthquake shaking in the recent geologic past, we undertook a field search for earthquake-induced liquefaction-flowage features. Liquefaction results from strong shaking of loose, water-saturated, subsurface sediment. Once liquefaction occurs, water and sediment can flow toward the ground surface along fissures opened through overlying finer grained sediments. Common evidence of liquefaction and flowage includes sand-filled dikes and small mounds of sand (sand volcanoes) ejected to the surface, called "sand blows" (*5*). The 1811–1812 earthquakes produced many large sand blows and sand-filled dikes in and near their epicentral region (*6, 7*), and small sand blows were reported in the southernmost 30 km of the Wabash Valley (*8*). As a result of our search in the lower Wabash Valley, we identified several tens of liquefaction features (Fig. 1) similar to but predating those produced by the 1811–1812 earthquakes. These features occur in Holocene meander-belt deposits along the Wabash and White rivers and in Upper Pleistocene glacial outwash and lake deposits.

The liquefaction features in the Wabash Valley are planar sand-filled dikes that are vertical to steeply dipping and that widen downward and connect to a sediment source at depth. The dikes cut through a low-permeability cap, generally rich in silt and clay, that overlies the source strata of silty to gravelly sand. Dikes are as long as 3.5 m and as wide as 0.6 m at depths near the source. Sediment in various dikes ranges from silty fine sand to fine and medium sand to silty gravelly sand; grain size tends to fine upward where gravel occurs. At two exceptionally large dikes (Sites BR and PB), sediment that vented onto an ancient ground surface is still visible in vertical section as a buried sand-rich zone beneath younger alluvium (Fig. 2).

In addition to the similarities with dikes near the epicenter of the 1811–1812 earthquakes, other evidence also shows that the features in the Wabash Valley were created by earthquake-induced liquefaction. Syndepositional processes can be eliminated as the origin because the dikes cut across sediment much younger than the source sands, or else the dikes cut across thick, highly plastic clay that accumulated slowly in a swamp environment; the possibility of rapid build-up of pore pressure due to sudden deposition of overlying sediments is therefore eliminated. Other non-earthquake origins that could have produced superficially similar features are permafrost, artesian springs, and landslides. These are rejected because of the following aspects of the dikes: (i) they widen downward; (ii) they are strongly aligned in local areas; (iii) they vented to the surface; (iv) material in the dikes fines upward and was transported upward; (v) bedding in the source beds is homogenized and contacts with overlying fine-grained material are highly convoluted in some cases; (vi) dikes occur in flat and topographically elevated landforms; and (vii) the size of the dikes generally decreases with increasing distance from a central area of large dikes (see Fig. 1).

Consideration of dike sizes and distribution in the Wabash Valley, in conjunction with the regional geological setting and seismic record, shows that the tectonic source area was near the lower Wabash Valley. The decreasing size of dikes with increasing distance from a central area probably reflects variations in the shaking of the underlying bedrock, because liquefaction susceptibility at the sites (Fig. 1) is relatively

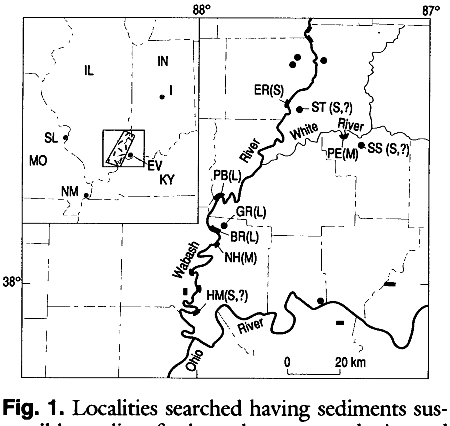

Fig. 1. Localities searched having sediments susceptible to liquefaction; dots are sand pits and heavy lines are stream banks. Sites having dikes are shown in capital letters. Maximum width of dikes shown as L (large, >15 cm), M (medium, >6 cm), or S (small, <6 cm); question mark indicates uncertain earthquake origin. County boundaries are shown as dashed fine lines. Patterned area on regional map shows Wabash Valley seismic zone; box indicates the study area. SL, St. Louis; I, Indianapolis; EV, Evansville; NM, New Madrid.

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