Exhibit No.:	
Issue(s):	Weather Normalization
Witness:	Steve Qi Hu
Type of Exhibit:	Rebuttal
Sponsoring Party:	MoPSC Staff
Case No.:	GR-99-315

ON BEHALF OF THE

MISSOURI PUBLIC SERVICE COMMISSION

UTILITY OPERATIONS DIVISION

REBUTTAL TESTIMONY

OF

STEVE QI HU, PH.D.

LACLEDE GAS COMPANY

CASE NO. GR-99-315

Jefferson City, Missouri

August, 1999

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Laclede Gas Company

Case No. GR-99-315

Q. Please state your name and business address.

A. My name is "Steve" Qi Hu, and my business address is 237 L.W. Chase Hall, University of Nebraska-Lincoln, Lincoln, Nebraska 68583-0728.

Q. Are you the same "Steve" Qi Hu who has previously filed testimony in this case?

A. Yes, I am.

Q. What is the purpose of your rebuttal testimony?

A. As an expert witness in this case, I was asked to comment on the "global warming" that was considered by the Company as a potential major cause of the anomalies of the weather in the Central United States in the recent 10 years and may continue to cause the increase of air temperature.

Q. How did the concern about "global warming" come about?

A. "Global warming" originated from atmospheric circulation models that were used to estimate global climate variations under different scenarios of carbon dioxide increase in the atmosphere. The early versions of these models projected a warming of various magnitudes after doubling of the atmospheric carbon dioxide amount in the models. As discussed in the article of Kerr, published in journal *Science* (Kerr 1997), these early models suffered severe defects in describing many essential processes in the atmosphere and, thus, made their predictions of the global warming questionable. This is not surprising given the enormous complexity of the earth's climate system and our limited knowledge of how this system works.

Q. Have the defects in the climate models been addressed?

A. Yes. A recent improvement of cloud processes by one of these models has led to a dramatic change of the predicted warming of global climate from the 5.2 Centigrade degrees (C) by its old version to 1.9 C (Kerr 1997). Some other models have also revised their early projections and suggested a smaller increase of temperature in a doubled CO_2 climate. In fact, some of them showed that the CO_2 effect is too small to affect temperature (Kerr 1997).

Q. What is the projected time span for the reduced estimate of the increase in temperature?

A. Should these projected temperature increases be realized, they would have to be achieved over a period of 60 to 70 years during which the atmospheric CO_2 concentration would be doubled at the assumed current rate of increase. Therefore, the "global warming" effect on temperature in a 10-year period may be too small to be detected, at about 3/10 of a Centigrade degree.

Q. How does this rate of increase compare with the natural variability in the climate?

A. The climate system has its own variations from seasonal to interannual and to interdecadal scales. Historical data analysis showed that there were periods with anomalously warm temperatures, such the 1930s and 1950s in the central United States. The temperature fluctuations of these natural variations of regional climate could be much greater than the warming projected by the model due to the anthropogenic CO2 effect.

Q. Could the recent occurrence of several mild winters be the result of "global warming?"

A. I acknowledge the fact that some of the recent years had relatively warmer temperatures in summer and mild temperatures in winter in the central US. However, it is unknown at this time what has been causing these anomalies. The Company agrees that the normals calculated using the past data should not be used for projections of the climate. We cannot say this current condition is a trend of the region's climate, nor can we say it should be used in projections of the climate condition of the region in future years.

Q. Does this conclude your rebuttal testimony?

A. Yes, it does.

LACLEDE GAS COMPANY
RATE CASE NO. GR-99-315

REBUTTAL WORKPAPERS OF STEVE QI HU PHD.

Greenhouse Forecasting Still Cloudy

An international panel has suggested that global warming has arrived, but many scientists say it will be a decade before computer models can confidently link the warming to human activities

The headlines a year and a half ago positively brimmed with assurance: "Global Warming: No Longer in Doubt," "Man Adversely Affecting Climate, Experts Conclude," "Experts Agree Humans Have 'Discernible' Effect on Climate," "Climate Panel Is Confident of Man's Link to Warming." The official summary statement of the UN-sponsored Intergovernmental Panel on Climate Change (IPCC) report that had prompted the headlines seemed reasonably confident, too: "... the balance of evidence suggests that there is a discernible human influence on global climate." But as negotiators prepare to gather in Bonn in July to discuss a climate treaty that could require nations to adopt expensive policies for limiting their emissions of carbon dioxide and other greenhouse gases, many climate experts caution that it is not at all clear yet that human activities have begun to warm the planet—or how bad greenhouse warming will be when it arrives.

What had inspired the media excitement was the IPCC's conclusion that the half-degree rise in global temperature since the late 19th century may bear a "fingerprint" of human activity. The patchy distribution of the warming around the globe looks much like the distinctive pattern expected if the heat-trapping gases being poured into the atmosphere were beginning to warm the planet, the report said. But IPCC scientists now say that neither the public nor many scientists appreciate how many if's, and's, and but's peppered the report. "It's unfortunate that many people read the media hype before they read the [IPCC] chapter" on the detection of greenhouse warming, says climate modeler Benjamin Santer of Lawrence Livermore National Laboratory in Livermore, California, the lead author of the chapter. "I think the caveats are there. We say quite clearly that few scientists would say the attribution issue was a done deal."

Santer and his IPCC colleagues' overriding reason for stressing the caveats is their understanding of the uncertainty inherent in computer climate modeling. The models are key to detecting the arrival of global warming, because they enable researchers to predict how the planet's climate should respond to increasing levels of greenhouse gases. And while predicting climate has always been an uncertain business, some scientists assert that developments since the IPCC completed its report have, if anything, magnified the uncertainties. "Global warming is definitely a threat as greenhouse-gas levels increase," says climate modeler David Rind of NASA's Goddard Institute for Space Studies (GISS) in New York City, "but I myself am not convinced that we have [gained] greater confidence" in recent years in our predictions of greenhouse warming. Says one senior climate modeler who prefers not to enter the fray publicly: "The more you learn, the more you understand that you don't understand very much." Indeed, most modelers now agree that the climate models will not be able to link greenhouse warming unambiguously to human actions for a decade or more.

NCAR

Rough approximation. Models can't reproduce clouds, but they incorporate some cloud effects, including those of water (white) in the atmosphere, seen in the above model output.

The effort to simulate climate in a computer faces two kinds of obstacles: lack of computer power and a still very incomplete picture of how real-world climate works. The climate forecasters' basic strategy is to build a mathematical model that recreates global climate processes as closely as possible, let the model run, and then test it by comparing the results to the historical climate record. But even with today's powerful supercomputers, that is a daunting challenge, says modeler Michael Schlesinger of the University of Illinois, Urbana-Champaign: "In the climate system, there are 14 orders of magnitude of scale, from the planetary scale—which is 40 million meters—down to the scale of one of the little aerosol particles on which water vapor can change phase to a liquid [cloud particle]—which is a fraction of a millionth of a millimeter."

Of these 14 orders of magnitude, notes Schlesinger, researchers are able to include in their models only the two largest, the planetary scale and the scale of weather disturbances: "To go to the third scale—which is [that of thunderstorms] down around 50-kilometers resolution—we need a computer a thousand times faster, a teraflops machine that maybe we'll have in 5 years." And including the smallest scales, he says, would require 10^{36} to 10^{37} more computer power. "So we're kind of stuck."

To get unstuck, modelers "parameterize" smaller scale processes known to affect climate, from the formation of clouds to the movement of ocean eddies. Because they can't model, say, every last cloud over North America, modelers specify the temperatures and humidities that will spawn different types of clouds. If those conditions hold within a single grid box—the horizontal square that represents the model's finest level of detail—the computer counts the entire area as cloudy. But as modelers point out, the grid used in today's models—typically a 300-kilometer square—is still very coarse. One over the state of Oregon, for instance, would take in the coastal ocean, the low coast ranges, the Willamette Valley, the high Cascades, and the desert of the Great Basin.

Having the computer power to incorporate into the models a more detailed picture of clouds wouldn't eliminate uncertainties, however, because researchers are still hotly debating the overall impact of clouds on future climate. In today's climate, the net effect of clouds is to cool the planet—although they trap some heat, they block even more by reflecting sunlight back into space. How that balance would change under greenhouse warming, no one knows. A few years ago, a

Model Gets It Right—Without Fudge Factors

Climate modelers have been "cheating" for so long it's almost become respectable. The problem has been that no computer model could reliably simulate the present climate. Even the best simulations of the behavior of the atmosphere, ocean, sea ice, and land surface drift off into a climate quite unlike today's as they run for centuries. So climate modelers have gotten in the habit of fiddling with fudge factors, so-called "flux adjustments," until the model gets it right.

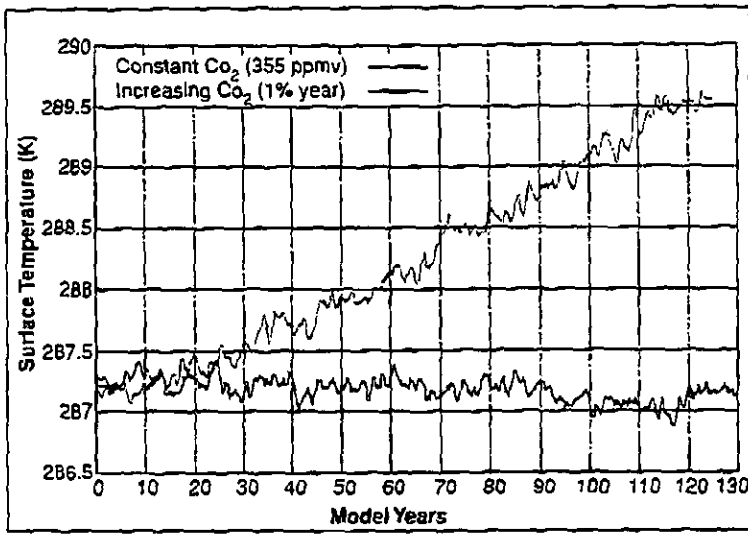
No one liked this practice (*Science*, 9 September 1994, p. 1528). "If you can't simulate the present without arbitrary adjustments, you have to worry," says meteorologist and modeler David Randall of Colorado State University (CSU) in Fort Collins. But now there's a promising alternative. Thirty researchers at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, have developed the first complete model that can simulate the present climate as well as other models do, but without flux adjustments. The new NCAR model, says Randall, "is an important step toward removing some of the uneasiness people have about trusting these models to make predictions of future climate" (see main text).

The NCAR modelers built a host of refinements into their new Climate System Model (CSM). But the key development, says CSM co-chair Byron Boville, was finding a better way to incorporate the effects of ocean eddies, swirling pools of water up to a couple of hundred kilometers across that spin off strong currents. Climate researchers have long known that the eddies, like atmospheric storms, help shape climate by moving heat around the planet. But modelers have had a tough time incorporating them into their simulations because they are too small to show up on the current models' coarse geographic grid. The CSM doesn't have a finer mesh, but it does include a new "parameterization" that passes the effects of these unseen eddies onto larger model scales, using a more realistic means of mixing heat through the ocean than any earlier model did, says Boville.

Even when run for 300 model "years," the CSM doesn't drift away from a reasonably realistic climate, says NCAR's Climate and Global Dynamics director Maurice Blackmon. "Being able to do this without flux corrections gives you more credibility," he says. "For better or worse, we're not biasing the results as was necessary before."

The first results from this still vastly simplified model imply that future greenhouse warming may be milder than some other models have suggested—and could take decades to reveal itself. Doubling atmospheric carbon dioxide concentrations in the model raised the global temperature 2 degrees Celsius, which puts the model's sensitivity to greenhouse gases near the low end of current estimates. Based on an array of different models and other considerations, the UN-sponsored Intergovernmental Panel on Climate Change estimated in 1995 that a carbon dioxide doubling could raise global temperatures by as much as 4.5°C; their best guess was 2.5°C.

A 300-year run without any increase in greenhouse gases produced slow, natural variations in global temperature of about 0.5°C. If the real climate behaves the same way, "two-thirds to three-quarters of the [temperature variations of the] last 130 years



Drift-free. The NCAR model, which suggests that Earth will warm moderately (red), can reliably simulate present climate (blue).

can be explained as natural variation," says Blackmon. That would make the detection of a modest-size greenhouse warming all the more difficult.

The CSM is available on the Internet, but Blackmon warns that if you want to check out future climate scenarios, you'll "need the biggest supercomputer you can get." Indeed, even NCAR researchers haven't been able to experiment with the model on as large a computer as they would like. While their purchase of an NEC SX4 computer is tied up in a trade dispute with Japan (*Science*, 30 August 1996, p. 1177), they are making do with a leased Cray C-90 with perhaps 20% of the speed of the SX4. That worries some modelers. Americans have "been among the leaders of the field from the beginning," says CSU's Randall, but "if we can't get access to the most powerful machines, we are going to be left behind."

–R.A.K.

leading climate model—developed at the British Meteorological Office's Hadley Center for Climate Prediction and Research, in Bracknell—predicted that an Earth with twice the preindustrial level of carbon dioxide would warm by a devastating 5.2 degrees Celsius. Then Hadley Center modelers, led by John Mitchell, made two improvements to the model's clouds—how fast precipitation fell out of different cloud types and how sunlight and radiant heat interacted with clouds. The model's response to a carbon dioxide doubling dropped from 5.2°C to a more modest 1.9°C.

Other models of the time also had a wide range of sensitivities to carbon dioxide, largely due to differences in the way their clouds behaved. That range of sensitivity has since narrowed, says modeler and cloud specialist Robert Cess of the State University of New York, Stony Brook, but "the [models] may be agreeing now simply because they're all tending to do the same thing wrong. It's not clear to me that we have clouds right by any stretch of the imagination."

Nor are clouds the only question mark in researchers' picture of how climate works. Modelers saw for the first time the fingerprint of global warming when they folded an additional process into the models: the effect of pollutant hazes on climate. Windblown soil and dust, particles from the combustion of fossil fuels, and ash and soot from agricultural burning all reflect sunlight — shading and cooling the surface beneath them. Including this aerosol effect in four independent climate models at three centers—Livermore, the Hadley Center, and the Max Planck Institute for Meteorology (MPI) in Hamburg, Germany—produced geographic patterns of temperature changes that resembled those observed in the real world over the past few decades, such as the greater warming of land than ocean.

Fingerprinting work since then has only strengthened the confidence of IPCC's more confident scientists that greenhouse warming has arrived. "I've worked with the models enough to know they're not perfect, but we keep getting the same answer," says Tim P. Barnett, a climatologist at the Scripps Institution of Oceanography in La Jolla, California, and a co-author of the IPCC chapter. Another climatologist and IPCC contributor, Gerald North of Texas A&M University in College Station, is similarly heartened. "I'm pretty optimistic about climate modeling. … I don't know anybody doing [fingerprinting] who is not finding the same result."

NCAR

Crucial component. Thunderstorms like the one above help to shape climate by lofting heat and moisture.

But the assumptions about how hazes affect climate may have taken a hit recently from climatologist and modeler James Hansen of NASA's GISS—the man who told Congress in 1988 that he believed "with a high degree of confidence" that greenhouse warming had arrived. In a recent paper, Hansen and his GISS colleagues pointed out that recent measurements suggest that aerosols don't just cool; they also warm the atmosphere by absorbing sunlight. The net effect of this reflection and absorption, Hansen estimates, would be small—too small to have much effect on temperature.

Hansen and his colleagues conclude that aerosols probably do have a large effect on climate, but indirectly, through clouds. By increasing the number of droplets in a cloud, aerosols can amplify the reflectivity of clouds, and thus may have an overall cooling effect on the atmosphere. If true, this would greatly complicate the modelers' work, because meteorologists are only just starting to understand how efficiently particles of different sizes and compositions modify clouds. "I used to think of clouds as the Gordian knot of the problem," says cloud specialist V. Ramanathan of Scripps. "Now I think it's the aerosols. We are arguing about everything."

And the complications don't stop with the multiplication of aerosol effects, according to Christopher Folland of the Hadley Center. Folland and his colleagues have been trying to sort out what was behind the intermittent warming of recent decades, which in the third quarter of the century was more rapid in the Southern than Northern Hemisphere. Earlier work by Santer and a dozen other colleagues showed an increasing resemblance between the observed pattern of warming through 1987, the end of their temperature record, and the results of a model run that incorporated aerosol effects. The researchers suggested that the North's more abundant pollutant aerosols could have been moderating the warming there from greenhouse gases. But when Folland compared the results of his model run with a longer, more recent temperature record, the resemblance that had been building into the 1980s faded by the early 1990s. Contrarian Patrick Michaels of the University of Virginia, Charlottesville, also has pointed out this trend.

The Hadley model suggests that "there appears to be more than one reason" for the variations, says Folland. The waning of aerosols as pollution controls took effect probably helped the North catch up, he says, but so did natural shifts in atmospheric circulation that tended to warm the continents (*Science*, 7 February, p. 754). Most provocatively, Folland and his colleagues are suggesting that a shift in North Atlantic Ocean circulation that has tended to warm the region also has contributed. "There's no doubt," says Santer, "that multiple natural and anthropogenic factors can contribute, and probably have, to the interhemispheric temperature contrast. … We've learned something about detection."

All of which only adds to the skepticism of scientists who might be called the "silent doubters": meteorologists and climate modelers who rarely give voice to their concerns and may not have participated even peripherally in the IPCC. "There really isn't a persuasive case being made" for detection of greenhouse warming, argues Brian Farrell of Harvard University, who runs models to understand climate change in the geologic past. Farrell has no quarrel with the IPCC chapter on detecting greenhouse warming, but he says the executive summary did not "convey the real uncertainties the science has." He further contends that if IPCC scientists had had real confidence in their assertion that global warming had arrived, they would have stated with more precision how sensitive the climate system is to greenhouse gases. But the IPCC left the estimate of the warming from a doubling of carbon dioxide at 1.5°C to 4.5°C, where it has been for 20 years. "That's an admission that the error bars are as big as the signal," says Farrell.

Climate modeler Max Suarez of NASA's Goddard Space Flight Center in Greenbelt, Maryland, agrees that it's "iffy" whether the match between models and temperature records is close enough to justify saying that greenhouse warming is already under way. "Especially if you're trying to explain the very small [temperature] change we've seen already," he says, "I certainly wouldn't trust the models to that level of detail yet."

Rather than dwelling on model imperfections, IPCC co-author Barnett emphasizes some of the things that current models are doing fairly well—simulating present and past climates and the changing seasons, predicting El Niño a year ahead, and producing good simulations of decades-long climate variations. But he agrees that too much confidence has been read into the IPCC summary statement. "The next 10 years will tell; we're going to have to wait that long to really see," he says. Klaus Hasselmann of the MPI also sees a need to wait. He and his colleagues "think we can see the [greenhouse warming] signal now with 97% confidence." But, as North notes, "all that assumes you knew what you were doing to start with" in building the models. Hasselmann has faith in his model but recognizes that his faith is not universally shared. "The signal is not so much above the noise that you can convince skeptics," he observes. "It will take another decade or so to work up out of the noise."

That's no excuse for complacency, many climate scientists say. Basic theory, this century's warming, and geologic climate records all suggest that increasing carbon dioxide will warm the planet. "I'd be surprised if that went away," says Suarez, as would most climate researchers. North suggests that while researchers are firming up the science, policy-makers could inaugurate "some cautious things" to moderate any warming. The last thing he and his colleagues want is a rash of headlines saying the threat is over.

–Richard A. Kerr