Testimony before
House Energy & Utilities
6 February 2008

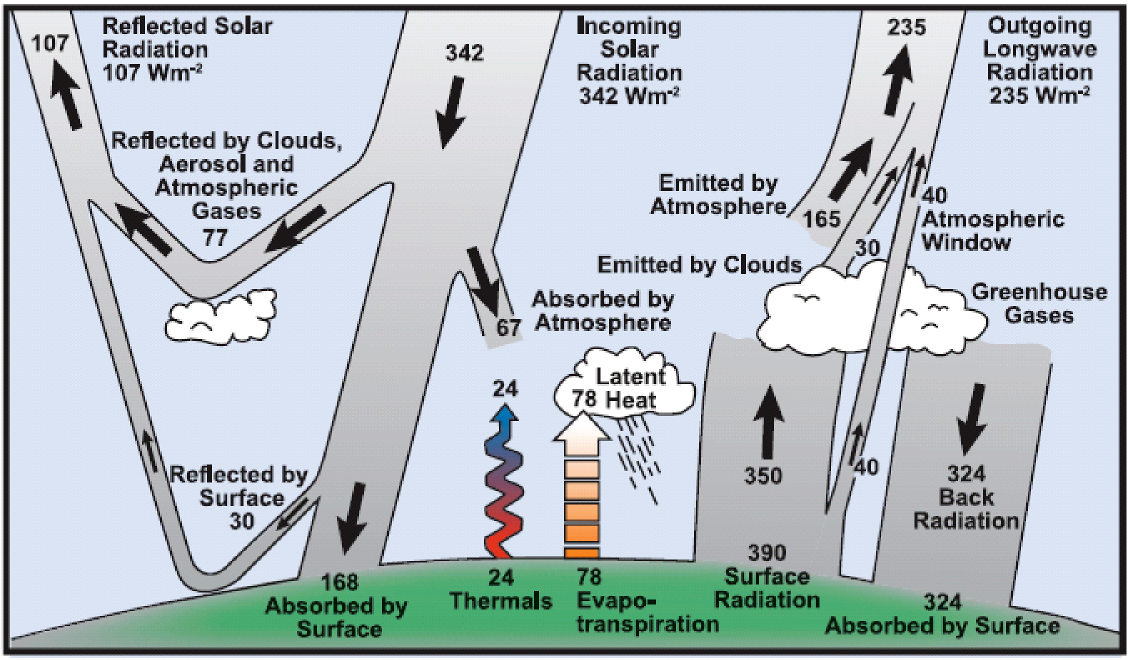
Thank you, Mr. Chairman, and members of the committee. I appreciate the opportunity to speak to you today. I do so not to support or oppose the bill in question but to provide relevant background information on the state of knowledge about global climate change and to illustrate some of the projected impacts of climate change on the State of Kansas.

I have studied the climate system for the last 25 years after graduating with a PhD degree in Climatology from the University of Delaware. I have published a number of papers in climate journals including *Climate Research, Climatic Change, Climate Dynamics, Science* and I was a contributing author to the Intergovernmental Panel on Climate Change (IPCC) report entitled *Climate Change 2007: The physical science basis*. I teach in the Geography Department of the University of Kansas.

The climate system and global climate change projections

I would like to begin by introducing the basic concepts of climate science and to show you that the climate science is based on understanding the energy balance of our plants. The main source of energy is from the sun, and comes to Earth in the form of electromagnetic radiation. In order to maintain a stable climate system (or temperature), the Earth must emit the same amount of energy it receives also in the form of electromagnetic radiation (figure 1). Within the Earth atmosphere system the transport of energy can be performed by a number of processes, including electromagnetic radiation, transport of energy by conduction in materials and by the transport of energy as part of convective processes in the atmosphere and oceans.

Figure 1: TheEarth energy balance(IPCC 2007)



FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*

Climate scientists typically use mathematical representations to replicate the different energy transport mechanisms on a global scale. Global climate models (GCMs) are a compilation of the different models used to represent all the different energy transport mechanisms on the planet. These models are driven by known inputs into the climate system, including solar radiation intensity, changes in the composition and state of the atmosphere, and atmosphere-surface boundary conditions. It is well understood that each of these boundary conditions can change the Earth's climate.

Over the last few decades Climate scientists have become concerned about the rate at which human emissions from fossil fuel burning has changed the composition of the Atmosphere. The composition of the atmosphere is a critical component of the climate system and regulates the rate at which electromagnetic radiation from the Sun passes through the atmosphere, and the rate at which electromagnetic radiation from the Earth's surface is absorbed by the atmosphere. The atmosphere in turn reradiates a greater portion of its energy back to the Earth, the so called greenhouse effect, and radiates a lesser amount of energy out to space. The amount of energy emitted to space from the atmosphere must balance the energy absorbed from solar radiation to maintain a stable climate system.

After water vapor carbon dioxide (CO_2) is the second biggest greenhouse gas, although it makes up only a small portion of the atmosphere. The amount of CO_2 in the atmosphere has changed significantly over the history of the Earth. Its concentration on geologic time scales is largely regulated by rock weathering and degassing associated with orography (mountain building and the rate of volcanic activity). One the time scale of 100,000s of years, this control is largely associated with the extent and productivity of plants, both in part influence by climate. However, in the last 100 years the concentration of CO2 in the atmosphere has increased dramatically, going from about 270 part per million (ppm) at the beginning of the industrial revolution to about 380 ppm today (figure 2). Based on ice core and atmospheric sampling (IPCC, 2007), it is clear that the values today are more than 30%greater than any other time in the last 700,000 years. Almost all this increase can be attributed to emissions from human activities, including fossil fuel burning (mostly from coal), land use change and other activities.

Increases in CO2 in the atmosphere increases the rate at which surface radiation is absorbed by the atmosphere, increasing atmospheric temperatures and increasing counter radiation from the atmosphere back to the Earth surface. This in turn results in warmer surface temperatures. This process is well understood. However, the warming initiated by CO2 also results in the evaporation of additional water vapor, the most significant greenhouse gas. This is a positive feedback mechanism that amplifies the warming initiated by CO2 changes. Other feedbacks also exist in the climate system, including changes in cloud cover that can reflect solar radiation (acting as a negative feedback), the positive snow and ice feedback that amplifies warming so that warming initiated by CO2 changes will lead to a specific warming “fingerprint,” or spatial pattern of temperature change, that leads to more warming in the polar regions and less in the tropics.

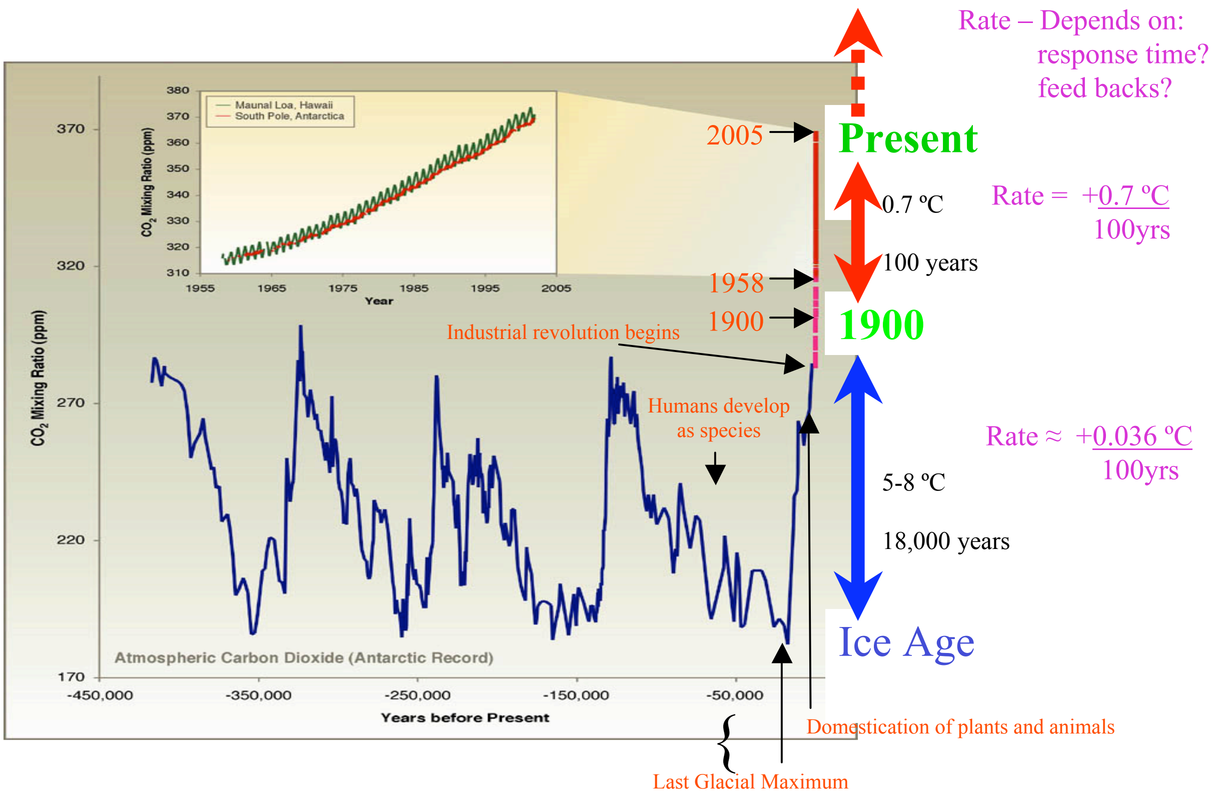


Figure 2: Atmospheric CO2 concentrations over the last 450,000 years

Global climate models have been shown to demonstrate the effects of CO2 on the 20th century climate remarkably well. The main factors affecting the 20th century climate are changes in solar radiation intensity, volcanic emissions of particulates (typically leading to a 3-5 year cooling), the impacts of CO2 and anthropogenically produced of sulfate aerosols which act to cool the climate much like volcanic emissions. If the models are run only with natural forcings (a forcing is a perturbation that leads to a climate response – in this case volcanoes and solar activity), then they show a steady climate trend, or a slight cooling towards the end of the century (figure 3). However, with CO2 and sulfate aerosols included in the forcings, the simulated global temperatures show a dramatic increase by the end of the century; as is also observed in the instrumental record and satellite data. It is important to note that without the human forcings the models cannot replicate the observed temperature trends. This and direct observations form the basis of the conclusion that human activities are having a direct impact on the climate of the Earth.

The IPCC has used results from 23 climate models from 16 climate modeling groups in 11 countries to attempt to simulate potential future climate outcomes into the future. The
Figure 3: GCM simulations of the 20th century climate using different forcings (source NCAR)

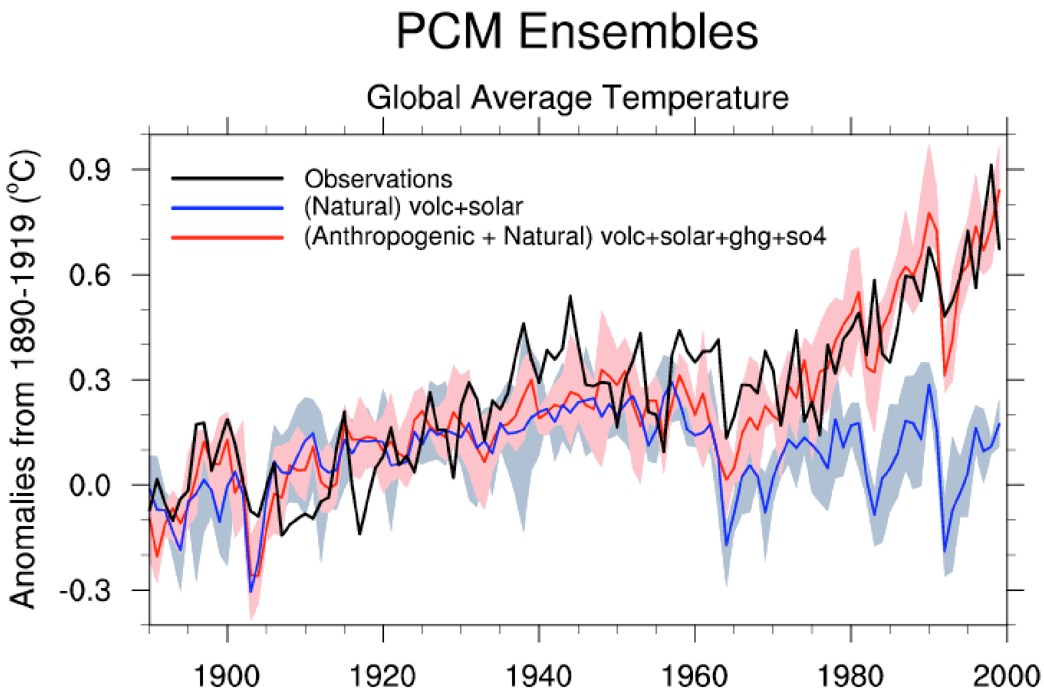


Figure 3: GCM simulations in the 20th Century using natural and human forcings

projections are based on estimated human greenhouse gas (CO2 and others) emissions in the future. Several scenarios were developed to simulate different development paths, and greenhouse gas concentrations associated with each scenario are shown in figure 4, with resulting temperature simulations shown in figure 5. As is illustrated in the bottom of figure 4 our current global emissions path is above any of the simulated scenario pathways. Based on these simulations global temperatures are projected to change from 2 to 4 ˚C in the future (figure 5; IPCC, 2007).

In addition to global average temperatures, GCMs also simulate other climate variables. One simulation is the extent of ice in the arctic. A series of projected ice extent simulations are shown for the National Center for Atmospheric Research (NCAR) Parallel Climate Model (PCM). This model projects that in the summer the arctic ocean will be largely ice free (upper left images in figure 6). However, rapid changes do not occur until well after 2030 in the model. Arctic ice is particularly important, because it currently reflects the majority of energy coming from the sun and thus cools the arctic region. Once the ice begins to melt it can set in motion a rapid feedback cycle (ice melts, more energy is absorbed, and leads to additional melting etc) resulting in a rapid melt of the ice cap. Recent observations of the arctic icecap suggest that in fact this may already be happening, raising concerns that our models may in fact be under-predicting the rate of climate change.

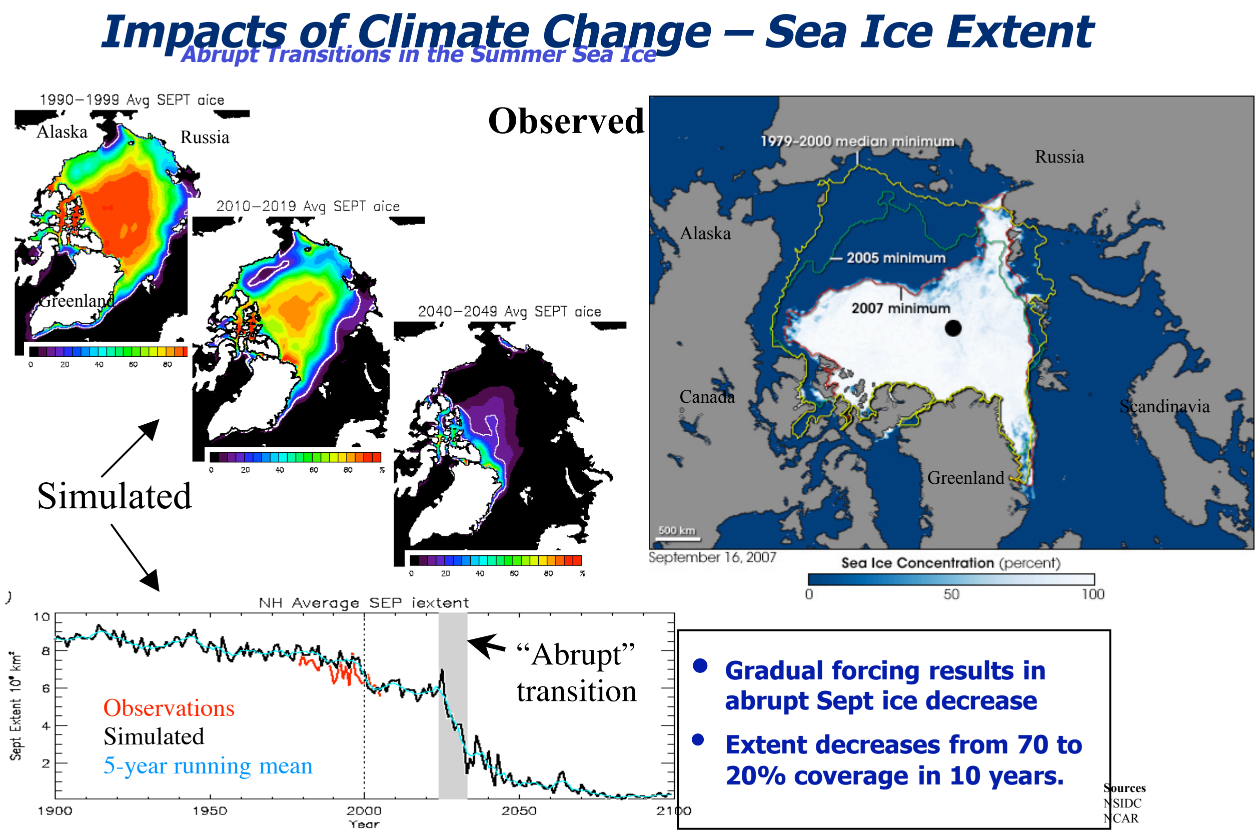


Figure 7: Future simulations of arctic sea ice and recent observations

Climate Impacts on Kansas

The climate of Kansas is highly variable, and particularly in the western part of the state is very dry. Because of this moisture and changes in rainfall in the future are the key to the impacts climate change will have on the environment and economy of the state. For this reason I will focus on how the moisture balance of the state is projected to change in the future. Because there are significant differences in the state and driving forces of climate in the eastern and western parts of the state I will evaluate the impacts for the eastern and western parts of the state.

Using the average climate projections form all the models used in the analysis by the IPCC, and analyzing only the results from the IPCC A1B future scenario (a middle of the road scenario in terms of total human emissions), temperatures in Kansas are projected increase by 3.5˚C (6.3˚F) annually. In addition precipitation is projected to increase by about 3 percent annually, however this is -3 percent in the summer, when many parts of Kansas receive most of their precipitation. To give a range of possible outcomes, water balance simulations were run for a 1.5˚C warming with a 5% increase in precipitation and a 2˚C warming with no change in precipitation for the year 2050. Similarly, and 3˚C warming with a 5% increase in precipitation and a 4˚C warming with no change in precipitation was used to simulate climates for 2100. These simulations are intended to bracket the most likely outcome of climate change impacts on the water balance for 2050 and 2100.

Using a well tested water balance model (as is often used to estimate irrigation requirements), I analyzed the potential changes in moisture deficit and moisture surplus quantities for eastern and western Kansas using observed climate statistics as a starting point. In both locations (figures 8 and 9) the climate projection resulted in significant drying of the climate. Moisture deficit conditions, that directly affect vegetation and crop productivity, are projected to increase between 0.86 and 1.89 inches by the year 2050 and to 2.36 to 4.09 inches in Eastern Kansas. Such a change is equivalent to a loss of rainfall in the current climate at this location. In addition, surplus water, water that makes up runoff for streams and reservoirs and ground water recharge was project to change insignificantly to a loss of 2.28 inches per year by 2050 and to a loss of 1.93 to 4.49inches in 2100. This represents a significant loss of water resource in eastern Kansas. Much of this drying can be attributed to the increase in temperatures and the increased water demand in the future. However, in eastern Kansas some of the increased water demand can be mitigated by the use of surplus water to meet this demand.

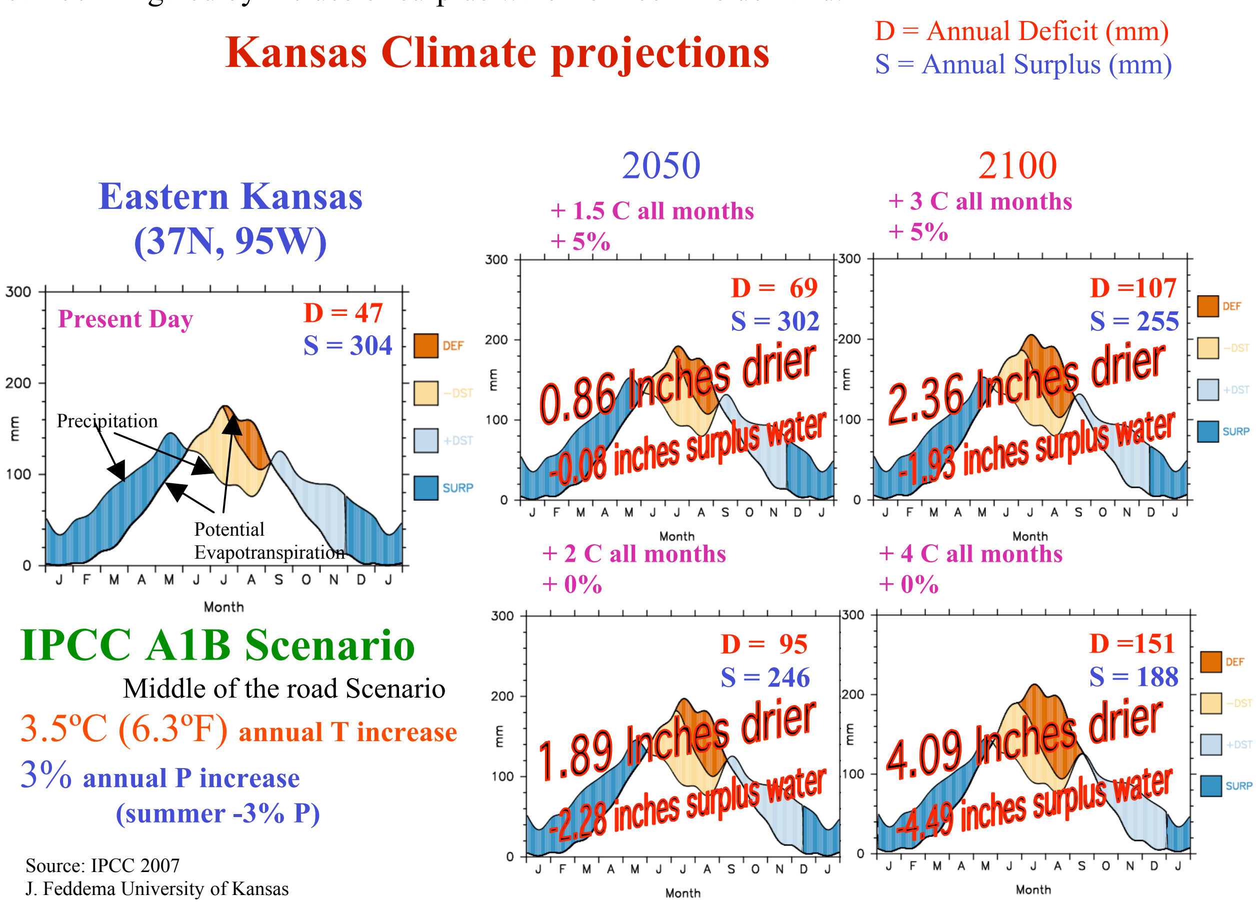


Figure 8: Projected water balance changes in eastern Kansas

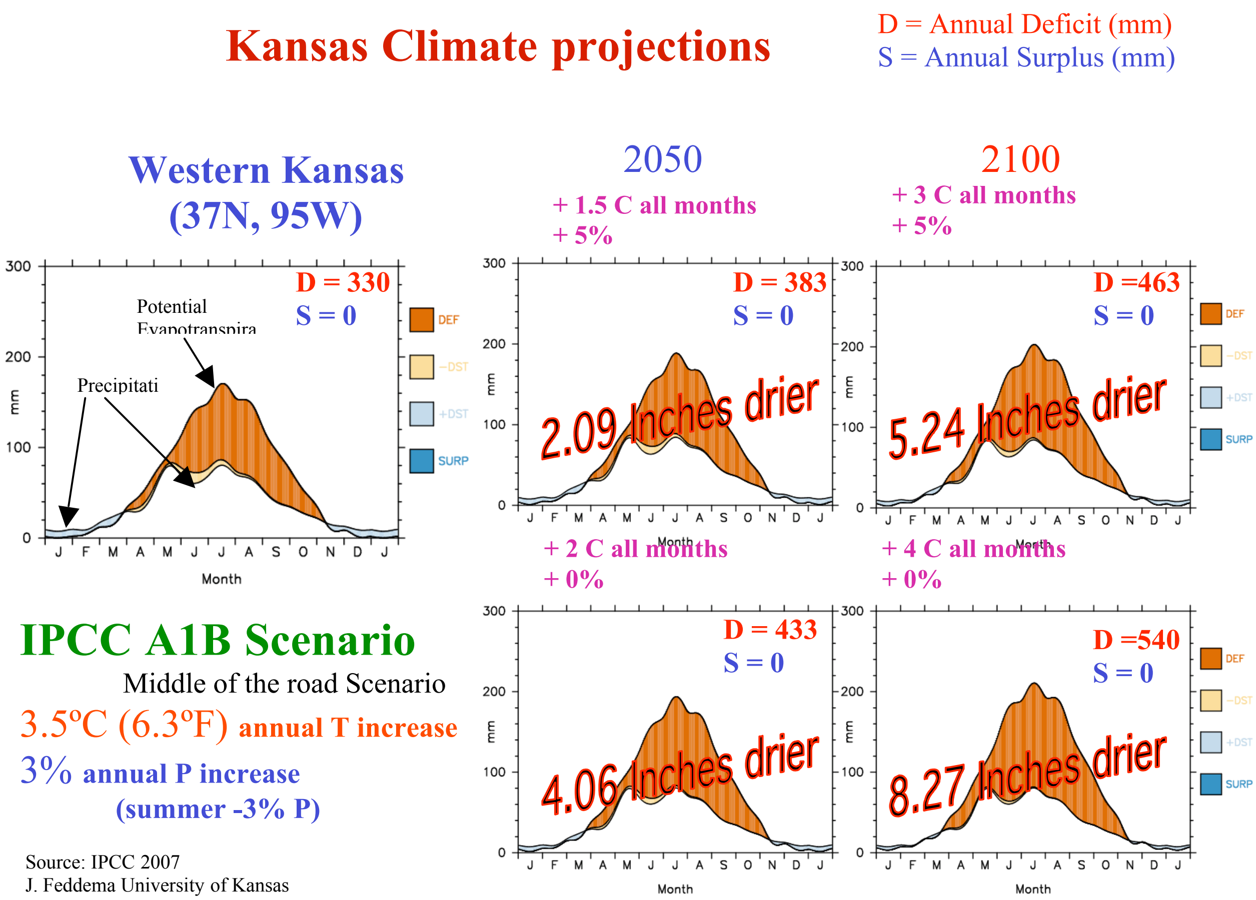


Figure 9: Projected water balance changes in eastern Kansas

In western Kansas the situation is significantly different. Because this is much dryer location to begin with, there is no surplus water to absorb some of the effects of increasing water demand. Hence the impact of global warming has a much greater and potentially more damaging effect on the natural environment and farm economy. Projected moisture deficits range from 2.09 inches to 4.06 inches by 2050, and from 5.24 to 8.27 inches by 2100. I believe these projections will have significant impacts on local communities in the future, although specific impacts will depend on the choices and adaptations made by the people of Kansas in the future.

In conclusion I find that the impacts of global warming are very likely to have a significant impact on the people and environment of Kansas, and that it is wise for us to plan accordingly,in terms of the consumption of our resources and possible measures to reduce the impact of climate change in the future.