Testimony to the Joint House and Senate Committee on Energy and Environment

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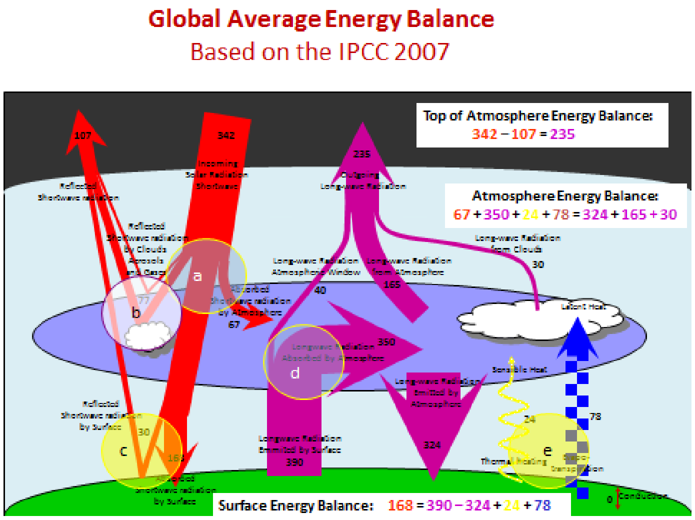
I was asked to come before you to provide some background information on the state of knowledge about global climate change and how that is related to potential energy and environmental policy in the State of Kansas. What I present here is reflective of my own thoughts and knowledge about this topic, but all of it is information that has been carefully vetted through the scientific literature and is reflected of what most climate scientists consider the present state of knowledge on the topic. 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) reports in 2001 and 2007.

Our understanding of climate processes and causes for climate change

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 flows and balance of our planet. 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 (heating and movement of air molecules and heating. evaporation, transport and condensation of water molecules) in the atmosphere and oceans. As part of this energy balance of the Earth system, energy is absorbed and released from numerous parts of the system, including the oceans, land surface and biological systems. These same energy sources not only give us our weather, but they support and sustain all living systems.

Figure 1: Average Earth's energy balance
(based on the IPCC 2007)



On average the global system receives almost all energy for use in climate and living systems from the sun in the form of sunlight. Sunlight is a form of electromagnetic radiation, which is the only way energy can be transported through space (sometimes it is referred to as shortwave radiation in the climate literature). Once this light enters our atmosphere, some of that energy, specifically the ultraviolet portion of it, is absorbed by the atmosphere; specifically by oxygen and ozone atoms (circle a, figure 1). This absorbed energy warms the atmosphere, resulting in the characteristic temperature profile of the atmosphere. Additionally, particles in the atmosphere (aerosols) and clouds reflect a portion of that light back to space (circle b, figure 1), this light has no real impact on the Earth system as it never is absorbed to perform work. The remaining light passes through the atmosphere to the surface, where it is either reflected back through the atmosphere or is absorbed by the surface (circle c, figure 1). Overall about half of all this light energy is absorbed by the surface, and about 1/3 is absorbed by the atmosphere, because of this ratio, the surface tends to be warmer than the atmosphere. In order for the surface and atmosphere not to continuously heat up they must release the absorbed energy. The surface does this in three ways (energy partitioning by the surface): 1) emission of electromagnetic radiation, but because the surface is much cooler than the sun this is in the form of infra-red (IR) radiation (also called long-wave or terrestrial radiation); 2) by evaporating water (much like sweating in humans) in a process called latent heat flux; and 3) by direct heating of the air above the surface (sensible heat flux). The rate of energy loss by latent and sensible heat fluxes (circle e, figure 1) is controlled by many variables including, water availability, wind speed and the temperature difference between the surface and atmosphere, while the emission of IR radiation is controlled by the surface temperature.

Almost all the energy released by the surface is absorbed by the atmosphere. Because latent heat is carried by water molecules, and sensible heat by air molecules, and because these molecules cannot be carried out to space due to gravity, the energy carried by these systems can only be used to heat up the atmosphere. IR radiation, unlike sunlight, does not readily pass through the atmosphere. About 90% of this energy is absorbed by the atmosphere, effectively heating the atmosphere; the remaining 10% is lost to space (circle d, figure 1). It is well established (in 1859) that this absorption is done by so called greenhouse gasses (water vapor, carbon dioxide (CO2), methane and a number of other gases in the atmosphere). Since only electromagnetic radiation can transport energy through space, the loss of energy from the planet has to be emitted as IR radiation, and this comes from the atmosphere (which has absorbed heat by all the processes mentioned above).

Changes in the climate then need to somehow change the flow of energy through the system as described above. Any of the processes that control how energy is partitioned or passed through the system have the ability to change the climate. Such changes are a continuous process. Thus the study of climate change is about understanding how these flows change over time, both in the short term (last few decades) and long term (in geologic time). Climate scientists often refer to these controlling factors as boundary conditions. Specifically the following things are known to cause climate changes:

1. Changes is solar radiation because of:
    a. Changes in solar output or activity
    b. Changes in the orbit of the Earth around the Sun
2. Changes in the atmosphere that interfere with either reflection or absorption of light (circles a and b, fig 1)
    a. Changes in oxygen and ozone are critical to this process
    b. Changes in the amount of particles (e.g. volcanic activity and smoke)
    c. Changes in cloud cover (affected by evaporation and particles)
3. Changes in the Earth's surface properties that affect its reflectivity (circle c, fig 1)
    a. Changes in albedo (reflectivity) including:

        i. Temporary conditions such as snow and ice cover,
        ii. Permanent changes such as deforestation and land cover change
4. Changes in the way energy is portioned at the surface (circle e, fig 1)
    a. Changes is water availability because of
        i. Natural changes in precipitation
        ii. Human manipulation of surface water and irrigation etc.
5. Changes in the number of and intensity of greenhouse gasses (circle d, fig 1)
    a. Changes in the composition of the atmosphere from
        i. Natural system (volcanic activity
        ii. Emissions from human systems

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 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. These models include all the processes described above and many other systems beyond the scope of this document.

It is also well established that all the processes described above are changing continuously, thus the focus of climatology is on understanding which factors are changing, how fast and to what extent they influence out climate and thereby our daily weather. While many people think of climate change as a recent topic of research, there is a considerable history to this science, and it help to understand the timeline of our understanding of these processes when we think about how much we know and why. Table 1 shows a time line of some of the key findings about the climate system. Thus we have known since the early 1800s that the atmosphere plays a major role in creating a habitable planet, the greenhouse properties of the atmosphere have been established since the mid-1800s, and the first estimate of human impacts on the global climate through greenhouse gas emissions was made just prior to 1900.

It is presently well recognized that all of the boundary conditions mentioned play a role in climate changes. Some of these conditions tend to have localized effects, thus we know that human build cities tend to be significantly warmer than the surrounding country side, a process known as the urban heat island effect. The main reasons for this are the reflectivity of buildings, the loss of water from the city environment reducing the cooling effect of latent heat, and release of energy from heated or air conditioned buildings. Similarly, irrigated agricultural regions tend to be cooler because of increased latent heat losses relative to natural systems. However, most of these changes are local or regional in nature. Other systems that affect climate on larges scales are changes in ocean circulation, such as El Nino/La Nino events that can result in large areas of ocean being above or below average in temperature. On global scales we now know that of all these systems, the one undergoing the most change is the change in atmospheric composition with respect to greenhouse gasses (GHG). Changes in GHG concentrations result in changes in how much IR radiation passes through and is absorbed by the atmosphere (circle d, figure 1). From direct observations of CO2 gas concentrations in the last 50 years, and from remnant gas bubbles in ice sheets it has been possible to trace the amount of greenhouse gasses to beyond ½ million years in the past (Figure 2).

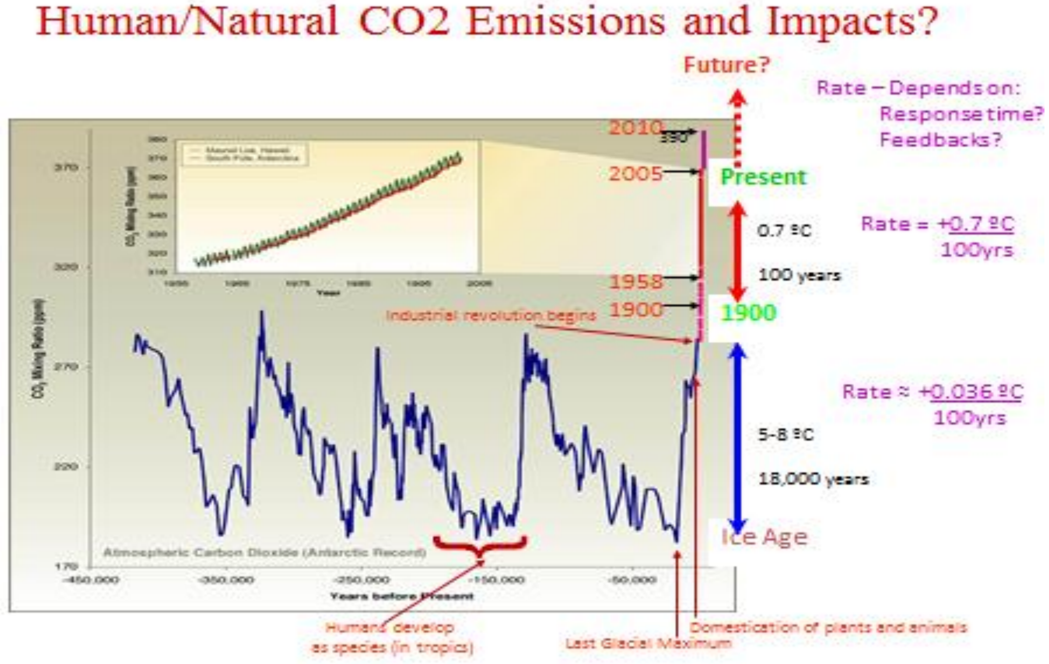
Table 1: Timeline of some of the major discoveries about the climate process

1824	**Joseph Fourier**	**Realization there was an insulation effect**
1859	**John Tyndall**	**Radiative properties of CO2, H2O and Green house gasses**
1896	**Svante Arrhenius**	**Humans could warm the climate through coal emissions**
1920-30s	**Milutin Milankovitch**	**Orbital influences on climate and ice ages**
1938	**Guy Steward Callendar**	**More complete understanding of the "green house effect" – could we prevent the next ice age?**
1957	**Roger Revelle**	**Concerns about human emissions, and role of Ocean**
1958	**C. David Keeling**	**Modern measurements of CO2**
1950-70s		**Aerosol effects and cooling (direct and indirect effects)**
1963		**Water Vapor Feedback**
1965	**Edward Lorenz**	**Chaos theory and understanding of**
1968		**Ice sheet melt concerns and ice albedo feedback**
1969	**Mikhail Budyko**	**Global energy balance measurements**
1972		**Greenland Ice-cores provide insight to last ice ages**
1983		**US National Academy and EPA reports lead to politics**

The historical CO2 record shows that GHG concentration were much lower during ice ages in the past, and that during the time of human civilization, the concentrations have been remarkably constant, to within 20 parts per million (ppm) until the beginning of the industrial revolution. Since then human emissions (we can tell from isotopic signatures what the source of CO2 is), have significantly increased the amount of CO2 in the atmosphere, from about 270 ppm to 396 ppm today. Most of that change has been in the last few decades, and the rate of change is still increasing. From the radiation laws of physics, we know that this must result in a warmer planet. However, there are questions about how fast the entire planet will warm and how much. This uncertainty arises from a number of factors including:

1. Future rates of GHG changes
2. How quickly the Earth system will respond (i.e. like a pot of water on a stove, it takes time to heat the pot once you start heating it, how fast will depend on the size of the pot etc.)
3. How energy is stored in the earth system, will the oceans heat more or land?
4. Feedback systems.
    a. Ice-albedo feedback: If the planet begins to warm that might change the amount of ice and snow, which in turn will then allow for more heat to be absorbed and more warming
    b. Cloud feedbacks (could reflect more or less, thus cooling or heating)
    c. GHG feedbacks, as polar areas warm, permanently frozen lands with high concentration of methane will release this strong greenhouse gas to the atmosphere also accelerating warming
    d. Water vapor feedback, as the atmosphere warms it can “hold” more water and thereby increase the greenhouse effect because water is the strongest greenhouse gas in the atmosphere

Figure 2 Atmospheric CO2 concentrations through time.



Models are used to try and sort out these different impacts, and figure 3 shows results of model simulations of global temperatures over the last century. There are two cases shown, the blue plot shows model simulations of the climate system is we include all the effects of natural system changes that were known to occur over the last century (changes in solar output, volcanic activity etc.), but for these simulation GHG concentration were held constant to what they were in 1870. The other set of simulations show the model predictions with increased GHG concentrations as they were observed over the 20th century. On both plots is a line of the actual observed changes from temperature stations.

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

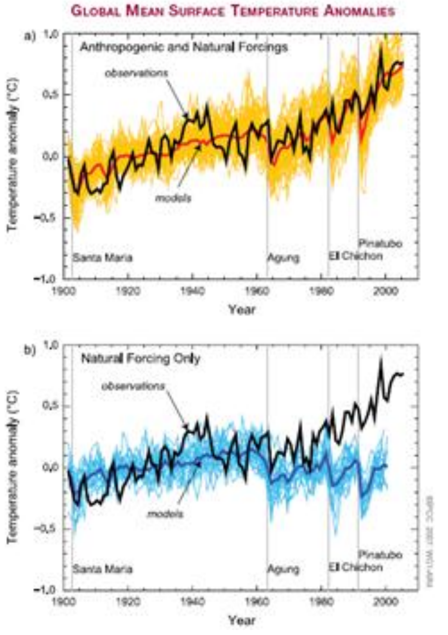


Figure TS.23. *(a) Global mean surface temperature anomalies relative to the period 1901 to 1950, as observed (black line) and as obtained from simulations with both anthropogenic and natural forcings. The thick red curve shows the multi-model ensemble mean and the thin lighter red curves show the individual simulations. Vertical grey lines indicate the timing of major volcanic events. (b) As in (a), except that the simulated global mean temperature anomalies are for natural forcings only. The thick blue curve shows the multi-model ensemble mean and the thin lighter blue curves show individual simulations. Each simulation was sampled so that coverage corresponds to that of the observations.* (Figure 9.5)

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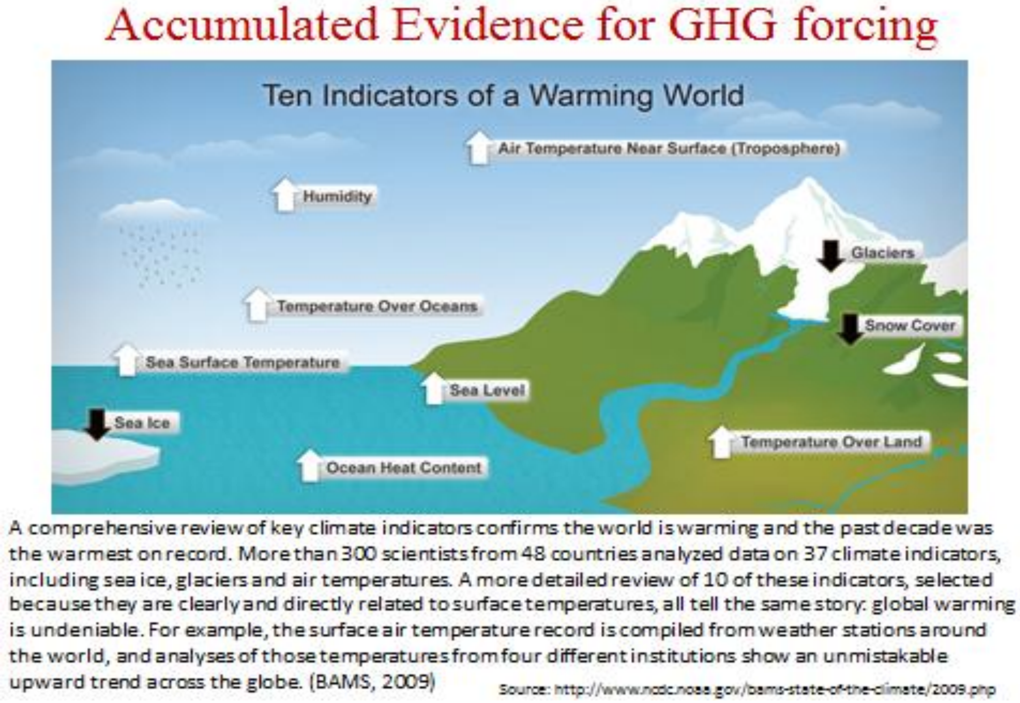
The values of a modeling study is that it makes it possible to test how warming might take place under different “forcing” conditions, where a forcing is the factor that forces the climate to change. Examples might be that if the sun intensifies, there will be warming because more solar radiation will force the system. In this case all the pathways will be forced increase, and more heat would be stored in all the systems. Similarly, if we increase GHG concentrations, we would not expect to see much change in measurements related to solar or shortwave radiation coming into the system, but we would expect a warmer atmosphere and surface and cooling in the upper atmosphere (because less IR radiation from the surface gets there to heat it). Thus different causes of climate change leave distinct “fingerprints,” or spatial patterns of temperature change, that can be measured. Figure 4 illustrates the measurements made to detect the fingerprint, and these match findings that would expect system changes caused by increased GHG concentrations

Figure 4: Fingerprint detection suggesting that GHG changes are the likely cause of observed climate changes over the last few decades.



Accumulated Evidence for GHG forcing

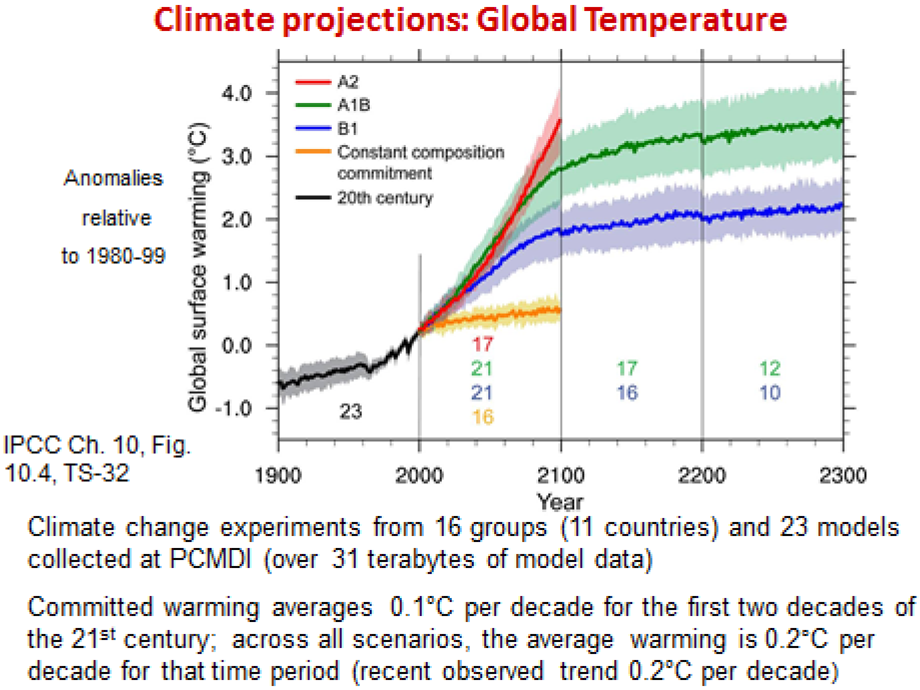
A comprehensive review of key climate indicators confirms the world is warming and the past decade was the warmest on record. More than 300 scientists from 48 countries analyzed data on 37 climate indicators, including sea ice, glaciers and air temperatures. A more detailed review of 10 of these indicators, selected because they are clearly and directly related to surface temperatures, all tell the same story: global warming is undeniable. For example, the surface air temperature record is compiled from weather stations around the world, and analyses of those temperatures from four different institutions show an unmistakable upward trend across the globe. (BAMS, 2009)

Source: http://www.ncdc.noaa.gov/bams-state-of-the-climate/2009.php

These combined theoretical underpinning to understanding the observed climate changes have led 98% of climate scientists to conclude that humans are at the center of the current observed climate changes, and that this is “beyond a reasonable doubt” or greater than 95% certainty.

The same models used to estimate the historical changes and causes of climate change can also be used to project future changes in climate. With the caveats that we do not know about future volcanic activity and little about trends in solar activity, it is possible to alter conditions related to human land use and future human GHG emissions. Future emissions are to a large extent controlled by political decisions on how we generate and use energy, hence climate scientist can only provide estimates of change for different emissions scenarios. Climate model simulations from many different models are used to make such projections. With very low future emissions, the world is projected to experience an additional 2.7 to 3.6 °F of warming on top of what has already occurred over the last century (1° F) (Figure 5). With higher emissions, representing observed rates as they occur today (actually it turns out they are still low estimates of actual fossil fuel consumption over the last decade), climate is expected to warm an additional 5-8 °F. From these experiments it is clear that our political decisions about fossil fuel consumption and alternative energy pathways will have a significant influence on the climate that the next generation will experience.

Figure 5: Future climate projections



Climate projections: Global Temperature

IPCC Ch. 10, Fig. 10.4, TS-32

Climate change experiments from 16 groups (11 countries) and 23 models collected at PCMDI (over 31 terabytes of model data)

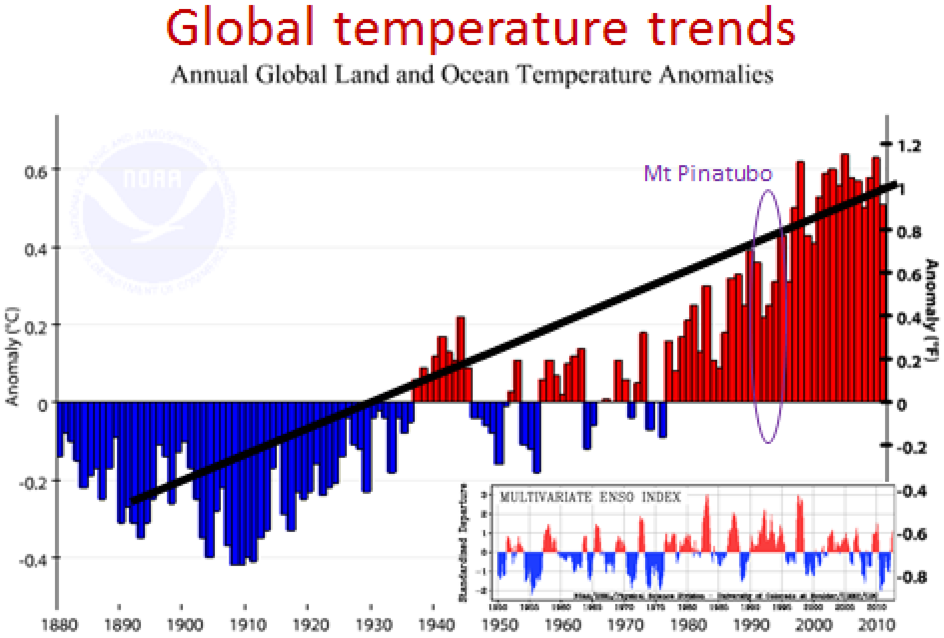
Committed warming averages 0.1°C per decade for the first two decades of the 21st century; across all scenarios, the average warming is 0.2°C per decade for that time period (recent observed trend 0.2°C per decade)

Evidence for Climate Change

There is significant evidence that the climate is changing, and that these changes are occurring at a rate that is much faster than observed in the past, with exceptions of catastrophic events in the Earth's history (e.g. very large meteor impacts, or massive volcanic eruptions). We have only been able to effectively measure surface temperatures for about the last 100 to 150 years, but for that time frame the 9 out of the 10 warmest years have all been measured since the year 2000 (the exception is 1998, associated with one of the largest E Nino events on record). This is illustrated in figure 6.

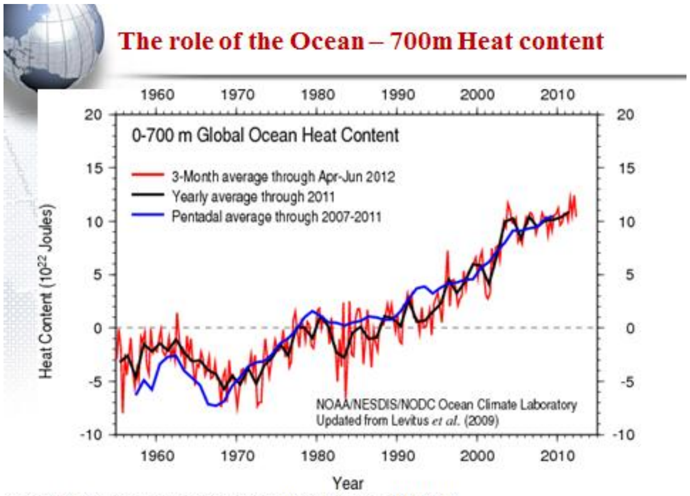
Figure 6 also shows that climate does not change on a regular basis, and this is to be expected given that there are many factors that can affect energy flows and temperatures (where temperature represents the amount of energy stored in the material measured (e.g. the atmosphere)) from year to year. One major source of variability from year to year is associated with ocean conditions. For example El Nino conditions change ocean surface temperatures over large areas of the tropical Pacific Ocean which changes global temperature averages. From figure 6 it can be seen that La Nina conditions (blue periods in the small graph) coincide with

Figure 6 global temperature trends during the instrumental record



cooler than normal global temperatures, and that during El Nino (red periods in the small graph) conditions global temperatures are a little higher. The only major exception to this rule is during the Mt Pinatubo volcanic eruption in the early 1990s when global temperatures were cooled for a number of years because of aerosols from the volcano. Further evidence is provided by the measured heat content of the oceans (figure 7), any heat absorbed by the ocean means that atmospheric temperatures will not warm as much, but eventually that heat will be released back to the atmospheric system.

Figure 7: Heat absorption by the oceans

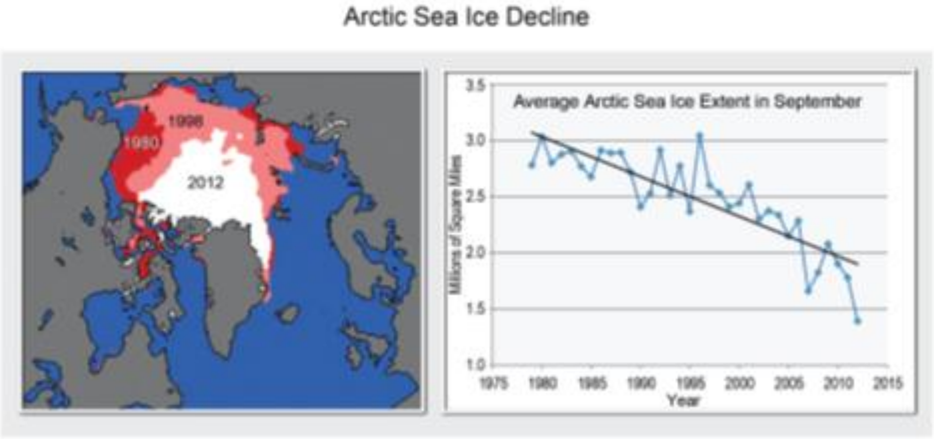


Source: NOAA http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/

There are a number of other lines of evidence of climate change, including observations or arctic sea ice conditions (figure 8). Although model projections suggest that eventually sea ice would begin to melt, this has happened much faster than the models and observers had expected. This set of observations also gives an indication of how unusual some of the observed changes in the recent record are. Observations of the sea ice are relatively recent because they are satellite based and hence there is some uncertainty about historical sea ice extent. However other measurements of species composition in the ocean sediments and other factors make it clear that arctic sea ice has not been at levels presently observed for at least 2000 years. Measurements from 1980 to 2000 show that on average the vast majority of the Arctic Ocean was covered in sea ice in September when the annual minimum amount of sea ice is reached. When we compare the last 5 years of sea ice extent to those conditions (figure 8b), every observation falls out of the normal range of the 1980-2000 observations, and each should be considered an extremely rare (less than 5% chance) event. Yet we have observed 5 years in a row of such events suggesting a permanent change is occurring. Climatologists are particularly concerned with the polar changes because the ice-albedo feedback is likely to lead to major changes in the global circulation system and the path of the jet stream, and thus is likely to mid-latitude climate, including Kansas.

Figure 8: Sea ice extent over the historical and recent period: a) spatial extent in 2 record years relative to normal (red line) and b) recent trend as relative to normal conditions from 1980-2000

a)



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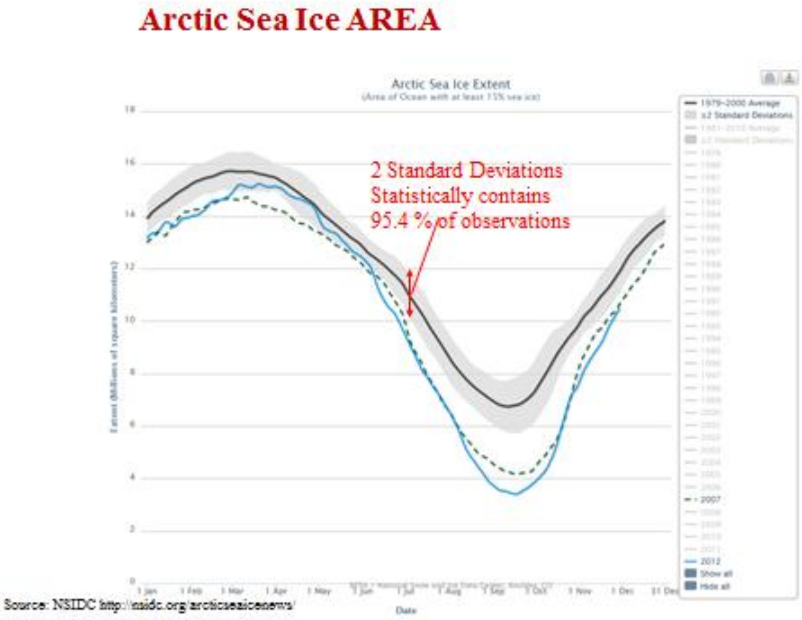
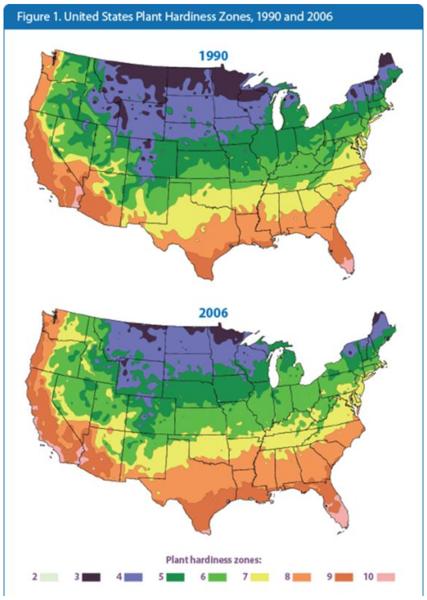


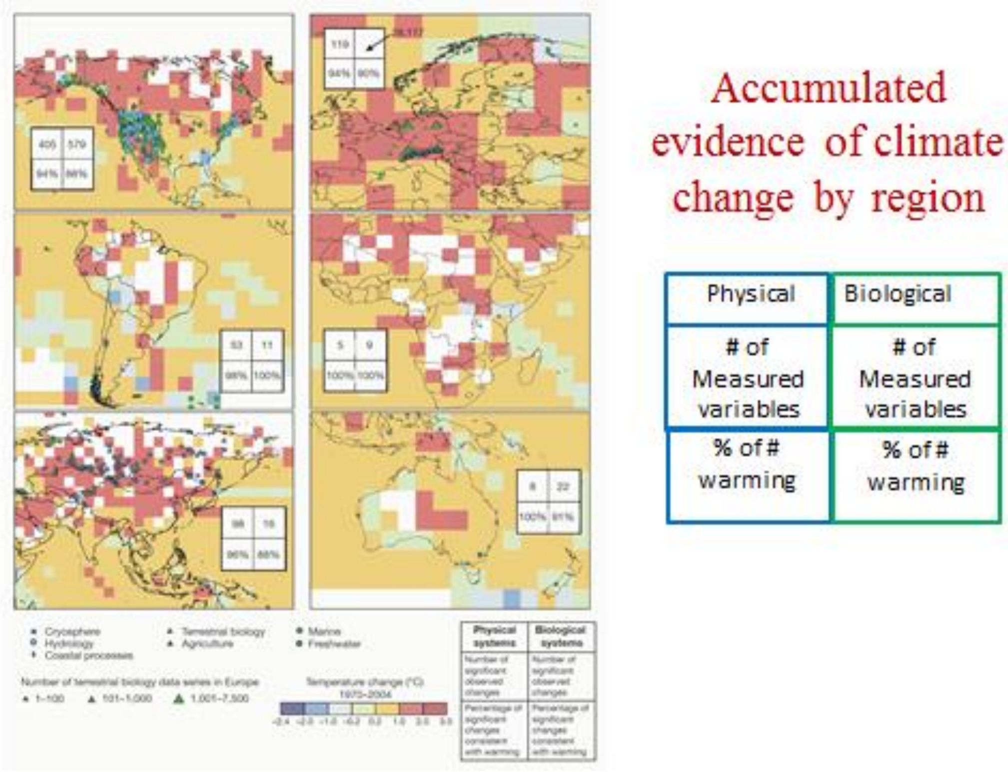
Source: NSIDC http://nsidc.org/arcticseaicenews/

Other lines of evidence for changing climate conditions include many indirect measures of changing climate conditions observed in physical and biological systems. For example plant hardiness have shifted sufficiently that the Arbor Day Society redrew its maps in 2006 (figure 9a). Figure 9b illustrates that in the US of 405 physical processes measured, 94% of the observations indicate a changing and warming climate, and of 579 biological measurements 88% indicate warming conditions.

Figure 9a: Example biological indicator change, change in plant hardiness zones for the US from 1990 to 2006 (Arbor Day Foundation



b: Number of physical and biological measurement and the percentage of each that indicate warming climate conditions.



Climate Impacts on Kansas

There is significant evidence that the climate of Kansas is changing for a number of different reasons (figure 10a). The global effects of GHG changes is a major background signal, but there is also evidence that local land use changes are changing our climate, especially associated with large scale irrigation in the western half of the state. Despite this local cooling, 2012 is now the warmest year on record (figure 10a) for the state, and annual average temperature conditions are approaching those of the dust bowl years. However, the "fingerprint" of the observed changes is quite different from the causes associated with the changes during previous dry periods (30s and 50s) (figure 10b and c). While the dustbowl years tended to have very hot summer and primarily hot high temperatures in large part because of very dry soil conditions, present warming is associated with much warmer winter and spring conditions, and also more so with warmer minimum temperatures compared to maximum temperatures (figure 11).

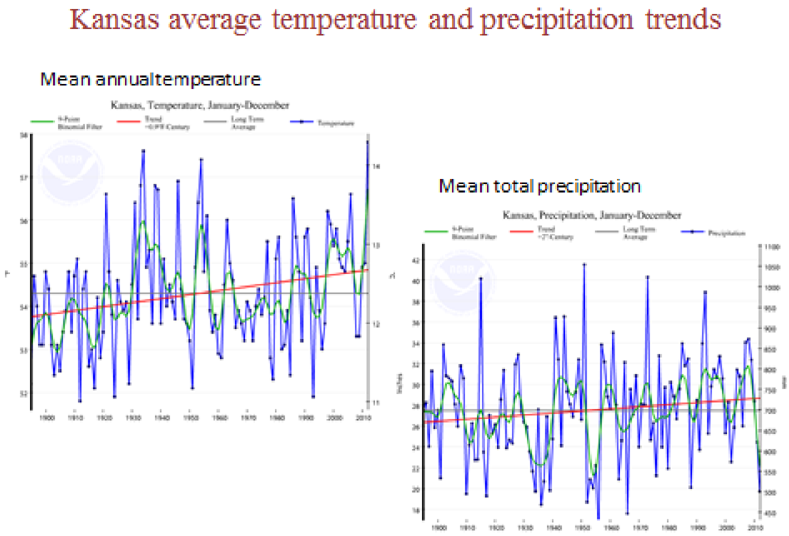
Kansas is particularly vulnerable to climate change in large part because of the existing climate conditions across the state. There is considerable evidence that already the warming of the polar region, and the associated ice loss is changing the energy gradient (temperature difference between the equator and pole), which is what drives the intensity of global wind systems and the path of the Jetstream. A lower equator-pole temperature gradient will result is a weaker wind system, and this will allow the jet stream to meander more and change rainfall frequency and intensity in areas that receive rainfall from storm tracks associated with the jet stream. Weaker large scale flows mean intensification of local storm, but also slower movement of storms across the plains. This is likely to change our rainfall patterns to be more extreme and less frequent in nature. There is already significant evidence of such patterns emerging from observations (figures 12).

The best current projections for different emissions scenarios for the US for temperature change, precipitation change, soil moisture availability and other factors affecting agriculture are shown in figures 12, 13, and 14. For additional information I would refer you to read the Upcoming National Climate impact assessment report (www.globalchange.gov/) or the forthcoming 2013 IPCC report due out later this year (www.ipcc.ch). From these figures it is clear that the outlook for Kansas is not very clear. To the north conditions are expected to get wetter, and to the south they are expected to get drier. However, which GHG emissions scenario we follow also makes a significant difference in likely outcomes for the state. Hence our own choices about our energy future will impact this outcome. The high emissions scenario is unlikely to be beneficial to industry and agriculture in the state, given the expected change to very dry summer conditions.

Climate variability must also be considered for Kansas. Although Kansans are used to a very variable climate and weather conditions, subtle changes in the probability of dry v.s. wet years could have major consequences. Thus if (as an example only) we presently experience 1-2 year of dry conditions in every 10 years, and this changes to 2-3 years per 10 years, this could have significant consequences on the farm economy. Indications are that this variability will increase, that that for example, we will have on average warmer winters, but with a weak jet stream, also infrequent but potentially very severe cold spells.

Figure 10: a) Annual temperature and precipitation trends in Kansas b) Seasonal temperature trends and c) seasonal precipitation trends

a)



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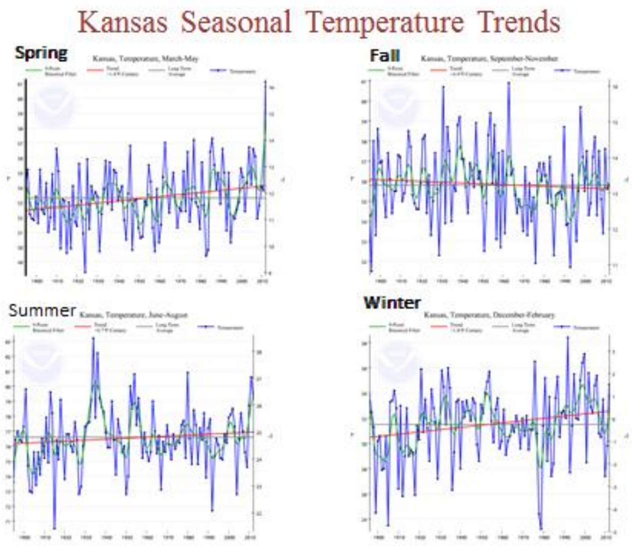

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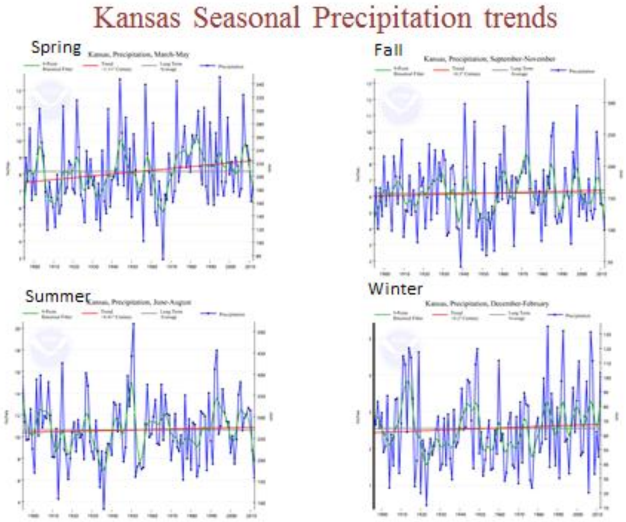
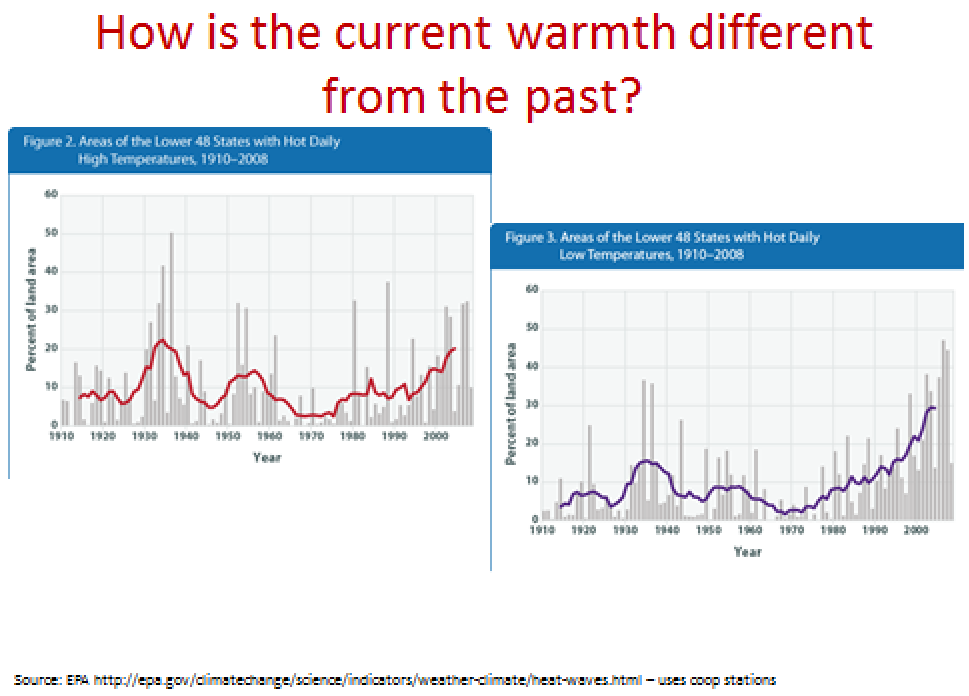


Figure 11: Observed changes in US minimum and maximum temperature trends



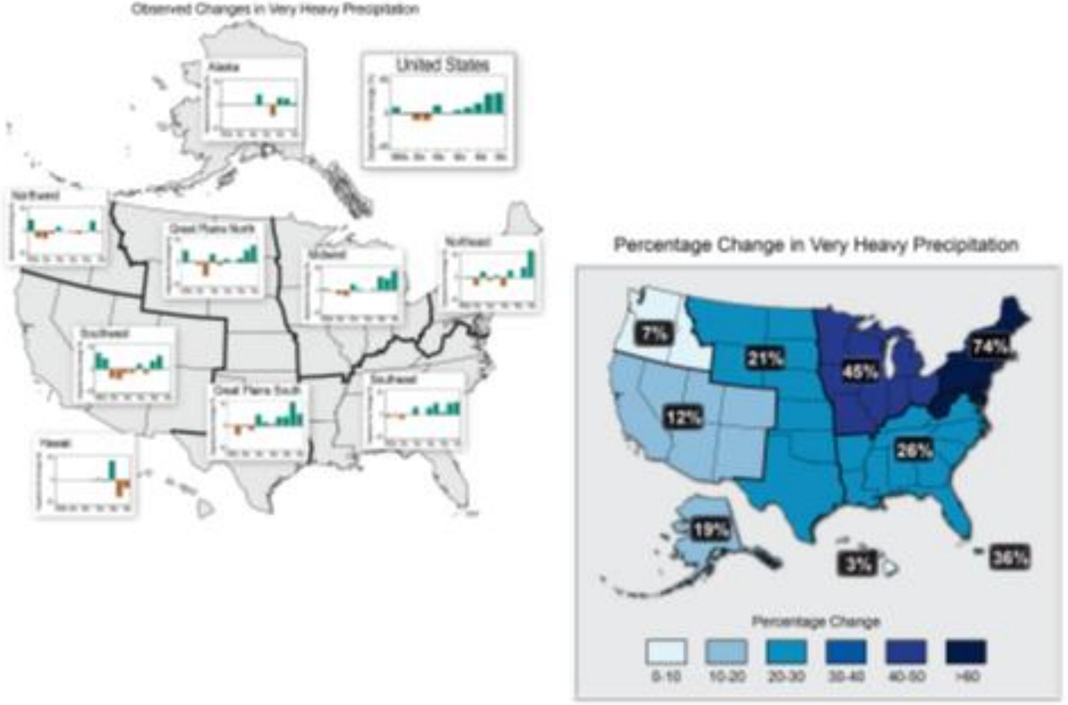
How is the current warmth different from the past?

Figure 2. Areas of the Lower 48 States with Hot Daily High Temperatures, 1910–2008

Figure 3. Areas of the Lower 48 States with Hot Daily Low Temperatures, 1910–2008

Source: EPA http://epa.gov/climatechange/science/indicators/weather-climate/heat-waves.html – uses coop stations

Figure 12: Observed changes in extreme rainfall events (very heavy precipitation is a 2 day total greater than is expected once every 5 years – from draft National Assessment 2013



Observed Changes in Very Heavy Precipitation

Percentage Change in Very Heavy Precipitation

Figure 13: projected temperature changes for different emissions scenarios (2.6 is very low, 8.5 is business as usual or current path) – from draft National Assessment 2013

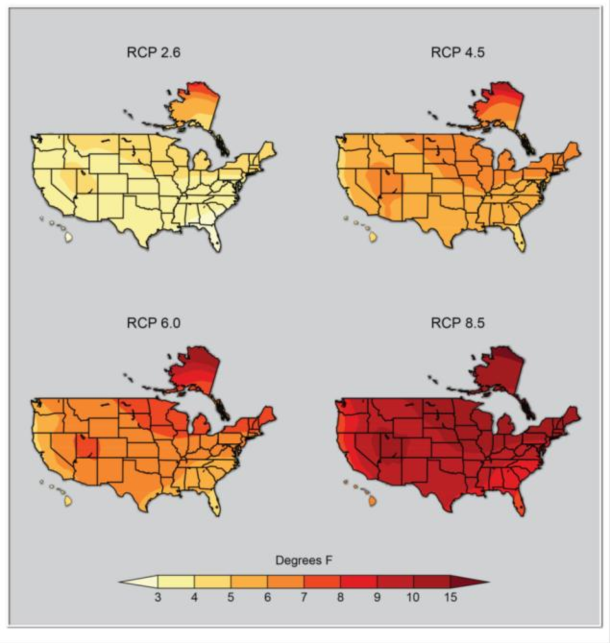


Figure 14: projected precipitation changes for different emissions scenarios (2.6 is very low, 8.5 is business as usual or current path) – from draft National Assessment 2013

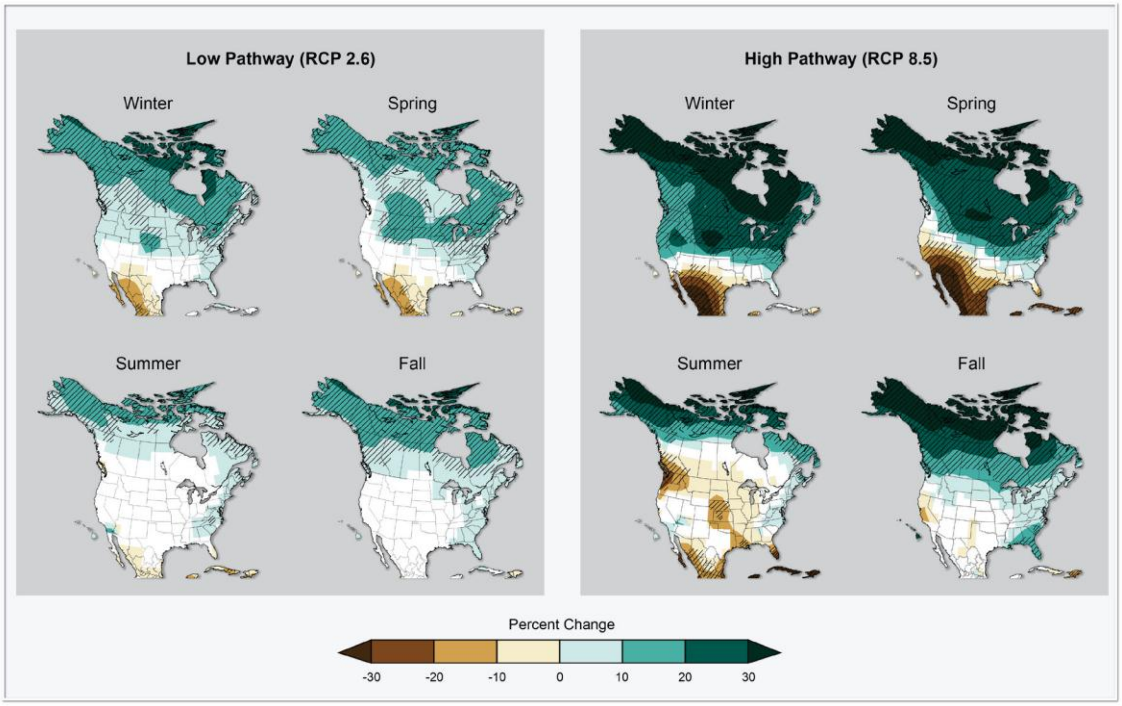
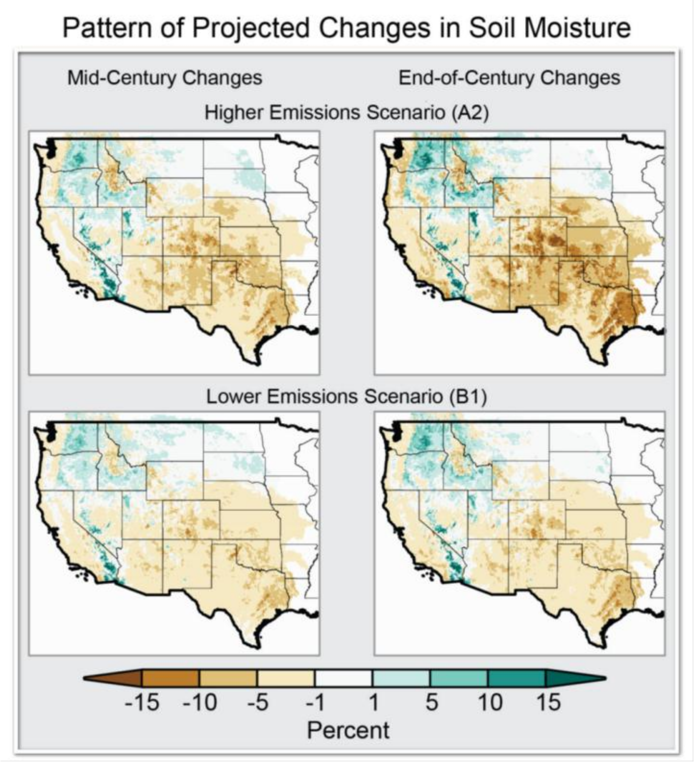


Figure 14: projected temperature changes for different emissions scenarios (2.6 is very low, 8.5 is business as usual or current path) – from draft National Assessment 2013



Connections to Energy Policy

There are a number of climate connections to energy policy. First, all future scenarios of climate change are completely dependent on the energy development path we choose as a global society. At the same time changes in the climate will vary likely to affect the state economy in a number of ways, including energy and water needs. Therefore the following points might be of interest as the committee explores energy policy options in the future:

1. Climate is changing, and the primary cause of change is associated with human GHG emissions from fossil fuel burning (based on evidence of the source of CO2 in the atmosphere and increasing rates of CO2 emissions).
2. Kansas will be one the states most affected by climate change due to its geographical location and because the state straddles a climate gradient which with minor changes can alter conditions significantly (for better or worse), although the best projections today suggest we will dry out significantly
3. We already have water stress in the state, and this is only likely to increase in the future
    a. Consider the water costs associated with different energy technologies, many fossil fuel technologies require water, which may in the long run become a cost burden
    b. Any water intensive energy technology will compete directly with water for agriculture

4. Observed and projected increases in rainfall intensity and lower frequency will have negative impacts on agriculture and will also negatively affect water infrastructure (more soil loss and sediment flows), this will require adaptation by our agricultural industry
5. While the world still needs, and relies on, fossil fuels cost are likely to increase significantly especially if climate policies are implemented in the future (this is more likely as the climate impacts become more evident).
6. Our choice of energy production technology will have consequences on climate and our economy in the future
    a. Different energy mixes will affect our GHG emissions, and any policies to curb these emissions will be more painful if we do not develop alternatives to take their place
    b. Developing alternative methods can provide new business opportunities, especially if we create technologies that other societies can purchase and implement to curb emissions in the future

Most climate scientist have no doubt that our climate will change in the future along the lines of present trends and the future projections from the models. While it is a political decision to act on that information, and one choice might be to live with it, good policy will consider the alternatives as part of long term planning, especially in relation to water and energy resources. Infrastructure for these resources is expensive, and tends to be long lived (often well past our own life times), hence planning for potential changes and incorporating some of the uncertainties in the climate projections could be a very useful tool in making such decisions; as was in evidence during Governor Brownback's recent water conference. For Kansas this is especially important in the context of developing policies related to water extraction from aquifer systems across the state.