Anthropogenic Climate Change:

What We Know,
What We Think We Know and
What We Wish We Knew

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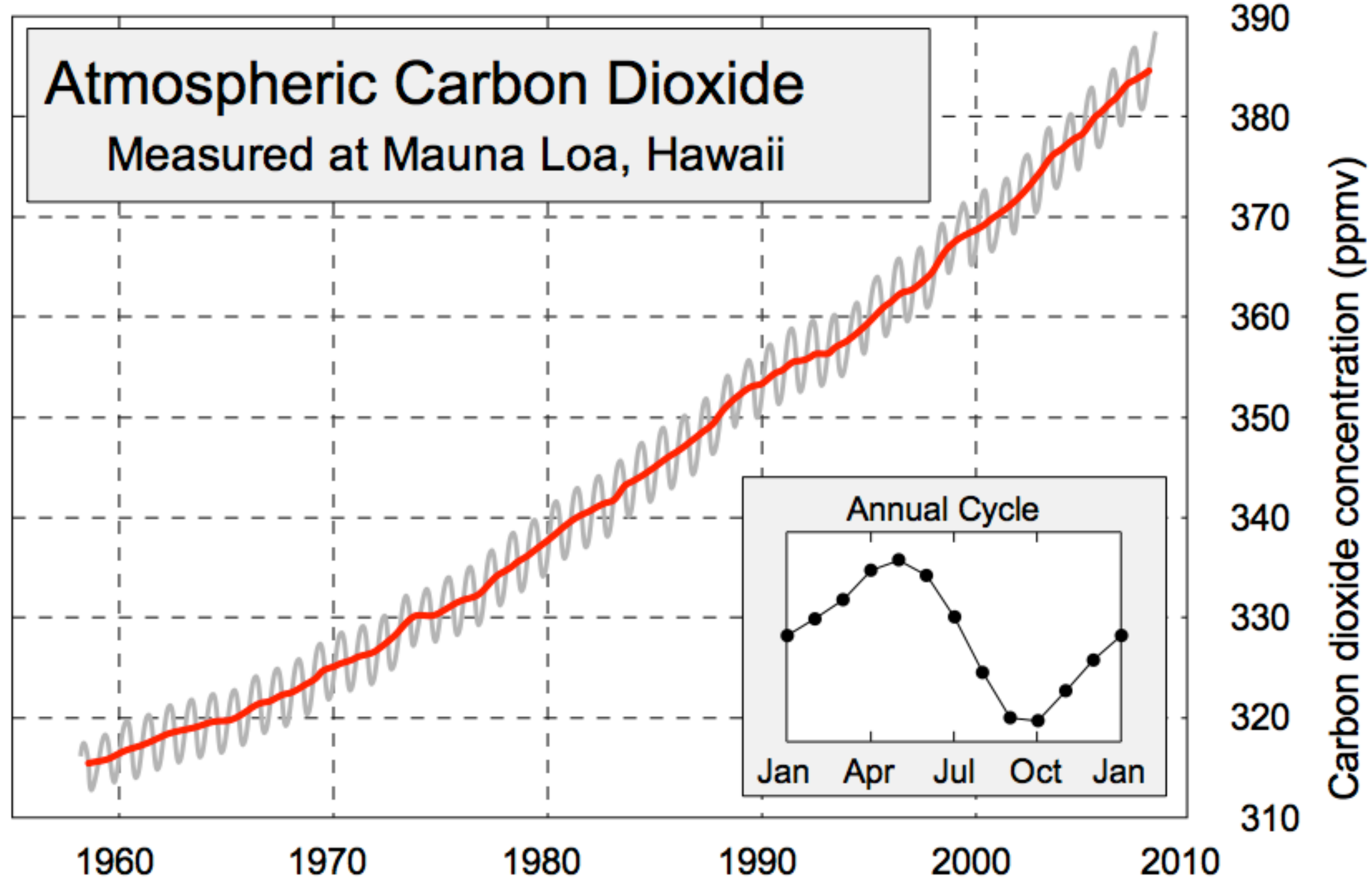
The reality of anthropogenic climate change
is that it is both simple and complex ....

Simple: The basic mechanism of anthropogenic climate change is well understood and beyond reproach.

Complex: How the Earth systems will respond to this warming is complicated and nonlinear.

The Keeling Curve



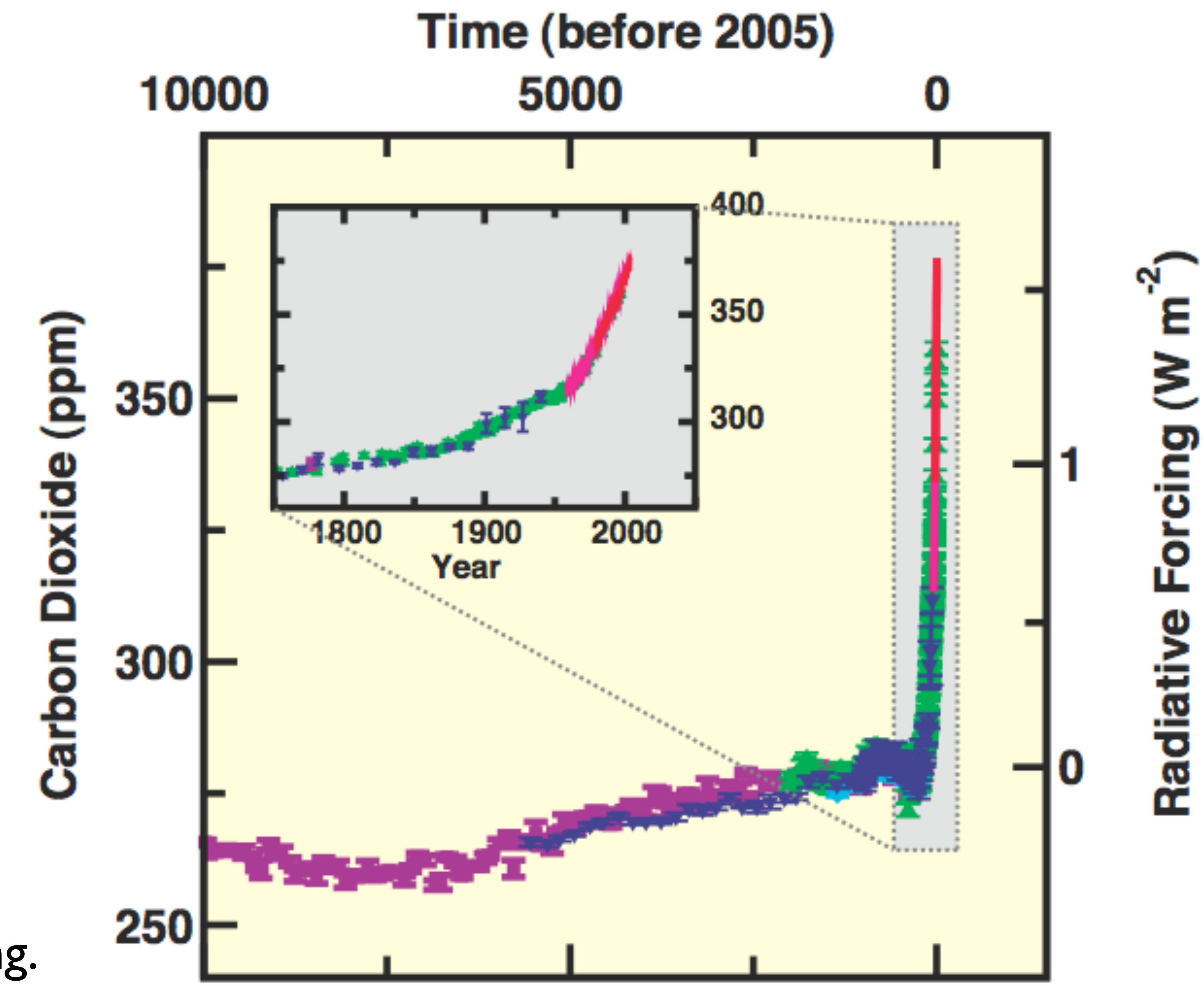
In the late 1950s Charles Keeling set out to determine how much carbon dioxide from fossil fuel burning remained in the atmosphere.

Important numbers
385 ppmv: present day
270 ppmv: pre-industrial
540 to 1000 ppmv: sometime this century.

1. CO_2 concentration is rising.

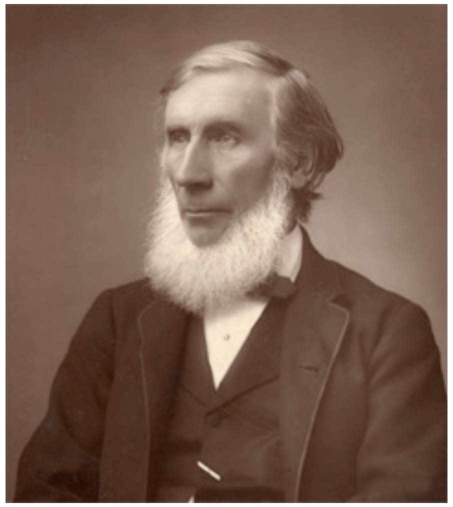
Carbon Dioxide Levels are Rising at Geologically-Unprecedented Rates

Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture. (IPCC AR4)



1. CO_2 concentration is rising.
2. We know **why** CO_2 concentration is rising.

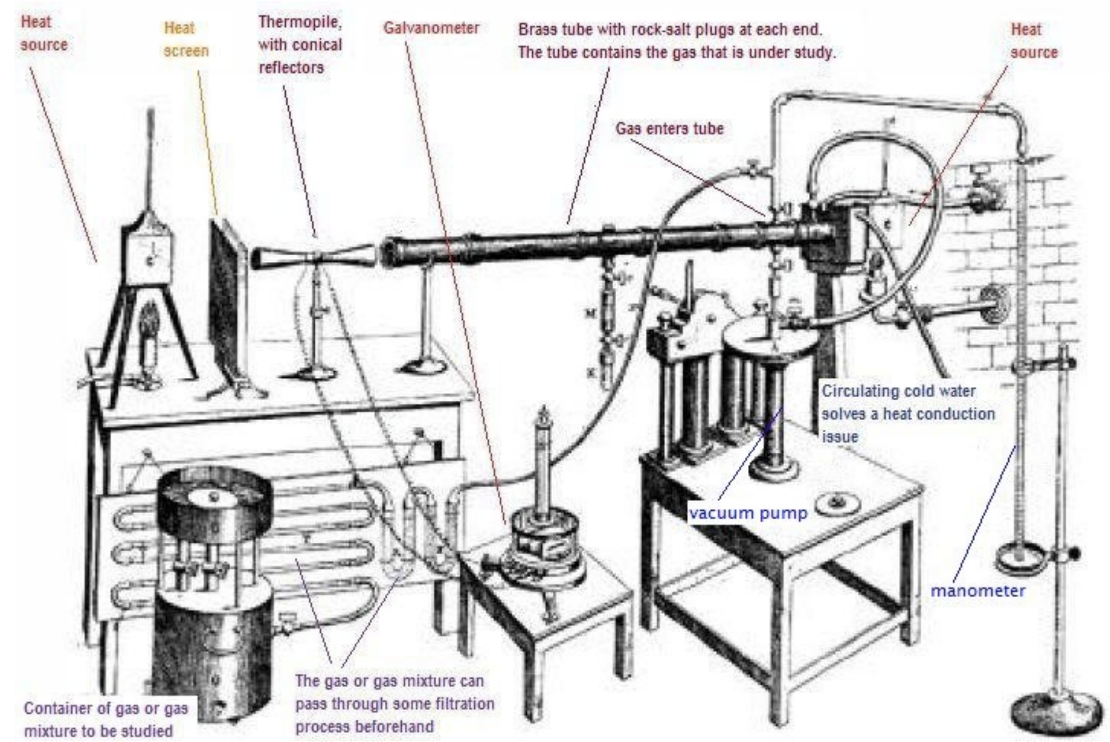
GHG-Induced Warming is Very Old News .....



In 1859, at the age of 39, John Tyndall discovered that certain gases, including carbon dioxide, "absorb and transmit radiant heat."

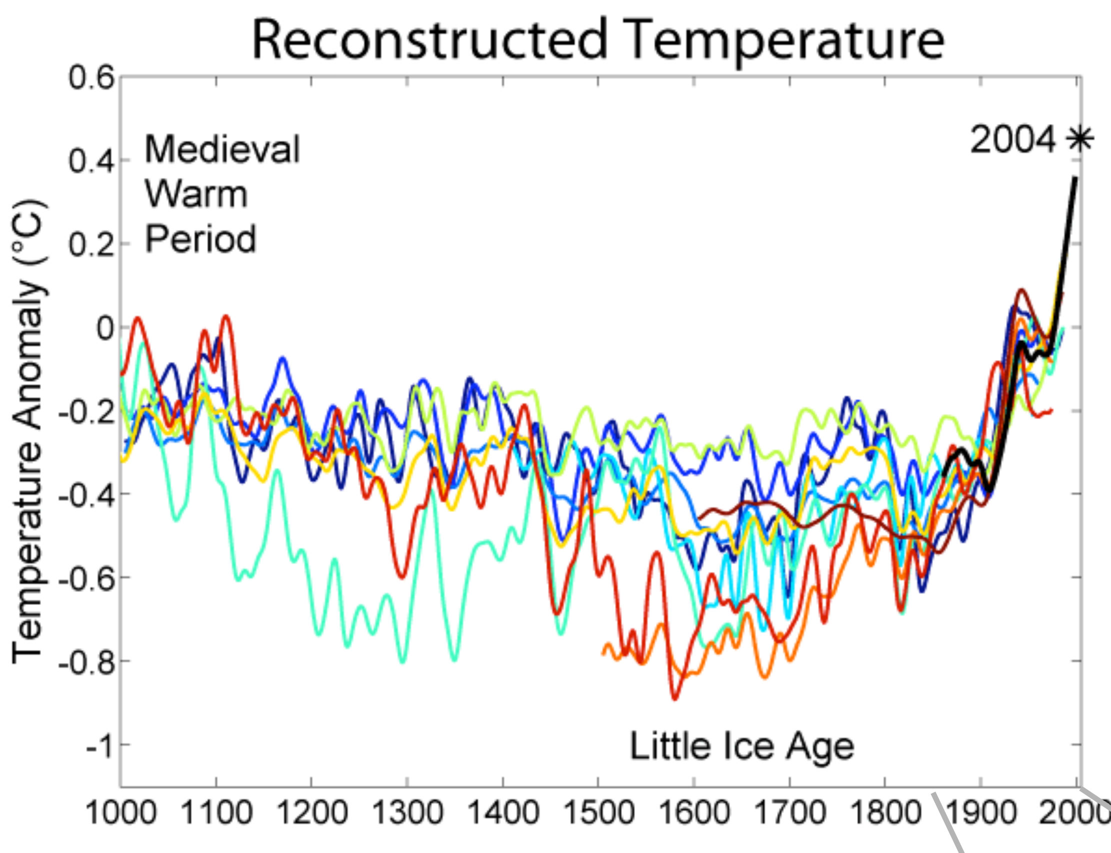
So we have known for 150 years that the primary and direct effect of carbon dioxide is to warm the atmosphere.

Tyndall also conjectured that these gases (now called greenhouse gases) might play an important role in climate and ice ages.



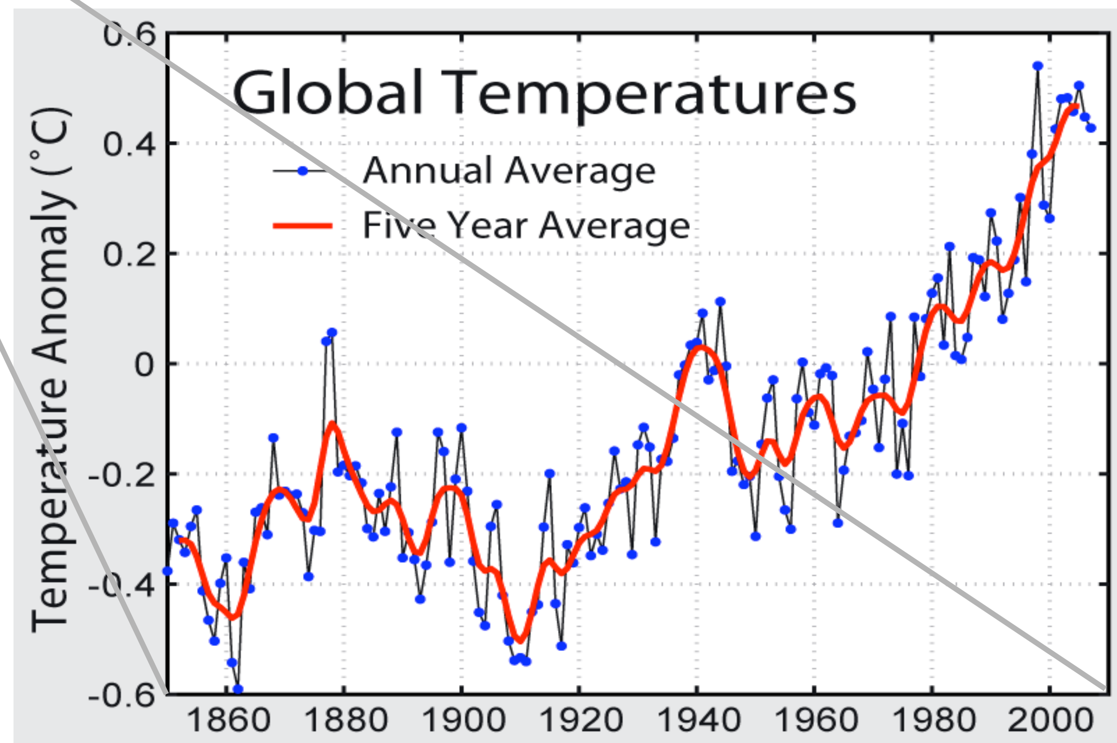
1. CO_2 concentration is rising.
2. We know why CO_2 concentration is rising.
3. We know that CO_2 tends to warm the atmosphere.

We have observed a warming during the 20th Century.



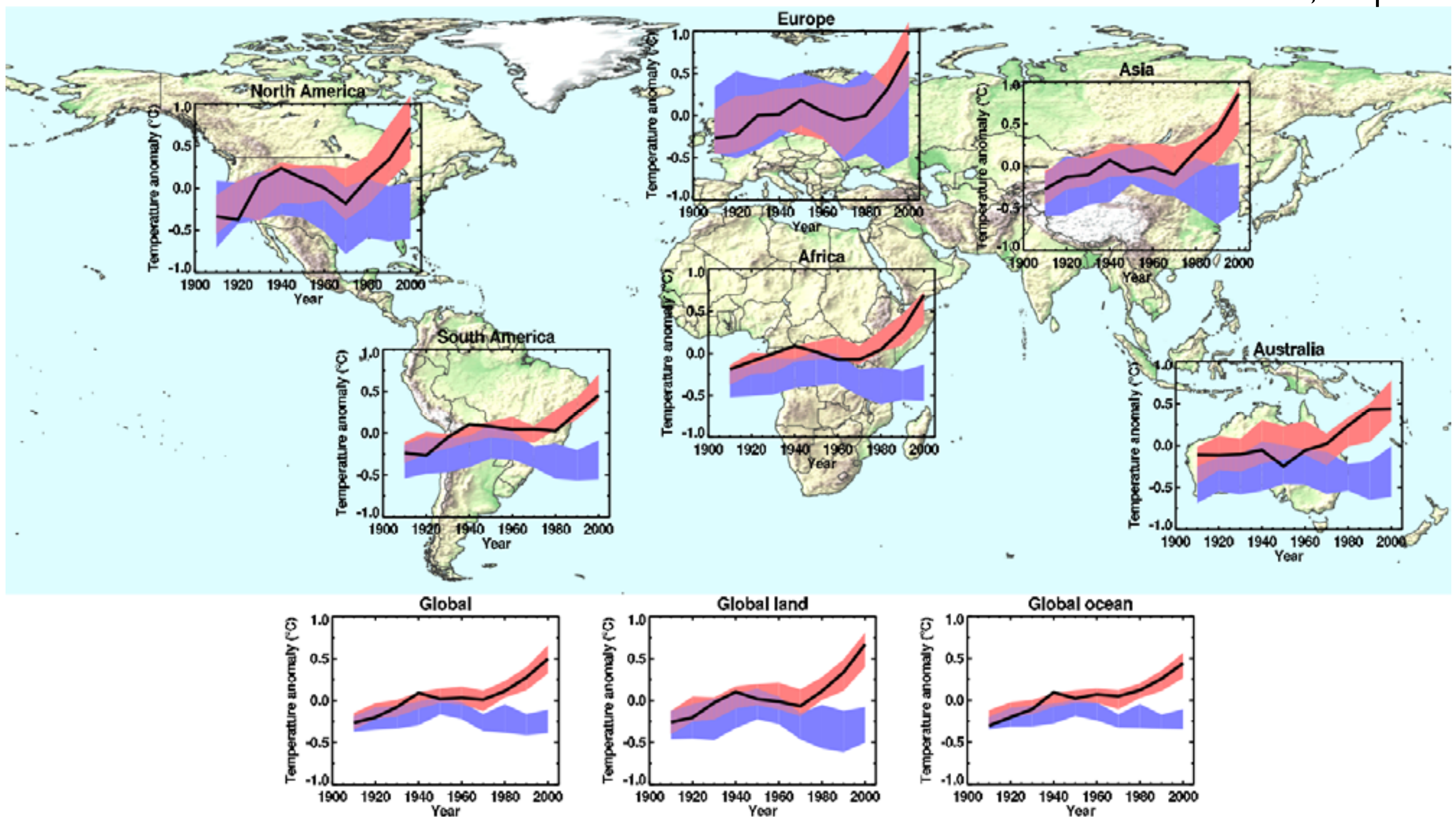
1. CO_2 concentration is rising.
2. We know why CO_2 concentration is rising.
3. We know that CO_2 tends to warm the atmosphere.
4. Observed a warming of about 1.5 °F during the 1900s.

But is the warming due to CO_2?



Understanding the Observed Warming

IPCC WG1 AR4, Chapter 9



Black Line: Observed Temperature
Red Region: 5th-95th percentile of model with CO_2 rise.
Blue Region: 5-95th percentile of models without CO_2 rise.

1. CO_2 concentration is rising.
2. We know why CO_2 concentration is rising.
3. We know that CO_2 tends to warm the atmosphere.
4. Observed a warming of about 1.5 °F during the 20th century.
5. We can not explain the observed warming of the 20th century without rising CO_2.

The scientific community has been very steady with respect the global relationship between CO_2 and temperature.

1990: http://www.ipcc.ch/ipccreports/far/wg_I/ipcc_far_wg_1_full_report.pdf

under the IPCC Business-as-Usual (Scenario A) emissions of greenhouse gases, a rate of increase of global mean temperature during the next century of about 0 3°C per decade (with an uncertainty range of 0 2°C to 0 5°C per decade), this is greater than that seen over the past 10,000 years. This will result in a likely increase in global mean temperature of about 1°C above the present value by 2025 and 3.0°C before the end of the next century.

1995: http://www.ipcc.ch/pdf/climate-changes-1995/ipcc-2nd-assessment/2nd-assessment-en.pdf

Combining the lowest IPCC emission scenario (IS92c) with a “low” value of climate sensitivity and including the effects of future changes in aerosol concentrations leads to a projected increase of about 1°C by 2100. The corresponding projection for the highest IPCC scenario (IS92e) combined with a “high” value of climate sensitivity gives a warming of about 3.5°C.

2001: http://www.ipcc.ch/pdf/climate-changes-2001/synthesis-spm/synthesis-spm-en.pdf

The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100. These results are for the full range of 35 SRES scenarios, based on a number of climate models.

2007: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf

Best estimate for a "low scenario" is 1.8 °C with a likely range of 1.1 to 2.9 °C (3.2 °F with a likely range of 2.0 to 5.2 °F)
Best estimate for a "high scenario" is 4.0 °C with a likely range of 2.4 to 6.4 °C (7.2 °F with a likely range of 4.3 to 11.5 °F)

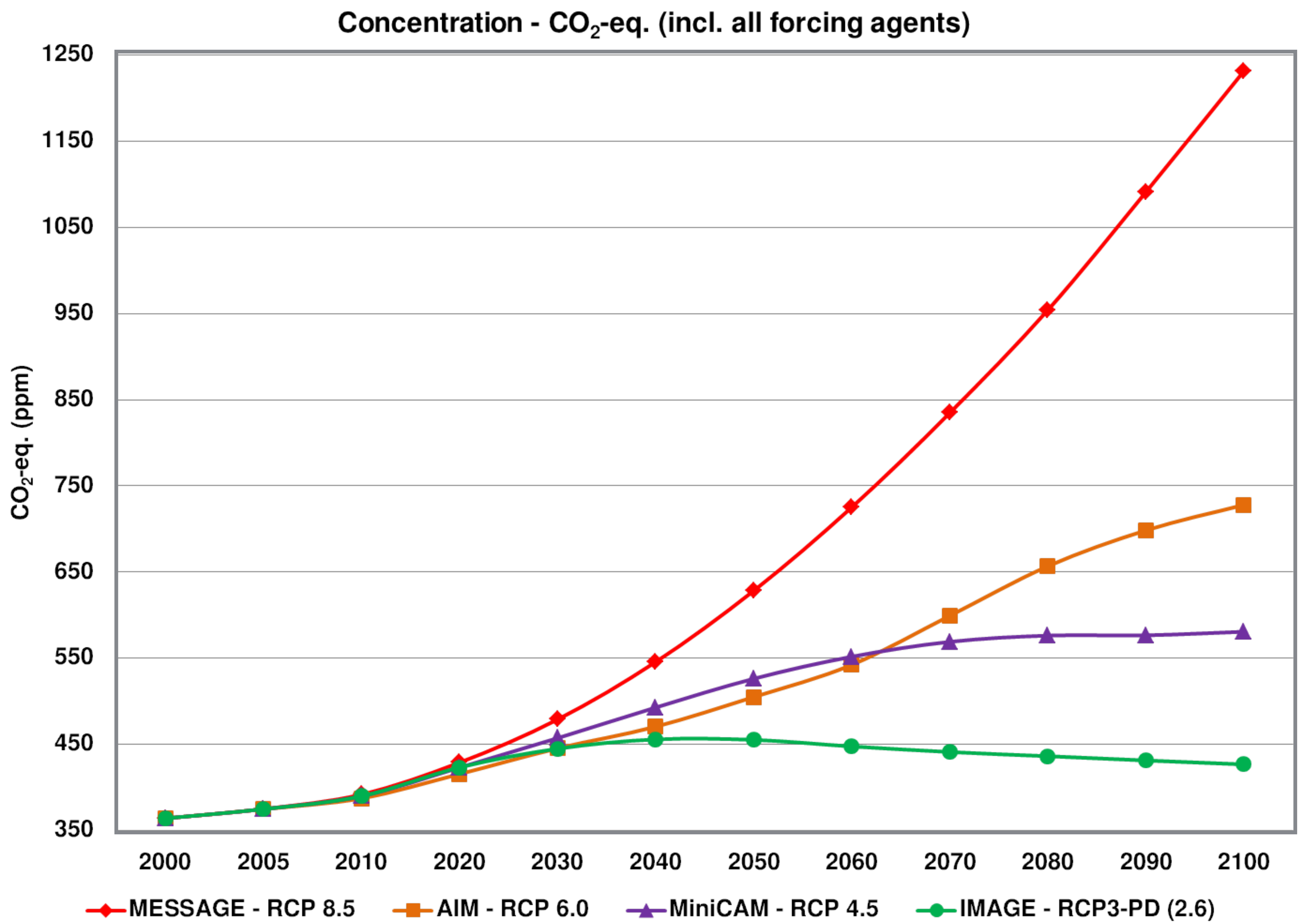
2013: http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf

Best estimate for a "low scenario" is 2°C with a likely range of 1.1 to 2.6 °C (RCP 4.5)
Best estimate for a "high scenario" is 4°C with a likely range of 2.6 to 4.8 °C (RCP 8.5)

For the last 30 years the scientific community has estimated a global warming due to GHGs of between 1.0 °C and 6.0 °C over the course of the 21st century.

Why hasn’t the range of warming been reduced?

The Largest Source of Uncertainty in our Predictions? Our Energy Future



Trajectory of CO_2 concentration is basically a choice that society will make.

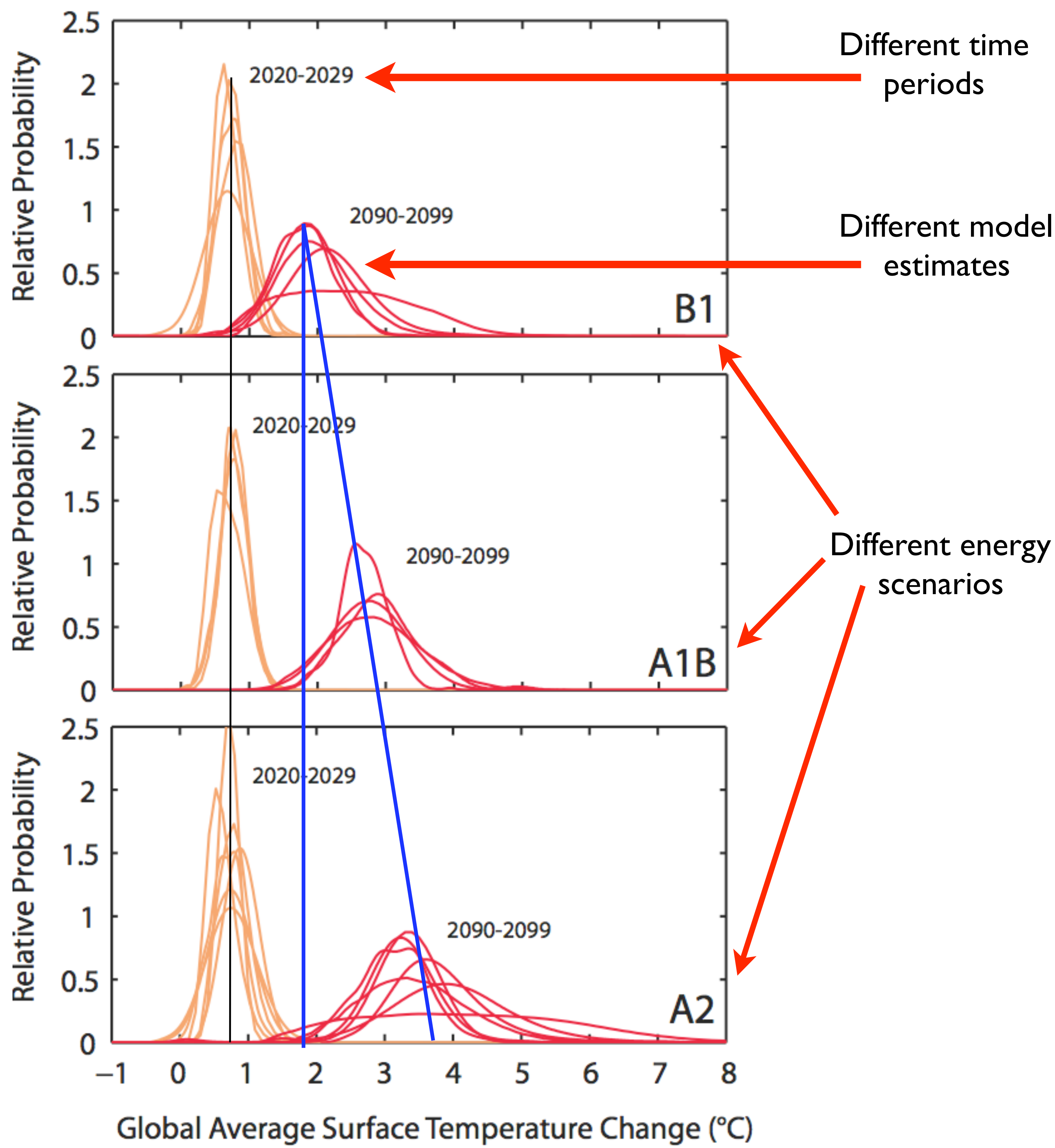
The Largest Source of Uncertainty? Our Energy Future

Different red lines provide estimate of inter-model uncertainty.

Different graphs provide explore different energy futures, with increasing reliance on fossil fuels increasing toward the bottom.

2020-2029
Estimates of global temperature rise are primarily a function of model choice, not the energy future.

2090-2099:
Estimates of global temperature rise are primarily determined by our energy future, not by model choice.



A Summary of What We Know
(meaning "what we should expect to come to pass")

1. CO_2 concentration is rising.

2. We know why CO_2 concentration is rising.

3. We know that CO_2 tends to warm the atmosphere.

4. Observed a warming of about 1.5 °F during the 20th century.

5. We can not explain the observed warming of the 20th century without rising CO_2.

6. With respect to global temperature rise during the 21st century, the largest uncertainty is our energy future.

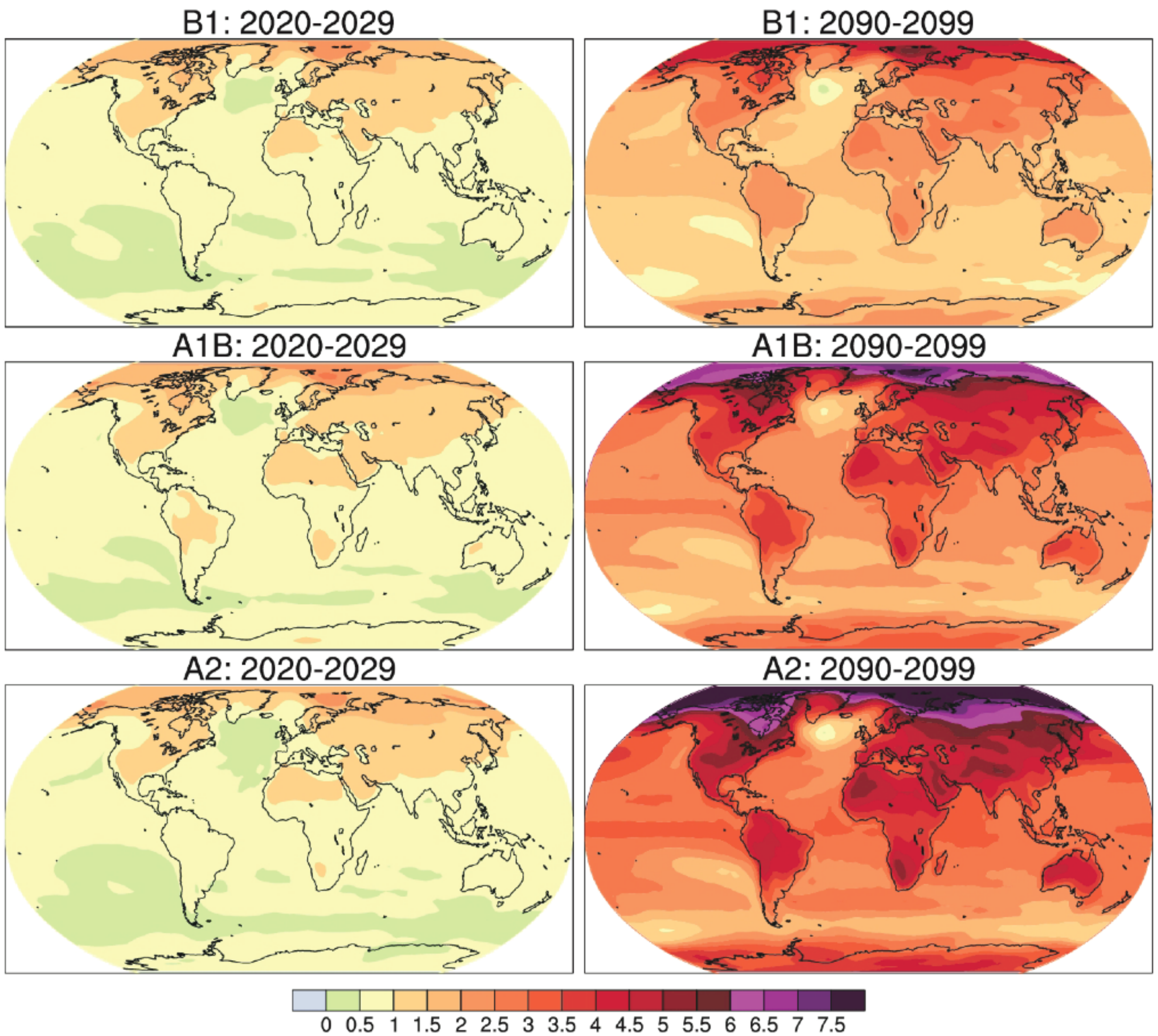
Moving on to less-firm ground ....

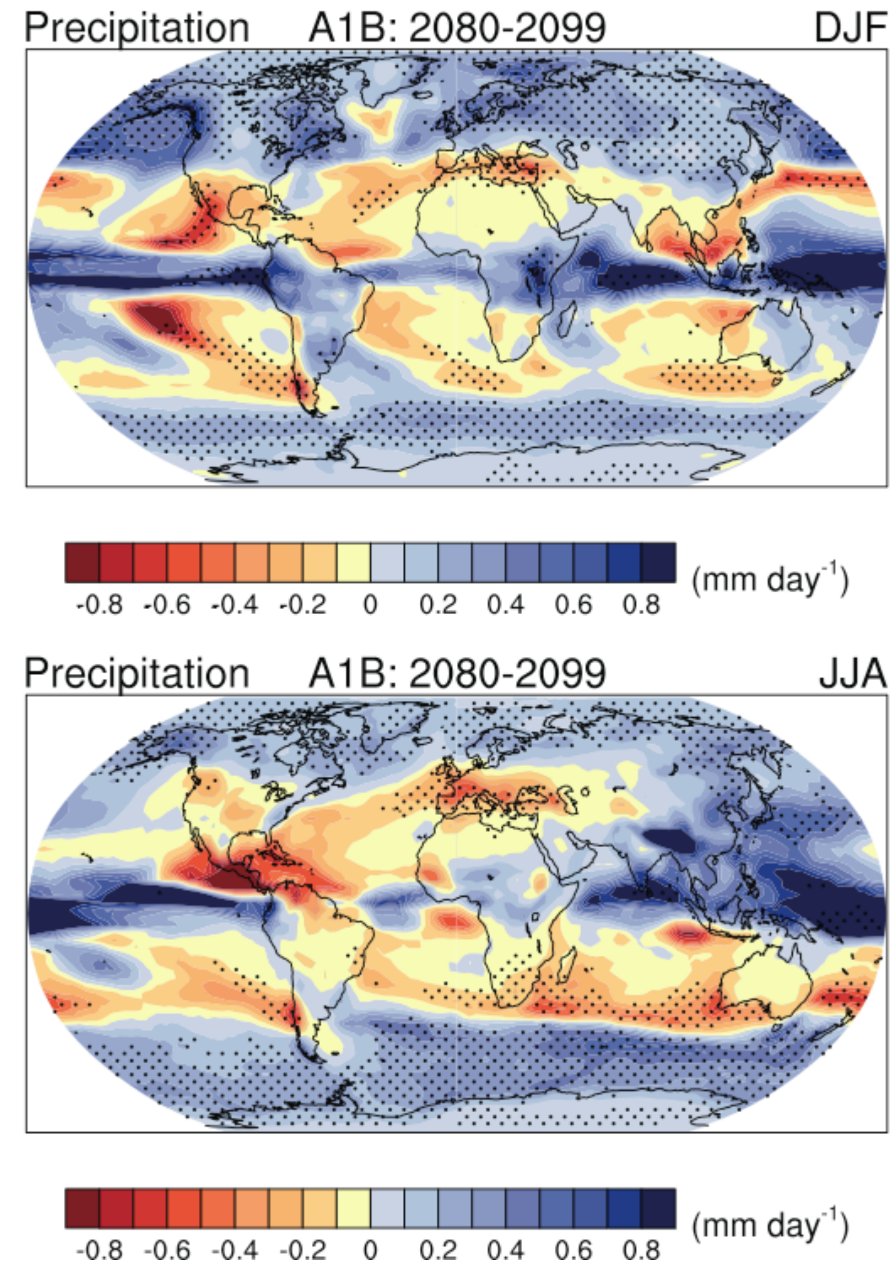
The reality is that no one lives at global-average temperature. What we really care about are the expected changes in our region.

What is the spatial pattern of the global signal?

Let's focus on the Southwest.

The Expected Scenario: Warmer and Drier for the Southwest

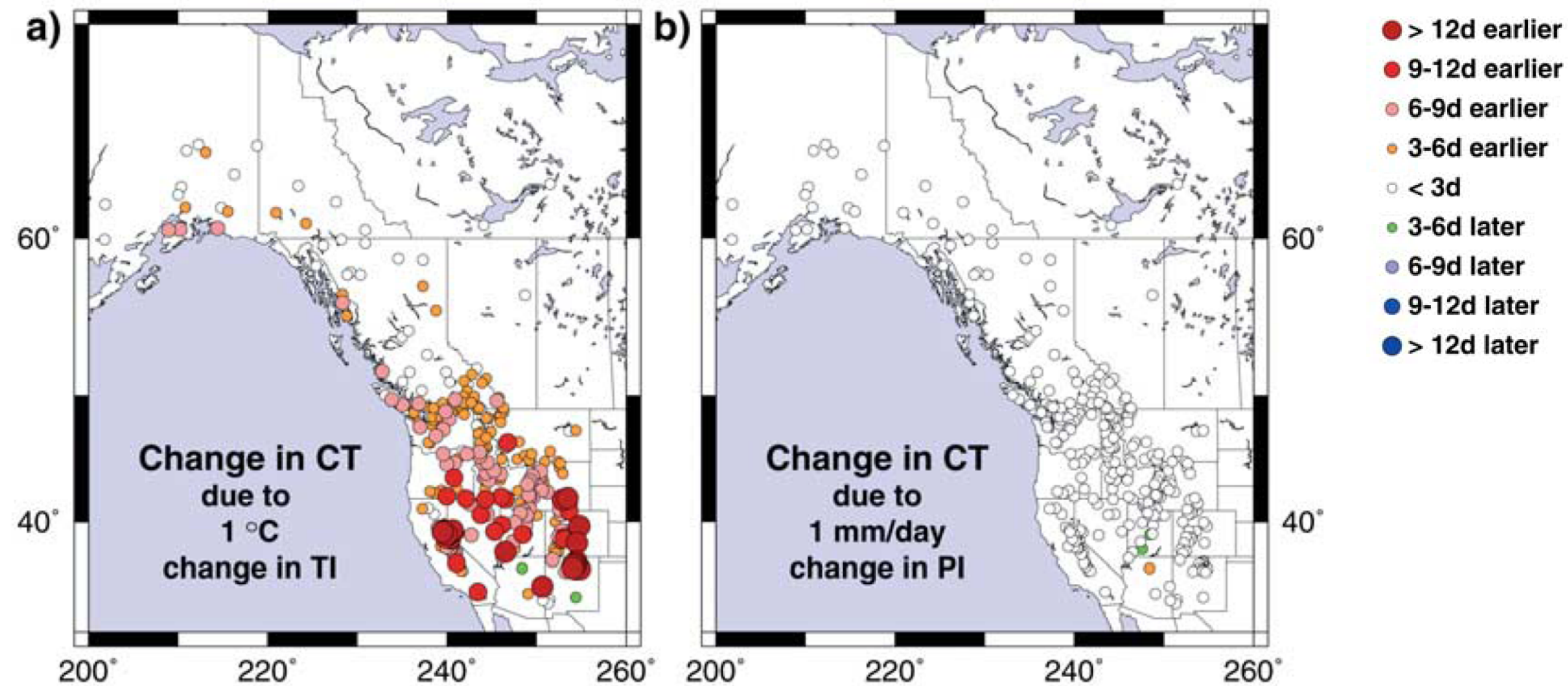




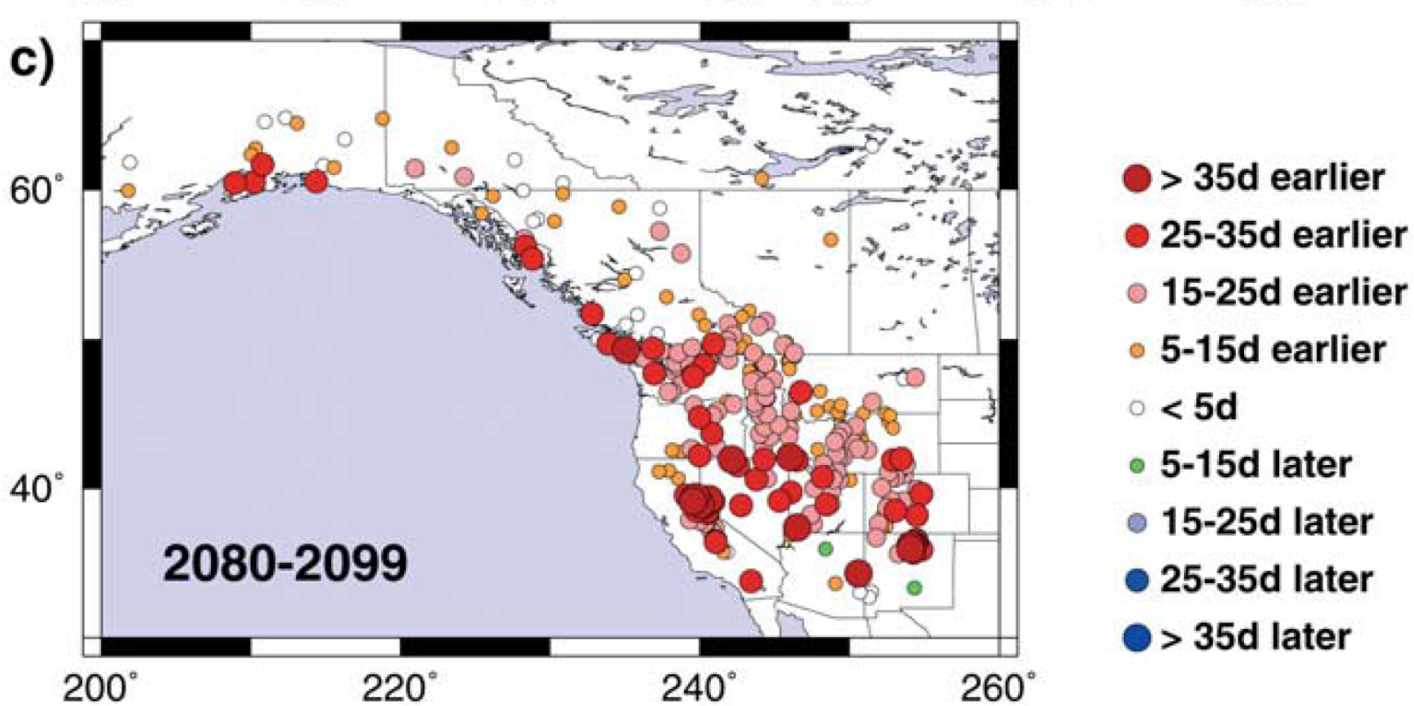
Temperature Change: +1.5C to +6C by year 2100 relative to 1980-1999 reference period.
Precipitation Change: 0% to -25% by year 2100 relative to 1980-1999 reference period.
Extreme Events: Present-day T95 temperature threshold exceeded ~75 days each year
Precipitation is skewed toward larger-sized events (even when total is reduced).

Warmer and Drier for the Southwest
Placing this Expected Scenario into context: Runoff

CT = Center Timing, "center of mass of run-off"



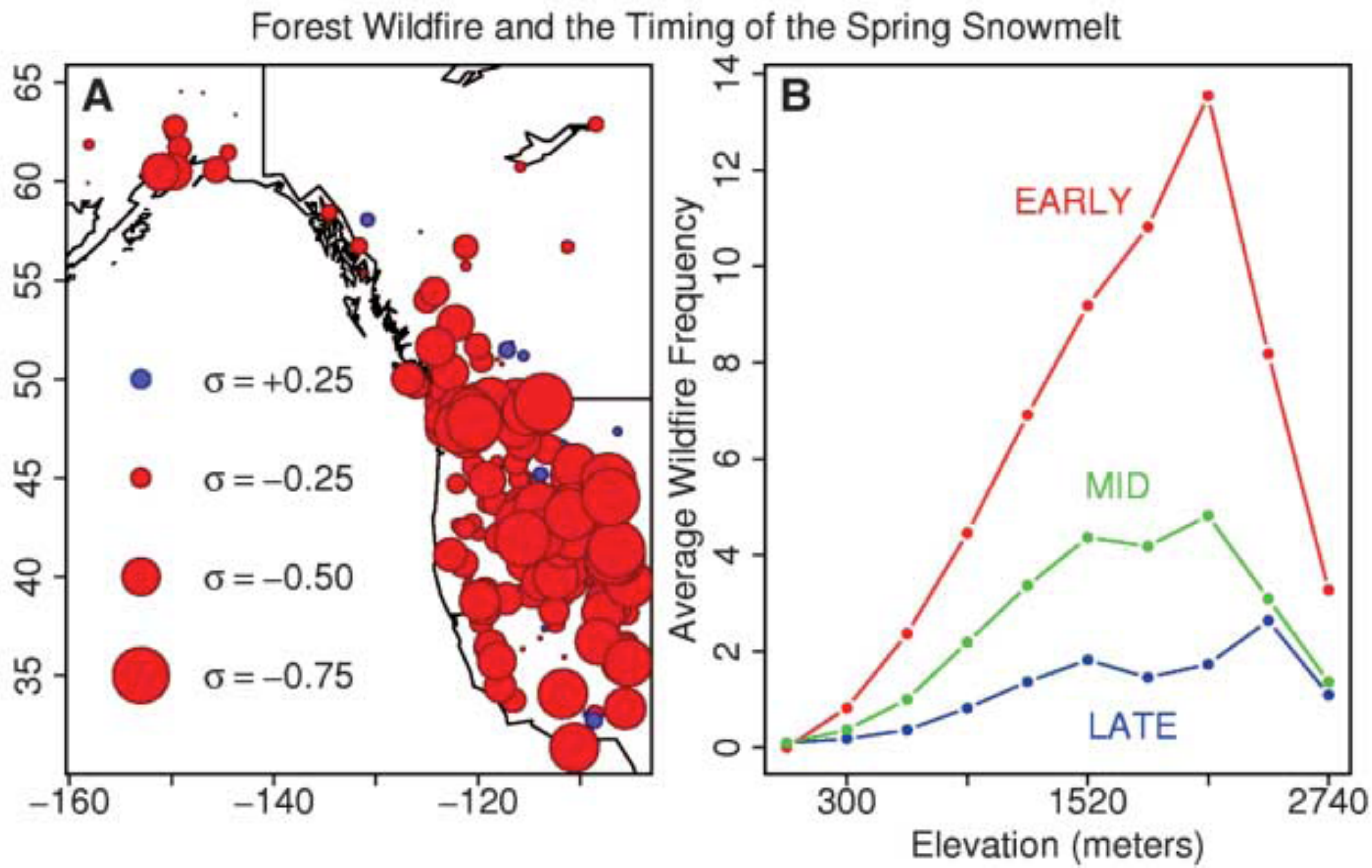
Note from a) and b) that temperature has a significantly greater impact on CT than precipitation.



This expected scenario includes significantly early peak run-off, higher winter base flows and lower annual yields.

CHANGES IN SNOWMELT RUNOFF TIMING IN WESTERN NORTH AMERICA UNDER A 'BUSINESS AS USUAL' CLIMATE CHANGE SCENARIO, Steward et al. 2004, Climatic Change. 10.1023/B:CLIM.0000013702.22656.e8

Warmer and Drier for the Southwest
Placing this Expected Scenario into context: Fire



(A) Pearson's rank correlation between annual western U.S. large (9400 ha) forest wildfire frequency and streamflow Center Timing (CT). (B) Average frequency of western U.S. forest wildfire by elevation and early, mid-, and late snowmelt years from 1970 to 2002.

Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity
A. L. Westerling et al, 2006, Science, DOI: 10.1126/science.1128834

A Summary of "What We Think We Know" about the Southwest US (meaning "if this happens we should not be surprised")

1. Warmer: +1.5C to +6C by year 2100 relative to 1980-1999 reference period.

2. Maybe Drier: 0% to -25% by year 2100 relative to 1980-1999 reference period.

3. Earlier springtime run-off (about a month earlier, primarily temperature driven).

4. More, larger wildfires.

5. Overall, present-day drought conditions become the norm (but we still get droughts in addition to this new, drier norm).

Moving on to even less-firm ground ....

What We Wish We Knew ....

(There is a lot under this heading! Most of which I will skip!)

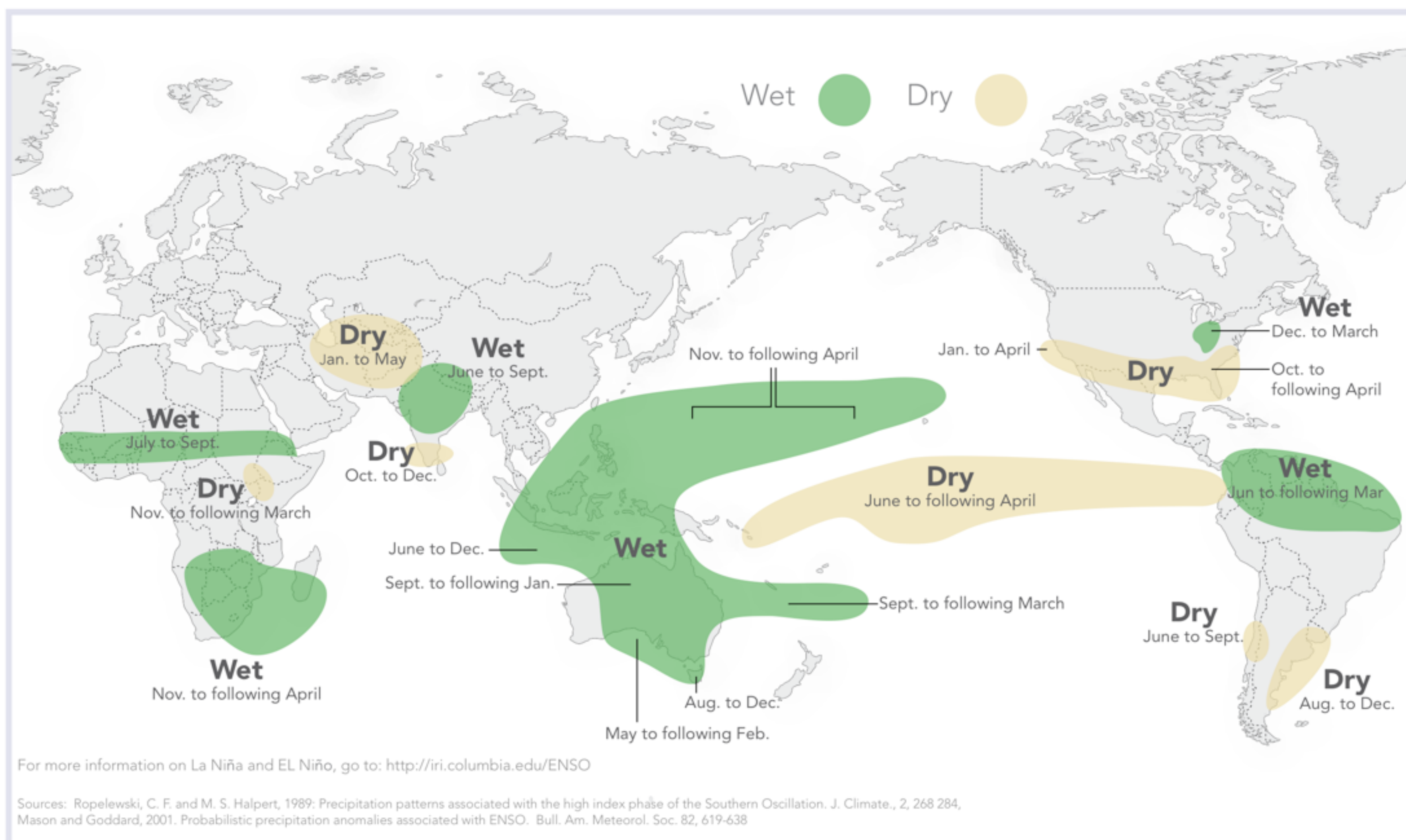
Winter Season: changes in El Nino Southern Oscillation amplitude and frequency

As we all know, ENSO has a profound effect on our winter-time precipitation.

ENSO is probably the most important mode of variability in the climate system. Our ability to simulate ENSO has improved markedly over the last decade, but we are still unsure how (if at all) this mode will change with increasing GHG concentrations.

La Niña and Rainfall

La Niña conditions in the tropical Pacific are known to shift rainfall patterns in many different parts of the world. Although varying somewhat from one La Niña to the next, the strongest shifts are fairly consistent in the regions and seasons shown on the map below.

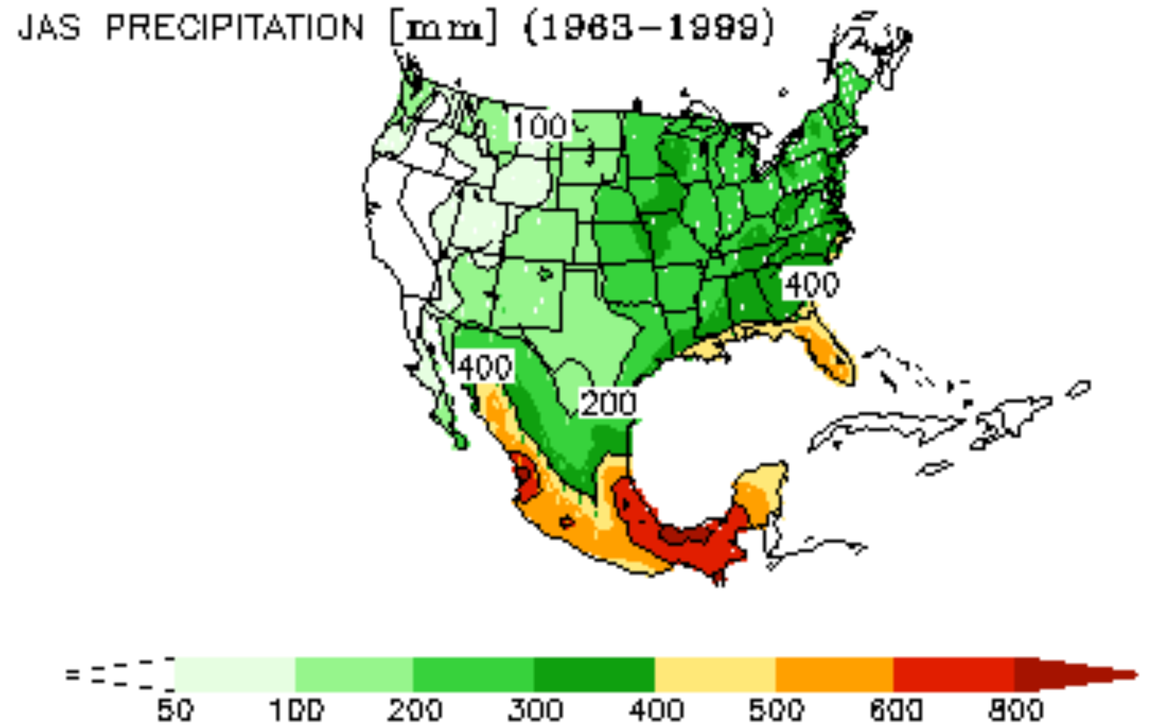


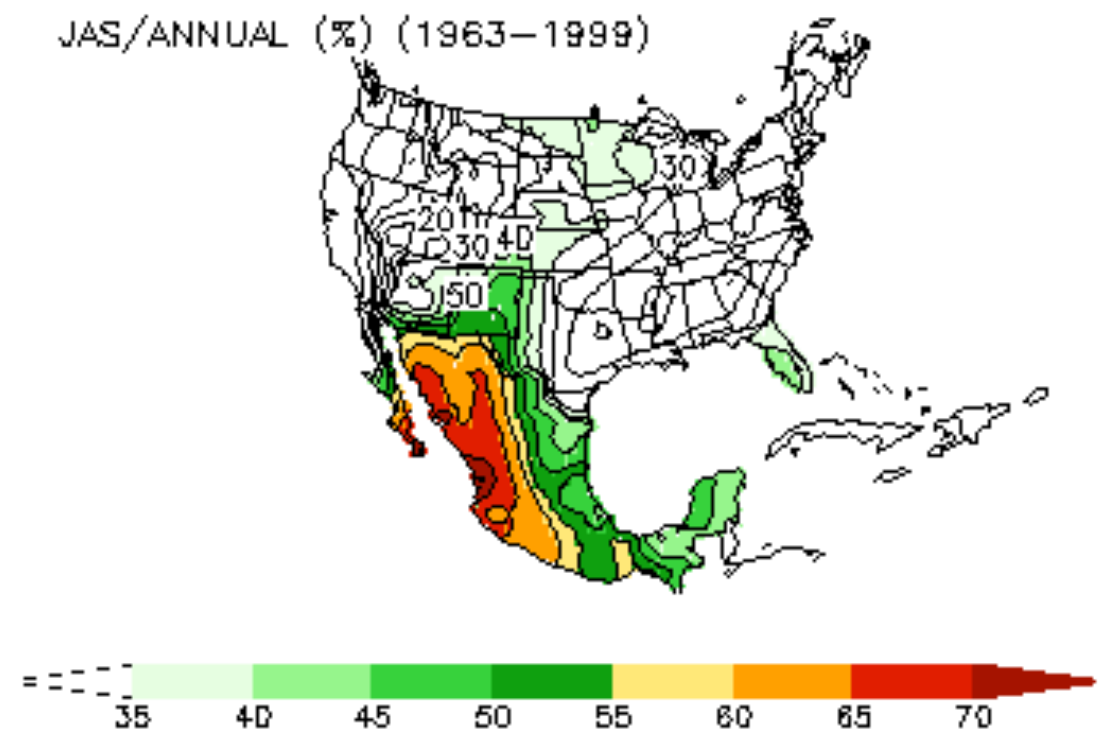
Summer Season: Changes in North American Monsoon System

We continue to struggle with the simulation of summertime precipitation. Parts of New Mexico get more than 50% of their annual precipitation with the North American Monsoon.

There is a plausible argument that the enhanced land/ocean contrast that will occur as anthropogenic warming advances will drive stronger monsoonal circulations.

JAS = {July, August, September}





In general, we are concerned about these topics:

1. Clouds and aerosols.

2. Changes in extreme events (i.e. does the 100 year flood become the 25 year flood?)

3. Tipping points (i.e. are there thresholds where the system rapidly evolves toward another (different) equilibrium.

4. The regional signal of global climate change and the feedbacks that those regional changes might have on the global system.

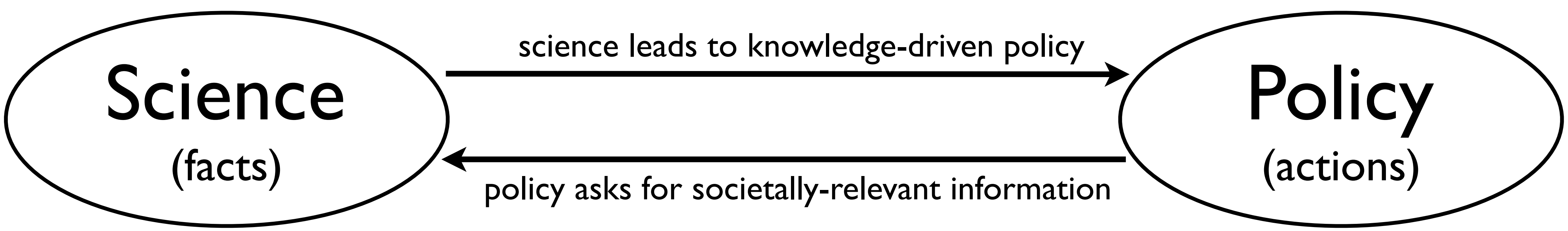
5. Global carbon cycle.

Now segueing to the relationship between science and policy ....

The Relationship between Science and Policy (as it should be)

Imagine, if you will, a hypothetical world that is fiercely focused on solving a problem not previously encountered. The society of this world is both concerned (because it is unfamiliar with this problem) and skeptical (because it is unfamiliar with this problem).

The society assembles a broad group of knowledge experts that cover all of the relevant aspects of the problem (e.g. physical scientist, economists, ethicists, engineers and policy experts). The task to this group is simple: Propose a suite of actions that addresses this problem.

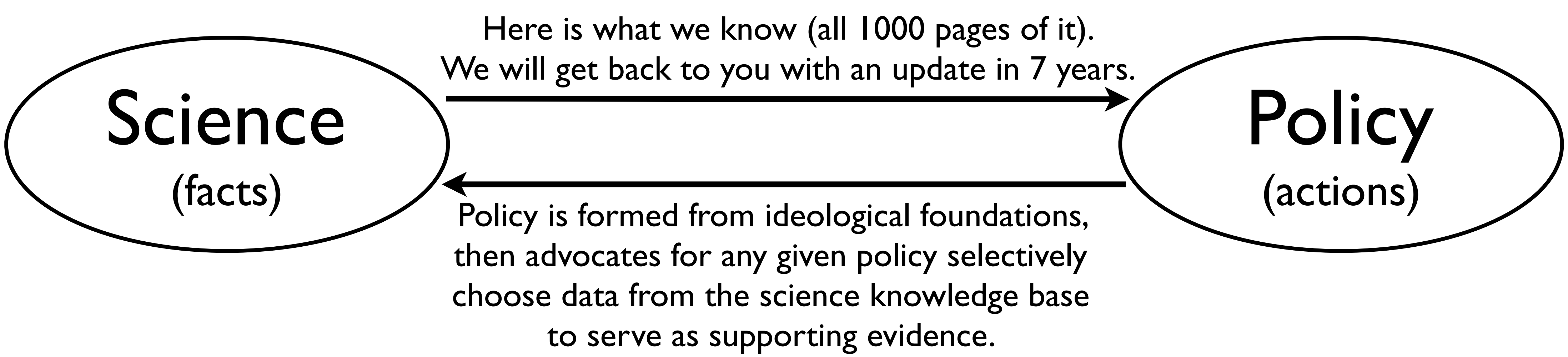


We don’t live in this world ....

The Relationship between Science and Policy (as it is)

Imagine, if you will, a (less) hypothetical world that is fiercely focused (at least temporarily) on ideology. The society of this world is both concerned (because this problem supports their world view) and skeptical (because this problem opposes their world view).

The society assembles a broad group of knowledge experts that cover all of the relevant aspects of the problem (e.g. physical scientist, economists, ethicists, engineers and policy experts). The knowledge created by this group is promptly ignored.



(It is not really this bad, but you get the idea.)

We need to have an evidence-based discussion on this issue.

Arctic melting Fast; May Swamp U.S. Coasts by 2099

Skeptics on Human Climate Impact Seize on Cold Spell

ClimateGate: The Fix is In

Study: Climate change strengthens hurricanes

Skeptics denounce climate science 'lie'

Climate change: Menace or myth?

Climategate: the final nail in the coffin of 'Anthropogenic Global Warming'?

We are not there yet ....

Unsolicited Advice to Policy Makers ....

The vast majority of people are not particularly interested in the science of climate change. This same group is often incredibly interested in the policy-implications of climate change.

Our beliefs and opinions do not change the underlying physics of greenhouse gases. It is useful to separate what we want to believe from the present-day knowledge base.

Relative to society at large, scientists are honest brokers. (I admit to bias here, but I still think it is a factually correct statement.)

We all come to this issue with a rather inflexible value system that predisposes us to either a "precautionary principle" or "cost-benefit analysis." We should each know where we reside on this spectrum.

Barring a technological miracle, the problem of anthropogenic climate change will be a century-long issue.

Our knowledge of anthropogenic climate change will continue to grow. We should be ready, willing and able to adjust policies accordingly.

Our knowledge of anthropogenic climate change will always be imperfect. If we are waiting for exact answers before making policy decisions, then we should stop our research now.

While we can aspire to create adaptive policies, there is no "do over".

Thanks!

The Science and Politics of Global Climate Change

It is hard to open up a paper these days without finding yet another article on global climate change. Editorials, letters to the editor, the City Council, and even the President have taken up the issue. The information comes so fast, from so many sources, and from so many directions, it must be all but impossible for even the most diligent to keep up. So I thought I would comment from what is probably the most under-represented perspective on this issue: the perspective of a mainstream climate scientist.

While a cursory read of the popular media would indicate otherwise, the scientific foundation of global climate change has continued to strengthen over the last two decades. Here is what we know: Carbon dioxide is a greenhouse gas, meaning that it tends to warm the atmosphere. Carbon dioxide levels are rising and are presently at concentrations higher than anytime in the last 650,000 years. The rapid rise in global temperature in the last 30 years cannot be accounted for without the inclusion of human influence through fossil-fuel consumption. All of this is to say that when we look to explain the rise in global temperature to date, we do not need to look much farther than ourselves.

As we look to the future, our climate models project an additional 3 F to 10 F of warming during this century. A warming of 3 F will definitely be noticeable and is something that we should be concerned about. A warming of 10 F will, in all likelihood, tear at the fabric of our society. Whether we find ourselves at the low end or the high end of these projections will depend primarily on whether or not we curtail our fossil-fuel consumption. Having developed climate model for the last 15 years, I have two bits of advice regarding these projections of global warming: do not take them as absolute truth and do not discard them as folly. These projections warrant serious deliberation when considering our future fossil-fuel consumption.

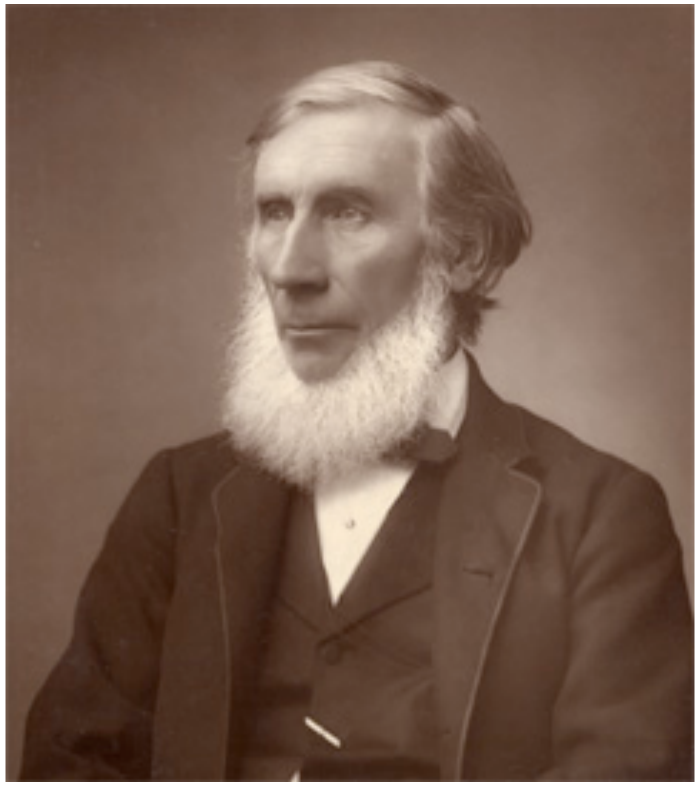
While we do know a great deal about the Earth's climate, we are far from a complete understanding. The role of clouds and aerosols in a changing climate continues to be a perennial problem. The amplitude of climate feedbacks that can both amplify and mitigate the impacts of our fossil-fuel consumption will continue to be an area of intense research. The Earth is a beautifully complex system, and science will continue to unravel and explain its complexity in the coming decades. But we need to be very clear here: complete, absolute knowledge is unattainable. An expectation that perfect understanding is a prerequisite for considering our future fossil-fuel consumption is unrealistic. At the same time, proceeding with the hope that the scientific consensus is wrong is, in my view, simply unreasonable.

We owe it to ourselves and to future generations to ask the following question: What if our present understanding of global climate change is correct? This question immediately leads to a long list of related questions, such as: What does this mean for our society? What will happen to water in the already arid West? What will happen to agriculture, both here and around the world? Can developing nations accommodate these changes? And if not, how will we deal with the climate-driven conflict that will surely follow?

The reality is that the questions scientists must answer to understand global climate change are easy in relation to the questions society must answer to deal with the potential impacts of global climate change. Curtailing fossil-fuel consumption strikes at many of our core values, so we should not expect answers to come quickly or easily. But that does not mean we should not try.

Todd Ringler
February 1, 2008

Greenhouse Gas Induced Warming is Very Old News .....



John Tyndall
(1820-1893)

"As a dam built across a river causes a local deepening of the stream, so our atmosphere, thrown as a barrier across the terrestrial [infrared] rays, produces a local heightening of the temperature of the Earth's surface."

Svante August Arrhenious
(1859-1927)

.... any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth's surface by 4° (Celsius); and if the carbon dioxide were increased fourfold, the temperature would rise by 8° (Celsius)."

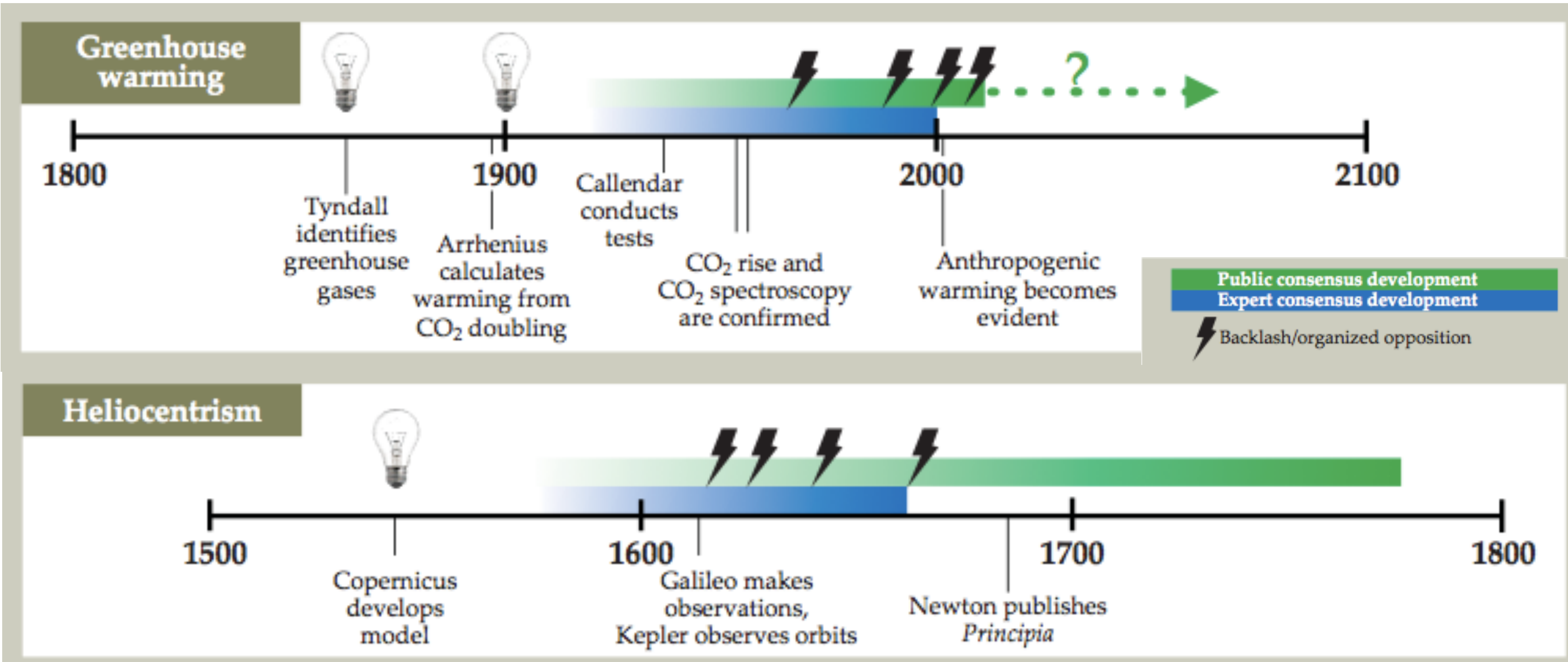
Guy Steward Callendar
(1898-1964)

"By fuel combustion, man has added about 150,000 million tons of carbon dioxide to the air during the past half century. The author estimates from the best available data that approximately three quarters of this has remained in the atmosphere."

Each of these statements found strong opposition in the scientific community!

It took a century for the scientific community to agree on the cause and effect of global climate change.

Will it take a century for the public to accept these facts? Maybe ....



from Science controversies past and present, Steven Sherwood, Physics Today, October 2011.

The challenge stemming from global climate change can be met, but it requires broad, sustained engagement from all of us.

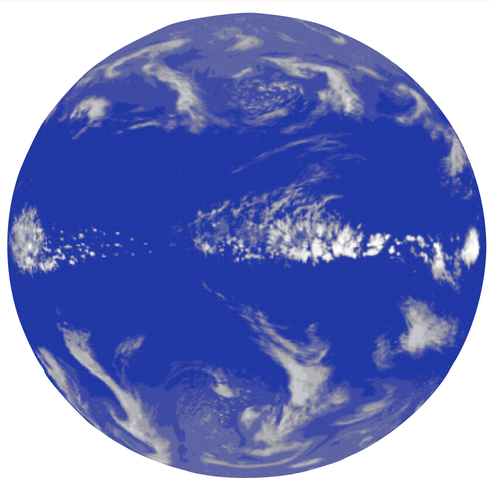
An Aside: Understanding and Accepting Uncertainty

Statistical Uncertainty: By varying model parameters, boundary conditions, initial conditions, etc., across likely ranges, the simulations shows a range of possible outcomes. (easy to measure)

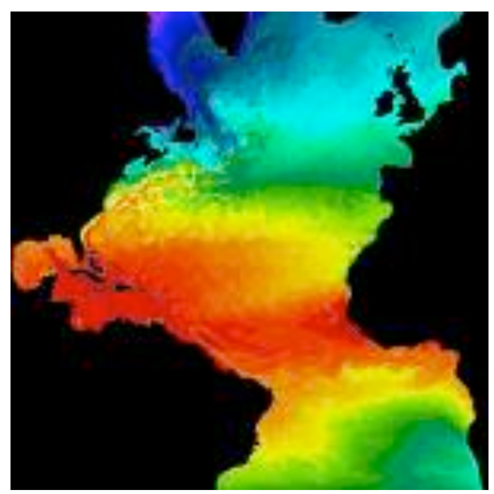
Systematic Uncertainty: The model does not contain all the important processes, so there is uncertainty regarding the scope of the physical model. (hard to measure)

Systematic Uncertainty is reduced by adding more physical processes to climate models. More robust climate models may or may not reduce Statistical Uncertainty.

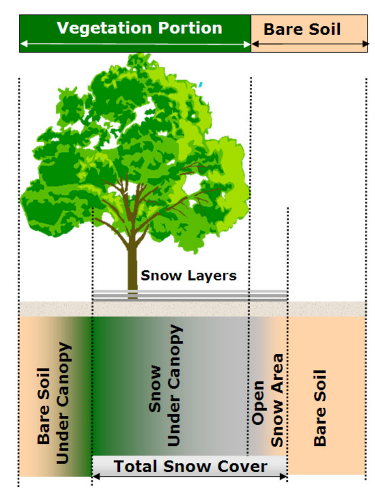
Atmosphere



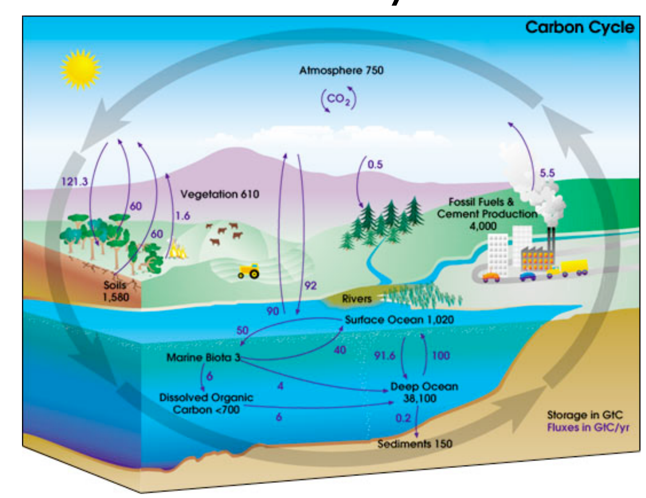
Ocean



Land Surface



Carbon Cycle



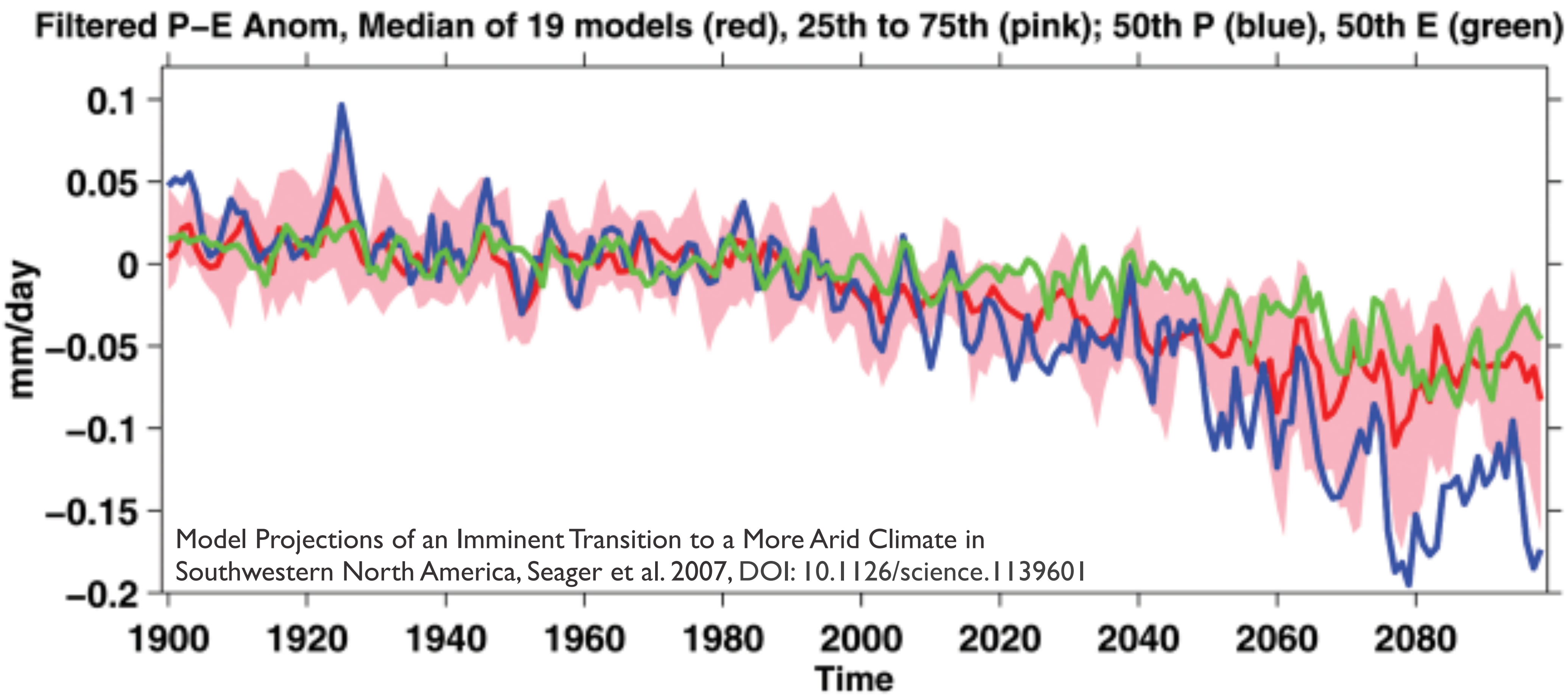
Models are better representations of physical climate system.

Systematic uncertainty is reduced.

Range of possible outcomes might increase due to the chaotic nature of the climate system.

1970 time 2010

Warmer and Drier for the Southwest
Placing this Expected Scenario into context: Precipitation



From Seager et al 2007: "The annual mean reduction in P for this region, calculated from rain gauge data within the Global Historical Climatology Network, was 0.09 mm/day between 1932 and 1939 (the Dust Bowl drought) and 0.13 mm/day between 1948 and 1957 (the 1950s Southwest drought). The ensemble median reduction in P that drives the reduction in P − E reaches 0.1mm/day in midcentury, and one quarter of the models reach this amount in the early part of the current century."

Average climate of SW is expected to look very similar to historic episodic drought conditions. Planning scenarios that expect "perpetual drought" conditions are not unreasonable.