



# Software Engineering for the Planet

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[Notes: This is a talk given at the 31st ACM/IEEE International Conference on Software Engineering (ICSE 2009)

<http://www.cs.uoregon.edu/events/icse2009/home/>

The talk was part of a special invitation session, set up by Steve Fickas, the conference general chair.]

We thank Steve Fickas for the opportunity to run this session at ICSE.

There are three parts to the session:

- (1) A review of the science of climate change, with implications of the model case for action [see slides 1-43]
- (2) A talk by Spencer Rugaber on several current research projects applying software engineering ideas to climate modeling and data sharing [see separate file]
- (3) A suggestion for broadening out the discussion of what else SE can do, by framing a brainstorming session on how SE research can be applied to the challenge of climate change [slides 44-73]



[Note: Conference attendees were able to select icons for their conference badges, to indicate which areas of software engineering research they are interested in].

I suggest a prize for the most creative re-interpretation of the icons on your badge. Here's mine: "The fate of the world hangs in the balance, and we desperately need some new thinking to save it"



I'm going to argue that we have a planetary emergency. And I'm going to argue that the problem is so big and so urgent, it needs everyone to play a part. But the action I'm going to call for is perhaps a little different from what we normally hear. I'm not going to argue for people to think about living greener lives. I'm not going to talk about changing your lightbulbs, avoiding plastic bags, giving up your car, or anything like that. I'm going to argue that those things are almost irrelevant. Instead, I'm going to argue that what we need is expertise. We need scientists, engineers, artists, policymakers, communicators, professionals of every kind to ask themselves how their particular skills and knowledge can help. For the ICSE community, I'm going to argue that we as software engineers have a lot to offer, and we need to engage with the challenge as a community. And I'm going to argue we have a moral imperative to do so.

In essence, I'm going to argue that a large number of us (maybe all?) should redirect our research and development activities to respond to some part of this planetary crisis.

But before I get to that, I suspect I need to explain why the problem is so big and so urgent. There's a lot of nonsense been written in the media on climate change. Very few journalists, very few industrialists, and even very few environmentalists really understand what the scientists have been saying. We need to establish some ground truths...

**STAND BACK**



**I'M GOING TO TRY  
SCIENCE**

source: xkcd

To do that, we need to explore the latest science. I'm going to rely on the peer-reviewed literature, and my discussions with some of the top climate scientists in the world.

This is made slightly easier by the work of the IPCC...[click]



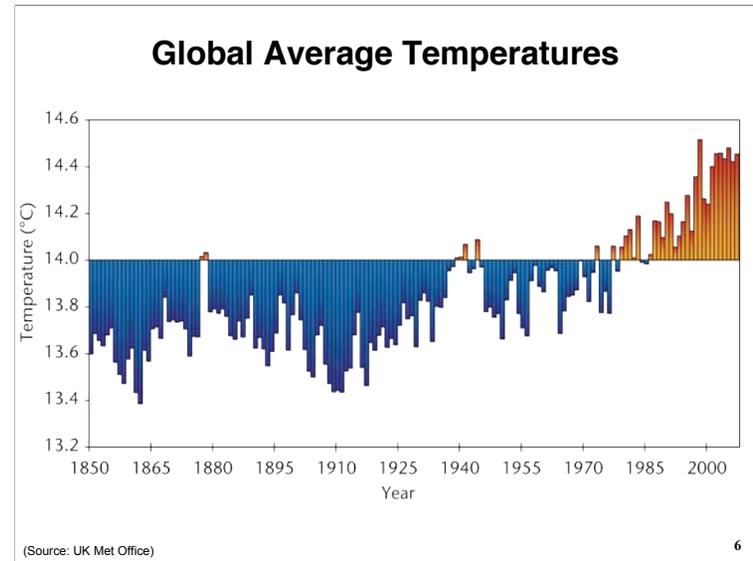
..., which is probably the largest most comprehensive state-of-the-art survey ever undertaken.

Their last report was published in 2007. There are three main volumes, representing three different working groups, plus a synthesis report that puts it all together.

There are also summaries for policymakers, which are a little less reliable, as they were subject to negotiation by politicians, and some of the wording was toned down and/or removed in the process.

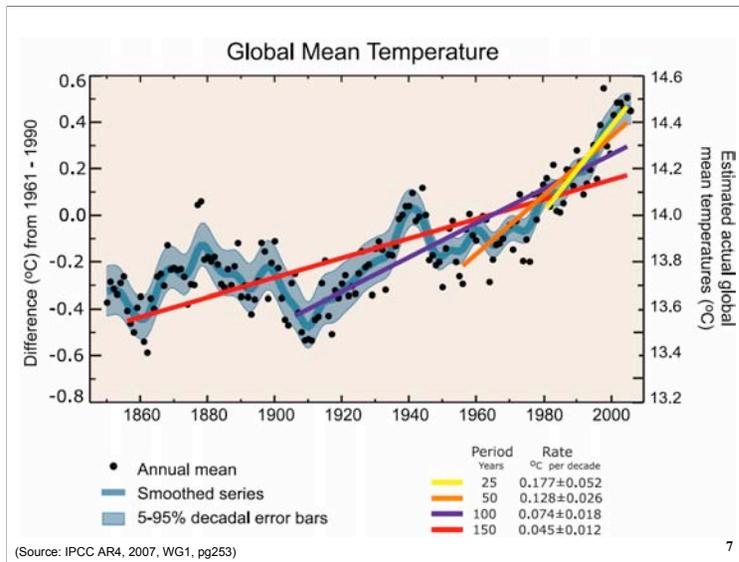
But there's another problem with the IPCC reports: they are out of date. First, the 2007 round excluded many important climate system feedback effects, because there is more scientific uncertainty on these than most of the rest of the science. A steady series of peer-reviewed papers since 2007 have suggested that by leaving out these effects, the IPCC reports seriously underestimated the urgency of the problem. And indeed, if you read the IPCC reports, they are very cautious documents, and that caution isn't reflected in the work being presented at climate science conferences, and when you talk to the scientists. So, to add to the IPCC assessment, I'm going to draw on papers published in the last two years to show how quickly the bad news is accumulating.

But first the basics...[click]



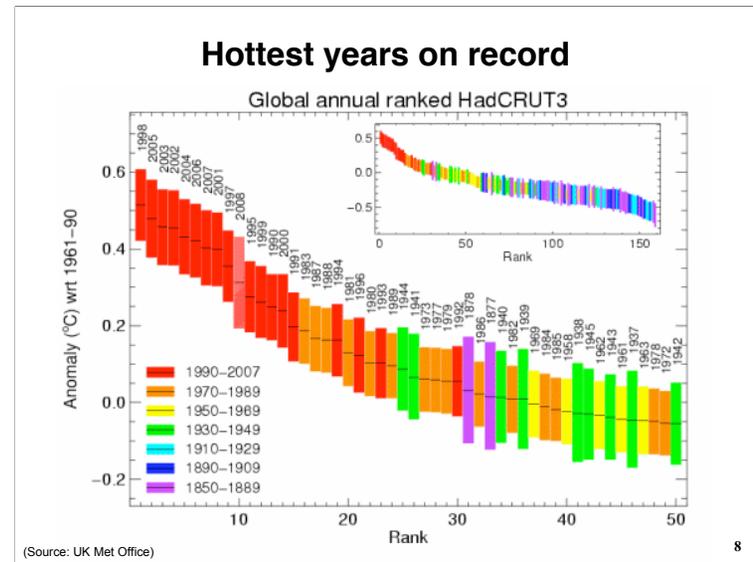
There's no doubt that the world has warmed steadily over the last half century. This is the temperature record for the last 150 years (or so).

We've warmed by about 0.4 degrees C since the 1970's, and about 0.8 degrees since pre-industrial times.



If you plot the trendlines, the warming is clearly accelerating. However, I should note that it is not scientifically valid to plot trends for much shorter periods, because many well-know shorter term cycles (e.g. El Nino/El Nina years, the 11-year solar cycles, etc) can swamp the warming signal. In other words, there's lots of noise in the data, and seasonal cycles have much larger variability than the warming trend.

The daily and seasonal variations of temperature gives us weather. The long term average defines the climate. Both matter a lot, but many people get them confused, and assume, for example that a colder winter must mean a colder climate. Not so. In some parts of the world (e.g. Toronto), a warmer climate is likely to lead to more extremes: i.e. both hotter summers and colder winters.

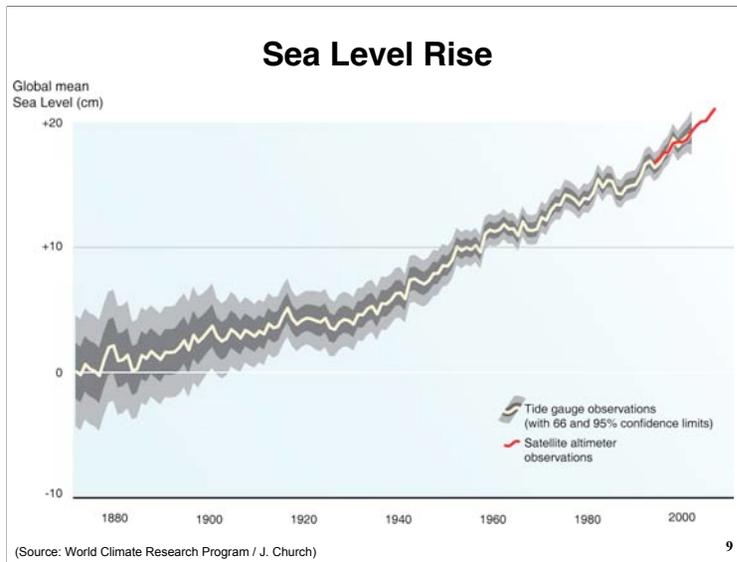


For example, there's been a lot of nonsense in the media and blogosphere that the hottest temperature on record was 1998, with people assuming this means global warming has stopped.

It is quite correct to state that last year, 2008, was the coldest year (so far) this century. But that completely misses the point: it was still hotter than 98% of the of the 20th Century.

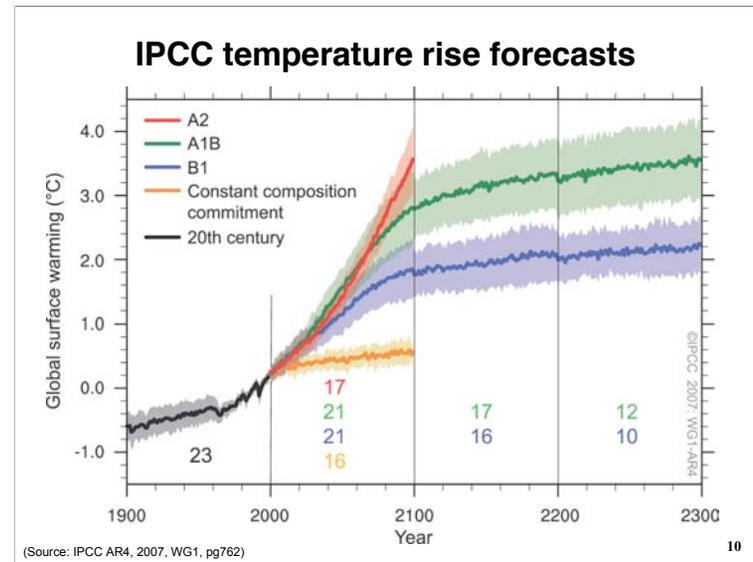
This decade has been hotter than any previous decade in human history. And for most of this decade we experienced a low in both the solar cycle and in the El Nino cycle. NASA predicts that as these cycles change, one of the next 2-3 years will top 1998 as the hottest ever. Bear in mind that "hottest year" here is according to average surface temperatures, which therefore do not include heat accumulating elsewhere in the earth system)

[Note the zero point on this graph: climate scientists generally take the 1961-90 average as a baseline for talking about climate change temperature gains: Here we see that this decade has been 0.4 degrees C warmer than the baseline]



And meanwhile the sea level have been rising, for two reasons: thermal expansion, and melting of land glaciers. In fact, the oceans act as a very simple thermometer, on exactly the same principles as a regular mercury thermometer.

We've already seen a 20 cm since the late 1880's.



Here's the summary of predicted temperature rise over the next few centuries, from the IPCC 2007 report. The different lines are different emissions scenarios. E.g. A2 assumes the industrialized countries make steady progress towards a greater mix of renewable energy sources, while experiencing strong economic growth. The three scenarios shown are effectively high, medium and low growth of emissions [although the scenarios are complicated, and it's worth reading up on them to understand how they were selected]. Also, note that none of these scenarios really show "Business as Usual (BAU)". The closest to this would be the A1F1 scenario. It exhibits faster temperature rise than A2.

The orange line shows temperature rise we're already committed to, if emissions fell to (effectively) zero today (i.e. there's more warming owed to us due to past emissions. More on that shortly...)

The graph shows 2-4 degrees rise by the end of this century, depending on which scenario you follow, with more warming to come in subsequent centuries. And as I said, there's plenty of evidence since this assessment was produced that this is a significant underestimate.

## What are the consequences?

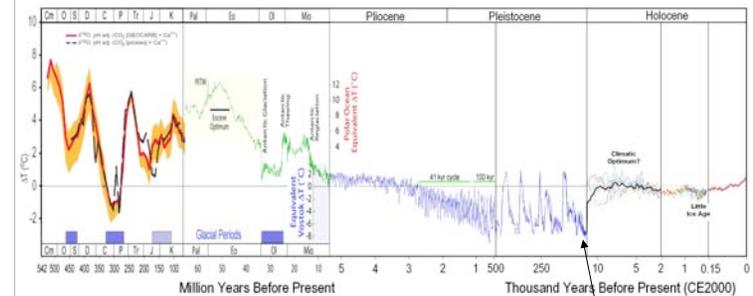
hint:  
If you're not scared,  
you haven't been paying attention

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So, 2-4 degrees by the end of the century doesn't sound that much - personally, I can barely feel such a temperature rise. And a few degrees warmer might be quite nice, right? The problem is that, like much of the science of climate change, common sense will give you the wrong idea. Let's put this into perspective...[click]

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## Temperature of Planet Earth



source: [http://en.wikipedia.org/wiki/File:All\\_palaeotemps.png](http://en.wikipedia.org/wiki/File:All_palaeotemps.png)

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Here's the earth's temperature over the last 500 million years. (Note that the graph is a little weird, as it is actually several different temperature records pasted together, so the x-axis is approximately a logarithmic timescale, and the zero point has been matched across these records according to best information available)

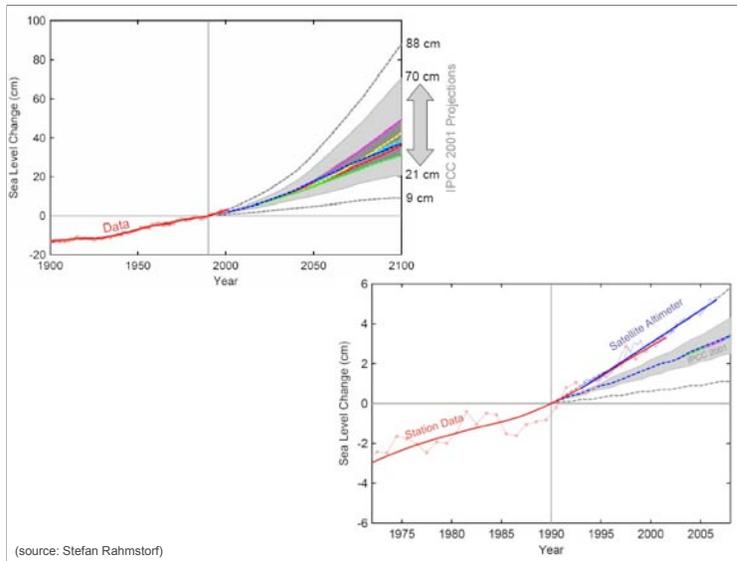
Note that the last time it was 2 degrees warmer was 15 million years ago, in the Miocene Era.

The last time the earth was 6 degrees warmer was the Middle Eocene period, around 50 million years ago. Back then, there were palm trees growing in the Arctic, and sea levels were 70+ meters higher than they are today.

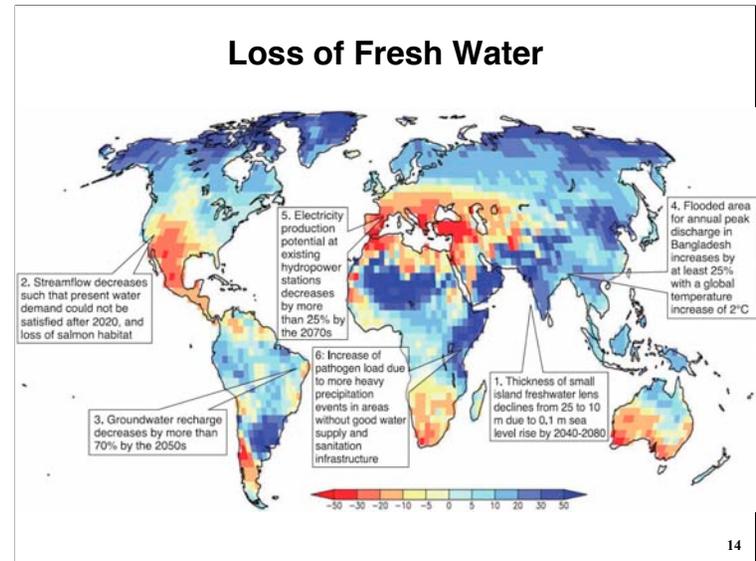
One of the key messages of this graph is the difference between the ice ages and the inter-glacial periods in the Pleistocene: just 2 degrees. Think about that: only 2 degrees difference in global average temperature separate a time when glaciers covered much of the northern hemisphere, from today's temperature.

[Note that if you go back 100s of millions of years, to the time of the dinosaurs, variations in the Earth's orbit and tilt (the Milankovitch cycle), caused larger swings in climate, because it turns out that the amount of sunlight falling on the landmass of the northern hemisphere is a strong influence on glaciation].

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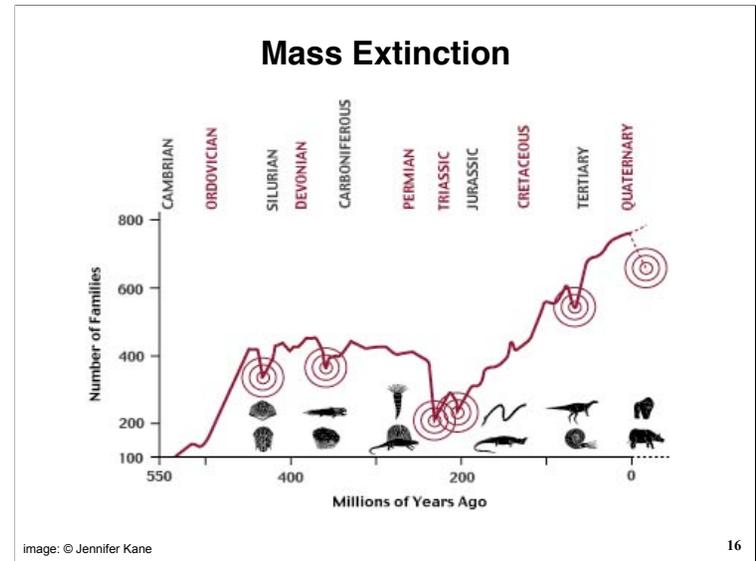
Sea level rise is the simplest impact to assess. The IPCC forecasts a rise of 21-70cm by the end of the century, again depending on emission scenarios. However, these forecasts assume there will be no substantial melting of the Greenland and Antarctic ice sheets this century. If both of these melt entirely, that would give us approximately another 12m. And even if they don't melt this century, they will melt eventually - the real question now is how fast they will melt. The worrying thing is that in the past decade, the actual rise has tracked the very upper range (the 95% confidence line) of the IPCC projections [See the bottom graph, which is an expansion of just the middle 30 year period of the top graph]. It appears these ice sheets are melting far sooner than expected.



Most of our freshwater comes from mountain glaciers, which are shrinking fast. Once they are gone, there will be widespread shortages. Water resources are already stressed in many parts of the world. A steady reduction in fresh water supply, coupled with a rising demand and growing population will spell disaster.



Another effect that is easy to predict is ocean acidification. As the concentration of CO<sub>2</sub> in the atmosphere increases, the oceans become more acidic and acidification will cause the collapse of coral reefs. It will also cause a collapse of plankton, which



Major climate shifts generally cause mass extinctions. In prehistory, there were five mass extinction events, associated with abrupt changes to the climate. We're currently witnessing the sixth. The latest studies suggest that by 2050, we should expect more than 25% of species to become extinct.

# “Climate change is the biggest global health threat of the 21st Century”

The Lancet, Vol 373, May 16, 2009

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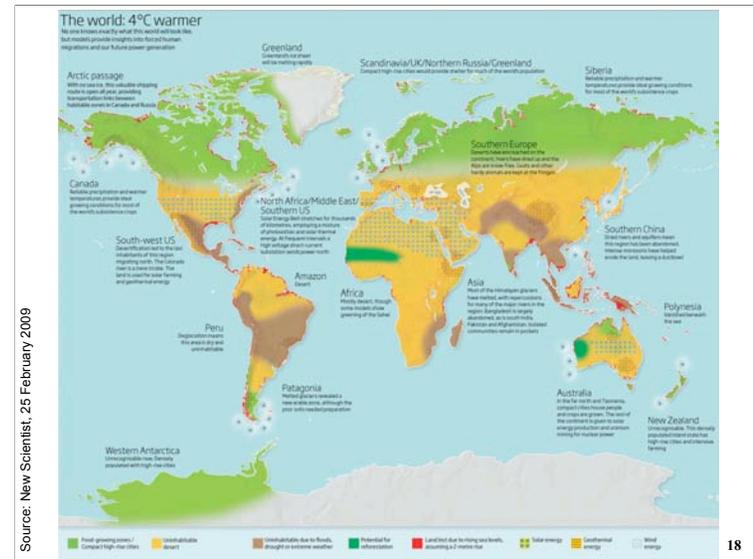
This recent report from the Lancet:

The health threats come from changing patterns of disease, water and food insecurity, vulnerable shelter and human settlements, extreme climatic events, and population growth and migration.

Vector-borne diseases will expand their reach.

But, according to the Lancet, the biggest threat is increased death tolls, especially among children and the elderly, because of heatwaves, water, food security, and extreme climatic events.

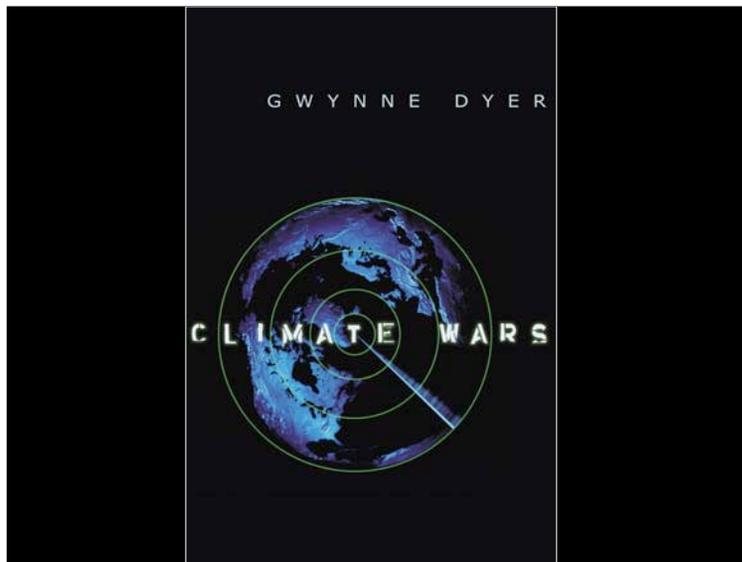
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This is a scenario for what the world would be like if it was 4 degrees warmer, constructed by New Scientist earlier this year. It has much of the subtropics as uninhabitable desert, with the surviving population relocated to dense cities in northern Canada, Siberia, and Western Antarctica. Based on rough calculations of the remaining agricultural land, only 10% of the human population has survived, the rest wiped out by starvation, disease, and wars over dwindling resources and wars caused by mass migration of billions of people fleeing the rising sea levels.

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And what happens to national security? If you want a terrifying glimpse, read Gwynne's book. He interviewed top military planners across North America, and discovered that governments are already being briefed by their militaries, and while the politicians generally don't get it yet, their top military planners do get it, and are busy getting ready for a new world characterized by closed borders, mass migrations, and governmental collapse. Within a few decades, these wars will start and at that point any hope of international cooperation to solve the problem is gone.

### Tipping Points

Tipping element	Feature of system, F (direction of change)	Control parameter(s), p	Critical value(s), $p_{crit}$	Global warming*	Transition timescale, $\tau$	Key impacts
Arctic summer sea-ice	Areal extent (-)	Local $\Delta T_{sea}$ , ocean heat transport	Unidentified <sup>f</sup>	+0.5-2°C	~10 yr (rapid)	Amplified warming, ecosystem change
Greenland ice sheet (GIS)	Ice volume (-)	Local $\Delta T_{sea}$	+~2°C	+1-2°C	>300 yr (slow)	Sea level +2-7 m
West Antarctic ice sheet (WAIS)	Ice volume (-)	Local $\Delta T_{sea}$ , or less $\Delta T_{ocean}$	+~5-8°C	+3-5°C	>300 yr (slow)	Sea level +5 m
Atlantic thermohaline circulation (THC)	Overturning (-)	Freshwater input to N Atlantic	+0.1-0.5 Sv	+3-5°C	~100 yr (gradual)	Regional cooling, sea level, ITCZ shift
El Niño-Southern Oscillation (ENSO)	Amplitude (+)	Thermocline depth, sharpness in EEP	Unidentified <sup>f</sup>	+3-4°C	~100 yr (gradual)	Drought in SE Asia and elsewhere
Indian summer monsoon (ISM)	Rainfall (-)	Planetary albedo over India	0.5	N/A	~1 yr (rapid)	Drought, decreased carrying capacity
Sahel-Saharan and West African monsoon (WAM)	Vegetation fraction (+)	Precipitation	100 mm/yr	+3-5°C	~10 yr (rapid)	Increased carrying capacity
Amazon rainforest	Tree fraction (-)	Precipitation, dry season length	1,100 mm/yr	+3-4°C	~50 yr (gradual)	Biodiversity loss, decreased rainfall
Boreal forest	Tree fraction (-)	Local $\Delta T_{sea}$	+~7°C	+3-5°C	~50 yr (gradual)	Biome switch
Antarctic Bottom Water (AABW)*	Formation (-)	Precipitation-Evaporation	+100 mm/yr	Unclear <sup>g</sup>	~100 yr (gradual)	Ocean circulation, carbon storage
Tundra*	Tree fraction (+)	Growing degree days above zero	Missing <sup>g</sup>	—	~100 yr (gradual)	Amplified warming, biome switch
Permafrost*	Volume (-)	$\Delta T_{permafrost}$	Missing <sup>g</sup>	—	<100 yr (gradual)	CH <sub>4</sub> and CO <sub>2</sub> release
Marine methane hydrates*	Hydrate volume (-)	$\Delta T_{ocean}$	Unidentified <sup>f</sup>	Unclear <sup>g</sup>	10 <sup>6</sup> to 10 <sup>8</sup> yr (>T <sub>0</sub> )	Amplified global warming
Ocean anoxia*	Ocean anoxia (+)	Phosphorus input to ocean	+~20%	Unclear <sup>g</sup>	~10 <sup>4</sup> yr (>T <sub>0</sub> )	Marine mass extinction
Arctic ozone*	Column depth (-)	Polar stratospheric cloud formation	195 K	Unclear <sup>g</sup>	<1 yr (rapid)	Increased UV at surface

source: Lenton *et al.*, PNAS, vol 105 (6) 1786-1793, Feb 12, 2008

And here's something even more worrying.

We know from the paleontological record that the earth is "twitchy". Push the climate a little in a particular direction, and then feedback effects kick in, which take it to a dramatically different state. We know a lot about these tipping points, but we don't know when they would kick in. A few of them (e.g. the greening of West Africa) are negative feedbacks - they would dampen the warming. Most of them are positive feedbacks - they would accelerate the warming. These include the reduced albedo of the polar regions, as the ice melts and is replaced by darker ocean, and the release of methane from the melting of the permafrost. One of the reasons most scientists believe that 2°C is the safe upper limit for warming is that beyond this point we are bound to reach some of these tipping points, and we can't predict when that will be. Note that some scientists argue we've already passed the first of these tipping points: the loss of arctic summer sea-ice.

## Why is it happening?

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Now let's look at the basic physics that explain why the climate is changing.

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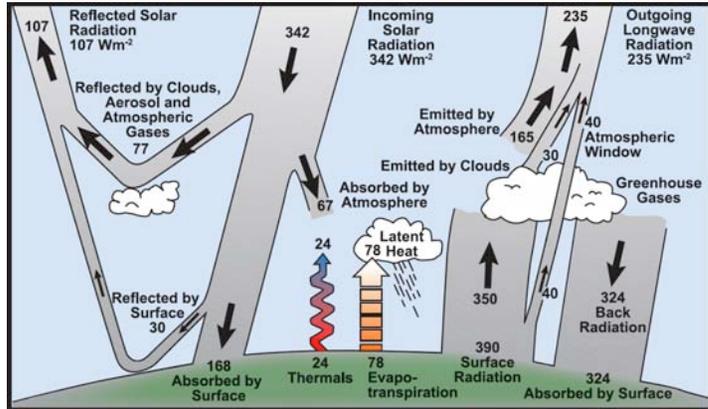


Photo Credit: Greenhouse Effect © Me vs Gutenberg@flickr

Greenhouse gases trap the outgoing radiation, thus warming the planet. If you removed all CO<sub>2</sub> from the atmosphere, the average surface temperature of the planet would be about -18°C degrees (about 30 degrees colder than now), and we wouldn't be here. If you increase the concentration of greenhouse gases in the atmosphere, that changes the energy balance of the earth. The planet warms until it reaches a new equilibrium, where outgoing radiation once again balances with incoming. If you keep increasing the concentration, you keep forcing the earth to warm up.

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## Basic Energy Balance Model



(Source: IPCC AR4, 2007, WG1, pg96)

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The earth's (surface) temperature is simply the equilibrium point at which incoming radiation from the sun is balanced by outgoing radiation from the earth.

So, you can build a simple energy balance model to compute climate sensitivity to greenhouse gasses.

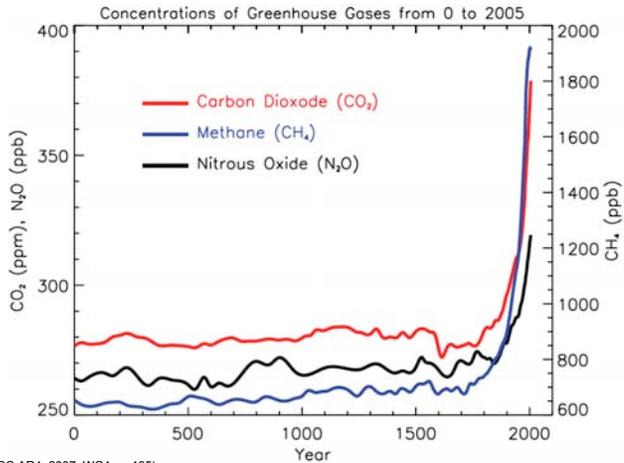
The first person to compute this was Arrhenius, in the 1890's, prompted by observations that industrialization was already starting to affect the composition of the atmosphere. He created a simple one dimensional model (taking into account latitude). He framed the question as "what is the effect of doubling the CO<sub>2</sub> concentration in the atmosphere?". It took him several years to calculate this, using pencil and paper, and he came up with an answer of 3-4 degrees, which is broadly consistent with the IPCC's projections. However, Arrhenius considered this to be a good thing.



Photo Credit: Death's Day © Jude@flickr

So, if you want accurate forecasts of climate change, you need to know how fast we're emitting greenhouse gases.

## Greenhouse Gas Concentrations



(Source: IPCC AR4, 2007, WG1, pg135)

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In fact we need to understand two distinct processes: the change in atmospheric concentrations and the change in emissions. They are different, but most commentators mix them up.

First, concentrations of greenhouse gases in the atmosphere. It's the concentration that determines the warming effect - higher concentrations are like having a thicker blanket.

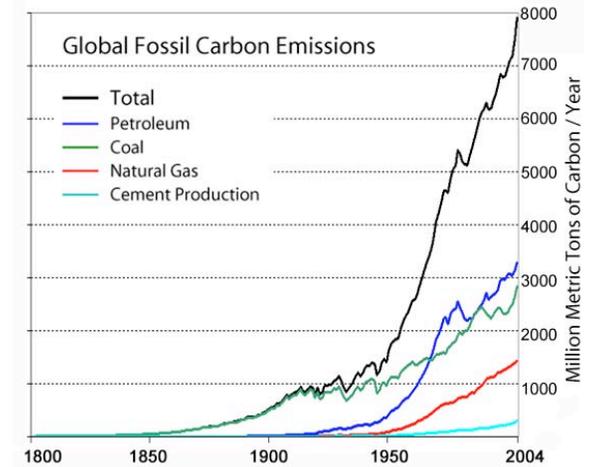
In 2008, we reached 384 parts per million (ppm) of CO<sub>2</sub>, which is more than 1/3 higher than the pre-industrial average of 280ppm.

The concentration levels are growing by 2.5% per year

At this rate, we'll reach 420-430ppm by 2025, and 500+ppm by mid-century - getting very close to Arrhenius's doubling of CO<sub>2</sub> concentrations.

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## Global Fossil Carbon Emissions



source: world climate report

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And of course, concentrations are driven by the rate of emissions of these gases. Think of a bathtub filling up. The water level is the current concentration; the inflow of water is the current rate of emissions.

And emissions are growing fast.

In 2007, we emitted 8.5 billion tons of Carbon, which is five times the rate of 1940's.

The emissions rate is currently growing by 3% per year, which is a growth rate nearly four times the growth rate of the 1990s.

[Note: The carbon emissions curve is almost identical to the population growth curve. In other words, emissions per person have remained roughly constant throughout 200 years of industrialization. So, in effect, what we have is really just a scale problem. When the human population was tiny, there was no problem living off fossil fuels. As the human population exploded, so did the climate change problem]

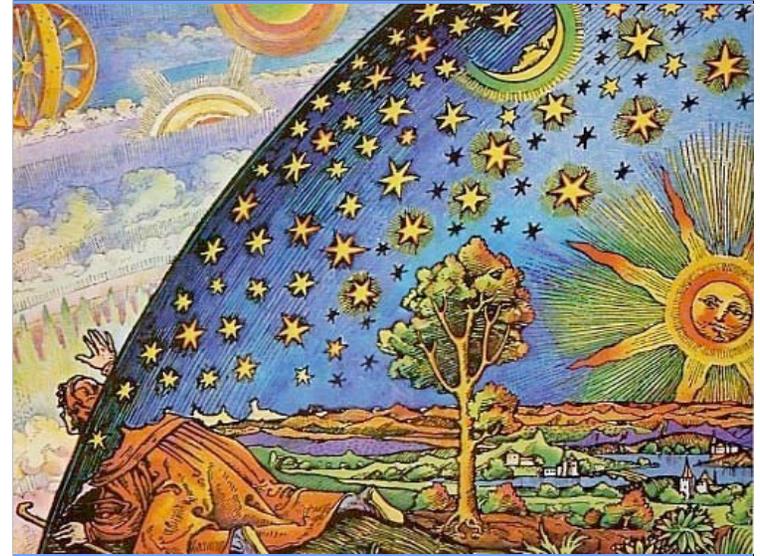
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## Why haven't we fixed it?

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So, the relationship between emissions of carbon into the atmosphere from burning fossil fuels, the concentrations of greenhouse gases in the atmosphere, and the resulting increase in the greenhouse effect has been known by scientists for over 100 years. In the 1960's and 70's, scientists began to realise that the projected warming would have a catastrophic effect on the quality of human life. But since then emissions growth has accelerated rapidly. Why have we done nothing to fix this?

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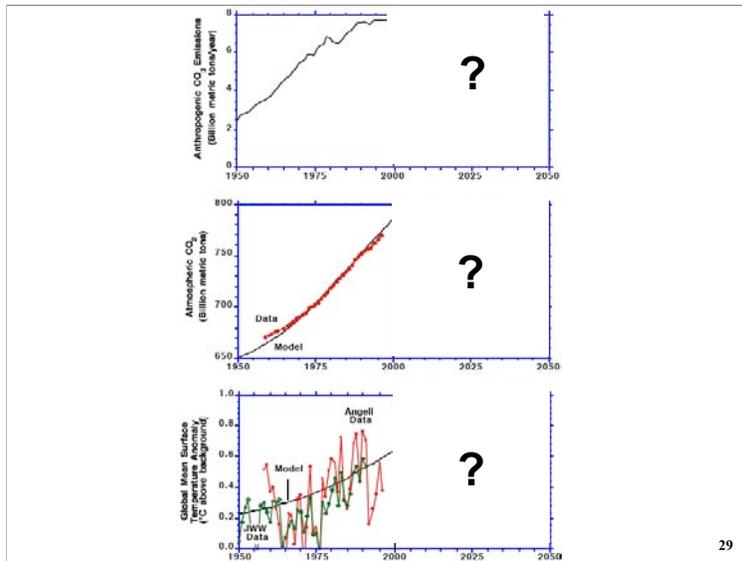
This is a picture of the Flammarion woodcut.

There are a large number of people who just don't understand the basic science. Many of them have no scientific training, and have no idea how science works. Some are paid by the industries most responsible (basically, anyone who owns supply or production of fossil fuels). The attempts by the fossil fuel industry to confuse the issue are well documented, and follow many of the tactics used previously by the tobacco industry to cast doubt on the link between smoking and cancer. As a well-funded public disinformation campaign it has been remarkably successful.

This sounds like a conspiracy theory. But remember: "It is difficult to get a man to understand something when his salary depends upon him not understanding it" (Upton Sinclair). The fossil fuel industry's entire revenue stream depends upon us continuing to depend primarily on these fuels for our energy needs. That's a lot of vested interest stacked against the scientific facts. Should we be surprised if the truth gets ignored in all this?

The key point of course, is that climate change isn't a matter of belief, nor convenience - it's a matter of basic physics.

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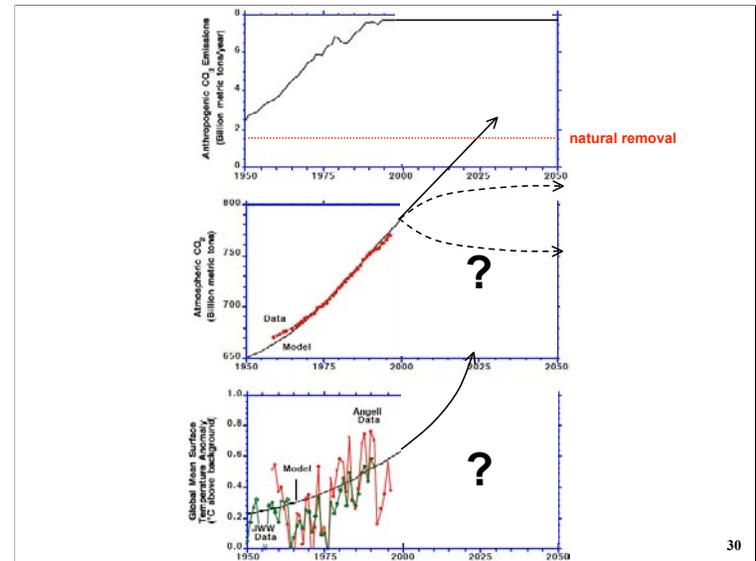


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But even those willing to engage honestly with the truth face a big problem. Most of the science is counter-intuitive, and very few people understand complex dynamic systems properly.

In a recent study, John Sterman at MIT demonstrated that even very intelligent people don't grasp the interconnection between emissions, concentrations and temperature, and that their naïve interpretations break the laws of conservation of mass. Let's explore some scenarios. Here are the three graphs again: emissions, concentrations, and temperature, from 1950 to 2050. Ignore the noise in the temperature record for now, and concentrate on the shape of the trend line.

First, let's imagine that through massive investment in renewable energy and energy conservation, we manage to hold emissions constant at today's levels...[click]



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[Note: this slide contains animations. It works better on the screen...]

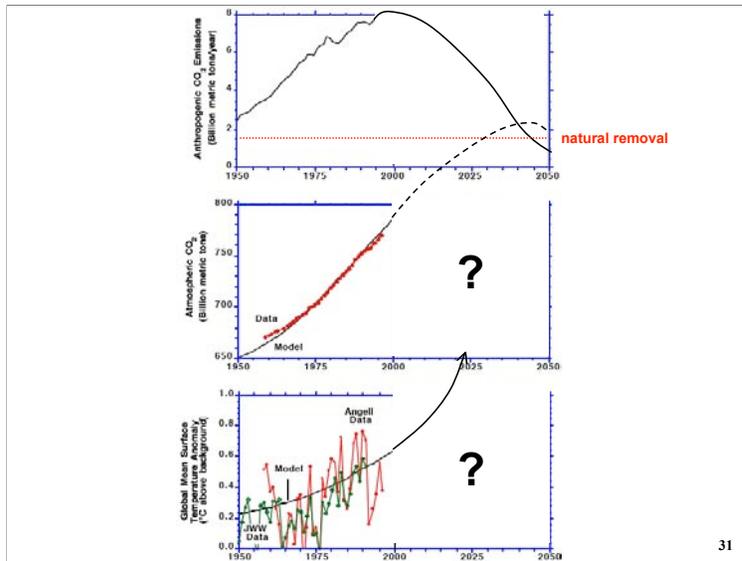
(1) Which of these curves on the concentrations chart (middle graph) best describes the effect on atmospheric concentrations? It will continue to rise and then stabilize? Or it will start to fall immediately and then stabilize?

Who thinks neither of these curves is right?

(2) Now, I didn't tell you that there are natural processes (oceans, forests, soils) that gradually remove CO<sub>2</sub>, but at a much slower rate than our current emissions?

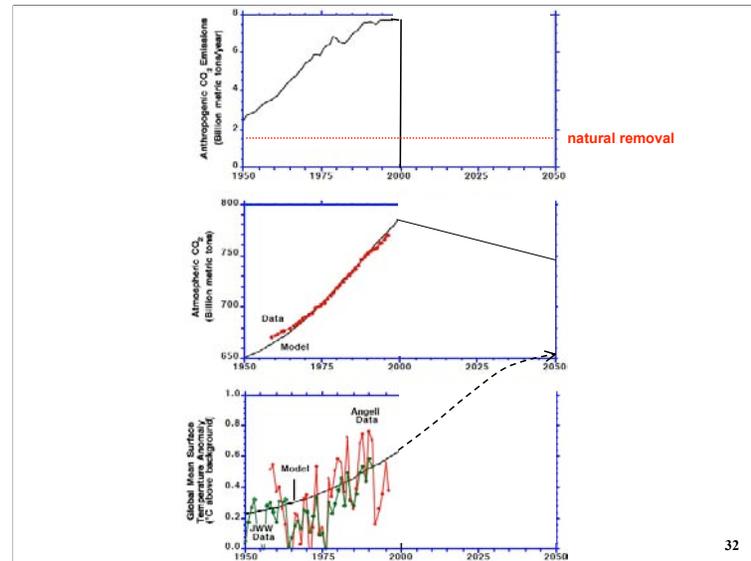
(3) Under constant emissions, the concentrations would continue to grow linearly as the difference between the input and output flows. (At least we lost the exponential curve on concentrations)

(4) But we still have an exponential curve on temperature, because linear growth in concentrations causes accelerating temperature rise.



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Okay next scenario - aggressive emissions reduction aiming at 80% reduction by 2050. Which is what political leaders such as Obama are beginning to talk about as a target. Unfortunately, even under this scenario, concentrations continue to rise. The inflection point is only reached when the emissions rate drops below the natural removal rate. So if it takes us 50 years to get emissions down to this level, we can expect the warming to continue to accelerate throughout this time.



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Finally, imagine emissions stopped entirely this year. That means we suddenly stop using all fossil fuels (oil, gas, coal), virtually overnight.

Perhaps the human race gets wiped out by aliens.

Our legacy lives on because it will still take a long time for the concentrations to drop, and so the planet will still continue to warm long after we've gone.

Most MIT undergrads flunked this test.

Very few people understand it properly, and even fewer take the time to explain it.

But if you do take the time to grasp the basic physics, the magnitude of the problem becomes pretty obvious.



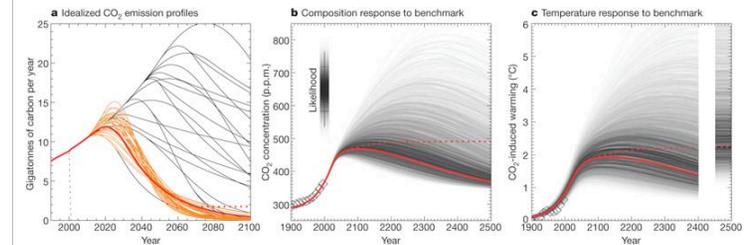
A couple of weeks ago, Nature published two papers that attempt to answer the question how much carbon can we afford to emit, while staying below the 2 degrees of warming threshold.

A simple answer emerged: about a trillion tonnes of carbon (which is equivalent to about 3.6 trillion tonnes of carbon dioxide).

We've emitted about half this amount already, since the dawn of industrialization. It took us 200 years to burn that much. And at the present rate of emissions growth, we'll burn through the rest within the next thirty years.

If we can cut emissions so that they peak within the next five years, and then reduce them by 3% per year through the rest of the century, we can make our remaining carbon budget last much longer. But the bottom line is that eventually, we have to be a carbon neutral global society. If we don't reach this goal before using up our trillion tonnes, we're unlikely to hold the warming to 2 degrees, and hence we're likely to hit some of those tipping points. Note, of course, that even 2 degrees of warming has some pretty serious consequences for life on earth. But unfortunately that is now completely unavoidable. The question for us now, is can we avoid the runaway warming that might follow if we exceed these thresholds.

## Emissions Profile for $\leq 2^\circ\text{C}$ rise



MR Allen *et al.* *Nature* 458, 1163-1166 (2009)

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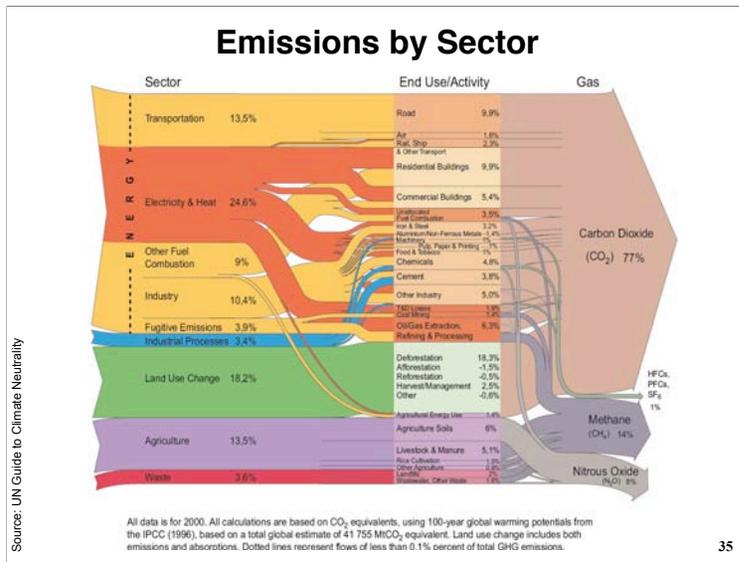
**Here's the analysis from the paper. It's a probabilistic forecast, achieved by running a large ensemble of climate models - a multi-model ensemble. Using an ensemble of models from different labs has been shown to give better reproductions of past climates than just using a single model.**

**The first graph shows some potential emissions pathways. The orange paths are those that stick within 1% of the 1 trillion tonne cumulative limit for the period 1750 to 2500. The solid red line is an example case, selected as a benchmark. The dotted red line represents a scenario that stabilizes concentrations at 490ppm.**

**The middle graph shows the resulting CO<sub>2</sub> concentration for (only) the benchmark scenario. The best-fit is shown in solid red, while the grey spread lines show a probabilistic forecast for this benchmark case, achieved by using systematically varied model parameter combinations. [Note the scale change: the emissions graph shows only 100 years, the other two are projected 500 years into the future]**

The third graph shows the resulting temperature response to the benchmark scenario. Again, note the likelihood profile in grey.

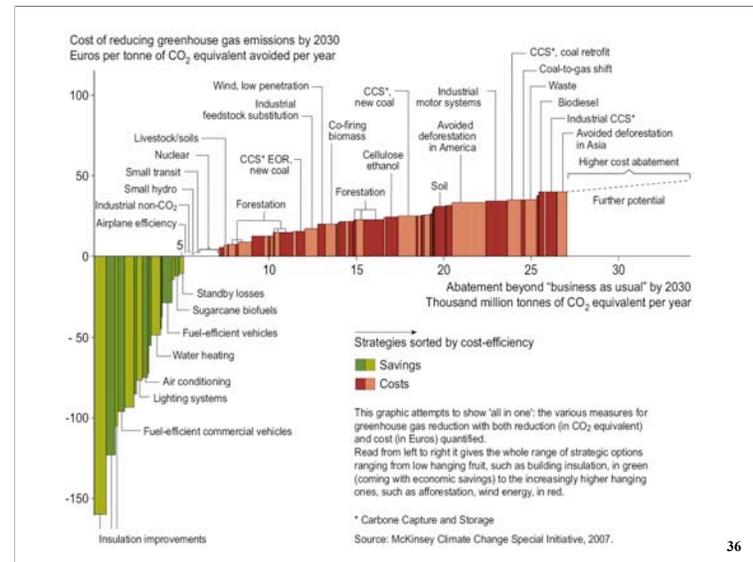
The take home message from this study is that it doesn't matter which of the orange lines we follow, it's the total area under the graph that matters (about 1 trillion tonnes total). If we overshoot these paths, we won't stay below the 2 degree threshold. If we follow one of these paths, we stand a 50:50 chance of staying below 2 degrees.



Here's another reason why we haven't fixed it.

There's no silver bullet, because the sources of emissions are so varied. Just about every aspect of modern life is a significant contributor.

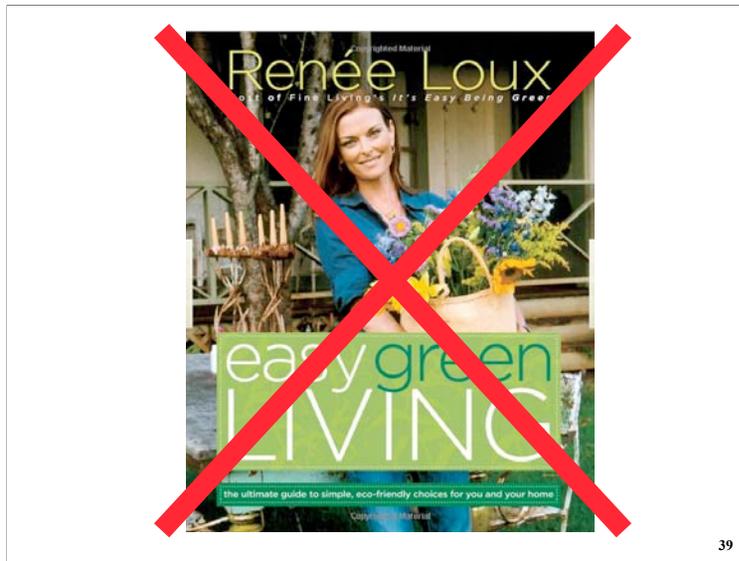
If we are to cut emissions by 80-90% by midcentury, every single one of these emissions sources will need to be completely re-thought. In other words, we're talking global systemic change. Within a single generation, we have to re-invent just about every aspect of modern industrial life.



The good news is that some of the necessary changes are free (actually, they save us a huge amount of money). But the harder ones come with a cost.

This graph shows the cumulative effect a large number of different options (along the x axis), sorted by whether they are cost savings (green) or costs (red).

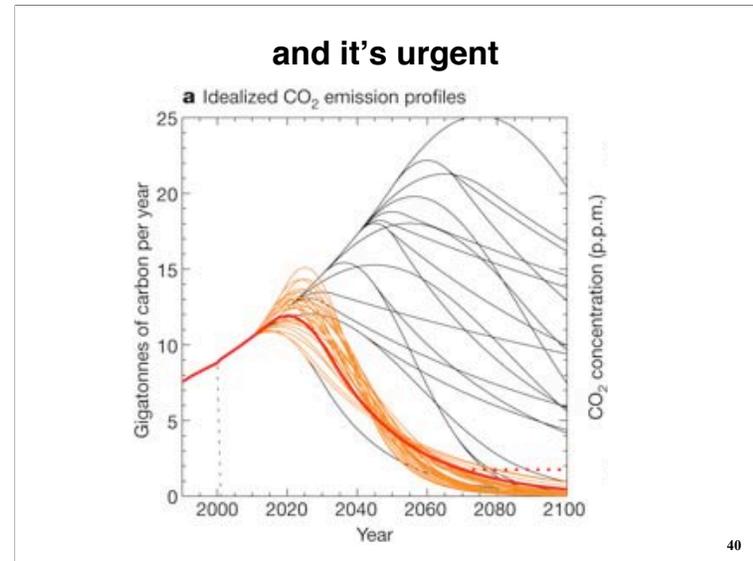




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Which means discussions about how to be greener are almost entirely irrelevant. That's not to say we shouldn't try to minimize our personal environmental footprints. But the problem cannot be solved by individual voluntary action, and agonizing about green choices such as paper vs. plastic bags, which lightbulbs to use, and so on just diverts attention from the real problem. It will take concerted change at every level of society: from international agreements, radical, aggressive governmental policy, and the redesign of cities, manufacturing, transport, energy production and transmission, communities. And even then we can't fix it all...

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And we have 5-10 years at most to reverse the growth of carbon emissions, and then we have to get it down basically to zero by the latter half of the century. The longer it takes to get to the inflection point (the peak of the curve), the more steeply we have to cut after that. It's a fixed total budget.

And even if we achieve this, we only get a 50:50 chance of staying below 2°C rise.

It's extremely likely that we're already committed to the first 2°C of warming, which on its own takes us to a climate that the earth hasn't seen for millions of years.

In addition to getting emissions on the downward path, we have to adapt to a vastly different earth no matter what.

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## The moral imperative

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Okay - bear with me. Take a deep breath. It's bad, and it's appropriate to freak out. But there's a lot of productive stuff we can do, and I'll get onto that shortly. I argue that we have a moral imperative to act.

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When our kids grow up they will ask us what they hell we thought we were doing. I want to be able to tell my kids and grandkids that I did my part.

It's going to take all expertise and knowledge from all disciplines to tackle this problem. We each need to ask ourselves how our particular skills and knowledge can be brought to bear on the problem.

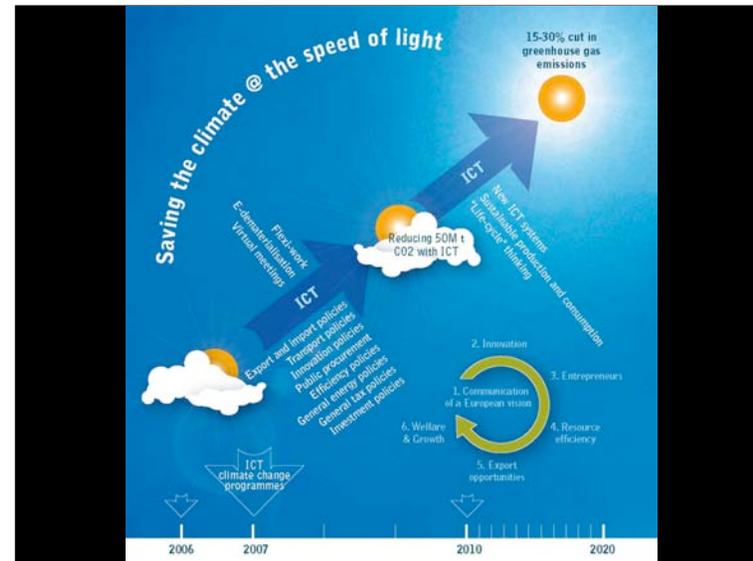
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## What should the ICSE community be doing?

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Which brings me to the second part of the talk. What should the software engineering community be doing? What should we as SE researchers be doing?

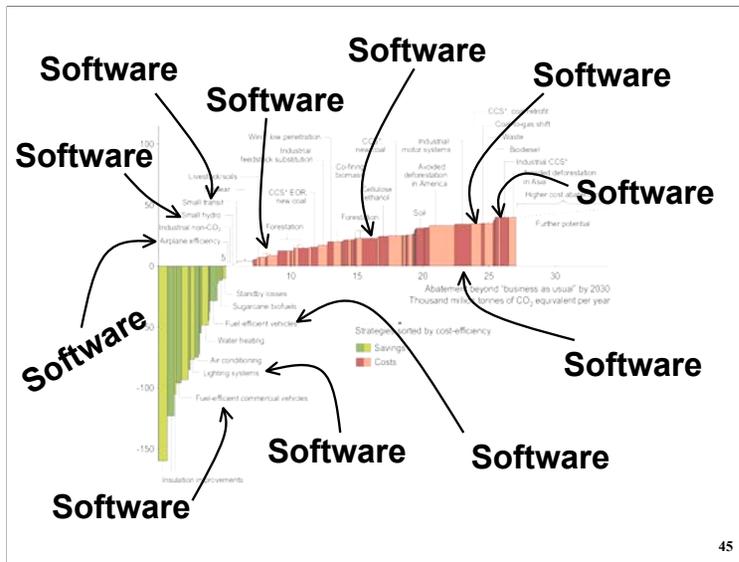
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First, obviously, Information and Communication Technology (ICT) is a major consumer of energy. Green IT, which Gerald talked about this morning, is a key piece of the solution.

This is from a report compiled last year by the EU, looking at the role of ICT in emissions reduction.

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But more importantly, the software is the enabling technology that makes just about everything else work...

Software is a critical enabling technology in nearly everything we need to achieve.

So, here's a simple thing we can all do. Whatever kind of software engineering research you're currently doing, choose to demonstrate your tools and techniques on examples relevant to this challenge. Don't use elevators and traffic light controllers as your example problems. Choose examples like electric cars, household energy monitoring, emissions visualization, etc. Demonstrate your stuff on things that matter.

But that's just the start. Software engineering also has a critical role to play in helping the climate science. Climate scientists build massive software simulations of the earth systems, and need to share huge data sets with other scientists. They need software engineering know-how to achieve this, but no off-the-shelf tools give them what they need. Hence, there's a big opportunity for SE research here.

[Now, Spencer will talk about some existing research projects investigating these issues, and then I'll attempt to frame the discussion with some ideas about a broader research agenda]