Energy, the Environment, and What Mathematicians Can Do

John Baez
http://math.ucr.edu/home/baez/what/

March 23, 2011
Hong Kong University

We use more and more energy. We get most of it by burning fossil fuels.

We use more and more energy. We get most of it by burning fossil fuels.

In 2007, the average human burnt 1.2 tonnes of carbon.

We use more and more energy. We get most of it by burning fossil fuels.

In 2007, the average human burnt 1.2 tonnes of carbon.

The average Hong Kong person burnt 5.8 tonnes.

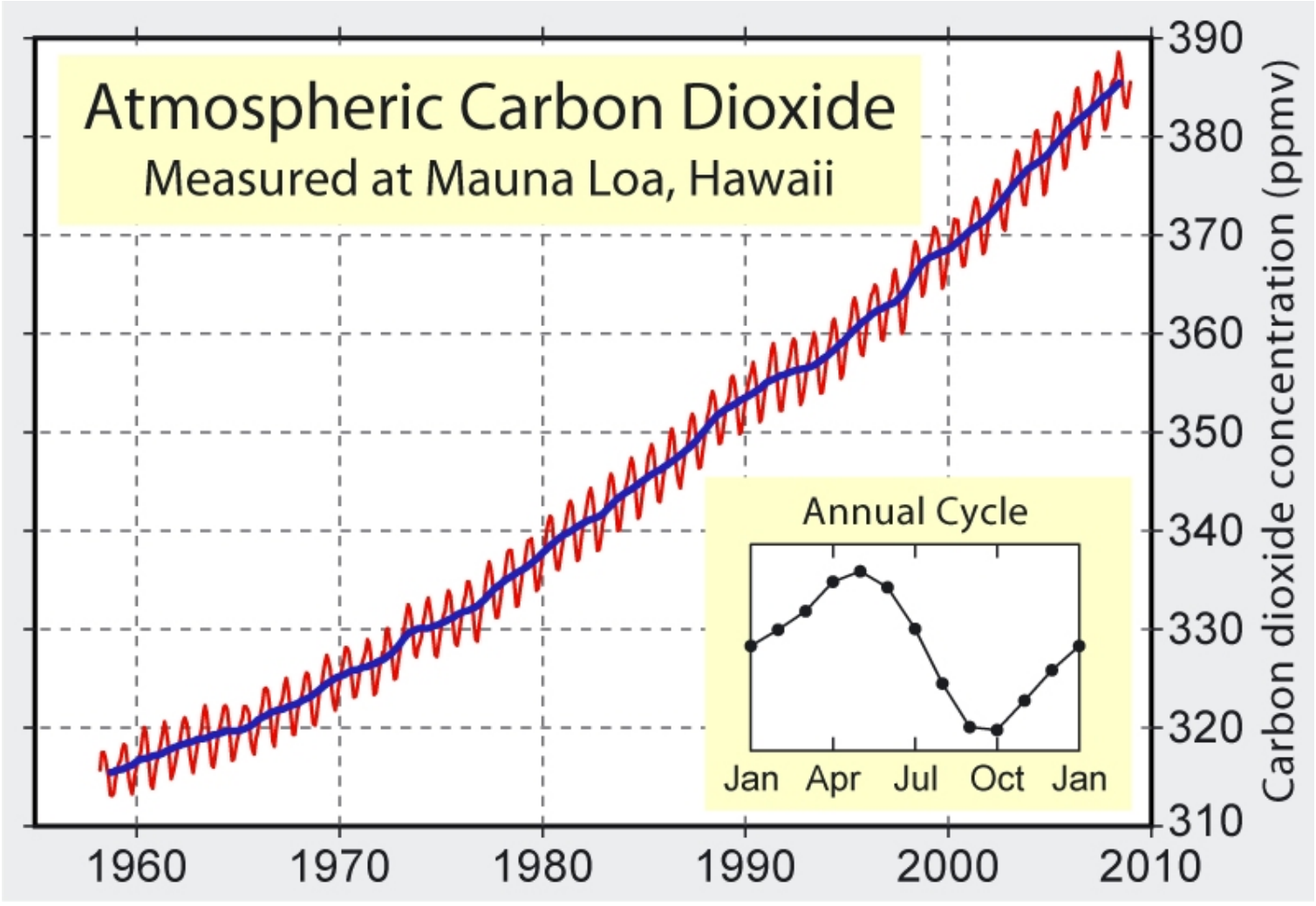
We use more and more energy. We get most of it by burning fossil fuels.

In 2007, the average human burnt 1.2 tonnes of carbon.

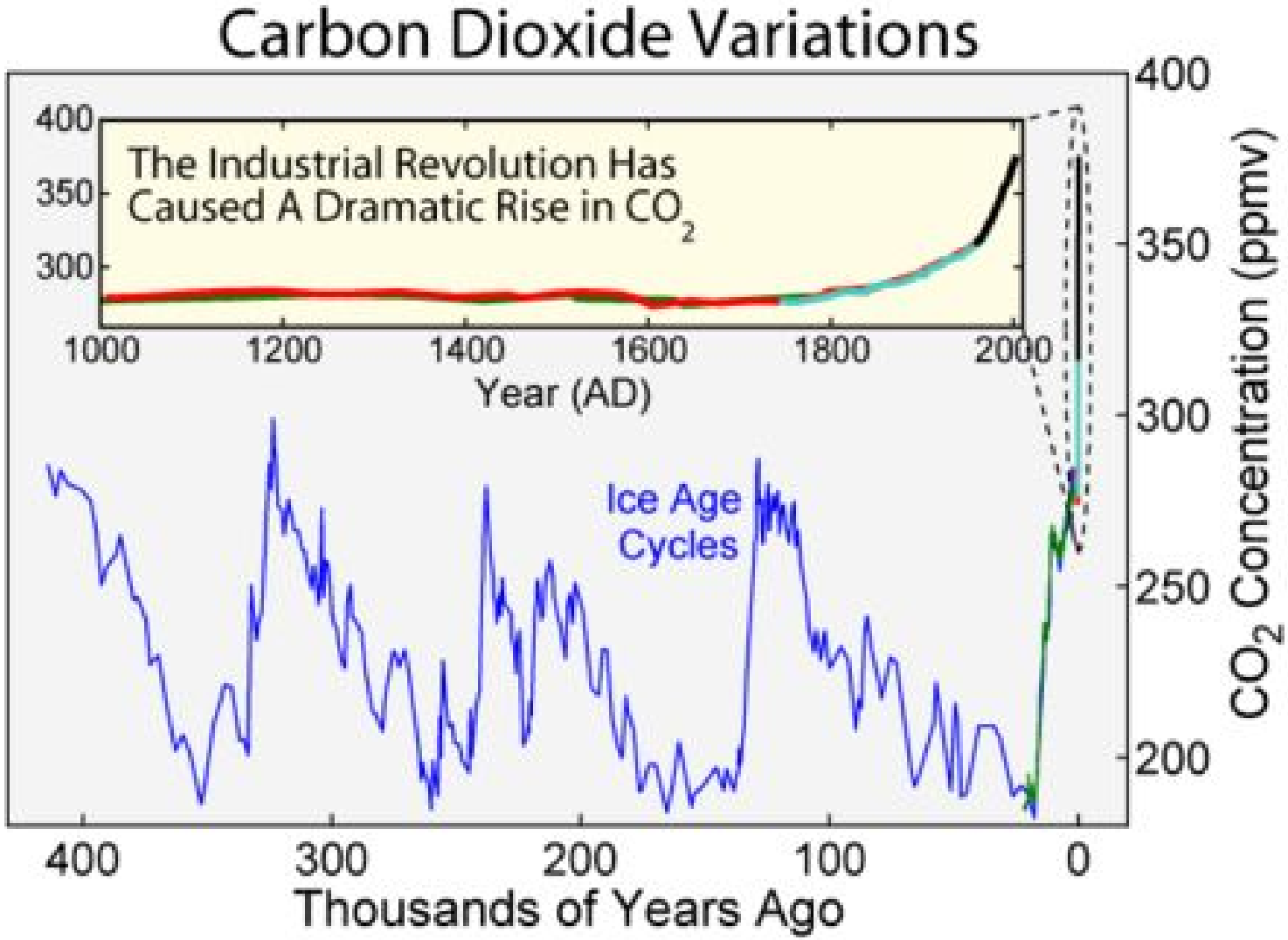
The average Hong Kong person burnt 5.8 tonnes.

Worldwide, we burnt 8 gigatonnes of carbon in 2007.

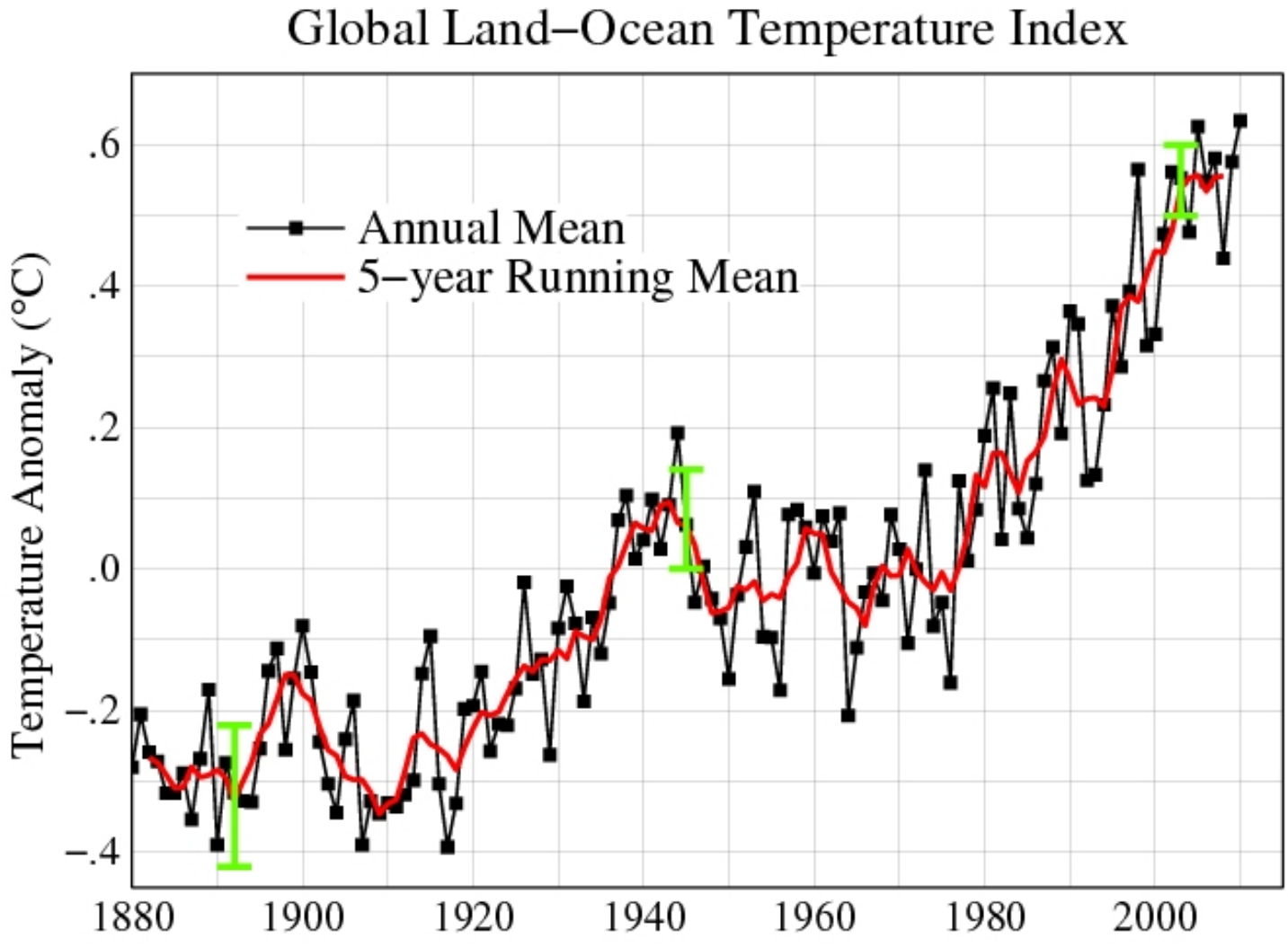
So, the amount of carbon dioxide in the air is soaring:



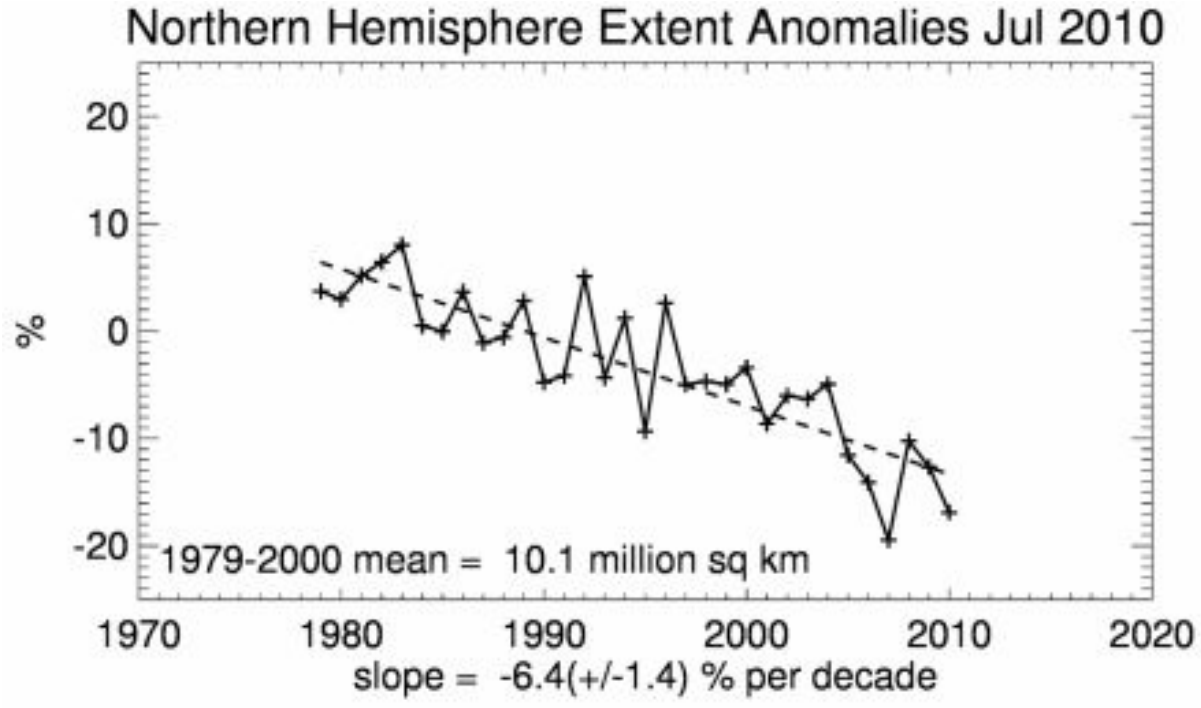
To understand just how much, we need to take the long view:



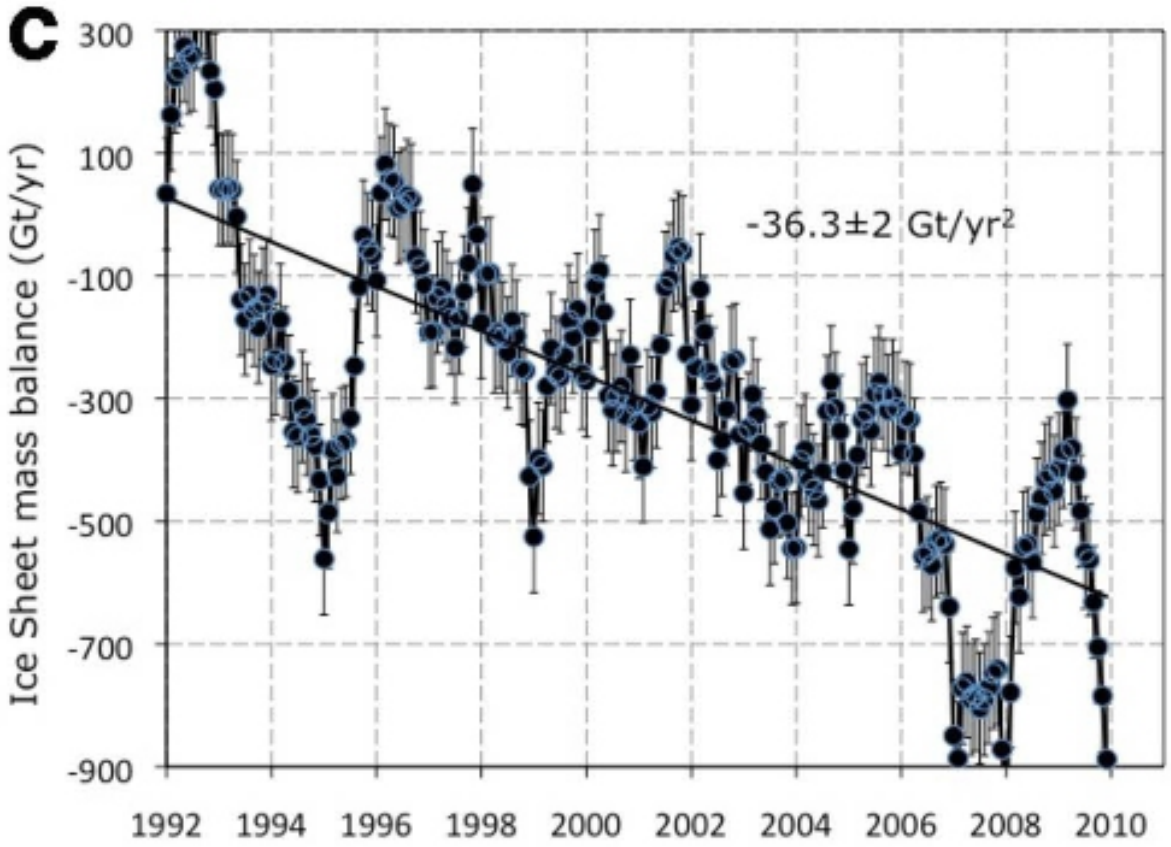
As you'd expect, the temperatures have gone up — about 0.8°C since 1880:



Arctic sea ice is shrinking in extent:



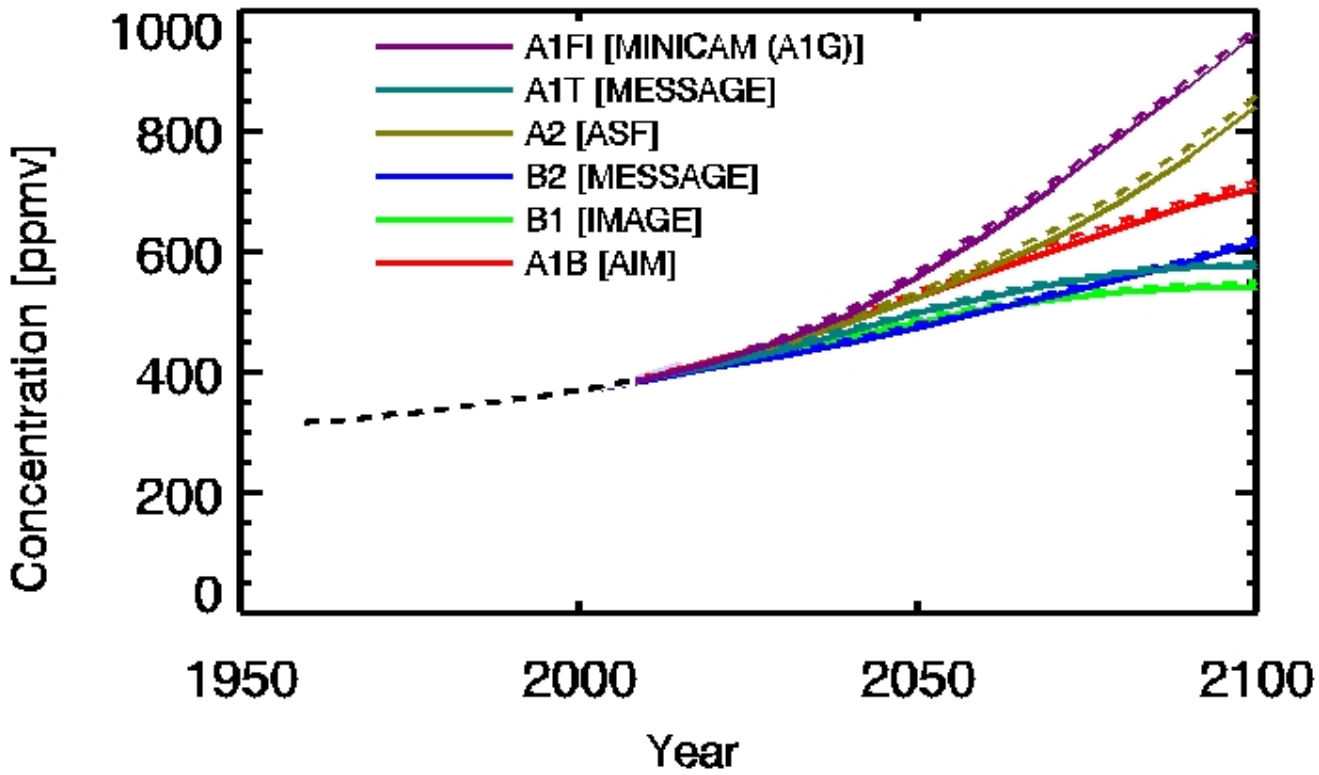
The melting of Antarctica and Greenland seems to be accelerating:



So far: *no projections or climate models*. But what do we expect to happen?

So far: *no projections or climate models*. But what do we expect to happen?

Before the industrial revolution, the CO_2 concentration was 290 parts per million. Now it's 390. What next?



Many different arguments say that doubling the carbon dioxide (CO_2) concentration will increase average temperatures by $2 - 4.5^{\circ}$C.

Many different arguments say that doubling the carbon dioxide (CO_2) concentration will increase average temperatures by $2 - 4.5^{\circ}$C.

With high economic growth and continued reliance on fossil fuels, the atmosphere could contain 950 parts per million of carbon dioxide by 2100.

Many different arguments say that doubling the carbon dioxide (CO_2) concentration will increase average temperatures by $2 - 4.5°C$.

With high economic growth and continued reliance on fossil fuels, the atmosphere could contain 950 parts per million of carbon dioxide by 2100.

This could cause temperatures roughly $2.4 - 6.4°C$ higher than today.

What effects might that have? With just 3°C of warming, the US National Academy of Sciences expects:

What effects might that have? With just 3°C of warming, the US National Academy of Sciences expects:

9 out of 10 northern hemisphere summers will be “exceptionally warm”: warmer than 1 out of 10 in 1980-2000.

What effects might that have? With just 3°C of warming, the US National Academy of Sciences expects:

9 out of 10 northern hemisphere summers will be “exceptionally warm”: warmer than 1 out of 10 in 1980-2000.

Much more land will be burned by wildfires in parts of Australia, Eurasia and North America.

What effects might that have? With just 3°C of warming, the US National Academy of Sciences expects:

9 out of 10 northern hemisphere summers will be “exceptionally warm”: warmer than 1 out of 10 in 1980-2000.

Much more land will be burned by wildfires in parts of Australia, Eurasia and North America.

Extreme precipitation events will increase by 9-30%

What effects might that have? With just 3°C of warming, the US National Academy of Sciences expects:

9 out of 10 northern hemisphere summers will be “exceptionally warm”: warmer than 1 out of 10 in 1980-2000.

Much more land will be burned by wildfires in parts of Australia, Eurasia and North America.

Extreme precipitation events will increase by 9-30%

Rainfall in some dry regions will drop by 15-30%

Rignot *et al* expect a sea level rise of 32 centimeters by 2050.

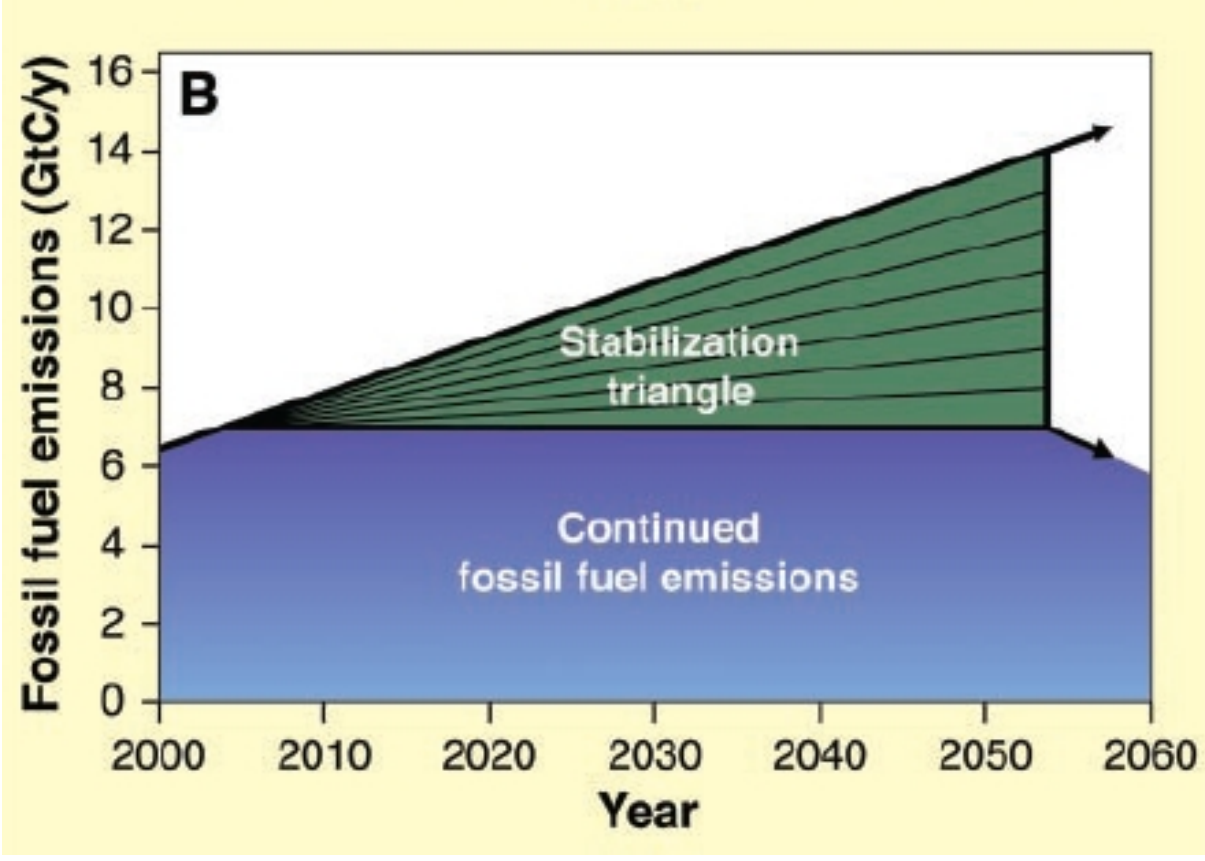
Rignot *et al* expect a sea level rise of 32 centimeters by 2050.

Even *not including* Greenland and Antarctica, we expect a 60 centimeter rise by 2100. This is enough to displace 3 million people.

What can we do? Slowing the rate of carbon burning is not enough: most CO_2 stays in the air a *very long time*, though individual molecules come and go. We need to:

- leave fossil fuels unburnt,
- live with a hotter climate,
- sequester carbon, and/or
- actively cool the Earth.

In 2004, Pacala and Socolow looked for ways to hold carbon emissions constant until 2054 — *not a solution, just a start!*



They said it would require 7 ‘wedges’. Each wedge is a way to reduce carbon emissions by 1 gigatonne/year by 2054.

Some examples of wedges (using numbers from 2004):

Some examples of wedges (using numbers from 2004):

Wind: Replace 700 gigawatts of coal-fired power plants by wind power.

Some examples of wedges (using numbers from 2004):

Wind: Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

Some examples of wedges (using numbers from 2004):

Wind: Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

Solar: Replace 700 gigawatts of coal power by solar power.

Some examples of wedges (using numbers from 2004):

Wind: Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

Solar: Replace 700 gigawatts of coal power by solar power. This requires *multiplying existing solar power by 700!*

Some examples of wedges (using numbers from 2004):

Wind: Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

Solar: Replace 700 gigawatts of coal power by solar power. This requires *multiplying existing solar power by 700!*

Nuclear: Replace 700 gigawatts of coal power by nuclear power.

Some examples of wedges (using numbers from 2004):

Wind: Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

Solar: Replace 700 gigawatts of coal power by solar power. This requires *multiplying existing solar power by 700!*

Nuclear: Replace 700 gigawatts of coal power by nuclear power. This requires *doubling existing nuclear power!*

Some examples of wedges (using numbers from 2004):

Wind: Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

Solar: Replace 700 gigawatts of coal power by solar power. This requires *multiplying existing solar power by 700!*

Nuclear: Replace 700 gigawatts of coal power by nuclear power. This requires *doubling existing nuclear power!*

Biofuels: Making 5.4 gigaliters of bioethanol to replace gasoline.

Some examples of wedges (using numbers from 2004):

Wind: Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

Solar: Replace 700 gigawatts of coal power by solar power. This requires *multiplying existing solar power by 700!*

Nuclear: Replace 700 gigawatts of coal power by nuclear power. This requires *doubling existing nuclear power!*

Biofuels: Making 5.4 gigaliters of bioethanol to replace gasoline. This requires *multiplying existing bioethanol production by 50!*

Conservation: Assuming the number of cars goes up from 500 million to 4 times that, *make everyone in the world drive half as much!*

Conservation: Assuming the number of cars goes up from 500 million to 4 times that, *make everyone in the world drive half as much!*

Efficiency: Under the same assumptions, make all cars twice as efficient *without people driving more!*

Conservation: Assuming the number of cars goes up from 500 million to 4 times that, *make everyone in the world drive half as much!*

Efficiency: Under the same assumptions, make all cars twice as efficient *without people driving more!*

Conservation/efficiency: Cut carbon emissions by 25% in buildings and appliances.

My personal thoughts, right now:

My personal thoughts, right now:

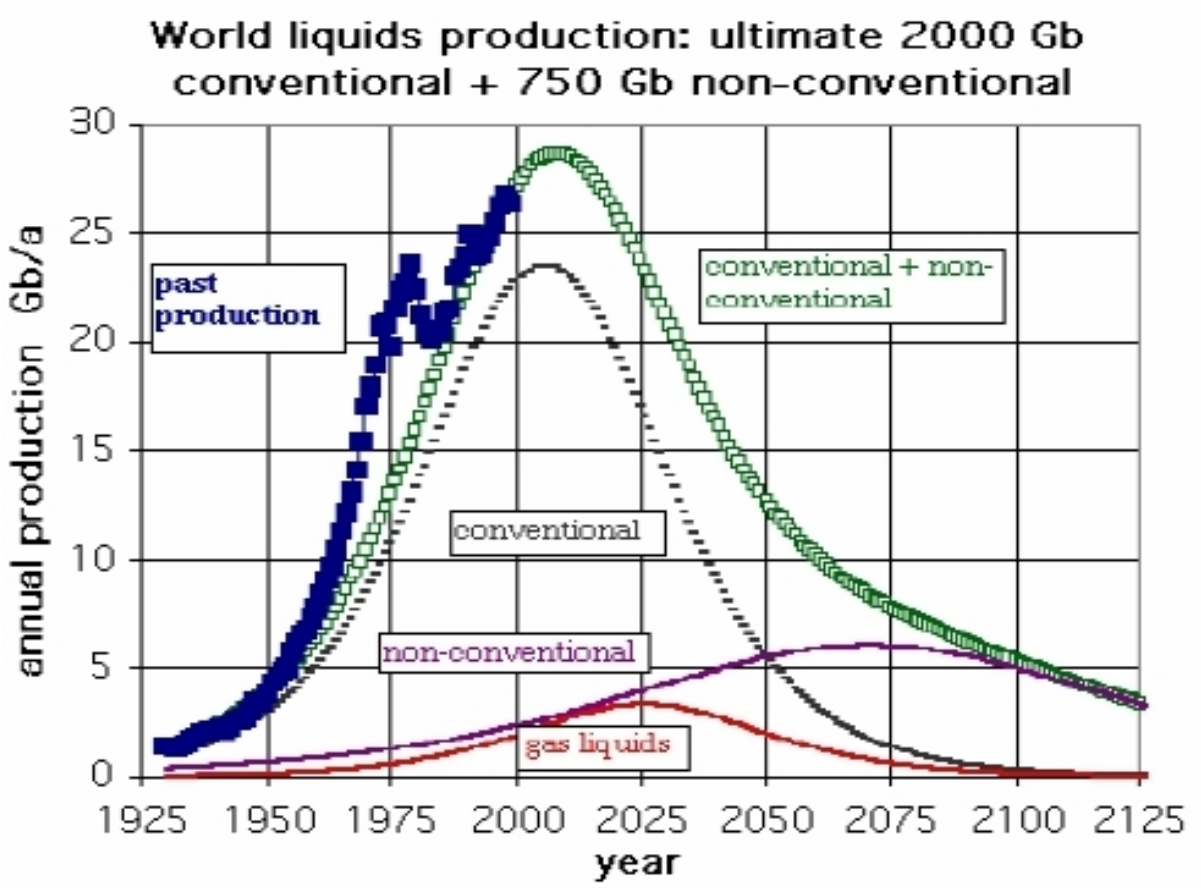
Each wedge is a massive undertaking, and we need to do *seven* of them just to hold carbon emissions constant.

My personal thoughts, right now:

Each wedge is a massive undertaking, and we need to do *seven* of them just to hold carbon emissions constant.

We probably won't bother unless conditions get worse *in a fairly dramatic way*. The floods in Pakistan covered 800,000 square kilometers, affecting 20 million people. That was not enough. How many events like this do we need?

If we wait 20 years, weather disasters and crop failures will combine with *declining oil supplies* to make us change our ways:



At that point, if we're not too busy *fighting wars*, governments will push scientists — and even mathematicians — to do something about the mess we're in.

At that point, if we're not too busy *fighting wars*, governments will push scientists — and even mathematicians — to do something about the mess we're in.

I decided to start now. But what can mathematicians do?