Energy, the Environment, and What Mathematicians Can Do

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

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Hong Kong University

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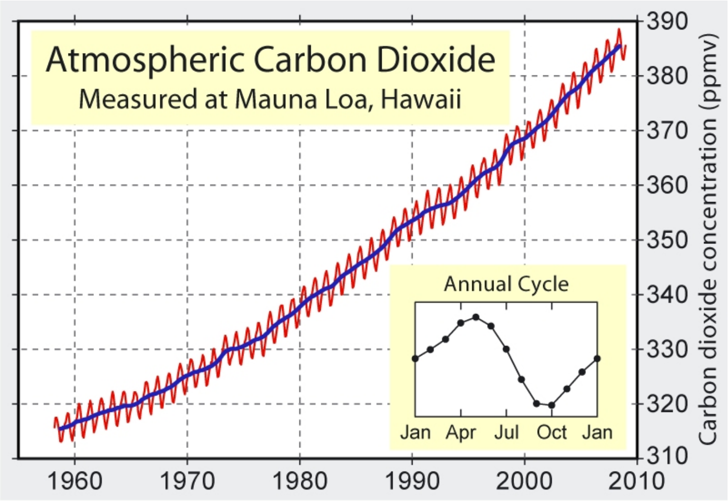
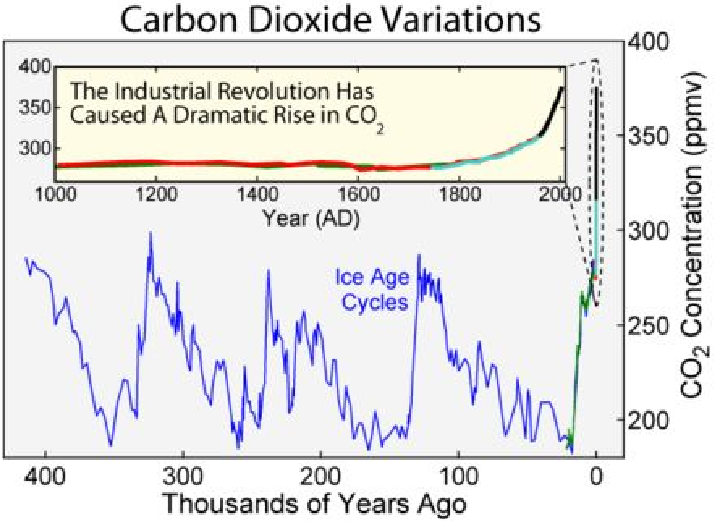
Worldwide, we burnt 8 gigatonnes of carbon in 2007.

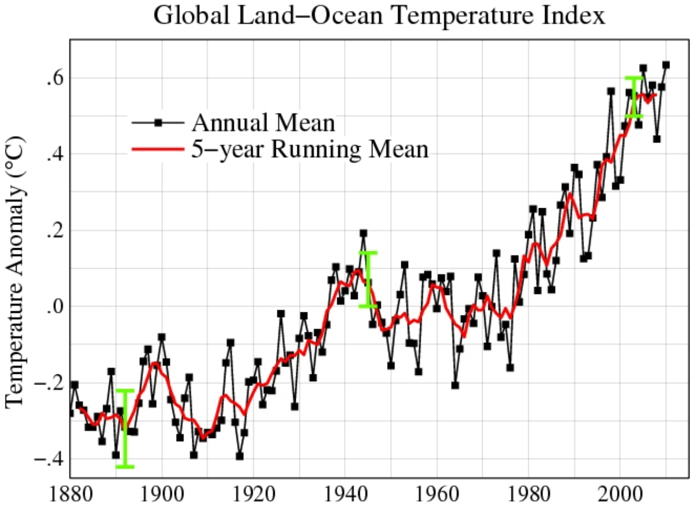
So, the amount of carbon dioxide in the air is soaring:



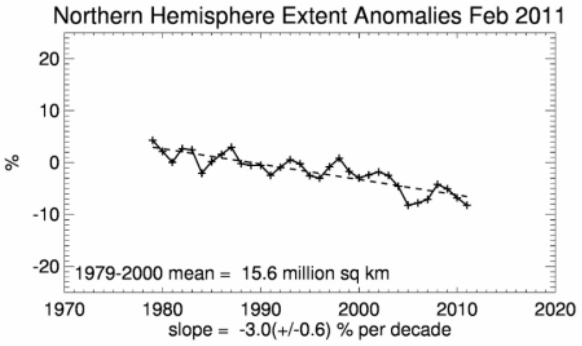
To understand just how much, we need to take the long view:



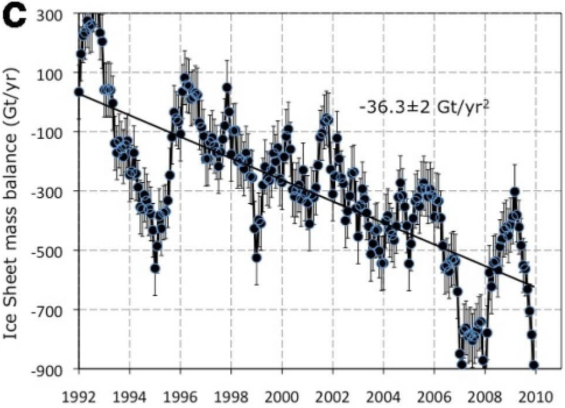
As you'd expect, the temperatures have gone up — about 0.8°C since 1880:



Arctic sea ice is shrinking in extent:



According to Rignot *et al*, the melting of Antarctica and Greenland is accelerating:



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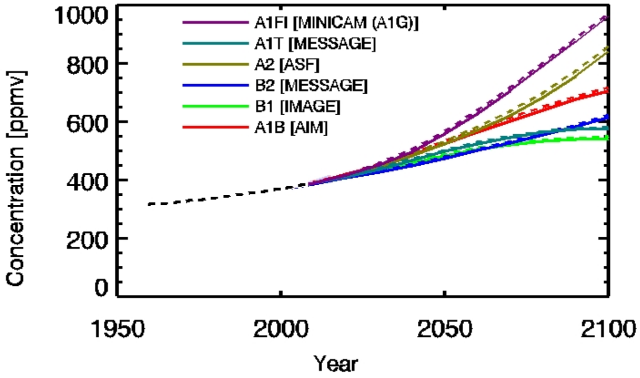
Before the industrial revolution, the CO_2 concentration was 290 parts per million. Now it's 390. What next?



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This could cause temperatures roughly $2.4 - 6.4^{\circ}$C higher than today.

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

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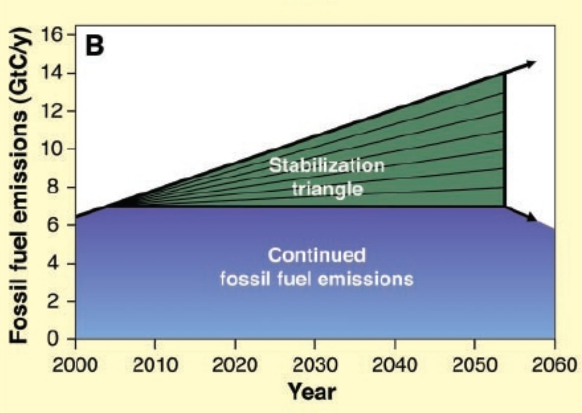
And it's not just people in trouble: species are already moving 6 kilometers closer to the poles each decade. The rate of extinction will increase.

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.

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

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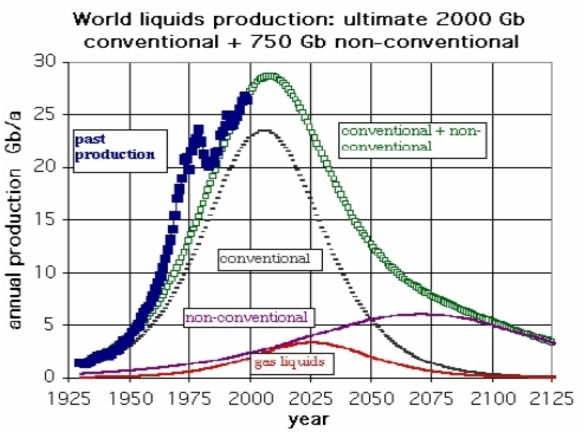
The floods in Pakistan covered 800,000 square kilometers, affecting 20 million people. Suppose events like this become more common. How many will it take before we:
1) decide global warming is to blame and
2) decide to do something very difficult to stop it?

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



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But I've cut back immensely... and I'm happier.

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It seems unthinkable... just like every other new thing we ever did.

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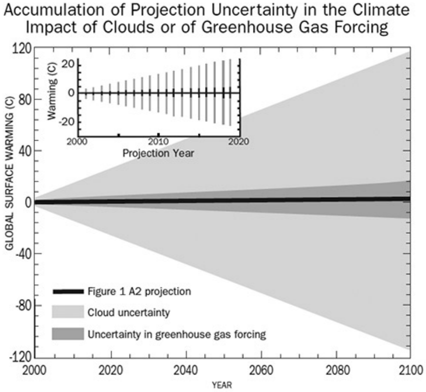
Innumeracy and illogic can be found on both sides of almost every argument about climate change and energy policy. I will unfairly single out one example!

Patrick Frank, in *Skeptic Magazine*, said: uncertainty in estimates of cloud cover causes a 1.1°C uncertainty *per year* in temperature predictions. So:

> *"By 50 years, the uncertainty in projected temperature is* $\pm 55°$*. At 100 years, the accumulated physical cloud uncertainty in temperature is* ± 111 *degrees."*




HUH??

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Let's see one example.

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Cao and Caldeira argue that if we double CO_2 in the air, *16% of land warming will be caused by this effect!*

But CO_2 also helps plants grow leaves. Bounoua *et al* say this effect would cool the land by 0.6° C with doubled CO_2.

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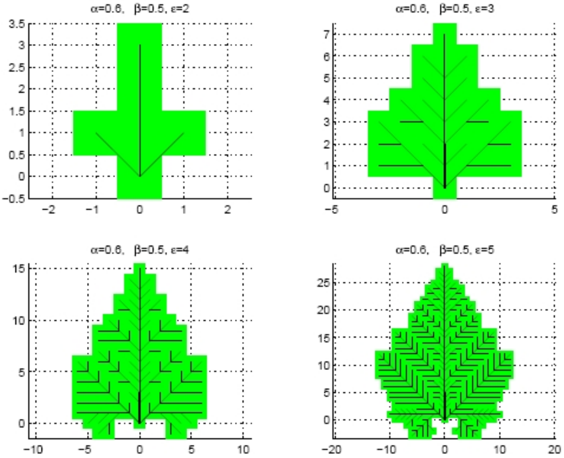
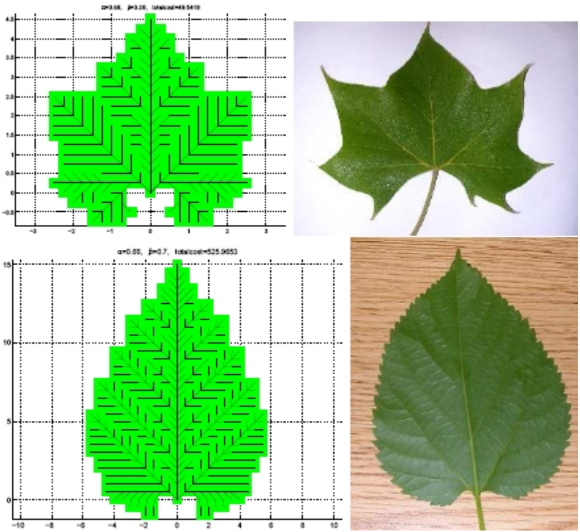
Is there math in a leaf?

Yes! A mathematician at U.C. Davis, Qinglan Xia, has written a paper called *The Formation of a Tree Leaf*.

He models a leaf as a union of square cells centered on a grid, together with ‘veins’ forming a weighted directed graph from the centers of the cells to the root. The leaf grows new cells at the boundary while minimizing a certain cost function.



The cost function depends on two parameters. Changing these gives different leaf shapes:



Qinglan Xia's work is definitely math:

Lemma 3.8. *Suppose* (Ω, G) *is an* (ϵ, h) *leaf and* $(\mu, \Theta) = \phi_h(\Omega, G)$. *Then the total mass of the Radon measure is bounded above by*

$$\mathbf{M}(\mu) \leq \pi (R_\epsilon + h)^2$$

and the total variation of the vector measure Θ *is bounded by*

$$\mathbf{M}(\Theta) \leq \epsilon \pi^{2-\alpha} (R_\epsilon + h)^{4-2\alpha}.$$

Proof. Since $\Omega \subset B_{R_\epsilon}(O)$, the mass of μ is given by

$$\begin{aligned} \mathbf{M}(\mu) &= \|\Omega\| h^2 \\ &= \operatorname{area}\left(\bigcup_{x\in\Omega}\left\{x + \left[-\frac{h}{2}, \frac{h}{2}\right] \times \left[-\frac{h}{2}, \frac{h}{2}\right]\right\}\right) \\ &\leq \operatorname{area}\left(B_{R_\epsilon + h}(0)\right) = \pi (R_\epsilon + h)^2. \end{aligned}$$

Also, since $w(e) \leq \|\Omega\| h^2$ for each $e \in E(G)$, the total variation of Θ is given by

$$\begin{aligned} \mathbf{M}(\Theta) &= \sum_{e\in E(G)} w(e)\, length(e) \\ &\leq \left(\|\Omega\| h^2\right)^{1-\alpha} \sum m_\beta(e^+) (w(e))^\alpha\, length(e) \end{aligned}$$

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