

Global Climate Destabilization: Optimal Opportunity for the Mathematics of Planet Earth

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Global Climate *Destabilization* (GCD) :

There's good news and bad news....

- Bad news first: destabilization is occurring, and is ominous. Are there any silver linings?"
- Good news: GCD is an interesting and engaging context for studying math. Why?
 - There is a bountiful variety of topics to choose from.
 - Graphics and data abound, and are useful for both the illustration and the application of ideas and techniques.
 - The mathematics have truly important (*some would even say critical and urgent*) implications. Small changes in models and assumptions lead to dramatic changes in projections and predictions, and many of these will be tested in the lifetimes of our students. We're engaged in a vast experiment....

GCD provides variety, is accessible, and is meaningful.

Variety: Pick your STEM subject matter

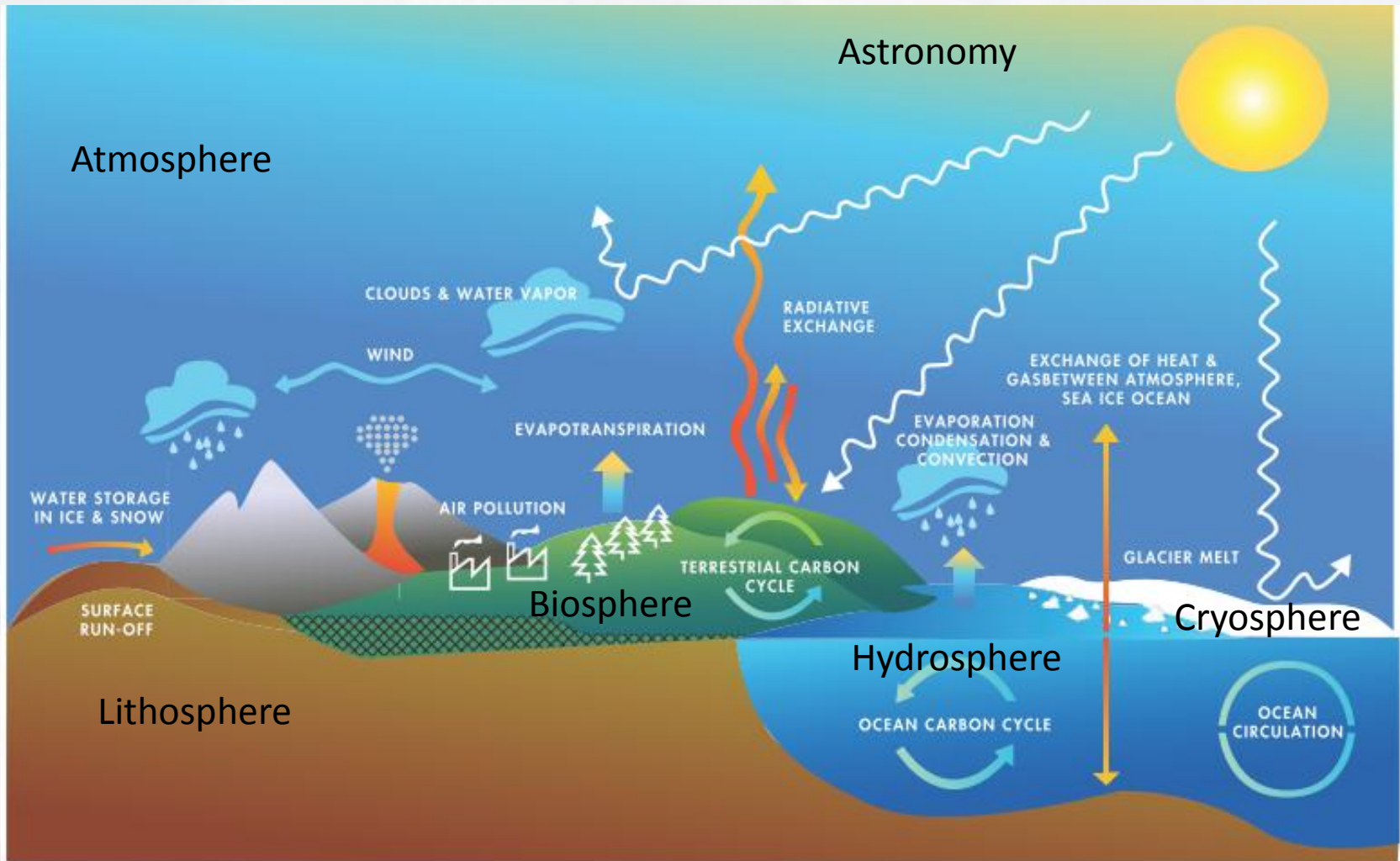


FIGURE 1.3 Climate models are mathematical representations of the physical, chemical, and biological processes in the Earth system. SOURCE: Marian Koshland Science Museum.

Example (Math) Topic: Non-Linearity versus Linearity

And let's focus on sea-level in this concrete example.

There are, of course, many issues offering a variety of lines of attack from the GCD perspective. E.g. one could address:

- Normal versus non-normal distributions
- Regression modeling
- Orthogonal functions and Fourier analysis
- Correlation versus causation
-

Let's start with Monotonicity...

- “As water warms, it expands... Most of the sea level rise predicted for the next hundred years — a total of up to three feet — is purely a function of thermal expansion.” p. 125, Kolbert, *Field Notes from a Catastrophe*. I.e.,
as water warms, it expands.
- But we don't know that the increase is linear. How do we know that a relationship is linear?

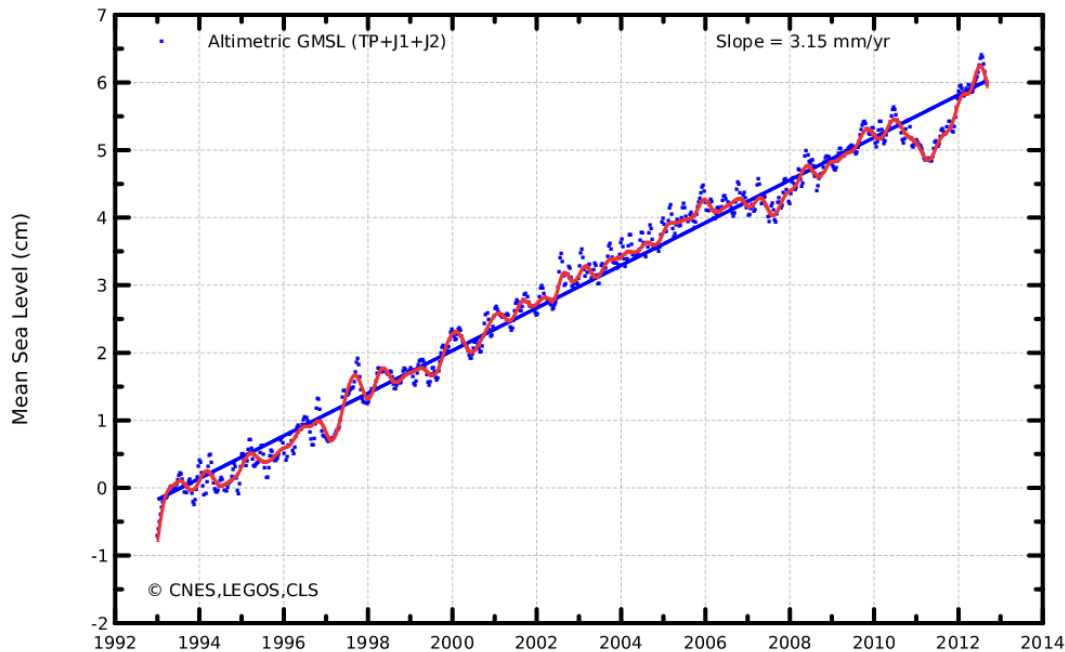
Linearity

- If you **double x**, does the **change in y double**? If so, y is an affine function of x, whose graph is linear. (If y itself doubles when x doubles, then y is truly linear.)
- So: if you double global output of CO₂, does the warming double? Does ocean acidification double? Does twice as much Arctic ice melt? Do twice as many species go extinct?
- “[The WAIS]’s melting currently contributes 0.3 millimeters to sea level rise each year. This is second only to Greenland, whose contribution to sea level rise has been estimated as high as 0.7 mm per year.” [West Antarctica warming more than expected](#) (NCAR, 2012) A statement like this is an implicit **declaration of linearity**, and we find such statements (predictions) made all the time.

Most Phenomena are Non-Linear

- An historical example (John Tyndall, 1861):
“...increasing the concentration of an absorbent gas does not always produce a **proportional increase** in heat uptake, because there is progressively less to be absorbed.” This explicitly **denies** linearity in a monotone relationship. In fact, linearity is generally rare in nature (*but don't tell our students!*).
- Even monotonicity is violated frequently: for example, Paracelsus (the “father of toxicology”) said that everything is a poison in the wrong dose.... This asserts that positive inputs have U-shaped responses.

Mean Sea Level



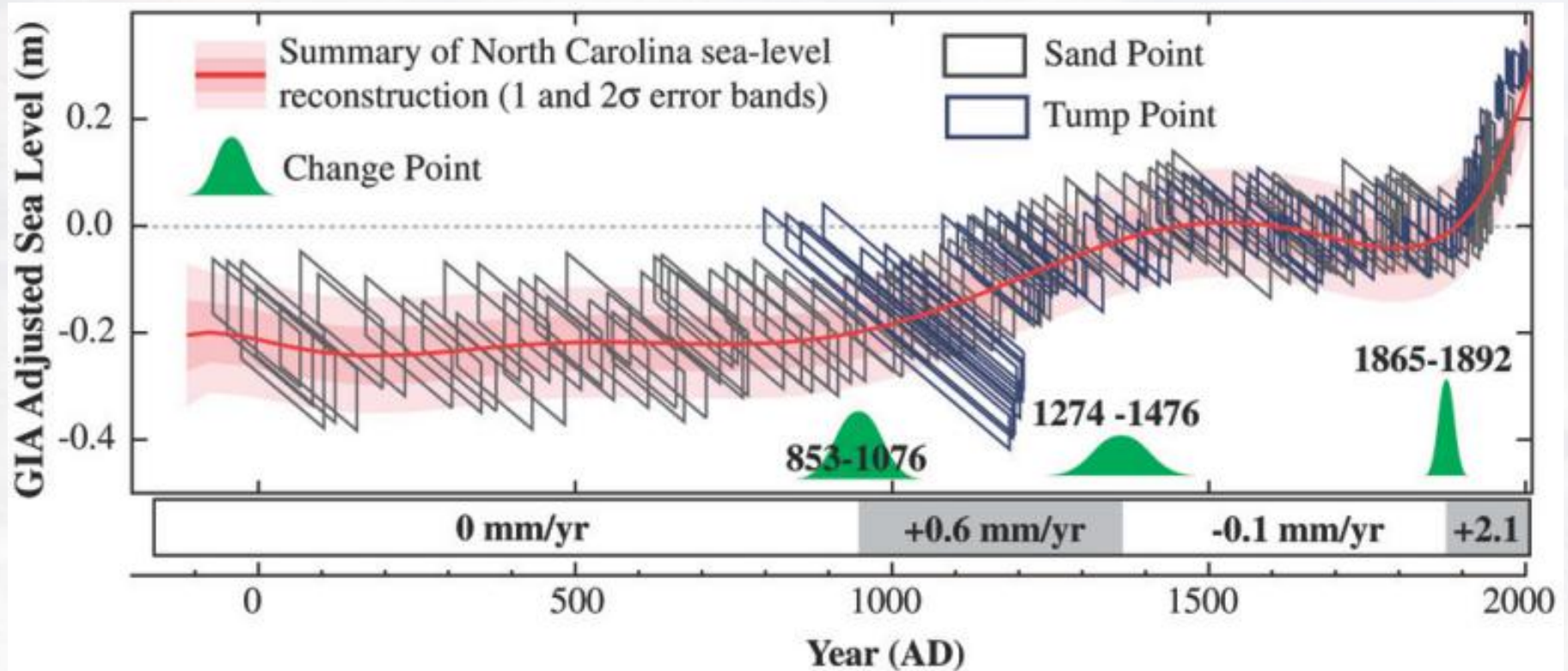
Looks like there's a linear trend, with a dramatic downtrend in the last few years (followed by a surge to “catch up” – [what's up with that?](#)).

Students need to realize that [data](#) – the dots – must be “connected” by the mathematician – and perhaps explained by the mathematician – or scientist – as well.

20 years of linear growth...? Apparently: if we measure from any fixed point in time, e.g. if we **double the time** from 1993, then the **change** in mean sea level appears to double.

At times during the Cenozoic (~65 million years ago) the world was ice-free, and sea level was around 70 meters higher than today. “Sea level rise, despite its potential importance, is one of the least well understood impacts of human-made climate change.” Hansen, 2012. At this rate, it will take 22222 years to get to 70 meters again....

Or IS it linear? If we zoom out...

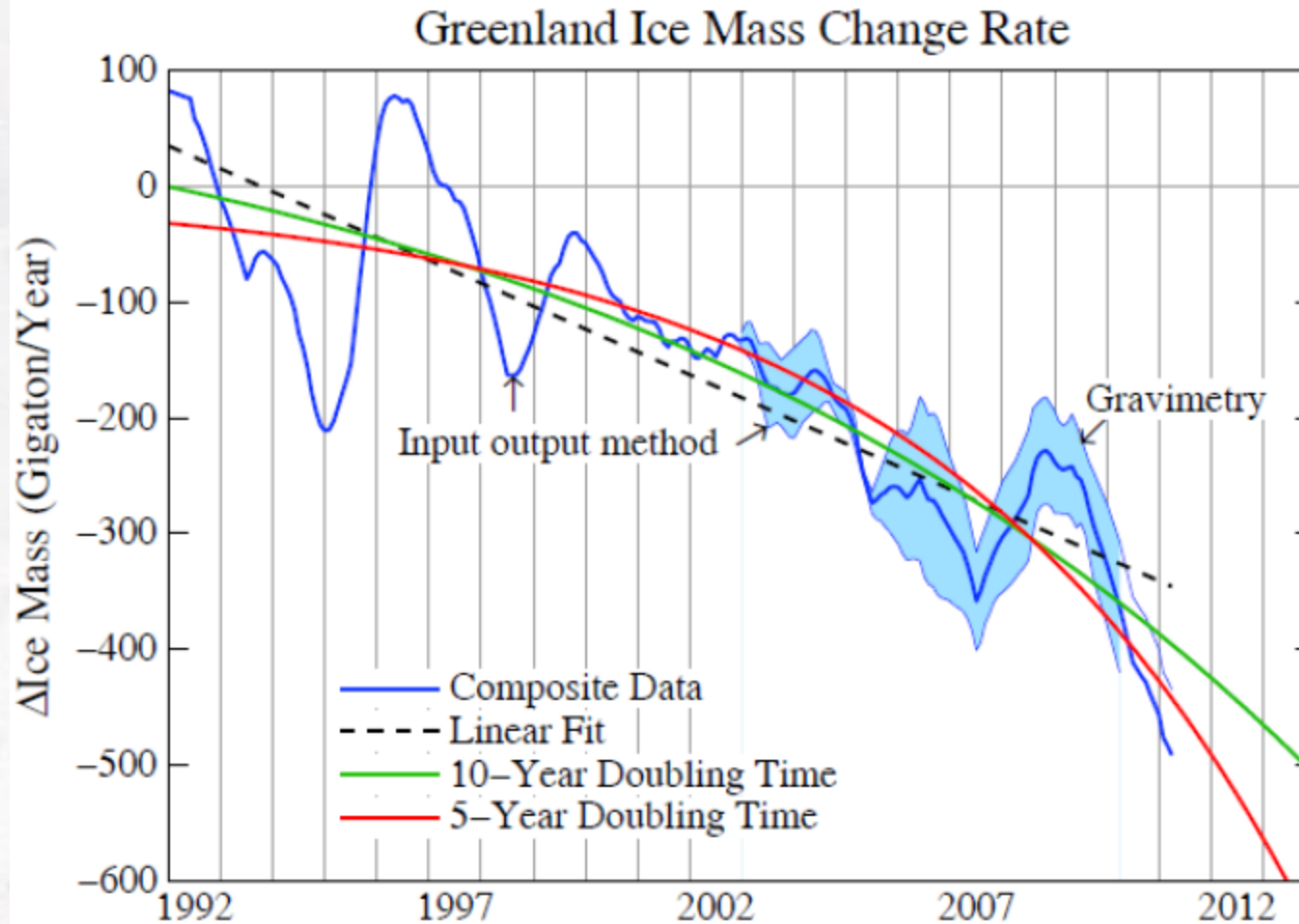


Two thousand years of sea-level rise estimates from two North Carolina salt marshes (Sand Point and Tump Point). Errors in the data are represented by parallelograms. The red [curve] is the best fit to the sea-level data. Green shapes indicate when significant changes occurred in the rate of sea-level rise. SOURCE: Kemp et al. (2011).

From: *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* (National Research Council, 2012).

James Hansen Reviews Sea-Level

Or at least the contribution from glaciers....



What about that glacial contribution?

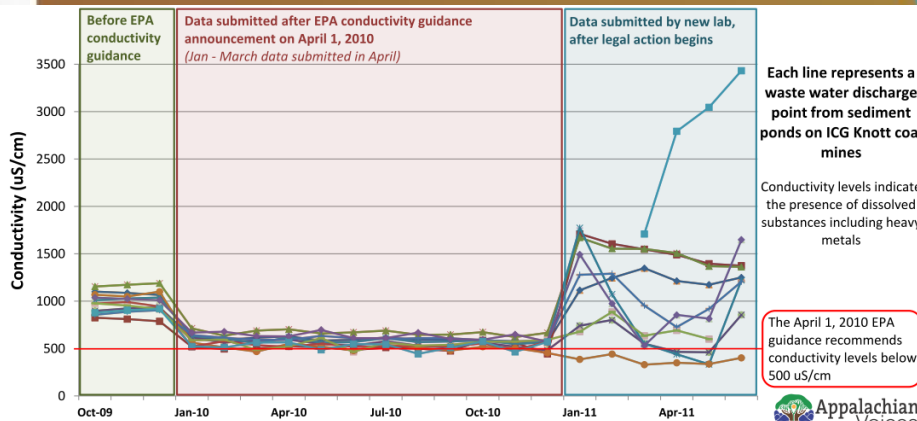
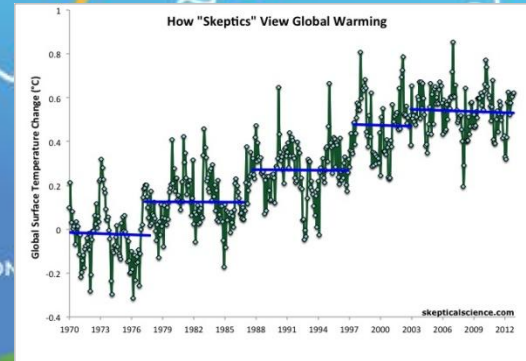
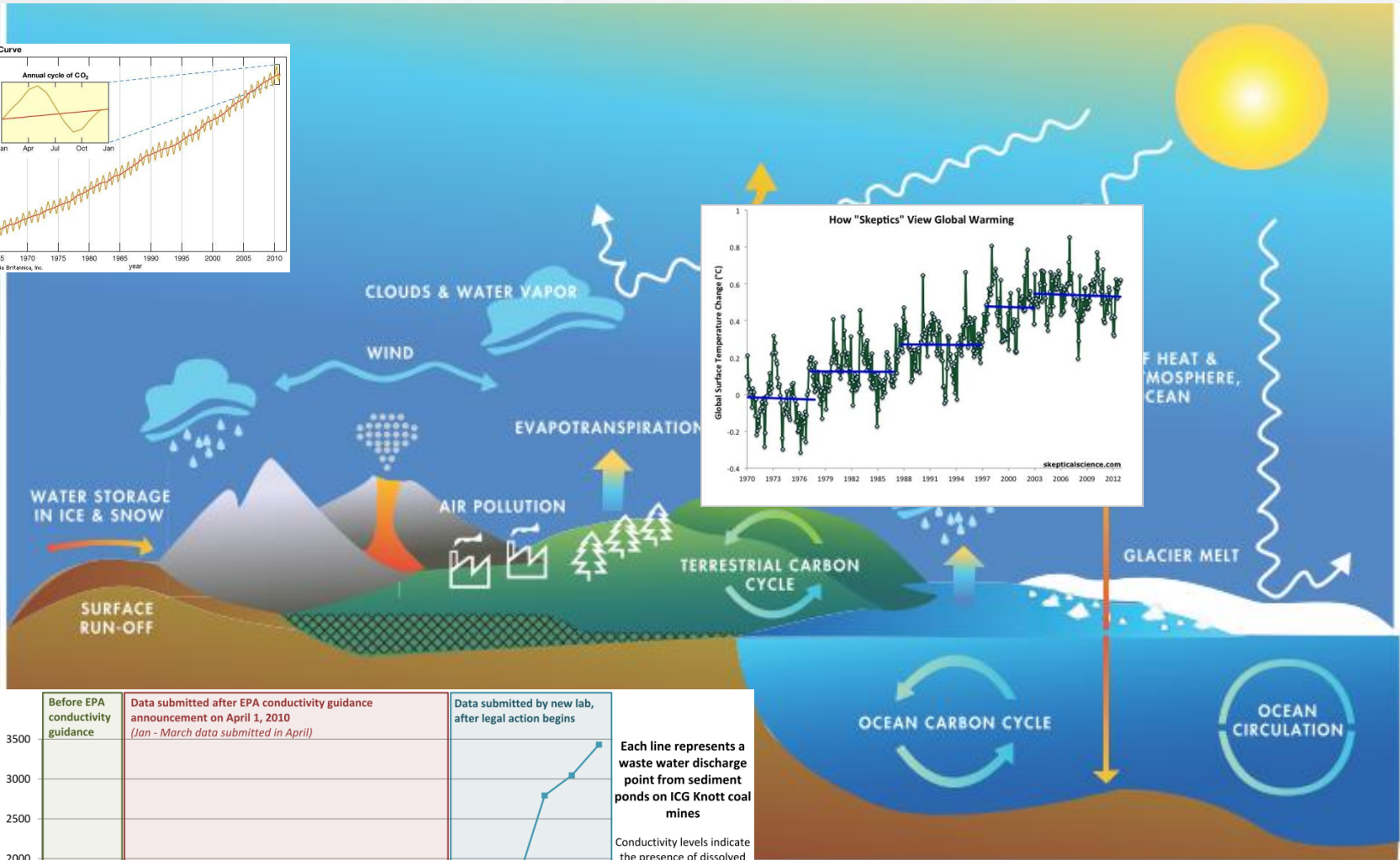
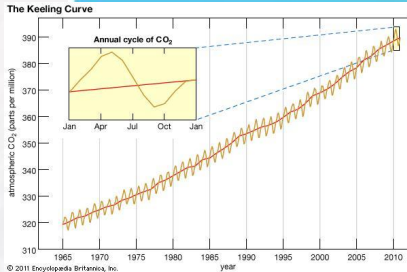
This graph of [Greenland ice melt](#) presents other issues which every student needs to address eventually, e.g. messy data (variability).

It also challenges students to think about which model is best – and perhaps even what model would be better!

[Update of Greenland Ice Sheet Mass Loss: Exponential?](#) 12/26/2012:

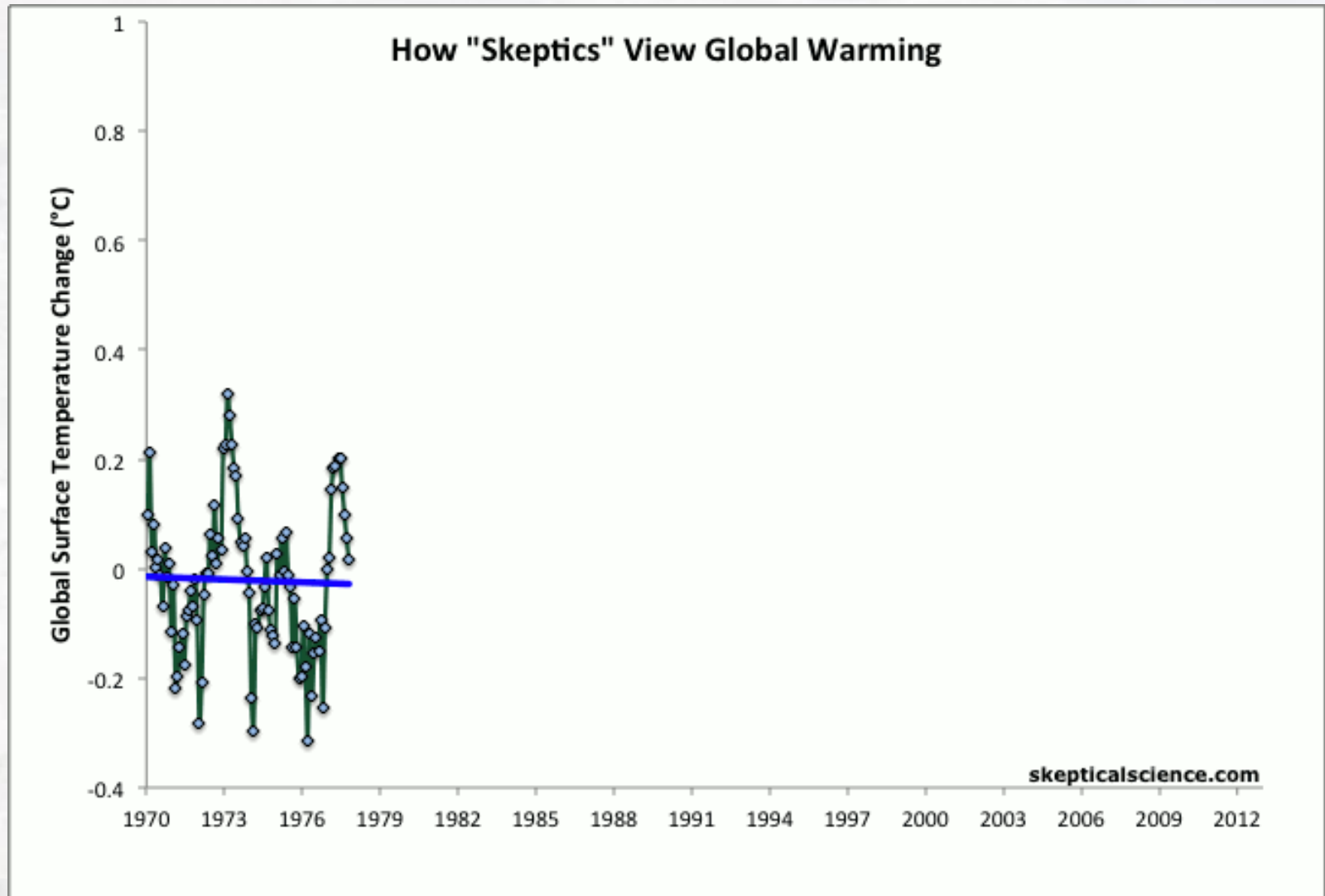
“... the fundamental issue is linearity versus non-linearity.”

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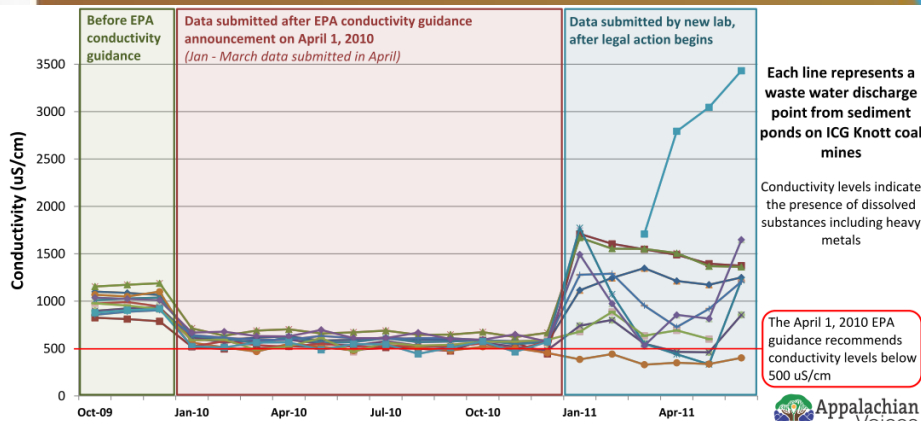
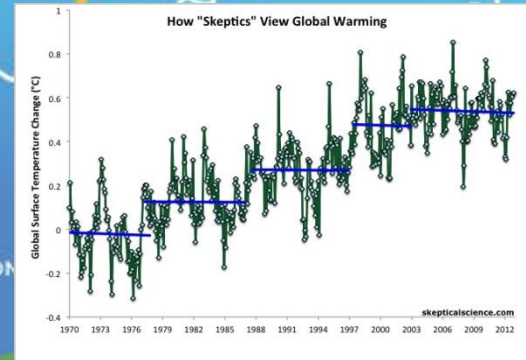
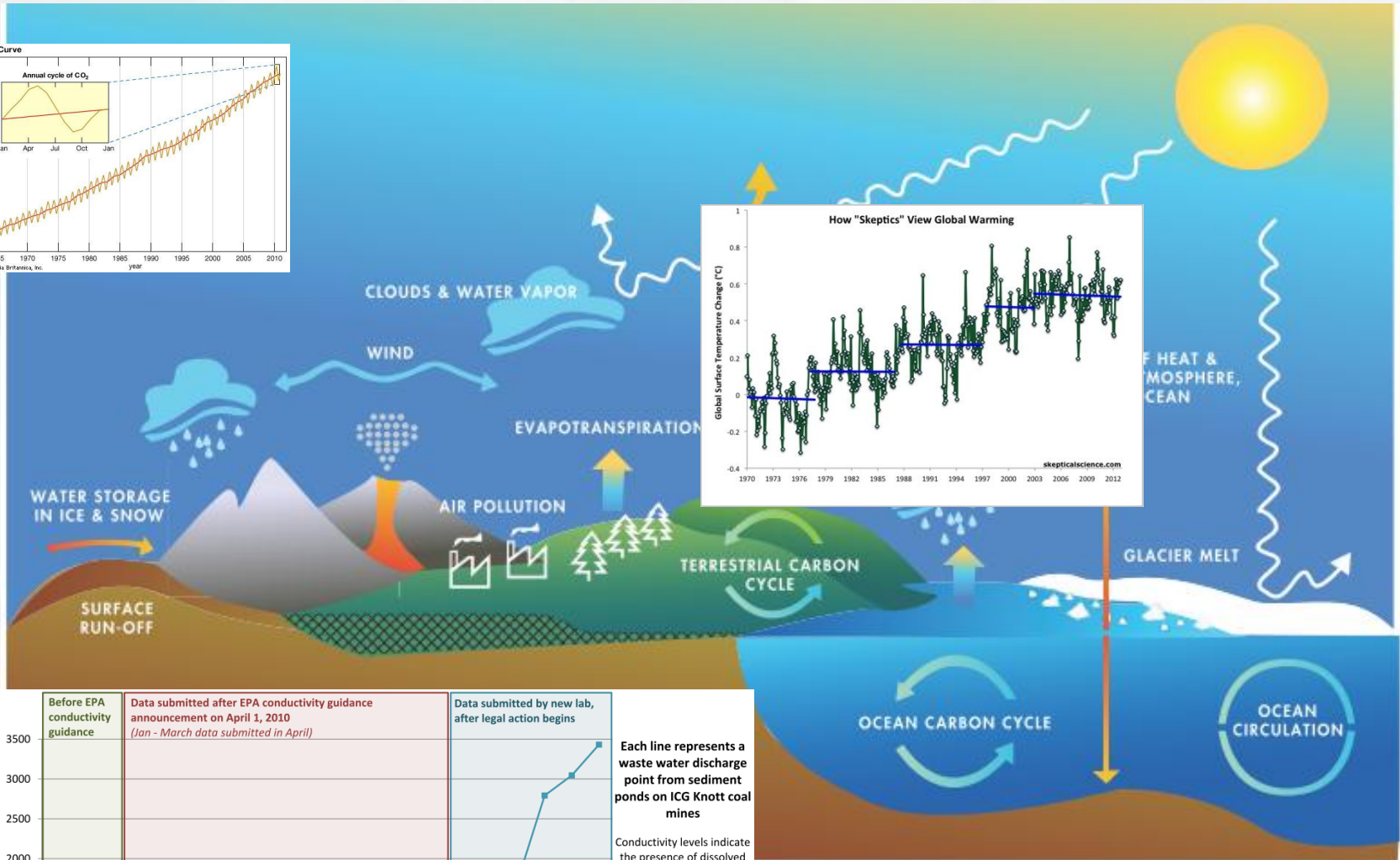
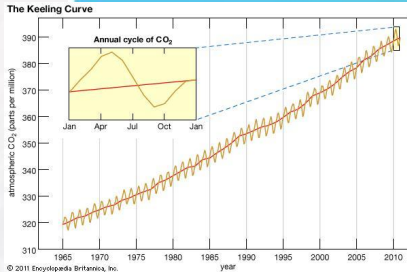


itions of the physical, chemical, and biological Science Museum.

Here's an interesting – very creative – model...



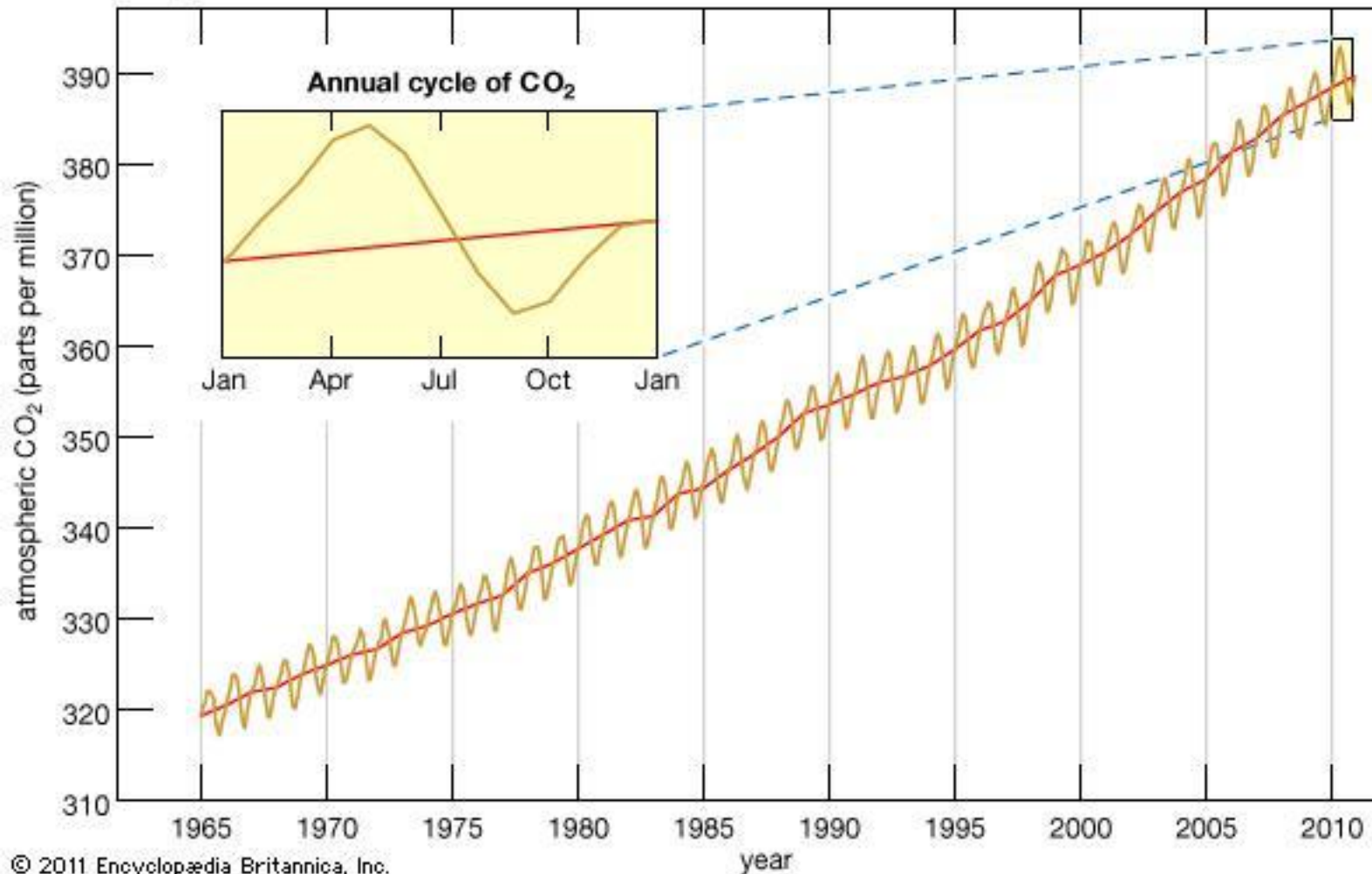
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Favorite Example of Non-Linearity: The Keeling Data, Graphed

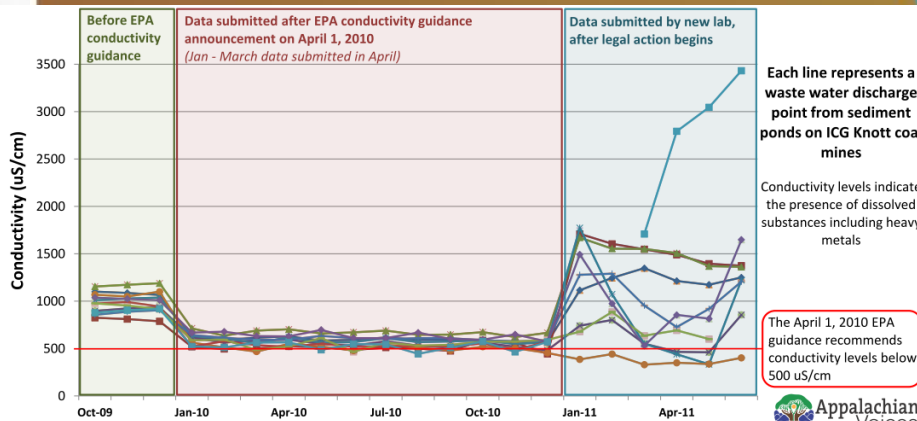
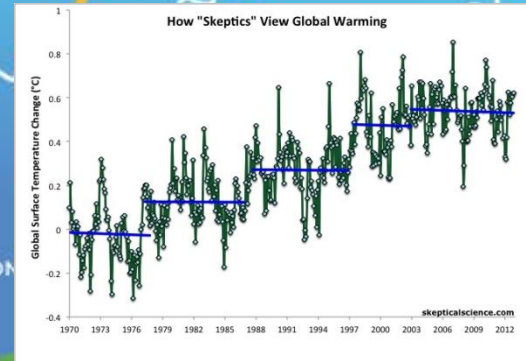
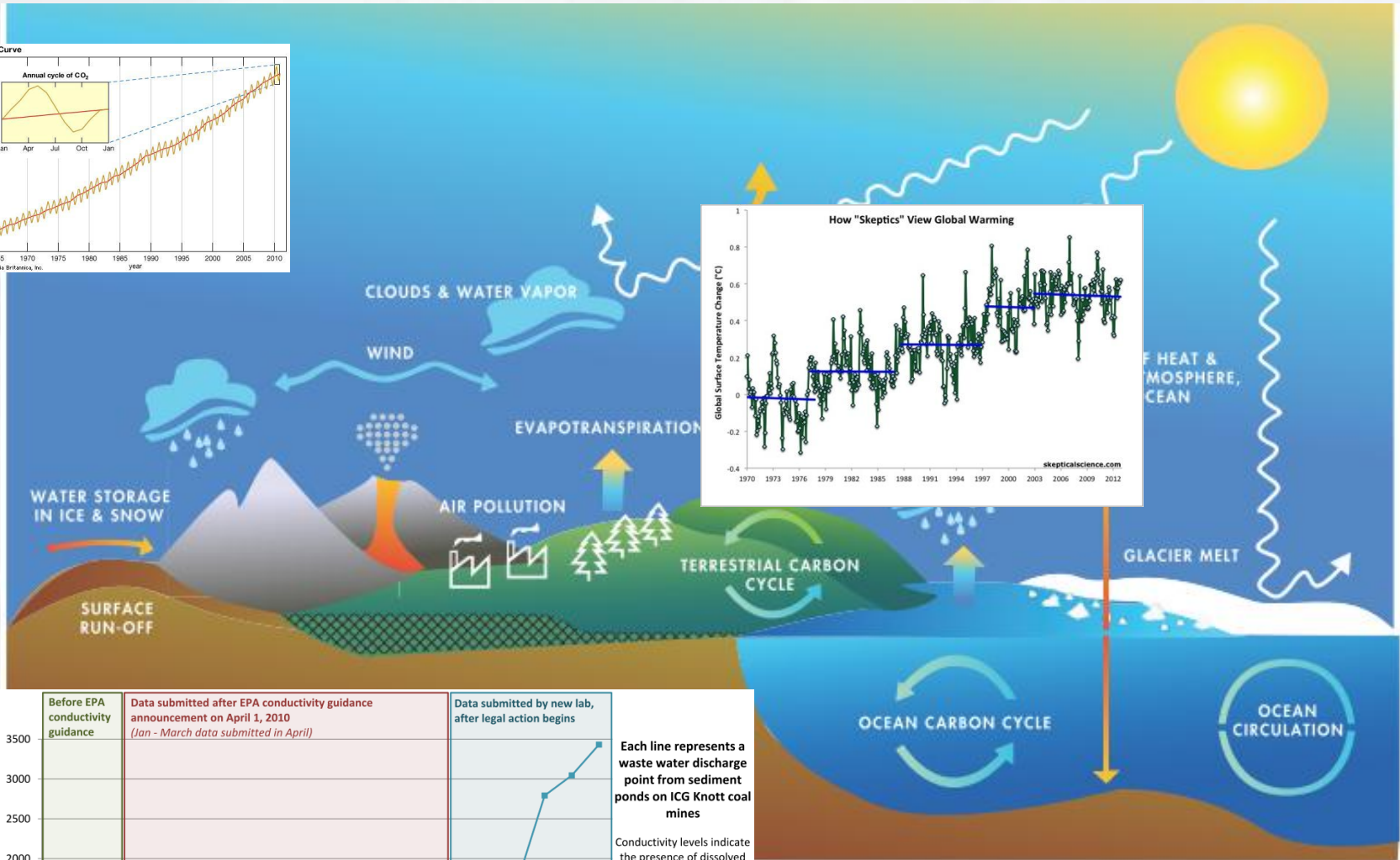
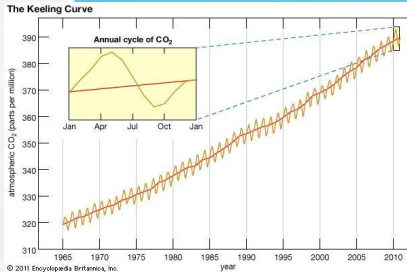
The Keeling Curve



There is the trend, and then there is the seasonal oscillation.

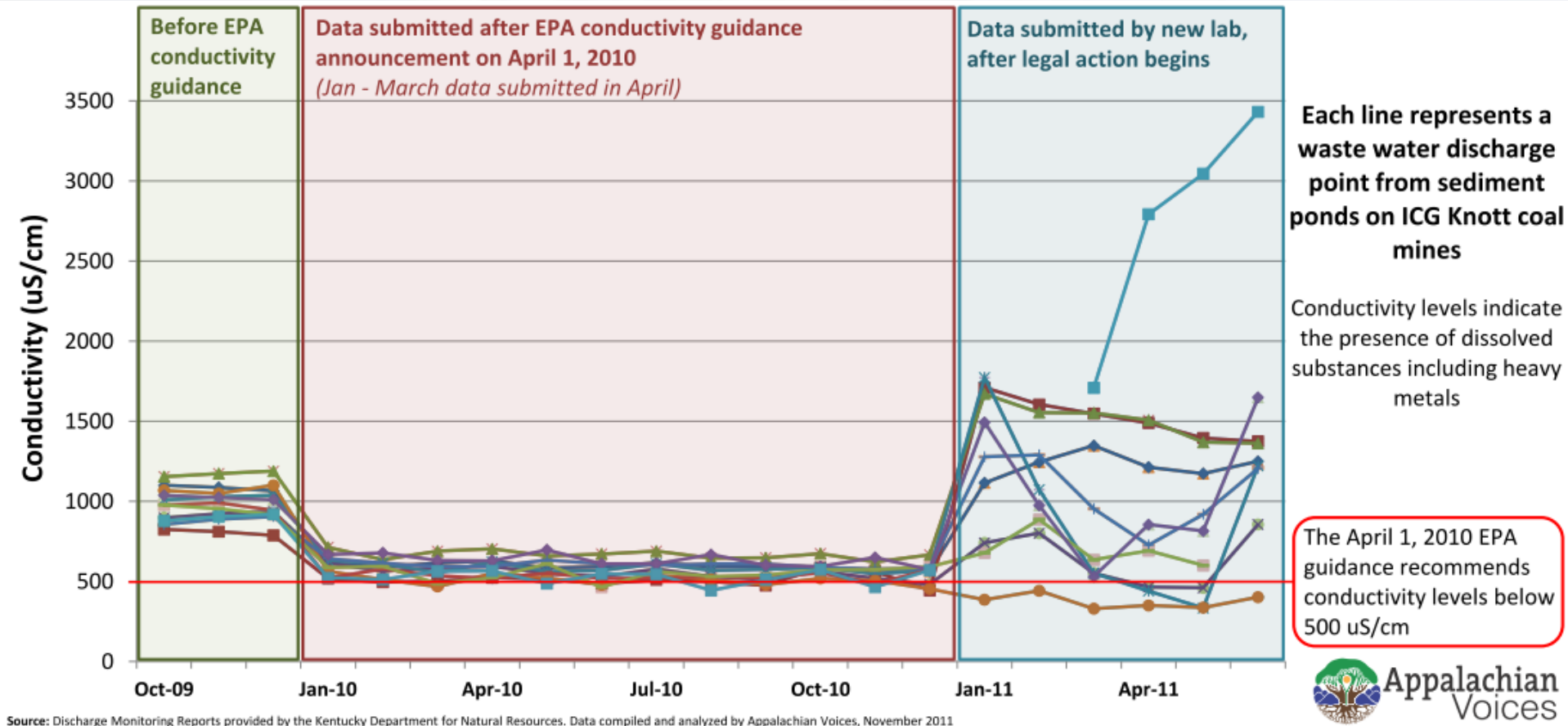
Each of these is a topic in its own right: non-linear versus linear growth, and periodicity.

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ICG Pollution Reports Show Pattern of Deception



An example of a piece-wise defined function, with three clear reasons for the distinct pieces. This example provides a lot of grist for the function mill: variation (or lack thereof) can help determine that someone is faking it. [But why fake slightly **above** the legal limit?!]

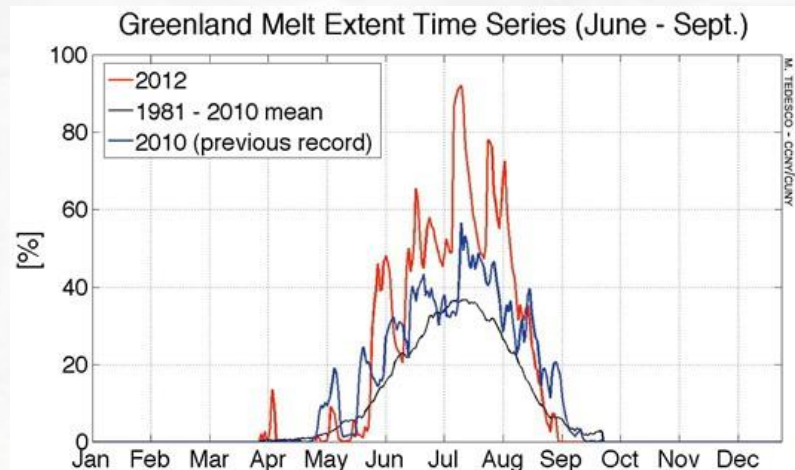
(Thanks to Eric Chance and Appalachian Voices for the use of this example.)

Conclusions

1. Data-based graphics are beautiful tools for investigating and teaching elements and techniques of math and stats.
2. Topics can be motivated, embellished, or illustrated using these graphics.
3. Data is often available to do your own analysis – to create your own graphics and analyses.

4. GCD provides

- variety,
- accessibility, and
- meaning and import.
- Now for some action?





Be persuasive. Be brave. Be arrested (if necessary)

A resource crisis exacerbated by global warming is looming, argues financier Jeremy Grantham. More scientists must speak out.

I have yet to meet a climate scientist who does not believe that global warming is a worse problem than they thought a few years ago. The fertilizer problem is seen also in the shocking lack of awareness on the part of governments and the public of the increasing damage to

- General Resources:
 - [Climate Change Indicators in the United States](#) (EPA, 2012) (and [graphics](#))
 - [Climate Change: Evidence, Impacts, and Choices](#) (National Research Council, 2012) (and [graphics](#))
- Additional Graphics resources
 - [Climate Graphics by Skeptical Science](#)
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Resource Greatest Hits

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 - [Climate Change: Evidence, Impacts, and Choices](#) (National Research Council, 2012) (and [graphics](#))
 - [Quantitative Environmental Learning Project \(QELP\)](#) – e.g. [Keeling Data project](#)
- Additional Graphics resources
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More from James Hansen....

“...the fundamental issue is linearity versus non-linearity....amplifying feedbacks make ice sheet disintegration necessarily highly non-linear, ...a nonlinear response that should be approximated better by an exponential than by a linear fit [which] ...would lead to a cumulative 5 m sea level rise by 2095.

“Nonlinear ice sheet disintegration can be slowed by negative feedbacks. Pfeffer et al. ...conclude that more plausible but still accelerated conditions could lead to sea level rise of 80 cm by 2100....They assume that ice streams this century will disgorge ice no faster than the fastest rate observed in recent decades. That assumption is dubious, given the huge climate change that will occur under BAU scenarios, which have a positive (warming) climate forcing that is increasing at a rate dwarfing any known natural forcing. BAU scenarios lead to CO2 levels higher than any since 32 My ago, when Antarctica glaciated.”