

Numbers Count—And a Challenge to Teachers

By Ray Weymann, March 7, 2013

A good friend of mine recently wrote an article with a similar title, and I liked it so much I decided to borrow it to make a point regarding climate science education. At the same time I would also like to suggest to high school science teachers that they consider asking their students to investigate the three examples I am going to discuss below. Consider it as an exercise in “critical thinking” and the ability to discern real from bogus information.

What I find discouraging in having discussions with those who deny the overwhelming consensus among climate researchers that humans are causing most of the changes we are seeing in our climate is this: Their readiness to accept at face value qualitative statements on some aspect of this topic, no matter their expertise or that of their source, and their unwillingness (or inability) to make, or obtain, *quantitative* statements about them instead.

I will illustrate this with three examples, and at the end describe what I think the lessons are that need to be learned from these examples. I also suggest as a challenge to high school science teachers that they ask students to investigate these questions on their own, find sources they consider reliable and draw what they think are the appropriate conclusions.

Here is the first of these examples:

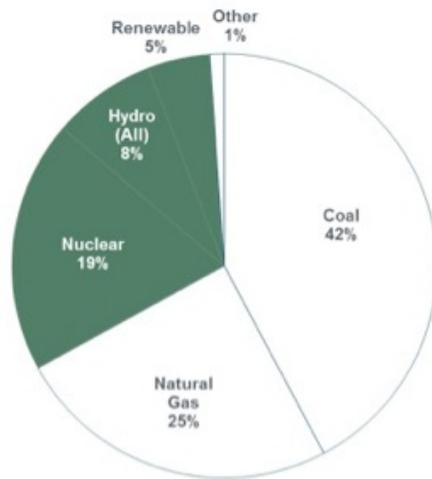
Example One

I am told that Rush Limbaugh has been disparaging the utility of electric cars because the electricity used to run them also produces greenhouse gases--so why bother? The implication of this qualitative statement is that a driver of an electric car ends up emitting just as much CO₂ as driving a normal internal combustion engine car. It has a superficially plausible ring to it. (Confession: I am not a habitual Rush listener: if I am misrepresenting him, my profoundest apologies.)

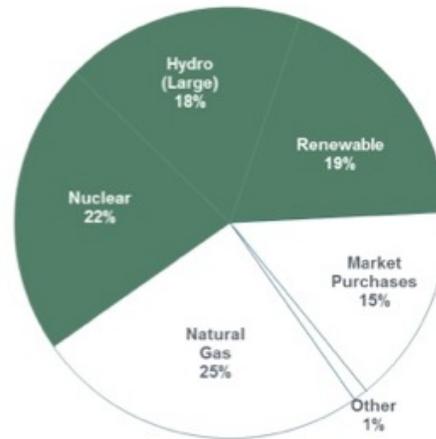
How hard is it to investigate this quantitatively? Let's give it a try. My son and daughter-in-law own a Nissan Leaf—an all-electric car, and I will use this as an example. A couple of Google keystrokes tell us that the Leaf uses 0.34 Kwh (kilowatt-hours) per mile. A Kwh is the unit of energy your electric utility bills you for. If you are one of those fortunate enough to be “off the grid” and get all your electricity from solar, wind or some other “clean” energy then the ratio of CO₂ emissions per mile from your car to that of the Nissan Leaf is approximately infinity. But most of us are not so fortunate (or committed). How about those of us in the PG&E service area in California? A few more Google strokes and we learn that a surprisingly large fraction of their electricity comes from non-CO₂ producing sources (nuclear, hydro, solar etc.) while the remaining 40% is nearly all from natural gas.



2011 Electric Generation Portfolio Mix PG&E vs. National Average



US National Average



PG&E's Portfolio

A few more keystrokes, and we learn from the U.S. Energy Information Agency “frequently asked questions” website that a typical generation plant running on natural gas produces 1.1 pounds of CO₂ for every Kwh of electricity. (There are questions about whether this number is for the “source” or for the “end user”—we will get to this below—but let’s keep going for now.) Since this amounts to just 40% of the electricity we are using, our effective emission is $0.4 * 1.1 = 0.44$ pounds of CO₂ per Kwh, hence $0.34 * 0.44 = 0.15$ pounds of CO₂ per mile from our Leaf.

Time for another quick Google search: 8900 grams of CO₂ per gallon of gas is produced in a typical private vehicle (note: per gallon of *gas*, not per *mile*). Yikes—we need to do some conversion here: Google “grams per pound” and you get 454 grams/ pound, so 19.6 pounds of CO₂ per gallon of gas is emitted. But some vehicles get more miles per gallon than others. Our Honda CRV (before it was totaled and we switched to a Prius V) got 23 miles per gallon—this also happens to be the approximate average mph even for new cars (<http://green.autoblog.com/2012/10/11/september-fuel-efficiency-holds-steady-at-23-2-mpg-for-us-fleet/>) so $19.6/23 = 0.85$ lbs of CO₂ per mile. So the Leaf in California is superior to our old Honda by a factor of about 5.7, though you can certainly do better as we now do with our Prius V, which gets about 38 mph. (Again, we have been rather sloppy since we have not accounted for the emissions used in exploring for the oil, drilling for it, shipping it, refining it, then shipping the gasoline and pumping it into our car—once again, see below.)

On the other hand if you live in an area where *all* your electricity comes from coal generation, then Rush has a point: A Leaf there generates about 5 times as much as in California: 2.5 from the 40% in California to the 100% in Coal Country and another factor of 2 since coal is twice

as “dirty” in terms of CO₂ generation per Kwh. Thus, (again ignoring the *total* emissions correction, our old Honda CRV is only slightly “dirtier” than the Leaf in those areas and our new Prius V is cleaner.

But that is not the whole story: A smaller and smaller fraction of America’s electrical energy is coming from coal as power plants switch to natural gas and renewables. At the beginning of 2012 only 40% of US energy generation was from coal and that fraction will continue to drop and we are on our way to gaining back that factor of two.

But there is yet another important aspect to the story: Natural gas is by far cleaner in terms of other pollutants than coal at the “source” end (sulphur dioxide, soot, mercury etc) and electric cars emit *no* pollutants at the “user end”. By contrast, internal combustion engines generate a large percentage of the dirty air that plagues our cities. Nor have we accounted for the environmental damage caused by the extraction of these fuel sources. The “mountain top removal” used in some coal mining is especially damaging.

What about those corrections we referred to several times above? Accounting for all the emissions from start to finish is sometimes called “life cycle accounting” or “wells to wheels” analysis. Knowing this terminology give us sources that account for all these factors. Here is an excellent link: http://www.ucsusa.org/assets/documents/clean_vehicles/electric-car-global-warming-emissions-report.pdf. It is a thorough analysis that basically confirms the conclusions we reached above, but in a much more thorough manner. You can find, for example, for given types of electric vehicles (including our Leaf example) how many miles per gallon any internal combustion engine car would need to get in order to produce the same amount of carbon dioxide emissions (strictly speaking, the equivalent amount including the admixture of other greenhouse gases). As we have seen, that depends upon where you get your electricity. But one interesting bottom line from the source above is this:

“There are no areas of the country where electric vehicles have higher global warming emissions than the average new gasoline vehicle.”

Example Two

I recently completed giving a class in climate science issues. During the final question and answer session, I was chided by a participant who complained that I had only concentrated on CO₂ emissions while ignoring the effect of paving the streets, highways and parking lots with asphalt. Is this a legitimate complaint?

In a very narrow sense “yes”, since *locally*, this and other effects cause large urban areas to be warmer than undeveloped rural areas. This is not a deep dark secret though—climate scientists are thoroughly familiar with this effect and even have a name for it: “Urban Heat Islands”. And, they take great pains to take urban heat islands into account when calculating *global* or *national* temperature trends.

So how do we estimate the effect of paving portions of the Earth’s surface with asphalt to calculate this warming effect compared to that of CO₂? (Regardless of which CO₂ sources are involved--by far the largest contributor is fossil fuel consumption, with deforestation and

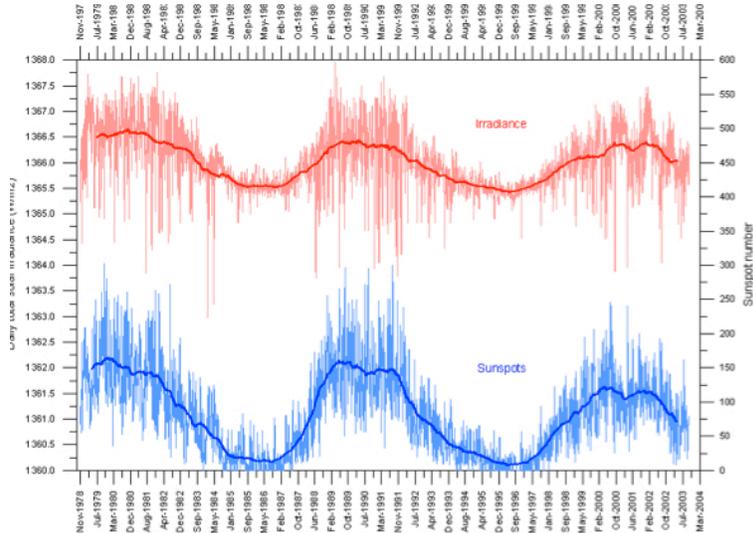
related changes in vegetation amounting to roughly 15%, and other sources, like cement manufacturing, being smaller still.)

This example is in some sense harder and in some sense easier to consider than example one. It's harder because finding reliable data on the area of the globe that has been paved with asphalt is hard to come by. It's easier because it doesn't take more than an "order of magnitude" calculation to realize it is a very small effect. This is what scientists do all the time: don't agonize over too many details if you don't need to.

As always, it's good to start from basics. In Lesson 1 of the Tutorial on this website the fundamental role of energy (im)balance in causing climate change was discussed; in Lesson 2 various "forcings" were discussed. The forcing that is by far the dominant one in causing the rapid increase in the Earth's climate system over the last several decades is the increase in the greenhouse effect from the greenhouse gases (Lesson 3), especially CO₂. This is the "benchmark" against which we should compare other effects and the standard time in the past against which to evaluate this forcing and others is just prior to the industrial revolution. Google "radiative forcing carbon dioxide" and you will have lots of choices. An old one (2005) I picked at random gave the result: 1.7 watts per square meter. Its higher by now, but that's good enough for us. Since CO₂ is distributed quite uniformly over the globe but other "forcings" are not, let's look at the total world-wide forcing from CO₂ Google: Earth's surface area: Answer: 510,100,000 km². Careful: that's square kilometers, not square meters! Converting to square meters and multiplying by the 1.7 number above we get 8.7×10^{14} watts. (If you are unfamiliar with "powers of 10 notation" google that.) As noted above, that is relative to the benchmark time near the start of the industrial revolution. Exactly what year doesn't really make any difference.

Now to the asphalt. There are, as always, some nuances here, but the questioner had in mind (I think) the notion that asphalt *absorbs* a lot more heat than a snowy dirt road that it perhaps once upon a time replaced. (It *radiates* more too, for that matter, but we will ignore that.) So this dark asphalt has a lower *albedo* (see Lesson 2) and a *decrease* in albedo would cause warming (since the albedo is the fraction of sunlight *reflected*.)

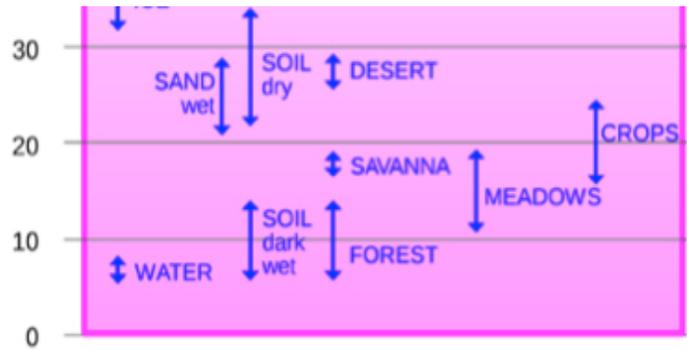
The amount of energy from the sun that is received and absorbed is : (a) The average amount of sunlight received multiplied by (b) the "anti-albedo" or [1.0-albedo]. (I don't think there is any commonly agreed-upon term for anti-albedo—I'll use "absorance".) The best estimate for the average albedo of the Earth is 0.3 so the absorance is 0.7. By what percentage does this absorance have to increase to match the CO₂ forcing in importance? To find this out we need to know the answer to (a) above. If you simply google "solar energy" or "solar power" you will have a hard time getting the answer without wading through a lot of stuff about solar panels for your roof. But "solar irradiance" gives some relevant choices and here is one with a nice graph:



It is hard to read, but you can get your own copy from the Google search above. Be careful that you don't mistake the blue curve (which is sunspot number—the scale on the right) for the red curve, the scale on the left. It measures the “solar irradiance” for the last few sunspot cycles—a few decades worth—and if you squint at the left hand scale you will see the average value is about 1366 watts per square meter (a more recent calibration is about 1361 but this detail is “down in the weeds”).

But here is a pitfall that you might very well fall into: That number (1366 watts) is what you measure with your measuring device pointed directly at the sun. (With no clouds or atmosphere in the way; that is part of the albedo consideration.) To begin with, it doesn't take into account the fact that half of the Earth at any given instant doesn't get any sunlight at all. Nor does it take into account that most of the radiation strikes the sunlit surface at a “slant”. When this is taken into account the effective input is reduced by multiplying by $1/4^{\text{th}}$. Then multiply by the 0.7 absorance and we get an input of 239 watts per square meter. Wow! That is huge compared to the little old 1.7 watts per square meter from the CO₂ forcing. Or, converted to total area, the Earth absorbs about $1.2 \cdot 10^{17}$ watts. Put another way, the absorbance need only increase by about 0.7% in order to match the CO₂ forcing.

Is it reasonable that the asphalt paving can account for something like this? To begin with, as far as I know, very little of the ocean has been paved over and the land surface of the Earth is about 30% of the total, so the increase required *over the land area only* is more like 2.3%. I googled “albedo” to find some numbers for various surfaces. There is a large difference between “fresh” and “old” asphalt—I used an average of these of 8%. But what did this asphalt replace? Another source provided the following figure for areas where urbanization since the industrial revolution might have taken place:



The number on the left is the albedo (in percent) for various natural surfaces—it is 1 minus this number that would be the absorbance, and as a rough average I will use 18% or 0.18 for the pre-asphalt surface albedo. When this is replaced by asphalt therefore, the gain in absorbance is $(1-0.08) - (1-0.18)$ or $(0.92 - 0.82) = 0.10$ so the total percentage of land area converted from natural surface to asphalt needs to be 10 times larger than our 2.3% above—or 23%.

Is this plausible? Take a tour with “Google Earth” or look at some satellite photos and you will be impressed at how little of the land surface of the Earth is urbanized despite the impressions of those of us living in large US Metropolitan areas. Even in the US the amount of urbanized area is small, to say nothing of South America, Australia, Africa and vast areas of Asia (and of course Antarctica).

But we would still like some estimate of the urbanized area: One of the “painting our roofs white will save us” websites tells us that the urbanized area is 1.3% of the land surface and of that, 60% is dark (asphalt plus roofs). So instead of 23% we might be getting an increase of about 0.8%, about 1/30th of the CO₂ forcings. So, in spite of all the many uncertainties, it seems that ignoring asphalt paving is not such a horrible omission—even if climate scientists *haven't* ignored it.

Which they haven't. A completely different approach might have saved us a lot of time: Google “Urban Heat Island Contribution Global Warming”. Here is one link:

<http://news.stanford.edu/news/2011/october/urban-heat-islands-101911.html>

whose headline reads: *Urban 'heat island' effect is only a small contributor to global warming, and white roofs don't help to solve the problem, say Stanford researchers .*

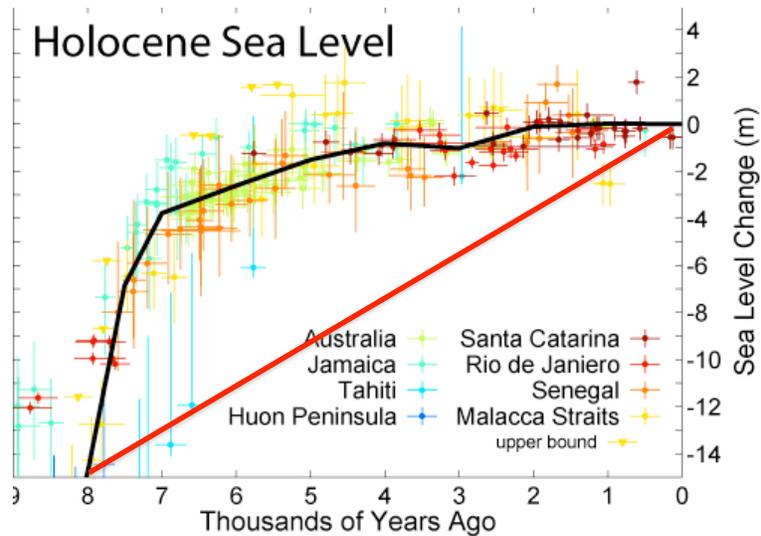
Example 3

This 3rd and last example is interesting because it illustrates that not only do (correct) numbers count, but they must be *interpreted* correctly too! In the town where I live our local paper features opinion pieces by local contributors. (I have begun to write one every month). Another contributor is a vehement denier of the assertions that: a) The earth is warming b) Humans are the main contributor. Hence he concludes that there isn't anything to worry about. Specifically, he has made the following observation about sea level rise: “Over the last 8000 years, sea level has increased at an annual rate of about 1.8 mm per year, almost exactly the same as measured over the last 100 years or so. And surely humans have been emitting a

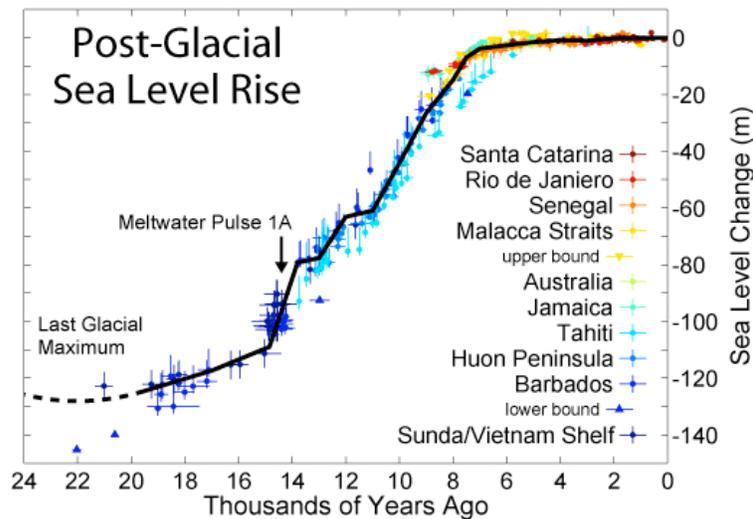
negligible amount of CO₂ over the vast majority of this time.” So take that you warmist alarmists! And guess what: He’s right! At least the numbers are. But the interpretation isn’t.

Paleoclimatologists who study indicators of ancient sea levels find that about 8000 years ago sea level was about 15 meters (about 50 feet) lower than it is today. When you convert that to an annual rate of sea level rise, by golly you get about 1.9 mm per year, almost exactly the same as the average over the past 100 years or so. What’s going on?

Well here’s what is going on: The picture below shows the rise in sea level over these past 8000 years, during the “Holocene” era:

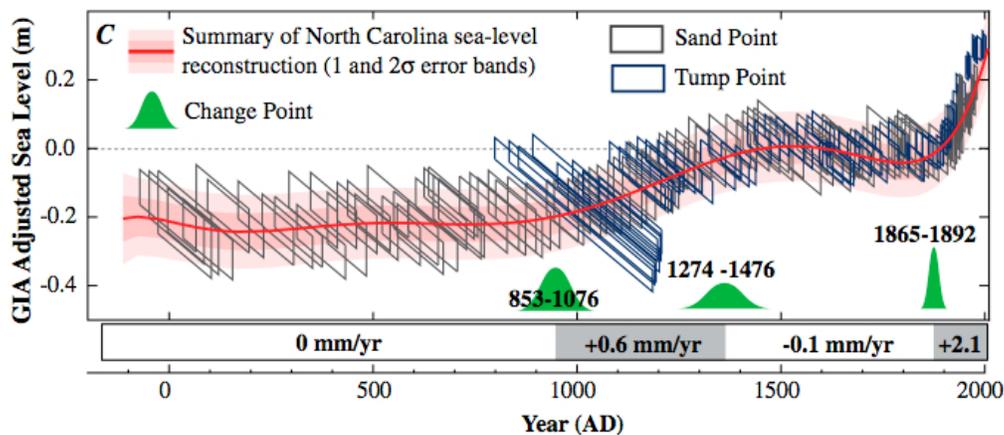


Notice that the heavy majority of this rise occurred during the first 1000 years of this graph, gradually diminished, and that for the last 2000 years the rise basically halted. I have drawn in with the red line what a *constant* rise in time looks like. But the rise was anything but steady. Why this early rise? Here is another plot going back a little further in time.

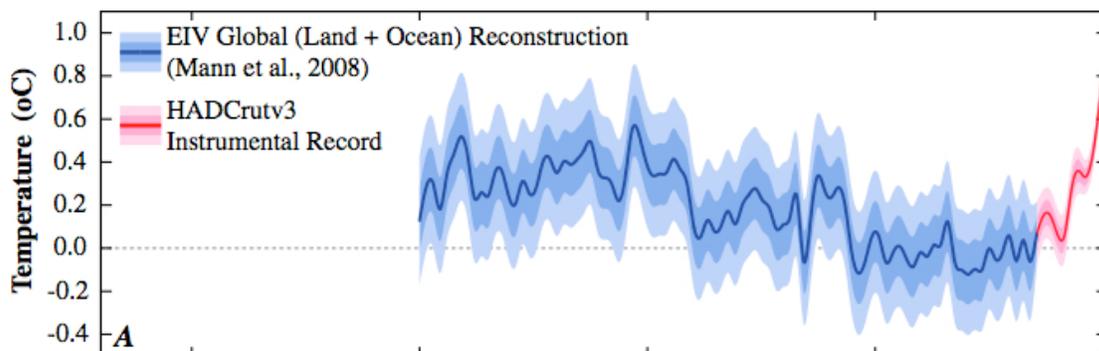


Now we can begin to see what was happening. Back about 22,000 years ago, the Earth was in the depth of the most recent great ice age and sea level was about 125 meters (or about 400 feet) below its present level. This fact has considerable significance for understanding how humans populated the “new world”—certainly western North America—since with that much water locked up in vast sheets of ice, what is now the Bering Strait was dry and humans could cross from Siberia into Alaska and work their way down into what is now the western United States. But I digress.

Looking back at the first of these two sea level graphs you can see why the red line—which assumes a constant linear rate of sea level rise—is grossly misleading. What we were seeing during most of the last 22,000 years was at first the rapid, then more and more gradual, retreat of the huge ice sheets of the ice age. But that has come to an end. Let’s take a closer look at the last 2000 years.

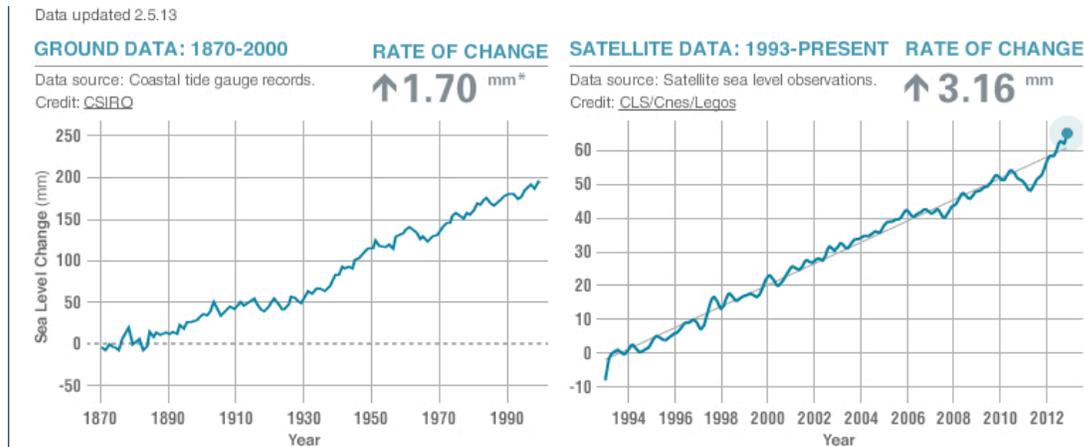


This is one attempt to look at sea level rise over this time period. It shows the estimated change in sea level. Note the rapid upturn during the last 100 years or so, along with the smaller changes that reflect periods of slight natural warming and slight natural cooling. The following plot is another reconstruction by Paleoclimatologists of the temperature going back only 1500 years instead of 2000 years, but the two are clearly related:



Warming temperatures are associated with rising sea levels—the laws of physics pretty much demand it: Warming ocean water expands and when ice and melt water flows into the ocean from the receding ice, together these effects cause sea levels to rise.

Moreover, as the TV hucksters promoting their products like to say “*But wait: There’s more!*” The next curve shows sea level rise during the last 100 years or so with the earlier portion relying on tidal gauge records and the last 20 years or so utilizing super-GPS and altimeter measures from a series of NASA satellites:



What we learn is that even over this brief period of 100 years the *rate* of sea level rise has *not* been constant but has been *increasing*: the current rate is now about 3.2 mm per year. Over the next 100 years that amounts to about a foot and if that were the end of the story we could, and should, take steps to deal with it. But I do not know of any oceanographers and glaciologists who think it will stay at this rate. And for good reason: As the ocean waters continue to warm—as they have been for the last several decades, and as more and more ice slides into the ocean from glaciers and the Greenland and Antarctic ice sheets—as they have been over the period for which good data exists—sea levels will rise faster. Just how much they will rise by the end of this century is an active field of research. But areas of the US with lots of development near seal level are especially prone to sea level rise and to storm surges like those that came with Sandy—and that includes much of the East coast, Florida and the Gulf coast. These areas and the San Francisco Bay area are coming to the realization that this is a problem that must be taken very seriously.

Lessons Learned?

I said at the beginning of this essay that I would try to state what lessons are to be learned from these three examples. During the course of writing this, however, I have changed my mind about what is to be learned. I started off by implying that with a little “due diligence” it didn’t take much to check some of the assertions typified by these three examples. But I realize now that it does take more than just a “little” due diligence. I have some familiarity with the science and the literature on these topics but even so it has taken a lot of effort to write this essay. And I may have committed some errors here myself, though I have solicited some outside expert advice.

Here I think is the real lesson to be learned: There are experts on the effects of high blood pressure, obesity and smoking on health, and their expertise goes way beyond what lay people can learn on their own. There will be areas of disagreement on some details but a solid enough

base of agreement exists for the rest of us to know what is good for our health and what is not. Similarly, there are experts who have spent their entire careers studying the problems discussed in the three examples here. On details they too will disagree but there is enough solid ground of agreement that their expertise must be taken seriously and utilized. Instead, on this topic (and indeed as it was for the issue of smoking many years ago) the notion that anyone's opinion on this subject is as good as anyone else's seems to dominate current discussion of climate science. It isn't--and people should stop deluding themselves into thinking it is.

Teachers: Have students analyze these issues, track down sources of information and draw their conclusions.