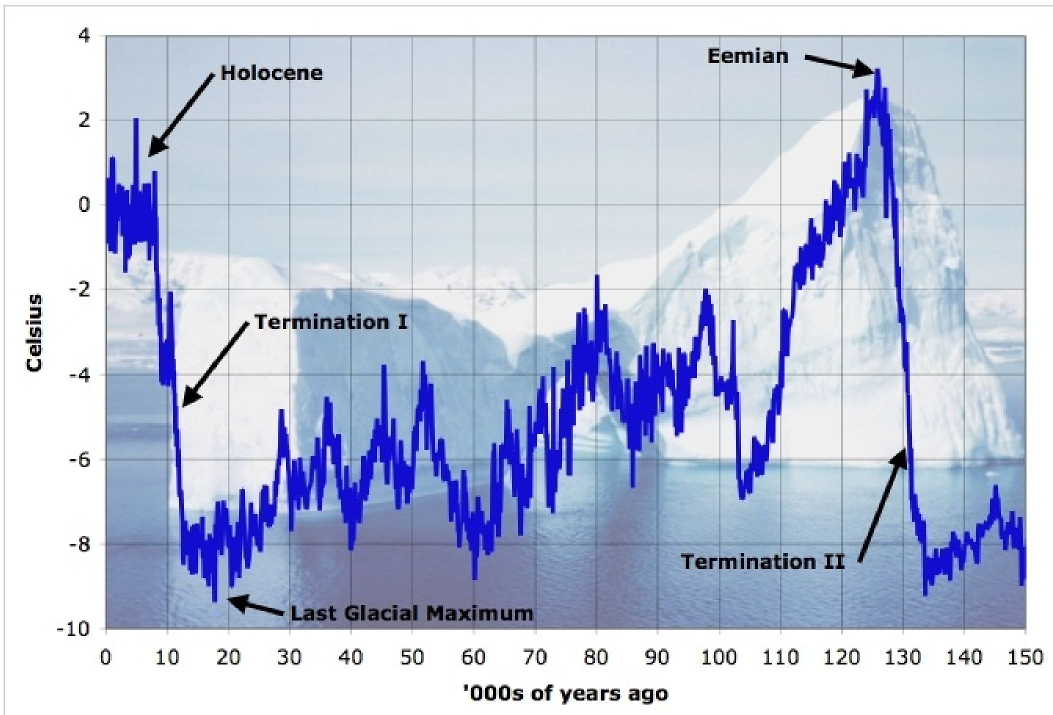
The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Living in the Eemian

Posted by Stuart Staniford on February 20, 2006 - 4:44pm
Topic: Environment/Sustainability
Tags: climate change, global warming, hubbert peak, peak oil [list all tags]



Temperature anomaly relative to present over last 150,000 years estimated from Vostok ice core deuterium measurements. Caution: oldest data is on the right. Click to enlarge. Source: NOAA.

After my short posting hiatus last week, I resume my slow progress to analyzing the carbon cycle, the consequences of carbon emissions, and what if anything can be done about it. Recall this is fourth in a series that so far includes:

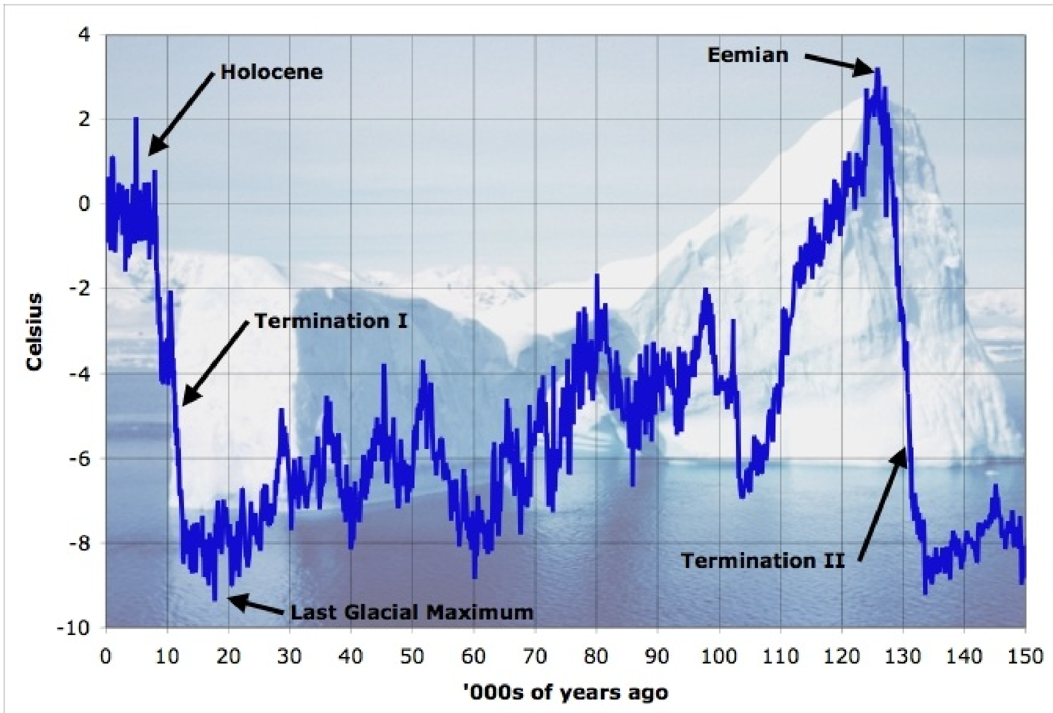
- The carbon economy
- How fast should you boil a frog
- "Dangerous Anthopogenic Interference"

In the more distant past, we have also talked about

- Greenland, or why you might care about ice physics

and today we return to the issue of sea level rise. Sea level rise is a slower-fuse issue than I have come to believe the hurricanes are, but in the long term it is potentially more broadly devastating, and the latest evidence suggest that, again, we cannot safely assume that this is strictly a problem for our grandchildren.

To orient ourselves, let's start by looking at recent climatological history. Over the last three million or so years, the planet has been going in and out of glaciations that are almost certainly controlled by changes in the seasonal distribution of sunlight due to slow changes in earth's orbit and rotation (a hyphothesis originally due to Serbian astronomer Milutin Milankovitch). If we focus just on the last cycle, we get this next graph (which also led off the piece). This is temperature at the Russian Vostok base in Antarctica as estimated from isotope ratio fluctuations in ice cores (a pretty well established method of estimating temperature at this point).



Temperature anomaly relative to present over last 150,000 years estimated from Vostok ice core deuterium measurements. Caution: oldest data is on the right. Click to enlarge. Source: NOAA.

I have labeled major features of the curve. The flattish period on the left for the last 9000 years or so is called the Holocene. Agriculture was invented for the first time pretty much at the beginning of the Holocene, so the entire history of civilization fits in that period (it runs a little earlier in the Northern hemisphere). All human (or pre-human) existence prior to that, as far as anyone can tell, involved tribal hunter-gatherer living. (My personal assumption would be that, given the felicity and frequency with which humans have invented agriculture and cities in the Holocene, cognitively fully modern humans cannot have existed in prior interglacials or there would have been civilization then too).

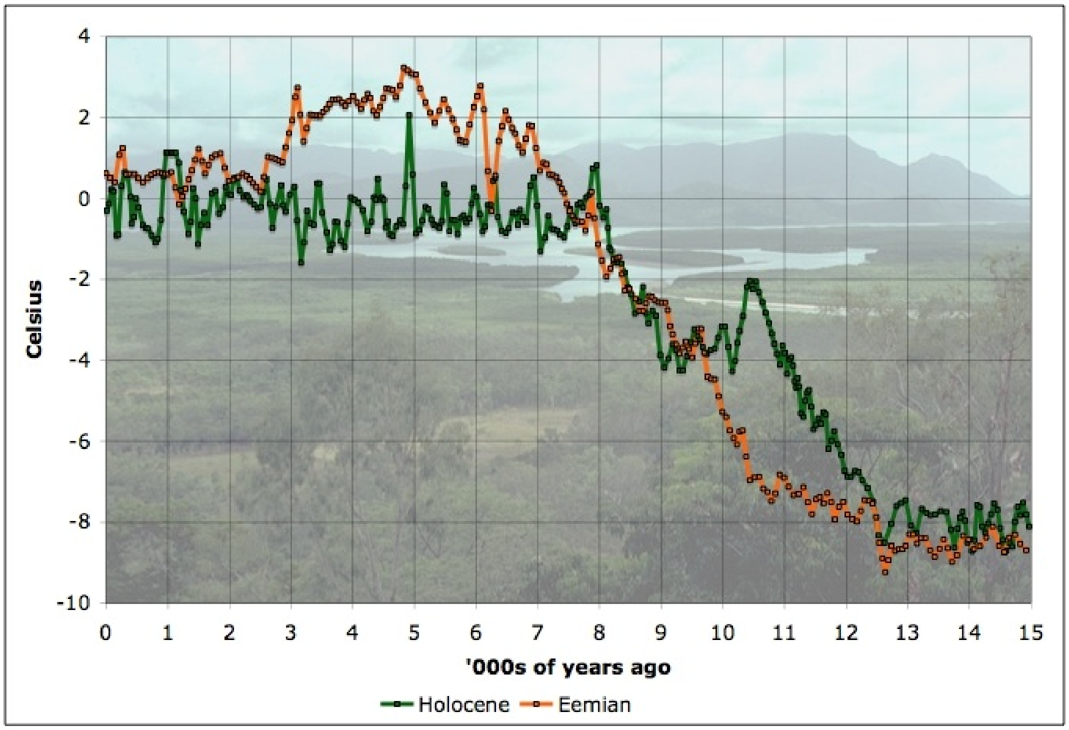
Anyway, working backwards in time, prior to the Holocene is a rapid rise in temperature as the ice sheets over North America, northern Eurasia, and Antarctica all melted (with a short interruption along the way). That's known as Termination I.

Before that is the last glacial maximum - the maximum extent of the glaciers, which occurs between 15000 and 20000 years ago. At least in Antarctica, the last glacial maximum was about 8 ^{o}C colder than today (that's around 13 ^{o}F).

As we go deeper into the ice than that, we find a long period of gradually lowering temperatures.

It appears that ice sheets form slowly, but collapse quickly - this pattern appears to be fairly typical in the available record (see, for example, the full 600k+ year record at Vostok). Eventually, we get back to the Eemian, which is the peak in temperature towards the right of my graph, about 125,000 years ago. The Eemian was the last warm interglacial period before the Holocene. Before that, we have Termination II, which was the deglaciation period leading up the Eemian.

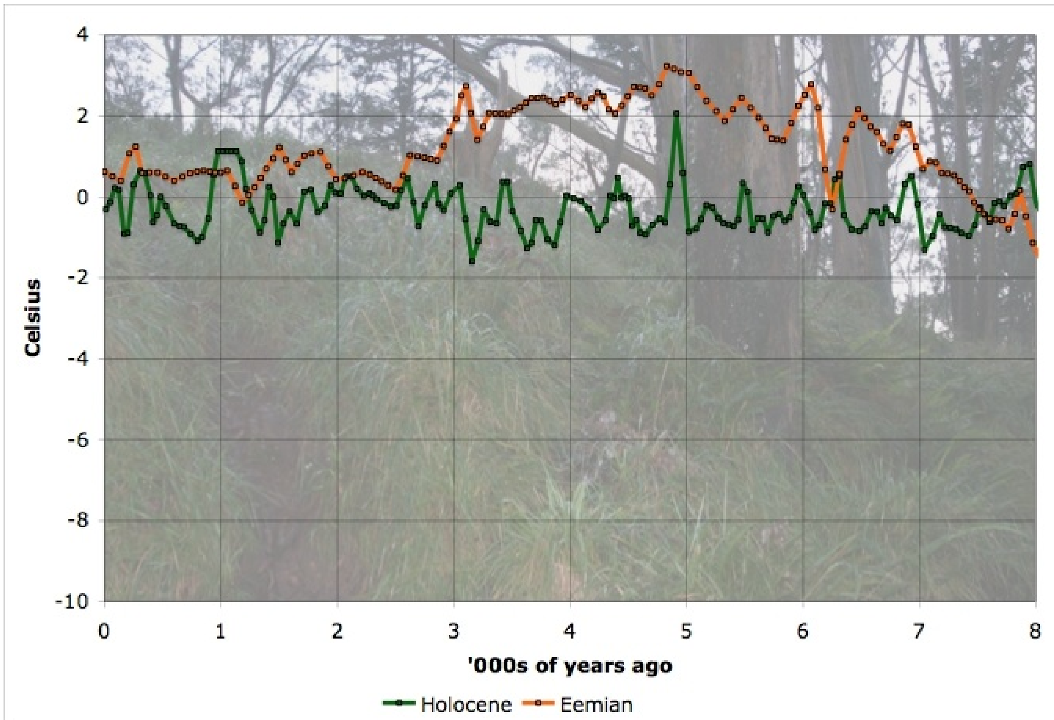
To get a better feel for the temperature history in the Eemian, I have moved 15,000 years of it forward by 121000 years and superimposed it on top of the Holocene temperature history.



Temperature anomaly relative to present over last 15,000 years (Holocene curve), together with temperature from 121,000 to 136,000 years ago, shifted over 121,000 years (Eemian curve). Estimated from Vostok ice core deuterium measurements. Caution: oldest data is on the right. Click to enlarge. Source: NOAA.

As you can see, the speed with which the temperature rose during Terminations I and II was around about the same. The Eemian got somewhat warmer, but that warmest interval was shorter than the Holocene. Also, the deglaciation going up to the Eemian (Termination II) lacked quite such a prominent setback along the way as Termination I has (though there is a small notch even in Termination II). This suggests a picture in which there is some scope for the planet to deglaciate in slightly different ways on different occasions, even though the overarching process generally went at the same rate.

If we now look just at the last 8000 years, and the corresponding period in the Eemian (ie with the end of the deglaciation lined up - the 121,000 year offset) we get:



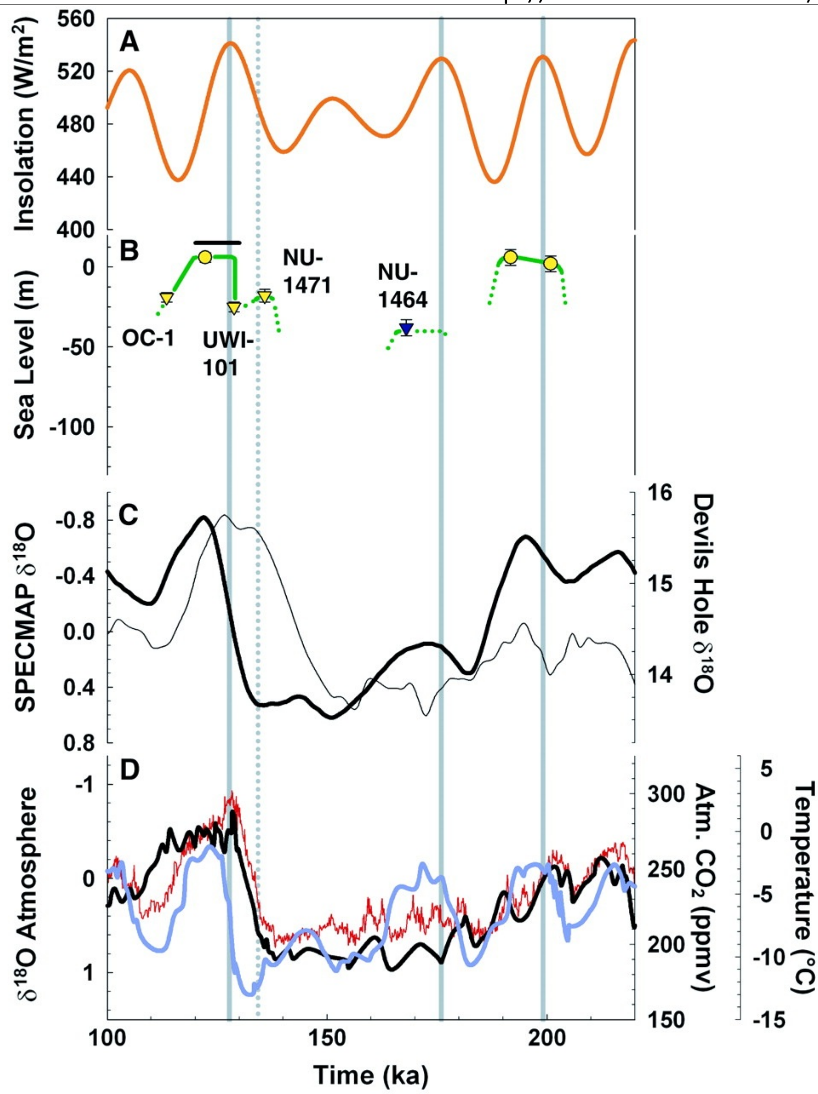
Temperature anomaly relative to present from now to eight thousand years ago, together with corresponding Eemian period (shifted 121,000 years). Caution: oldest data is on the right. Click to enlarge. Source: NOAA.

Clearly, at least in Antarctica, the Eemian was about 2 °C warmer for a few thousand years, and then as it start to cool, it reached temperatures similar to the Holocene. There's some uncertainty about how global temperatures relate to Antarctic temperatures. The Wikipedia's estimate of about 3 °C is at the top end of the range of estimates I've seen in the literature which go from 1 °C to 3 °C. Let's use 3 °C to be a little conservative.

Note that 3 °C over pre-industrial holocene climate is in the middle of the range for what climate models anticipate the temperature would be by 2100. We've had about 0.6 °C of warming from pre-industrial temperatures so far. So, in this period when temperatures were somewhat warmer, and then similar to holocene temperatures, how was the sea level?

Well, at least three meters, and probably more than five meters higher than today. Ie at least 10 feet, and probably more than 16 feet. This comes from a variety of evidence: the Baltic Sea was significantly bigger, that kind of thing. So that rather suggests we would be headed for a situation with inconveniently high sea level compared to what we are used to (though the rate of change is a big question mark - we'll get to that in a bit).

First, to get a slightly broader overview of the history, let me borrow this figure from a Science paper by Gallup et al, 2002. It's a bit of a complicated figure, but hold on and I'll do my best to make sense of it. If you have the means, you might want to click and get a larger version in a new window (or a printout) to follow along the discussion.



Source: This is Fig 2 of [Gallup et al, 2002](), available with a free registration. Click to get a large version in a new window.

Firstly, the timeframe is from 100,000 years ago to 220,000 years ago. So this covers the Eemian interglacial (which is around 130,000 years ago, and most of the glaciation prior to the Eemian. Older times are to the right of the picture. Let's start with the top (orange) curve. That's the amount of solar insolation at 65 ^{O}N latitude.

The general idea of the Milankovitch theory is that while these orbital twitches and gyrations do not change the total amount of sunlight very much, they do change the latitude and seasonal distribution of it. The thought is that it is the summer northern hemisphere sunlight that is critical in controlling things. The Northern hemisphere is more important than the Southern hemisphere because there's a lot more land there, so there's a lot more potential to build big ice sheets (and suck up all the water so the sea level drops - at the last glacial maximum there was several miles thick of ice over much of northern North America and Eurasia and sea level was around 120m -- 400 feet -- lower). The summer sunlight is important because an ice sheet can only form in a place where it is cold enough in the summer that at least some of last winter's snow stays throughout the summer. As long as that is true, the ice sheet can build and build. If that is not true, it doesn't matter how much snow fell in the winter or how cold it is then -- the summer will reset the snow level to zero every year. So northern hemisphere sunlight basically controls the extent of the major ice sheets in a glaciation, which in turn control everything else (via albedo feedbacks and a not-fully settled feedback into the CO_2 level).

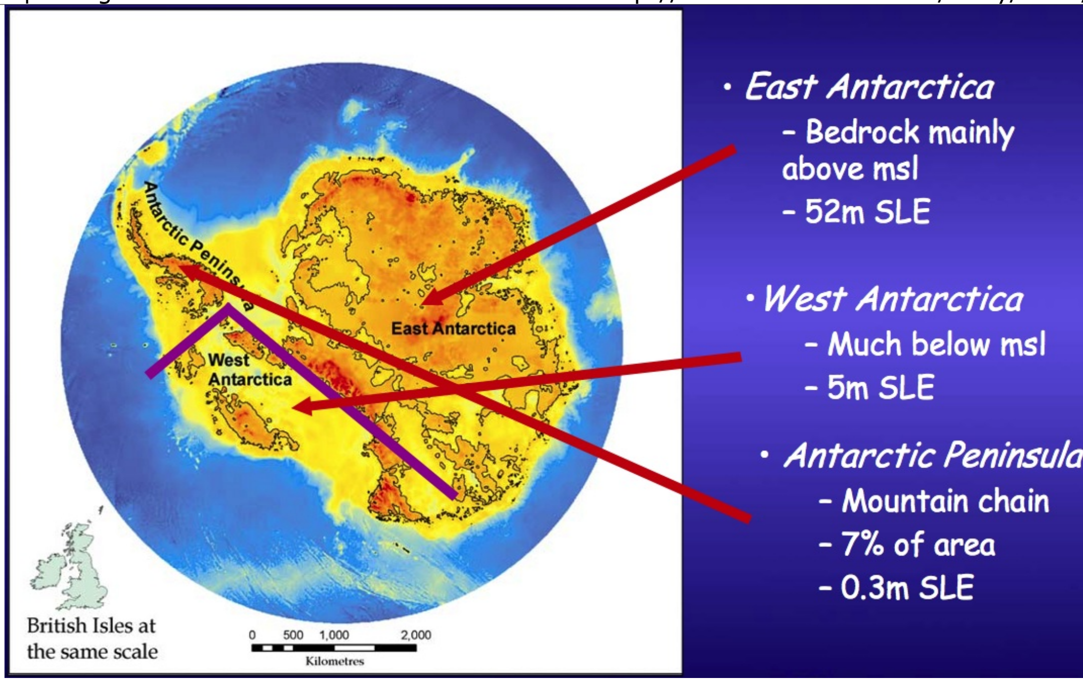
So that's the most basic version of the Milankuvitch theory - which is a bit too simple to fully explain the observations but probably captures most of what's going on and the paleoclimatologists seem to be still trying to sort out the rest. Anyway, back to the graph. The top orange curve is the average solar insolation at 65 ^oN in W/m^2 which comes from orbital calculations. As you can see, the forcing variations at that latitude really are quite significant - the range is around 10% of the total.

Now, Gallup et al have drawn three vertical grey lines through the peaks in the 65 ^oN insolation (which ought to be periods of higher temperature, lower glaciation, and higher sea level. Follow those all the way down to the bottom. That's Vostok data (same stuff we were looking at above). The red curve is temperature, and the blue curve is CO_2. You can see that they roughly follow the insolation signal, with CO_2 being closer than the temperature (probably because CO_2 is globally well mixed and appears to have been in a fairly strong mutual feedback loop with global temperature -- until we started messing with it anyway -- but Antarctic temperature has some degree of regional peculiarity).

Now the sea level data prior to the Eemian are a bit sketchy, but let's quickly cover it. The three black curves are different observations of the concentration of oxygen-18 in marine sediments (in the third picture down - C), and in the atmosphere at Vostok (bottom graph). The idea here is that oxygen-18 is a heavy, rare, isotope of Oxygen (it has two extra neutrons in the nucleus relative to the usual kind of oxygen which is oxygen-16). Those heavy oxygens are a little more prone than the light oxygens to be in the ocean rather than the atmosphere - they have a harder time evaporating because they are heavier. When a lot of the ocean evaporates and falls as snow in an ice sheet, the left-behind ocean gets heavier in oxygen-18. That gets incorporated into shells of creatures, who then get found and measured by paleoclimatologists. So that signal is a proxy for sea-level and glaciation. You can see that the black curves approximately follow the glaciation, deglaciation story, but there are significant discrepancies in detail that are in need of settling. Finally, in the second graph down there are some sea level measurements that come from dating corals that grow at known depths in the ocean. The record is quite sketchy but is in rough agreement with rest of the picture.

Anyway, returning to the question of why the Eemian had higher sea level than we do today. There are basically two main candidates for this sea level rise. One is the Greenland ice sheet could have been smaller, and the other is the Antarctic ice sheets could have been smaller. As far as I've been able to determine, the paleoclimatologists have not settled how much of one and how much of the other they think occurred. We talked about Greenland, and although I will have a little more to say on that subject at the end, I am going to turn to Antarctica for a while.

To that end, let me steal a few slides from an excellent overview presentation by Professor Chris Rapley of the British Antarctic Survey. This first picture shows the main important regions of Antarctica from a sea level perspective, and how much they would contribute to sea level if they all melted. SLE is "Sea Level Equivalent". I'll restate the sea level numbers in feet as we go, for those metrically challenged, or you can multiply the numbers by 3.3 in your head.



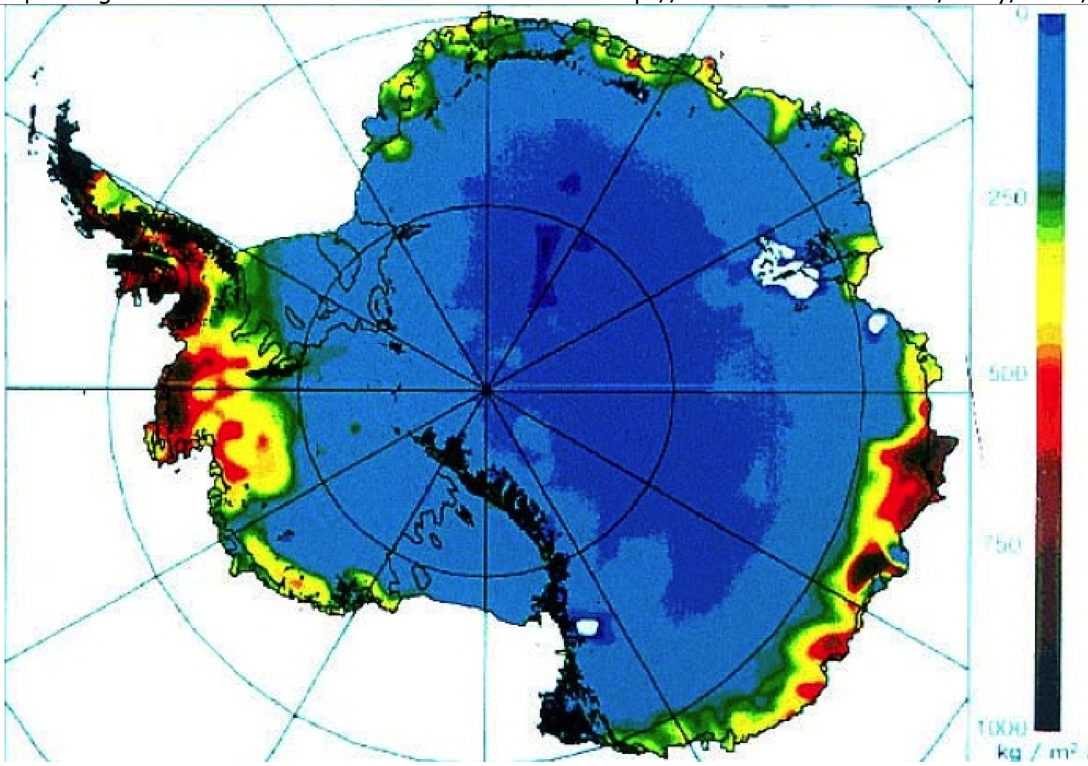
Summary of main regions of Antarctica. Source: [Chris Rapley presentation](#).

Clearly, the big beast is the East Antarctic icesheet which would cover the world's present coastlines in 170 feet of additional water if it ever melted. However, nobody thinks it will on any timescale we care about. The ice sheet is up on land, and a lot of it on relatively high land, and it's colder than purgatory there, and not warming up very quickly. If anything, the East Antarctic icesheet is considered likely to grow with global warming because more snow is likely to fall on it. There has been very little sign of temperature increase on land in East Antarctica during the last 50 years.

Next let's take the Antarctic Peninsula, which is basically a southern extension of the Andes mountain range. It has been warming quite rapidly, and it's ice is increasingly unstable, but it's only about one foot of sea level if everything melted.

So the area of most interest is the West Antarctic Ice Sheet, which could contribute about 16 feet to global sea level rise if it all melted. So it's enough to make a very important difference, but the thing that's most interesting about it is that, as you can see on the map, large amounts of the ice sheet are bedded on rock that is below sea level. The stability of this arrangement is not altogether clear - a warming ocean could potentially start working it's way into the ice sheet, melting parts of it and speeding up the flow of the rest of it. On the other hand, that ice sheet has been there through climate variations of the last few thousand years, so it can't be too easy to destabilize.

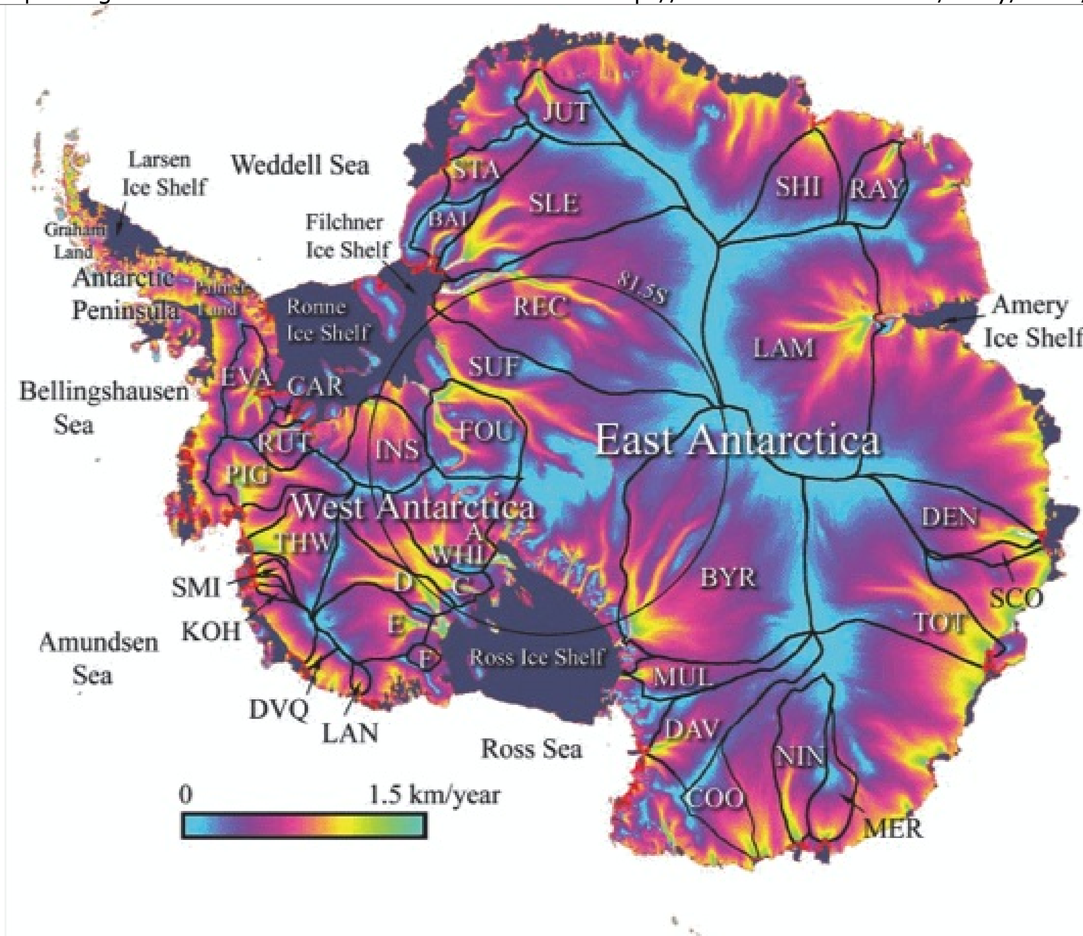
The next slide I borrowed from Prof Rapley shows where the annual snow accumulation occurs on Antarctica.



Precipitation on Antarctica. Source: [Chris Rapley presentation](#).

As you can see, most accumulation occurs near the coast, and especially the Antarctic peninsula. By the time air gets very far inland in Antarctica, it's gotten very cold and dry already (having given up it's moisture in precipitation near the coast) and isn't good for much more snow. Thus the continental interior is basically a cold desert which only accumulates snow very slowly.

The next picture, which I think is just a fantastic image, shows the estimated speed of ice flow as a function of location (estimated from satellite measurements).



Ice flow velocity on Antarctica. Source: [Chris Rapley presentation](#).

You can see that the interior ridges have slow flow (big blue areas), but as one gets into valleys, there are faster flowing glaciers carrying ice towards the coast. The highest velocities are right at the coast where the continent has to both shed the ice from the interior and all the snowfall that occurs near the coast as well in order to stay in overall mass balance (mass balance means that the amount of snow falling on the ice sheets is offset by the amount of surface melting plus the amount of ice shed into the ocean).

What this picture makes abundantly clear to me is that this is one big dynamical system that is all tied together to transport the ice away from the interior to the coast. There are fast flowing (over 1km/year) glaciers that reach well over 1000km into the interior. So once ice gets into one of those big glaciers, it gets to the ocean in about a millenium. However, it's also very important to note that a lot of the precipitation falls very close to the coast where it can get to the ocean via ice flow quite quickly, both because the ice flow is faster nearer the coasts, in all parts of Antarctica, but also because it doesn't have as far to go. In particular, eyeballing the two last pictures, it looks to me that a quite respectable proportion of the total Antarctic snowfall occurs in places where ice flow will get it back to the ocean in less than a century, suggesting the possibility of relatively dynamic responses for at least a portion of all of the ice sheets. (As an aside, it's also pretty clear that if you want an ice core to give you a 600,000 year record of temperature, it had better be in one of the blue regions with very little ice flow).

So obviously the main question of interest is how is this situation changing with global warming, and how much of a threat is that change in the future? This is another of those areas of science where the climatologists were rather too sanguine until very recently and are having to improve their understanding in a hurry in the face of events. Specifically, in the 2001 IPCC report, the operative words were:

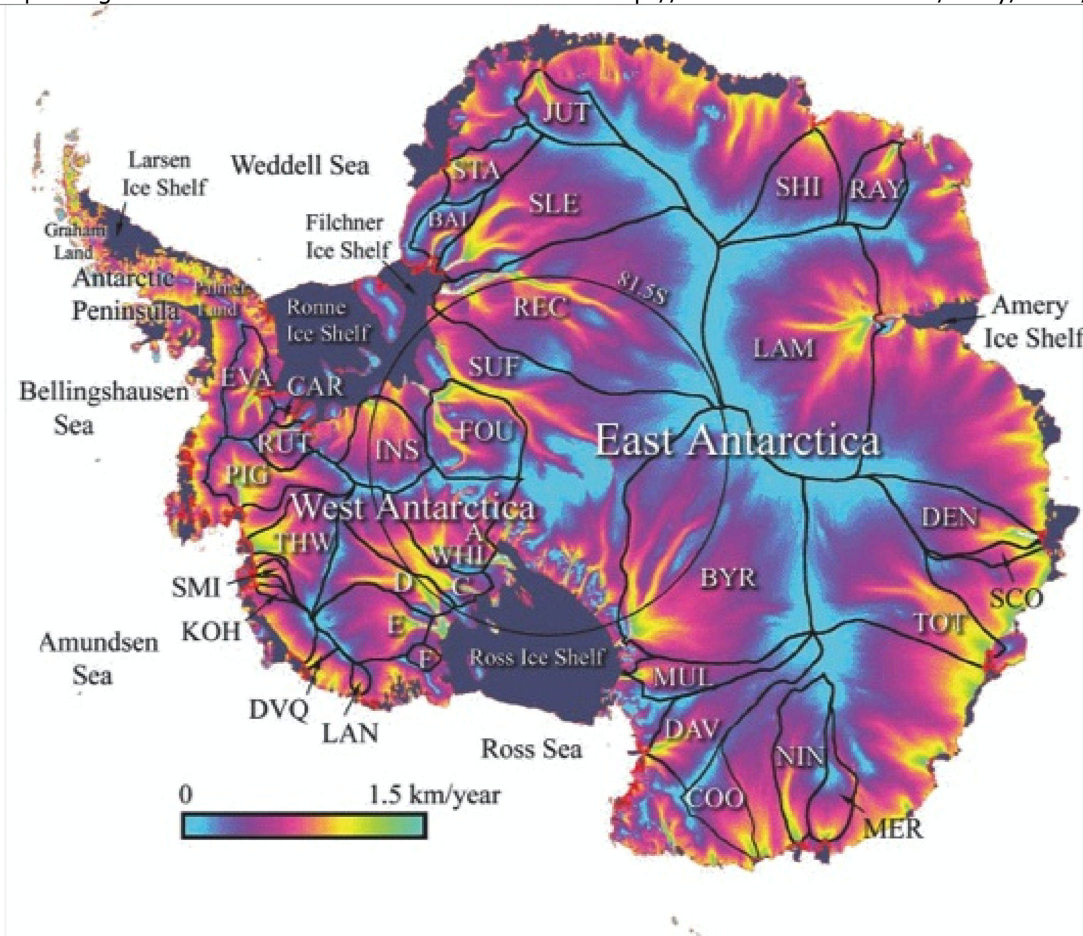
> In view of these considerations, it is now widely agreed that major loss of grounded ice, and accelerated sea level rise, is very unlikely during the 21st century. An interdisciplinary panel of international experts applying the techniques of risk assessment to the future evolution of WAIS concluded that there is a 98% chance that WAIS will not collapse in the next 100 years, defined as a change that contributes at least 10 mm/yr to global sea level change (Vaughan and Spouge, 2001). The probability of a contribution to sea level (exceeding 0.5 m) by the year 2100 was 5%. These results are broadly consistent with an earlier assessment by Titus and Narayanan (1996) based on a US-only panel, who found a 5% chance of a 0.16 m contribution and 1% chance of a 0.3 m contribution to sea level rise from WAIS by 2100. We note that Vaughan and Spouge also report a probability of 5% for WAIS giving a sea level fall exceeding 0.4 m within the same time frame, while Titus and Narayanan give 0.18 m.

There are two things going on that have been calling these conclusions into question. The first is that various ice shelves have been collapsing. (An ice shelf is the floating portion where a glacier or ice sheet loses contact with the ground but continues as a single solid sheet of ice floating on top of the ocean). Collapse means that the shelf breaks up into a bunch of icebergs (which will then float away and melt). This has been especially the case in the Antarctic peninsula: this next picture links to an animation of the Larsen B ice sheet which collapsed in 2002 to give you a feeling for the general idea.

Larsen B ice sheet. Click for animation of breakup. Source: NSIDC.

Some of these collapses had occurred before the IPCC report, but there have been more since. What is newer news, however, is the degree of glacier speedup that has been occuring in Antarctica. This has been true in the Antarctic peninsula where most ice sheet collapses have occurred. The glaciers feeding the Larson A and B regions have accelerated in speed by factors of 2-6. This is one of the things that have surprised glaciologists. The trend in recent years was to think that the main restraint on the flow of a glacier was friction with the bottom and sides of the valley, not resistance from the ice sheet at the mouth of the glacier. That's looking increasingly wrong. In general, the physics of ice flow is poorly enough understood that numerical models are not able to reproduce past deglaciation behavior or the recent behaviour of Greenland and Antarctic glaciers.

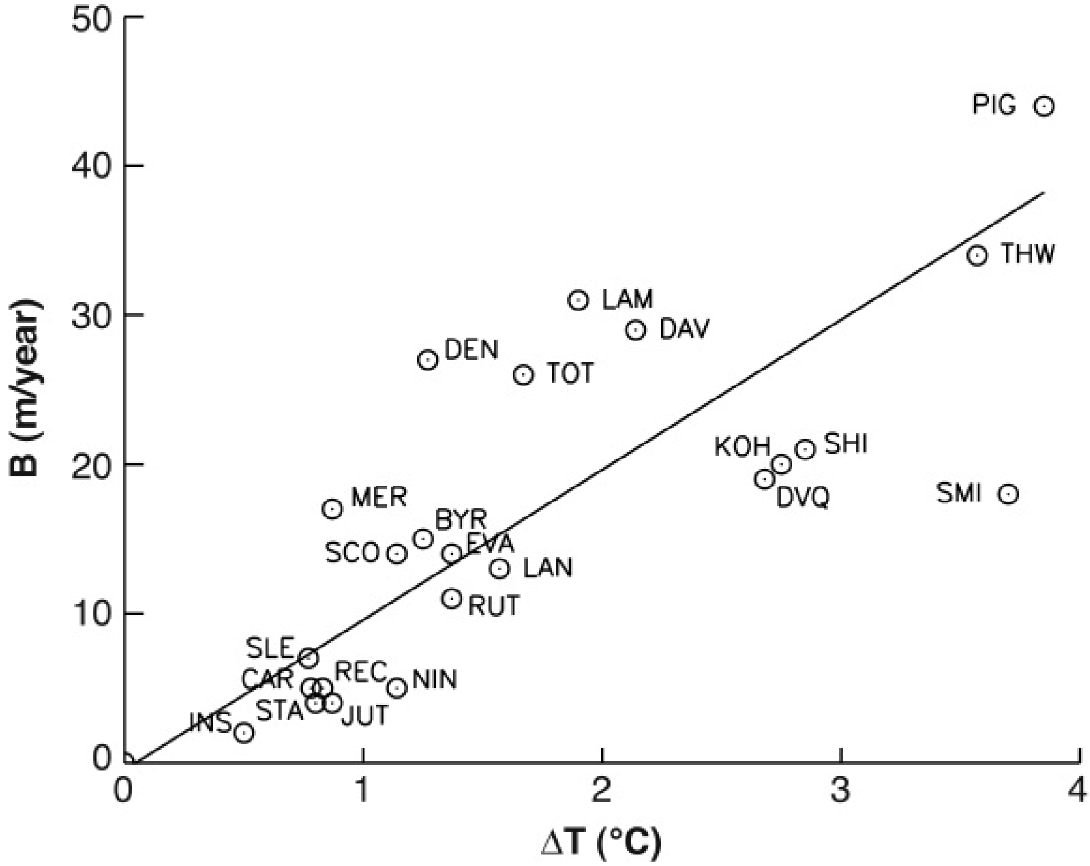
This isn't just affecting the Antarctic Peninsula however. For example, if you go back up the pretty pink, blue and yellow picture of ice flow speed above... Ah hell, let me just repeat it:



Ice flow velocity on Antarctica. Source: [Chris Rapley presentation](#).

Just above and below the left end of the words "West Antarctica" you can see the letters "PIG", and "THW". That stands for Pine Island Glacier, and Thwaites Glacier. Those glaciers have speeded up much like the ones in Greenland and now have 60% mass imbalance (ie they shed 60% more mass of ice each year than shows up as input from snow). This PIG/THW region is now contributing about 1/7 of the world's annual sea level rise.

It rather looks like in Antarctica, the dominant thing that's going on with glacier speed-up is ocean warming. This next picture is from a 2002 paper by Rignot and Jacobs (available from Science with free registration). They did a survey of glaciers all around Antarctica and looked at the amount of melting at the bottom of the glacier in the floating portion near the point where the glacier transitions from being grounded (which they can compute from satellite data) versus the number of degrees above the freezing point of the local water. Melting is measured in meters of depth per year.



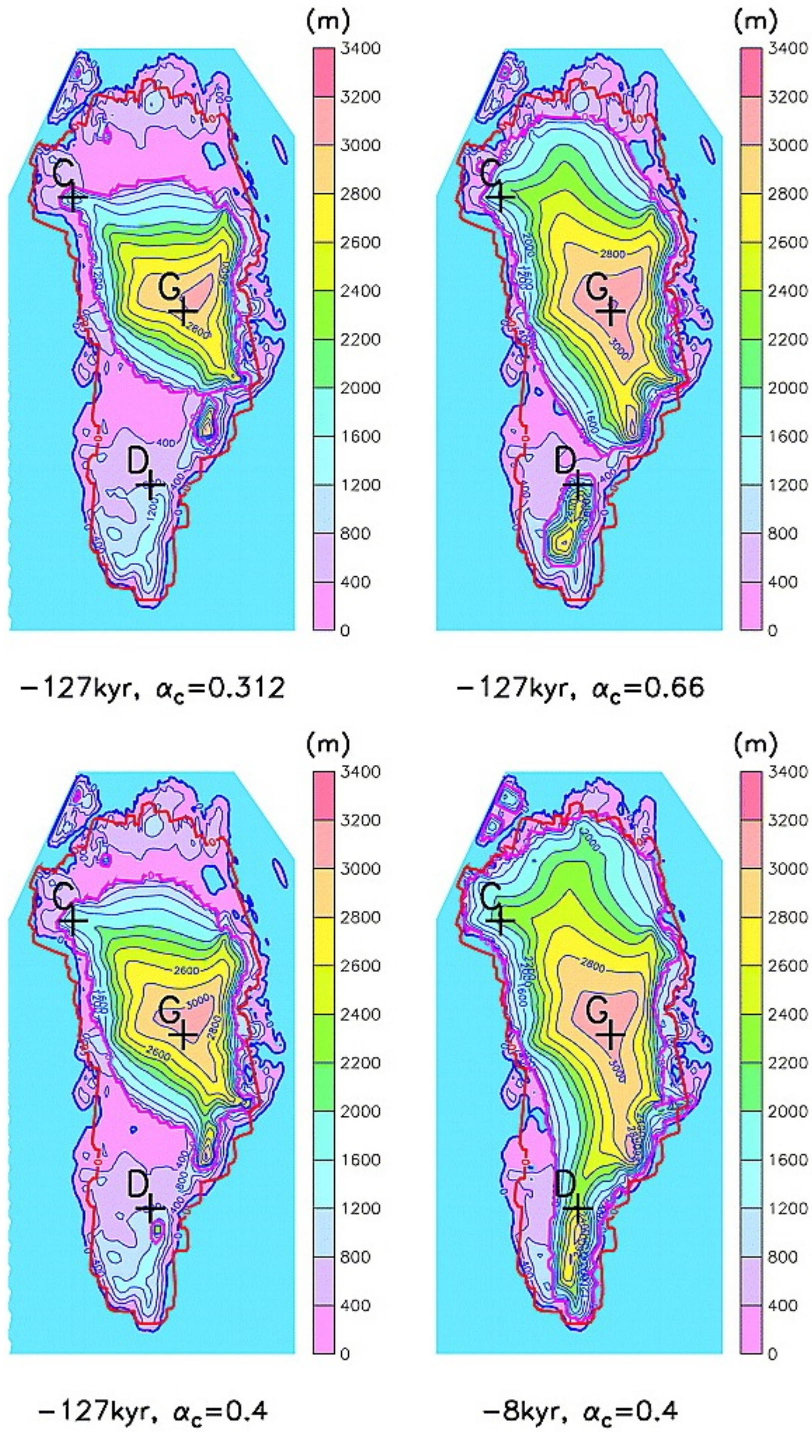
Source: This is Fig 2 of [Rignot and Jones, 2002]

As you can see, the warmer water melts the glacier pretty fast. You can see in particular the PIG and THW data points up near the top right of the picture which have high ocean temperatures and are melting rapidly at the sea end and have accelerated rapidly in their flow. Ocean waters off Antarctica have warmed about 0.2 ^{o}C so far as a result of global warming. The overall effect of that is roughly as follows. Whereas in the IPCC 2001 report, Antarctica was expected to contribute **negatively** to 21st century seal level rise (as it would sequester more water via increased snowfall), it's now thought that Antarctica is contributing at least 15% of the current sea level rise, and the future is unclear. Since the oceans have not yet equibilibriated even to the amount of CO2 and other forcing we've already created, they are going to warm significantly further. It appears possible that could drive quite a bit more Antarctic ice-flow speed-up and resulting sea level rise.

All things considered, it doesn't look to me like separating Antarctica into WAIS, East Antarctica, etc is the right way to think about it. It looks like the mass loss is going to be controlled by ocean temperatures. So the assessment is going to be about where and how much the ocean is going to warm off the coast of Antarctica, and how far inland the glaciers are going to speed up in response to the increased melting where they reach the ocean. This is going to have to be studied glacier by glacier all round the continent.

Let's now step back a bit and ask the following. The rough situation seems to be as follows. The Eemian was roughly 3 ^{o}C warmer than the pre-industrial holocene. Sea level was roughly 15 feet higher (there are significant uncertainties in both numbers). So if we've warmed the planet already by 0.5 ^{o}C, and there's at least another 0.5 ^{o}C in implied warming as the oceans catch up with emissions we've already put out, how much sea level rise have we already committed to? If the sea level response to temperature change was linear, then 1/3 of the Eemian temperature rise would give 1/3 of the sea level rise, right? Which would be about 5 feet, give or take. So with the forcings we've already added, we've committed to about 5 feet in sea level rise (assuming an approximately linear response). Add another degree Celsius, as we will in a few short decades of continued business as usual, and you'd get another five feet. (Eventually, that is - when the ice was back in equilibrium with the higher forcings. We'll get to the question of how fast the ice sheets might actually respond in a little while).

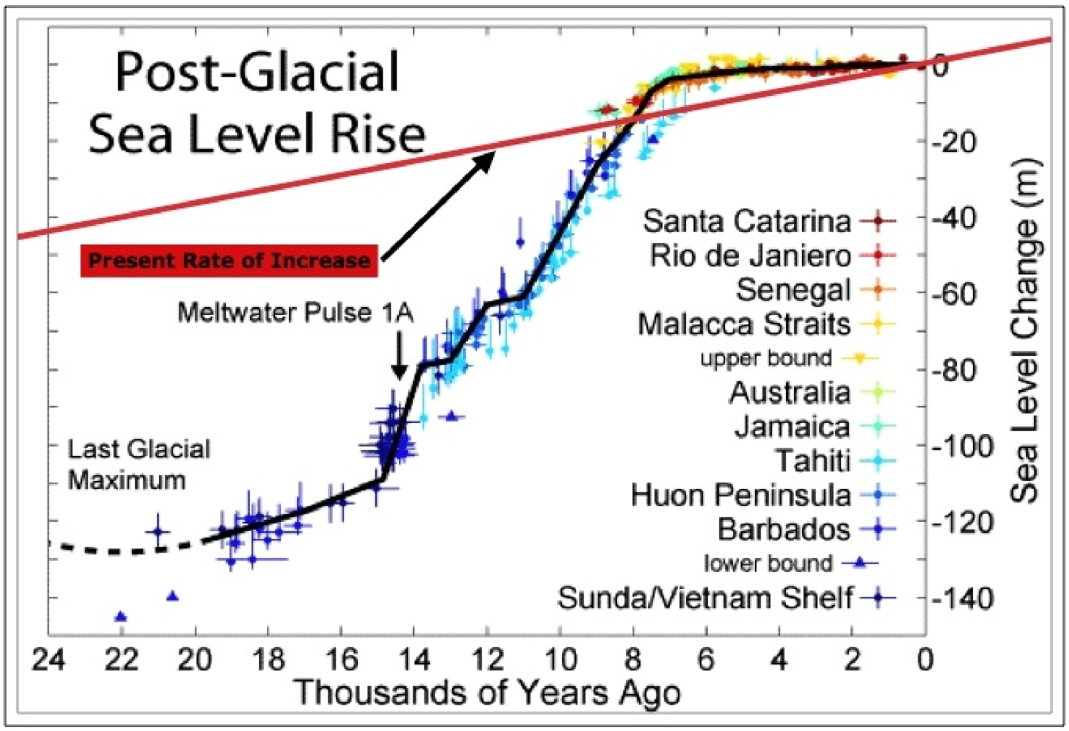
That line of reasoning suggests to me that we've already locked in quite a bit of sea level rise unless we lower the forcings in the future. I find further support for this thinking in figures like this one, from a recent modeling paper on the equilibrium size of the Greenland ice sheet under various conditions.



Source: This is Fig 16 of [Tarasov and Peltier, 2003](#)

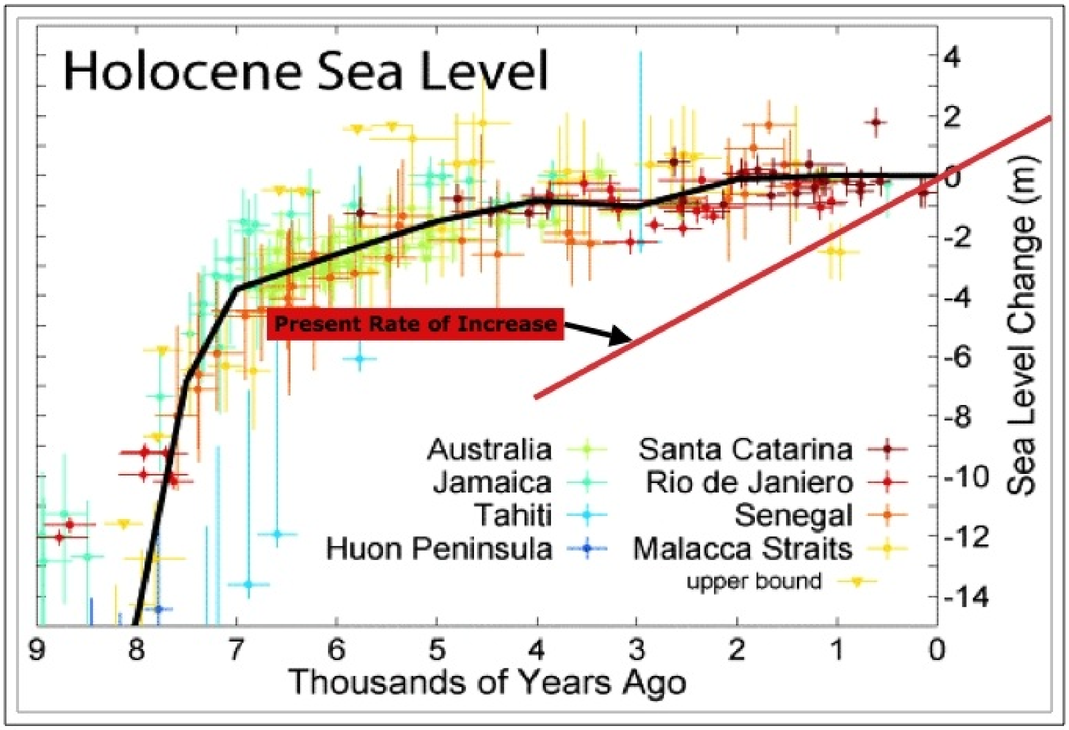
I'll spare you most of the details of what the paper was doing, but the point is that under a variety of different conditions, the ice sheets are not an all-or-nothing phemonenon. If it's warmer, you get less of them, and they retreat to higher ground. If it's colder they get bigger and start to fill ocean basins too. Obviously, the sea level changes are inverse to the ice sheet changes. The more ice, the less ocean, and vice versa.

So the final question is how fast could all this go? Let's have a look at the history of how fast the sea level rose during the deglaciation from the last glacial maximum to the holocene. This next picture shows the estimated sea level during that period, and to it I have added the current estimate of present day sea-level change, which is about 1.8 mm/year. 1.8 mm/year is about 0.7 inches/decade.



Sea level rise since the last glacial maximum. Source: [Wikipedia](#), with my addition of present rate of sea level rise.

Clearly, the current rate is nowhere near as big as the peak rates of the last deglaciation. During meltwater pulse 1A, around 14000 years ago, sea level was rising at about 50mm/year, or about 20 inches/decade. However, the current rate is large compared to our best understanding of past holocene changes. Here's a focus in on just the last 8000 years.

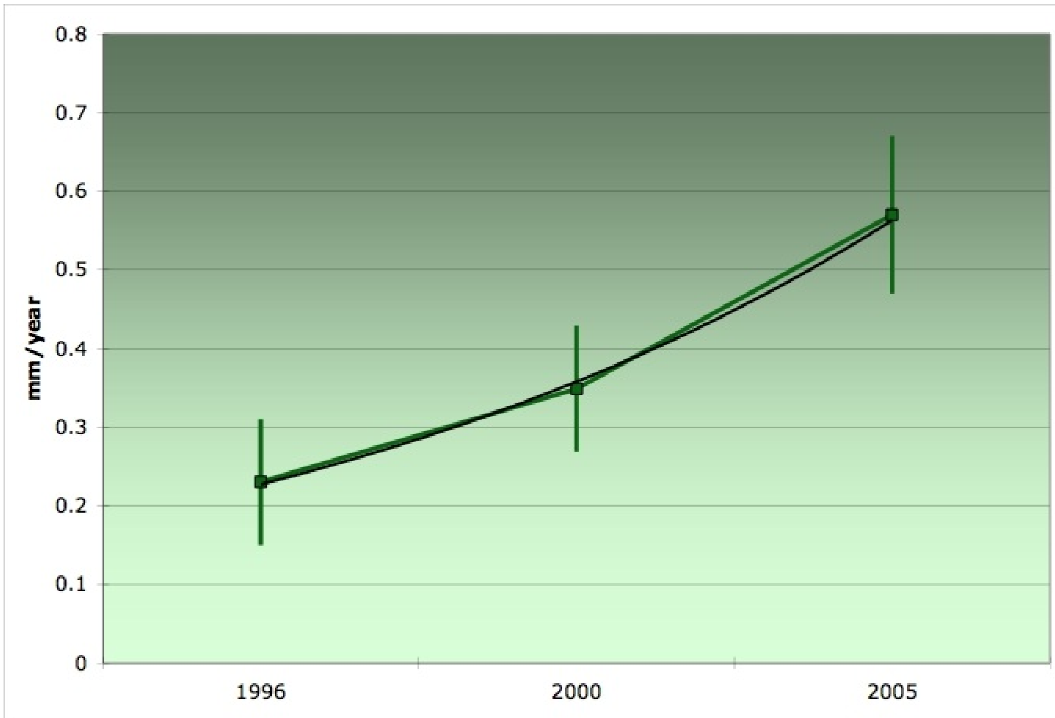


Sea level rise in the Holocene. Source: Wikipedia, with my addition of present rate of sea level rise.

So the rate of sea level rise now looks abnormal, but doesn't yet seem scary or hard to adapt to. However, we know that in the past, sea level could change fast - ice sheets can melt in a hurry when conditions are right - and recent evidence suggest considerable instability in the current rate of change. In particular, there was a paper on Friday (Feb 17th) in Science from Rignot and Kanagaratnam which has the latest updated numbers on Greenland's overall mass balance based on satellite surveys. The abstract says:

> Using satellite radar interferometry observations of Greenland, we detected widespread glacier acceleration below 66° north between 1996 and 2000, which rapidly expanded to 70° north in 2005. Accelerated ice discharge in the west and particularly in the east doubled the ice sheet mass deficit in the last decade from 90 to 220 cubic kilometers per year. As more glaciers accelerate farther north, the contribution of Greenland to sea-level rise will continue to increase.

Here's my graph of their bottom line (I have expressed their numbers for Greenland ice loss in sea level equivalent). The green vertical lines are the uncertainties in the estimates. The black line is an exponential fit to the central values.

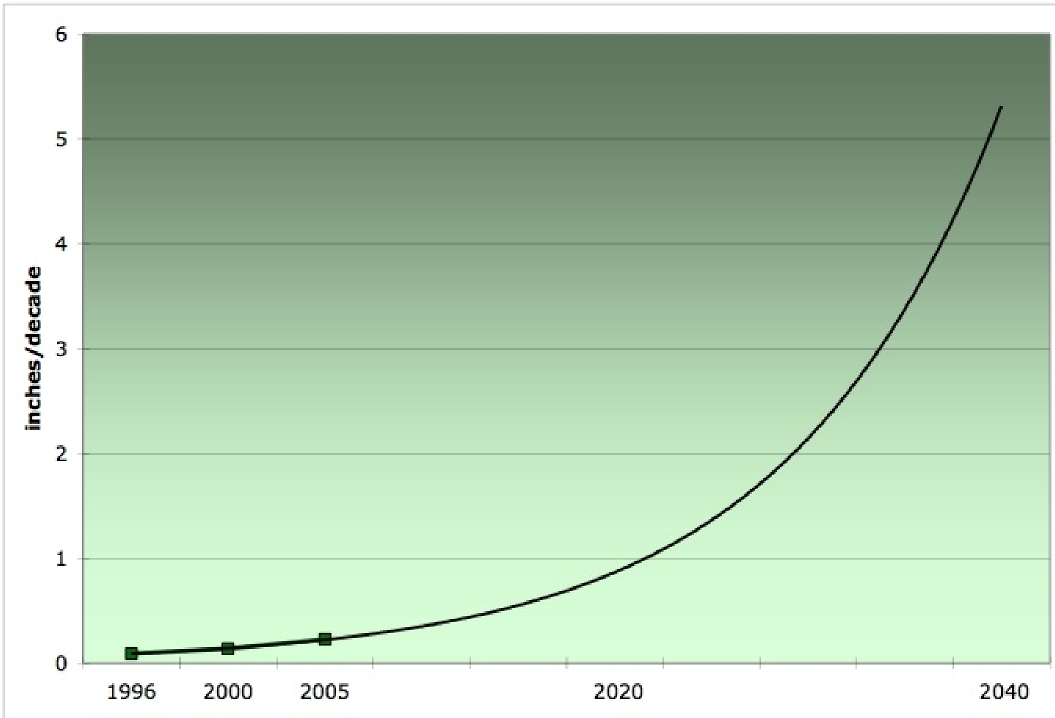


Sea level rise due to Greenland ice loss. Source: [Rignot and Kanagaratnam, 2006](). Unfortunately, you have to pay $10 to read it if you don't have access to a Science subscription.

Obviously, this is changing extremely dramatically. The rate of mass loss from Greenland has more than doubled in a decade, and this is primarily due to increased ice flow which has gone much faster than ice models predicted. Now, there seems to me considerable reason to expect this to increase further:

- The polar ice cap is shrinking, which reduces the albedo of the area around Greenland.
- The oceans will warm further in response to existing forcings.
- We keep increasing the forcing.

Now, how quantitatively this will play out in the future is obviously very uncertain. Is that doubling rate some kind of anomaly due to bad luck and really the true rate is much lower and thus will appear to decrease in the future? Those error bars do allow it quite a lot of freedom. Or alternatively, is the iceflow responding very non-linearly to temperature, so even a little bit more warming will cause a lot more flow? Nobody knows right now. However, one way to construct a SWAG (scientific wild-ass guess) about the future would just be to suppose that the doubling time for the ice-loss from Greenland stays constant. Thus we are just going to extend that exponential out to the right:



Sea level rise due to Greenland ice loss with approximate exponential extrapolation. Source: [Rignot and Kanagaratnam, 2006](#) for the data. Unfortunately, you have to pay $10 to read it if you don't have access to a Science subscription. Extrapolation is mine - see the cautions in the text.

Again, I caution - this cannot be seen as a reliable prediction method. To extrapolate that far into the future from only three data points is indeed wild-assed guessing. (But the icesheet models at this point are clearly not capturing the right physics, so we can't reason from them either). However, that particular wild-assed guess gets you 5-6 inches/decade of sea level rise by 2040. That's from Greenland. While we're in wild-ass guess mode, let's say we double it to allow for Antarctica (which has a lot more ice), which would give us a foot/decade.

A foot/decade is still somewhat less than the 20 inches/decade that was achieved during meltwater pulse 1A. So it's not off the charts for what the planet has done in the past. OTOH, a sceptic could reasonably argue that there was a lot more ice to melt during meltwater pulse 1A. OTTH, we could reply that the rate of change in the forcing was far lower in the past than we have created now with our emissions.

When we start to talk a foot/decade, that starts to get very serious. Low lying rural areas, especially in poor countries, will be lost to the sea - that's too much change to accomodate. Cities will no doubt build levees, but after Katrina, we know what can happen to cities below sea level in an era of big hurricanes. For those of us sitting smug here on the West Coast away from hurricanes, how well do you think levees will protect a below sea level neighborhood in an earthquake?

My point here is not to confidently predict that we know what will happen by 2040. We don't. The situation is extremely dynamic, and poorly understood. But what I will say is this.

It seems very clear to me that we are already operating the planet out of the safe zone. Major critical subpieces of the system are starting to change their functioning substantially on decade timescales. Suppose I was a senior engineer at the company that had built this planet for your civilization, and you called me up and said, "We'd like to run the planet a degree or two Celsius warmer; what will happen to our civilization?". I would say, "We don't know, that hasn't been properly tested. However, we strongly recommend against it - the limited testing we have done in the past suggests that might result in significant changes in the conditions inside the planetary product's environment. The company cannot guarantee the correctness of product sea level or weather conditions outside of the normal operating range. Your warranty will be void if you attempt to do this."

If you the customer want to come back and argue the point - let's say you sue my company for breach of contract - my question would be this: when the mass loss from Greenland is doubling that fast, and Antarctica is starting to undergo big changes too, and really we've only just gotten the ball rolling on warming up the planet compared to what's coming in the next few decades, what should give us confidence that these changes will slow down and stabilize in the future?