Our grandkids' grandkid's future …

Looking at James Hansen's PLOS ONE paper, December 2013[1]

The changing climate isn't discussed very much in our popular media - at least not compared with a lot of other things - and when it is you often hear stuff like this:
we should limit warming to 2℃ by 2100 … emission targets for 2080 … sea-level estimates for 2100.
You can easily get the impression from this that global warming will all happen in the twenty-first century - about the life span of my grandchildren. But this is dead wrong. Warming will not stop in 100 years, no matter what we do. Whether we put the brakes on now or in 50 years, it will keep going for many centuries - some of it for thousands of years. We can do plenty to moderate the warming by acting fast, but we can't stop it altogether because of the heat that's been stored deep in the ocean, and is yet to be spread around.

Heat waves will get worse; storms will be stronger; the sea will go on rising long, long after our grandkids have farewelled the good Earth. What we do now, and what we fail to do is for keeps. Yes, the climate system has been disturbed before by natural events (not exactly like this, but pretty severely) and the planet will eventually adjust, as it has in the past - but not on a human time scale - rather over tens or hundreds of thousands of years.

This is the theme of a recent paper by **James Hansen** and a group of colleagues. It's written for non-specialists, but like most of Jim's scholarly work, it isn't particularly easy for untrained readers to see exactly where the strength of his argument lies. Since it's an important statement, I thought I would try to summarize what it says.

Hansen is a physicist. He understands the climate system as well as anyone, but he also seems to see a big picture that's emerging all the time from the continuing work of many scientists in different disciplines. He has made it his business in recent years to try to turn this into a map so we can find our way to a decent future for our grandkids and all the people of the future, as well as the creatures who share the Earth with us. Deep knowledge and concern are in all his work. What he says is always worthwhile.

Here are the main points as I see them:

- Thinking about the climate problem, it's better to focus, not on temperature alone, but on the ***planet's energy balance***
- At the present time, and for about the last 100 years, Earth has been accumulating solar energy - absorbing more than it radiates. In its normal state, it is pretty close to energy balance … energy intake and output about the same … but not now.
- The surface temperature has risen 0.8℃ and will continue rising until Earth's radiation is again approximately equal to absorbed solar energy. This process of rebalancing will

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[1] The paper provides detailed justifications for all the arguments I have given here in brief. It is freely available at: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0081648

take many centuries - mainly because of the way the deep ocean takes up, and then slowly redistributes heat.

- This will still happen, even if we stop adding greenhouse gases immediately - again because of the ***ocean's thermal inertia***.
- We don't have to guess what a 'safe' level of warming will be because we have a couple of pretty good guides … currently observable climate trends, and knowledge of how Earth's climate behaved in the past.
- Analysis of these tells us the following:
  - If we want to preserve a climate resembling the stable Holocene (the last 10,000 years in which all of human civilization developed) we need to bring atmospheric CO_2 down to 350 ppmv - the quicker the better. That would return the Earth to approximate energy balance.
  - A 2℃ rise in global mean surface temperature that we hear so much about, which would result from sustained atmospheric CO_2 about where it is now, would not be safe, but disastrous. Paleoclimate evidence now makes this perfectly clear.
  - If we reversed CO_2 emissions after 2015 with very steep reductions at about 10% annually, and fixed the problem of tropical deforestation, and if we used farming practices to sequester CO_2 in agricultural soils, atmospheric CO_2 would be above 350 ppm for about a century.
  - If we delay peak emissions even a couple of decades, returning to energy balance (and the period of warming) will take much longer, and the eventual degree of warming will be much higher - it depends precisely on when we decide to act.
  - Since atmospheric CO_2 depends on the total cumulative historical emissions, you can prescribe a safe limit for this too. It turns out to be about 500 gigatonnes of carbon (GtC). We've already burned about 370 GtC, so we need to put the brakes on right away.
  - Known fossil fuel reserves are many times bigger than this, so most of them will have to be left in the ground.

- Known consequences of ignoring this advice - allowing CO_2 to rise to 500 ppmv or more - include the following:
  - Much more frequent weather extremes - severe heat waves, droughts, floods, severe storms;
  - Loss of the Arctic sea-ice;
  - Unavoidable century-scale sea-level rise of at least several metres (in the worst case, tens of metres);
  - Wholesale extinction of species;
  - Loss of productive land;
  - Severe damage to ocean ecosystems;
  - Multiple human health impacts;
  - Severe societal stress and economic loss;
  - Colossal injustice perpetrated on future people.

Temperature and energy balance are related in the following way: Like any physical body or system, Earth's surface will warm as long as a positive energy imbalance exists. Equilibrium temperature arrives when the planet's continuous energy losses equal its income. The time it takes to get to this state depends on the way heat moves through the various parts of the system - the crucial one in this case being the global ocean, because of its enormous heat capacity.

We can tell Earth is in a state of energy imbalance by observing the following:

- Arctic sea-ice has shrunk 80% in volume since 1975;
- Global sea-level is rising at 3.2mm a year, much faster than the Holocene mean;
- The Greenland and Antarctic ice sheets have begun to shed mass at accelerating rates;
- Mountain glaciers are receding on every continent and at every latitude;
- The dry subtropical climate zones have expanded polewards;
- Mega-heat waves, of very unusual severity have occurred several times since the year 2000, in Europe, Asia, North America, Australasia and Greenland.

We can measure the imbalance by recording the changing heat content of the major heat-containing parts of the planet's surface - land, air, ice and sea. Since the ocean holds over 90% of the total stored heat, this is by far the best place to measure. Data from Argo floats deployed since 2005 in all the ocean basins indicate an imbalance of about +0.7 Watts/m^2. Greenhouse gases aren't the only human-caused factors affecting the energy imbalance. For example, reflective aerosols exert an effect about twice this size in the opposite direction. [This is why the target CO_2 doesn't need to be 285 ppmv, where it was before the industrial revolution. If it happened that the aerosol forcing had been larger still, Earth might be cooling under human influence instead of warming. Contrariwise, if the opaque aerosols were to be significantly reduced by cleaning up developing world smokestack emissions, warming would be sharply aggravated.] The measured imbalance is a sum of all the separate "forcings".

There are two useful ways to work out how much warming to expect from a given amount of forced change in the planetary energy balance: geophysical theory; and the paleoclimate record. Hansen suggests that they should be used conjointly. Paleoclimate data, where it is well defined, can be used to constrain otherwise imprecise values derived from theory. In this way, it has been discovered that the climate response to a sustained forcing occurs first on a time scale of decades, then by slower-acting feedbacks, over many centuries - *e.g.* big albedo changes from reduced ice sheet size, and methane mobilized from thawed tundra. This discovery means if we can limit the duration of forced warming to less than a century we can expect to avoid triggering the slow feedbacks.

The climate history lesson closest to us occurred during the last interglacial, the Eemian (130,000 - 114,000 years ago). In the middle of this period, global temperature rose to about a degree warmer than now. Sea-level at this time (125,000 years ago) is variously estimated at 6-9m higher than the present. Further, there seems to have been an episode of rapid sea-level rise suggesting some instability threshold of the presently vulnerable polar ice sheets at temperatures not far from today's. While there is still debate among specialists about the details of Eemian peak sea-level, the evidence is quite sufficient to say that warming of 2℃ above 20th century mean would eventually raise the oceans several metres above where they are now - a colossal disaster. The immense cost and trouble of this would be handed to our descendants; people alive today would pay just the first installment.

Reducing CO_2 to 350 ppmv from its peak

No matter what peak concentration we produce, atmospheric CO_2 will decline by itself if we wait long enough - but that will be much too slow for us - something like 100,000 years. To save a familiar climate we will need to stash carbon away, either in the biosphere or in some geological repository. Of the two options, the first is an obvious choice because it is feasible with existing technology and fairly fast. Tropical deforestation contributes something like 50-150GtC to the atmosphere. If we halt destructive deforestation, re-plant available tropical land for managed forestry, and introduce farming techniques to sequester carbon in soils on a large scale, it's estimated we could remove 100GtC during the rest of the century. Together with a rapid phase-out of fossil fuel burning, that would be enough to get CO_2 down to 350 ppmv by 2100.

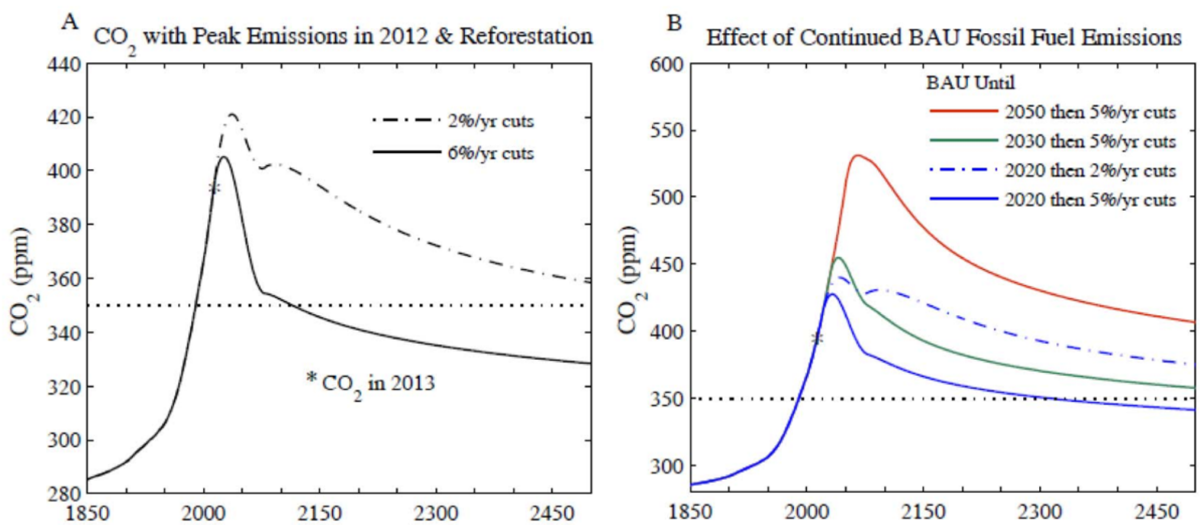

Figure 5 Showing (A) the effect of halting the rise of CO_2 emissions immediately, with annual reductions of 2% & 6% respectively. Notice what a huge difference this makes to the future atmosphere. The goal of 350 ppm by century's end can't be met with small cuts. In (B) you can see the effect of delaying peak concentration by even a few years. A 2020 peak with 5% annual reductions means we wouldn't see 350 ppm for another 300 years. This would certainly be long enough to start some slow feedbacks - with dangerous but incalculable consequences. After a 2050 peak of around 525 ppm and 5% cuts, CO_2 would be way above 350 ppm for at least a millennium.

Carbon capture - extracting CO_2 from smokestacks and burying it somewhere - is (or was recently) discussed in the media as if a bit more research would turn this neat idea into a catch-all solution to the climate problem. We could then burn all the coal and gas we want. Hansen shows that this is a pipe dream - either fantastic or disingenuous. Not only would it be much too costly on the scale required, but it wouldn't work well enough to correct the atmospheric consequences if we postponed emission reductions by even a few years.

How much warming can we expect?

Predicting how much the world will warm following a climate forcing is notoriously tricky. For one thing, nothing in Earth's climate history is quite like what's happening now … sudden transfer of hundreds of gigatonnes of fossil carbon to the atmosphere in 100 years. For another, we don't understand some feedbacks well enough to model them realistically. All the same, study of past climates does tell us about the real-world relation between a greenhouse forcing and equilibrium temperature (the sensitivity), allowing robust inferences about future temperatures under different scenarios.

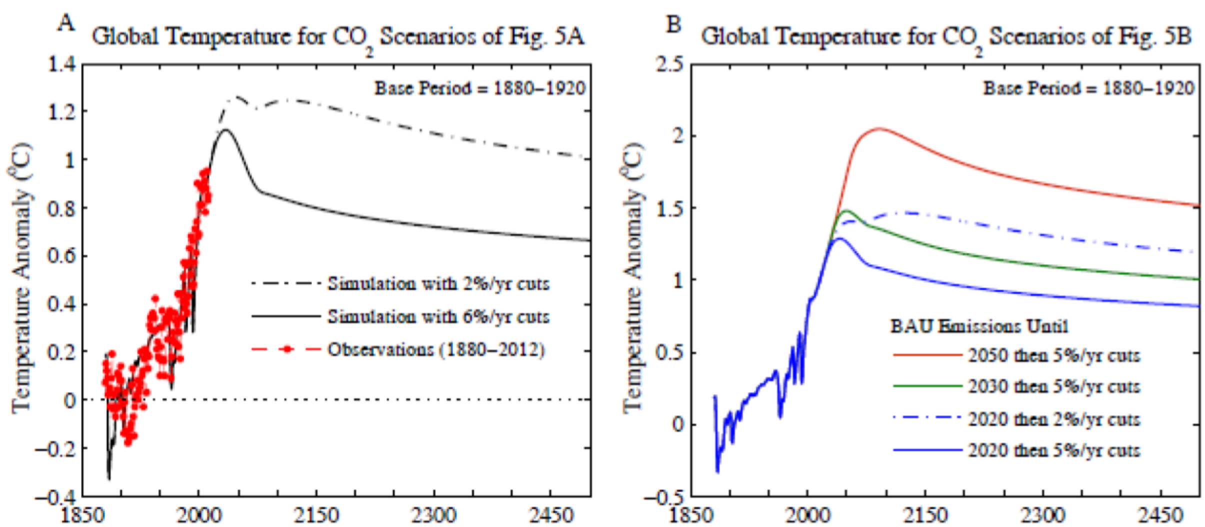

Figure 9 Showing how global temperature is determined in each of the scenarios of Figure 5. In (A) the red spots are the observed temperature record, overwritten on the simulation - indicating good agreement for the period of observation. Notice how the initial cooling over a few decades is followed by much slower cooling for at least a thousand years. The slow feedbacks associated with that degree of warming (0.5°C or so) are unavoidable. In (B) you see how a peak warming just over 2°C is sustained above 1.5°C for centuries, despite 5% annual cuts in emissions. Again, it's clear that delay is our worst enemy.

The essence of Hansen's message here is quite clear. We have no time to lose. We've had warnings, including his own, for more than 30 years, and the opportunity to get a really good outcome is past. The choice now is between catastrophic climate disruption and something manageable. Much public discourse - for instance, the often-heard talk of a "2°C safety barrier", and mid-century emission reduction targets, a 1,000 GtC cumulative emissions limit, and emission trading schemes is, according to him, no better than whitewashing - these proposals would lock in warming of 2°C or more, and are by no means "safe". If we are going to do the right thing by the people of the future, we have no alternative but an immediate commitment to ending all fossil fuel combustion, and pulling CO_2 from the air for the rest of the century.

What we must do

When it comes to actual policy, Hansen's group is adamant. Policy makers have been acting as though this were an economic problem (in the narrow sense, that its solution must, first and foremost, be economically rational - that is, it should not compromise growth of the economy as presently defined, and its costs must be warranted by economic benefits). This thinking ensues because the value of public goods *eg.* the atmosphere, is not admitted in economic calculations, and because the interests of future people are heavily discounted. The idea is utterly false. The problem is not economic, but geophysical and ecological. The primacy of economics in policy is simply getting in the way.

Furthermore, this failure of policy is *prima facie* immoral and should be repugnant to all thinking people. It may not be long, the authors warn, when young people begin to claim their right to a decent future using litigation - and in due course their case against our tardy leaders must be adjudicated.

Therefore, we should proceed while there is still time with a program like this:

- ***Carbon tax*** At present, our behaviour is perverse - we are going as fast as we can after the last sources of liquid fossil fuels and gas (the "unconventional" ones, as well as deep-water oil and gas, Arctic oil, *etc*) while climate alarm bells ring loud and clear. The biggest reason for this frivolity is that dumping combustion products into the air is still free. We should immediately impose a carbon "fee" on all fossil fuels at the point of extraction or import, to be returned to the populace as an equal *per capita* dividend. The fee would rise each year until it had the desired effect. This way, both energy consumers and producers would acquire incentives to emit less; alternative energy developers would become more attractive, and fixed fossil fuel investments could be amortized over a decade or two.
- ***R&D*** We are a long way from an ideal set of energy alternatives. There must be a big program of investment in zero-emission technologies.
- ***Alternative energy deployment*** We don't have time to wait for better sources of clean energy, but we must greatly accelerate installations of all the ones presently available. It is just as important that the rich world should undertake this as it is to ensure that the developing world side-steps a path through fossil energy dependence. The option of using nuclear power must be available.

- ***CCS*** There will be instances where carbon capture makes sense, and a program of research is warranted.
- ***Energy efficiency*** There must be a big commitment to improving the efficiency of energy use throughout the economy.
- ***"Non-conventional" fossil fuels must not be exploited*** Extraction and development of all non conventional fossil fuels … tar sands, shale gas and oil, coal-seam gas, 'heavy' hydrocarbons, coal-to-liquids, must be abandoned. The quantity of these substances is potentially so large that, if we commit to their extraction and use by making big investments now, it will be impossible to restrain emissions below a peak CO_2 of 500 - possibly much more. That would be equivalent to a guarantee of 3°C of warming or greater - enough to raise the sea tens of metres.
- ***Biosequestration*** Although the subject requires further research, enough has been learned already to justify a big program designed to withdraw CO_2 during the rest of the 21st century down to the 350 ppmv target. This could be achieved by a combination of phasing out wasteful tropical forestry, reforestation in the tropics, and converting agricultural soils (and possibly pastures) to carbon sinks. In our present state of knowledge it is reasonable to suppose we could take out about 100 GtC by 2100.

Hansen and his co-authors point out that the three essential geophysical changes that must be accomplished, *viz*, eliminating fossil fuel emissions of CO_2 (the main combustion product); reducing or eliminating land-use emissions, and reducing non-CO_2 forcings (especially methane) are interdependent. As well, the processes that produce these emissions are self-reinforcing - so if we allow fossil fuel use to grow, for example, methane emissions and land use emissions will rise too. But the reverse is also true, so that as we tackle one or more, they will decline together.

In summary, In view of what we know, this is a situation that can appear nearly hopeless … the response of our society has been and still is woefully inadequate … and yet it can also be an immense opportunity. Far from being economically prohibitive, the solution sketched here is incomparably better than the alternative - allowing a climate catastrophe to befall our innocent grandchildren, and theirs … and theirs, and theirs. This should be so unthinkable that we would dismiss it out of hand. Indeed if enough folks could see the thing as clearly as the authors of this paper, we'd be well on the way. Let us hope and strive, in order that understanding reaches enough people to overcome resistance and opposition before very long.