Making Things Clearer: Exaggeration, Jumping the Gun, and The Venus Syndrome

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I "retired" so that I can focus my time better on (1) climate science, (2) communications thereof, and (3) policy implications. I will do this via research published in the scientific literature and translations for a wider audience.

I have had the good fortune of my research being reported by top science writers: Walter Sullivan on the first major climate paper that my colleagues and I published[1], Richard Kerr[2] on my congressional testimony in the late 1980s, and Justin Gillis[3] on my retirement. Their articles raised some issues and queries, which are relevant to the task of getting the public to understand the urgency of effective policy actions.

1. Exaggeration?

I have been told of specific well-respected people who have asserted that "Jim Hansen exaggerates" the magnitude and imminence of the climate threat. If only that were true, I would be happy.

"Magnitude and imminence" compose most of the climate story.

Magnitude. CO_2, the dominant climate forcing on the long run, will stay in the climate system for millennia. The magnitude of the eventual climate response to increasing CO_2 depends especially on climate sensitivity. Our best evaluation of climate sensitivity comes from Earth's paleoclimate history, via comparisons of periods with differing climate forcings.[a]

Unfortunately, paleoclimate data show that our early estimates of climate sensitivity were not an exaggeration. This is made clear in a paper[4] in press at the Philosophical Transactions of the Royal Society (world's oldest scientific journal). The journal issue containing our paper will not appear until this summer. However, the publishers have allowed us to make available a nearly final version of the paper on the arXiv website for preprints.

This paper concludes, among other things, that climate sensitivity is in the upper half of the range that has usually been estimated. Furthermore, slow feedbacks, such as change of ice sheet size and methane emissions, make the sensitivity still higher.

Before the paper is published we will write a summary for a broader audience.

Imminence. Recently a smart young person told me that she tends to discount global warming as a concern, because of prior assertions that we only had 5 years or 10 years before disastrous consequences -- and her observation that not much has changed in the past 5 years.

That exposes another communications problem. Scientists did not expect sea level rise of meters or "a different planet" in 5 or 10 or 20 years. In 2005 (AGU meeting) I noted that we needed to get on a different global emissions path, with decreasing emissions, within 10 years -- not because dramatic climate change would occur in 10 years, but because otherwise we will build into the climate system future changes that will be out of our control.

Climate effects are occurring already and are generally consistent with expectations. The perceptive person should notice that the climate dice are now loaded. However, changes so far

[a] A frequently cited alternative, use of observed climate change of the past century, does not yield a useful constraint because the net climate forcing is unknown (assumed aerosol forcing can be described best as an educated guess) and inferred sensitivity also depend on uncertain transient ocean mixing.

are small compared with what will happen if we are so foolish as to continue down the path of extracting and burning every fossil fuel we can find. See below.

2. Jumping the Gun

It has been said that I reach conclusions before the evidence warrants them. Two examples suffice to illustrate the predicament that we face.

Late 1980s. Dick Kerr colorfully titled a 5-day scientific meeting after my 1988/89 congressional testimonies as "Hansen vs. the World on the Greenhouse Threat"[2]. Yet one of the participants told him "if there were a secret ballot at this meeting on the question, most people would say the greenhouse warming is probably there."

Scientific conclusions are based on integration of multiple sources of information: climate changes observed today, Earth's history, basic theory, models, etc. Interpretation inherently involves assumptions and subjectivity, yet valid conclusions are possible.

Communication of developing science might be affected by the phenomenon of scientific reticence.[5] In the 1980s I could shrug off criticism with "It's just a logical, well-reasoned conclusion that the greenhouse is here now,"[2] go back to research, and let nature clarify matters.

Today it is different. The science is much clearer. And we are running out of time.

Today. I was recently at a meeting that included many of the top researchers in climate change. There was universal agreement about the urgency of the climate crisis.

Certainty of our predicament follows from basic considerations including: (1) huge inertia and thus slow response of key parts of the climate system, especially the ocean and ice sheets, and improving observations by Argo floats and gravity satellites that confirm trends and the existence of further change in the pipeline, (2) long lifetime of any ocean warming that is allowed to occur, (3) millennial time scale that fossil fuel CO_2 will stay in the climate system, (4) paleoclimate confirmation of the magnitude of the eventual climate response to large CO_2 increase.

These scientists, people who know what they are talking about, were not concerned about jumping the gun, but rather about whether the race might already be over. So they were considering the potential for air capture of CO_2, in effect geo-engineering to counteract our unintended geo-engineering.

What's wrong with this picture? We can pass from "jumping the gun" to unavoidable deleterious consequences without passing through demands for common sense policy actions? Let's come back to this matter after "The Venus Syndrome".

3. The Venus Syndrome

I get questions from the public about the Venus Syndrome: is there a danger of "runaway" greenhouse warming on Earth leading to Venus-like conditions? Related questions concern specific positive (amplifying) feedbacks such as methane hydrates: as warming thaws tundra and destabilizes methane hydrates on continental shelves, thus releasing methane, won't this cause more warming, thus more methane release, thus more warming -- a runaway warming?

Amplifying feedbacks. Let's consider a positive climate forcing (say a solar irradiance increase or CO_2 increase) that causes a unit of warming. Let's ask how this unit warming will be amplified by a very strong feedback, one that increases the initial warming by 50%. The added warming of 0.5 induces more feedback, by $0.5 \times 0.5 = 0.25$, and so on, the final response being

1 + 0.5 + 0.25 + 0.125 + … = 2. So this very strong feedback causes the final warming to be twice as large as it would have been without the feedback. But it is not a runaway effect.

The strongest feedback that we observe on Earth today, from water vapor, is almost as strong as this example. Other feedbacks are occurring at the same time, some amplifying and some diminishing (negative). The net effect of all fast feedbacks can be assessed by comparing different well-characterized climate states in Earth's history, as described in our paper,[4] treating slow changes such as ice sheet size as specified boundary conditions. It turns out that the net effect of fast feedbacks is to amplify the global temperature response by about a factor of 2-3.[b]

Other feedbacks become important on longer time scales. As the planet becomes warmer the ice sheet area tends to decrease, exposing a darker surface that absorbs more sunlight. And as the planet warms the ocean and land release long-lived greenhouse gases, mainly CO_2 and CH_4 (methane). Thus Earth's climate is dominated by amplifying feedbacks on time scales of 10-100,000 years and less. For this reason, Earth can be whipsawed between glacial and interglacial conditions by the small climate forcings caused by perturbations of Earth's orbit.[6]

The dominance of amplifying feedbacks and the resulting high climate sensitivity make Earth susceptible to what we can call a mini-runaway. By mini-runaway, I refer to a case with an amplifying feedback large enough that the total feedback reaches runaway (the infinite series above does not converge), but eventually that process runs out of fuel. Evidence of such behavior is provided by hyperthermal events[c] in Earth's history, sudden rapid warmings that occurred during periods of more gradual warming.

The most studied hyperthermal is the PETM (Paleocene Eocene Thermal Maximum), which occurred in the middle of a 10 million year period of gradual warming. A rapid warming spike occurred in conjunction with injection of a large amount of CO_2 into the climate system on a time scale of the order of a millennium. The source of the rapid CO_2 increase is most commonly suggested to have been the melting of methane hydrates due to a warming ocean, with an alternative suggestion being incineration of large peat deposits, especially on Antarctica.

Whatever the CO_2 source, global temperature increased about 6°C over several millennia. The continental weathering process provided a negative feedback, as a pumped-up hydrologic cycle drew down atmospheric CO_2 and deposited it as carbonate on the ocean floor. However, this feedback requires tens of thousands of years, so the rapid warming stopped only when the fuel source was depleted.

Are hyperthermals relevant now, as a possible amplification of fossil fuel warming? Unfortunately, they may be. Burning all fossil fuels would produce such large ocean warming, which would continue to exist for centuries, that ignition of a hyperthermal amplification of global warming is a possibility. Consequences are unclear. Carbon release in prior hyperthermals occurred over a millennium or more, at a rate up to ~ 5 GtC/year. This can be compared with the present global rate of fossil fuel burning, which is ~ 9 GtC/year.

It is instructive to consider the task of dealing with such continuing carbon release, in the event that we did set it off. Humanity could defuse a continuous release of 5 GtC/year, thus avoiding hyperthermal warming, by capturing and sequestering the carbon. The American Physical Society estimates[7] the cost of capture and sequestration as ~ $2 trillion per GtC. Given that the United States is responsible for 26% of the fossil fuel CO_2 in the air today[8], the U.S. cost share for removing 5 GtC/year would be ~$2.6 trillion each year. Technology development

[b] Global warming in response to doubled CO_2 or a 2% increase of solar irradiance would be 1.2°C in the absence of climate feedbacks. Thus the net fast feedback factor of 2-3 yields 2.4-3.6°C warming for doubled CO_2.

[c] A brief discussion of hyperthermals on page 3 of our paper[4] includes many references to the scientific literature.

might be able to lower that cost, but fundamental energy constraints imply that cost reduction at most will be a factor of a few.[9]

We had better be sure to avoid a mini-runaway. If we phase out fossil fuels rapidly and move to a clean energy future in accord with a scenario that my colleagues and I have described[8], we could be reasonably confident of avoiding that situation. We know that prior interglacial periods were moderately warmer than the current (Holocene) interglacial. A fossil fuel emissions scenario similar to the one we have defined is needed for other reasons, especially for the purpose of maintaining reasonably stable shorelines, i.e., avoiding sea level rise of many meters, which would destroy thousands of coastal cities all around the world.

In contrast, if we burn all the fossil fuels it is certain that sea level would eventually rise by tens of meters. The only argument is how soon the rise of several meters needed to destroy habitability of all coastal cities would occur. It is also possible that burning all fossil fuels would eventually set off a hyperthermal event, a mini-runaway. Is it conceivable that we could get a runaway leading all the way to the Venus Syndrome, Venus-like conditions on Earth?

Runaway Greenhouse. Venus today has a surface pressure of about 90 bars, compared with 1 bar on Earth. The Venus atmosphere is mostly CO_2. The huge atmospheric depth and CO_2 amount are the reason Venus has a surface temperature of nearly 500°C.

Venus and Earth probably had similar early atmospheric compositions, but on Earth the carbon is mostly in Earth's crust, not in the atmosphere. As long as Earth has an ocean most of the carbon will continue to be in the crust, because, although volcanoes inject crustal carbon into the atmosphere as CO_2, the weathering process removes CO_2 from the air and deposits it on the ocean floor as carbonates. Venus once had an ocean, but being closer to the Sun, its atmosphere became hot enough that hydrogen could escape from the upper atmosphere, as confirmed today by the extreme depletion on Venus of normal hydrogen relative to heavy hydrogen (deuterium), the lighter hydrogen being able to escape the gravitational field of Venus more readily.

Earth can "achieve" Venus-like conditions, in the sense of ~90 bar surface pressure, only after first getting rid of its ocean via escape of hydrogen to space. This is conceivable if the atmosphere warms enough that the troposphere expands into the present stratosphere, thus eliminating the tropopause (see Fig. 7 in our paper[4] in press), causing water vapor to be transported more rapidly to the upper atmosphere, where it can be dissociated and the hydrogen can then escape to space. Thus extreme warming of the lower atmosphere with elimination of the cold-trap tropopause seems to be the essential physical process required for transition from Earth-like to Venus-like conditions.

If Earth's lower atmosphere did warm enough to accelerate escape of hydrogen it would still take at least hundreds of millions of years for the ocean to be lost to space. Additional time would be needed for massive amounts of CO_2 to accumulate in the atmosphere from volcanoes associated with plate tectonics and convection in Earth's mantle. So Venus-like conditions in the sense of 90 bar surface pressure and surface temperature of several hundred degrees are only plausible on billion-year time scales.

Is it possible, with the present surface pressure of ~ 1 bar, for Earth's surface to become so hot that that the planet is practically uninhabitable by humans? That is the situation I depicted in "Storms of My Grandchildren"[10], which was presumed to be a consequence of burning all fossil fuels over a period of several centuries, with warming further amplified by ignition of PETM-like hyperthermal warming. Support for the possibility of large warming was provided by global climate model simulations indicating an upturn in climate sensitivity at climate forcings ~10 W/m^2 (Fig. 30 in "Storms"[10]). If other forcings are unchanged, a 10 W/m^2 forcing requires a CO_2 increase by a factor of 4-8 times its pre-industrial amount (~280 ppm) -- an increase that is possible if all extractable fossil fuels are burned[4,8]. Other complex global climate models also find an upturn in climate sensitivity or climate model "crash" when CO_2 amount reaches such high levels[11], raising the question of whether such a level of climate forcing is already trending toward a runaway greenhouse effect.

The concept of a runaway greenhouse effect was introduced[12] by considering a highly idealized situation with specified troposphere-stratosphere atmospheric structure, a simple approximation for atmospheric radiation, and no inclusion of how clouds might change as climate changes, as is appropriate for introduction of a concept. More recent studies[13] relax some of the idealizations and are sufficient to show that Earth is not now near a runaway situation, but the idealizations are still sufficient that the studies do not provide a picture of where Earth is headed if all fossil fuels are burned.

An alternative promising approach is to employ the fundamental equations for atmospheric structure and motions, i.e., the conservation equations for energy, momentum, mass, and water, and the ideal gas law. These equations form the core of atmospheric general circulation models and global climate models. However, today's global models generally contain representations of so many additional physical processes that the models are difficult to use for investigations of extreme climatic situations, because invariably some approximations in the scores of equations become invalid in extreme climates. In contrast, my long-term colleague Gary Russell has developed a global model that solves the fundamental equations with the minimum additional physics needed to investigate climate sensitivity over the full range from snowball Earth to a hothouse uninhabitable planet. The additional physics includes accurate spectral dependence of solar and thermal radiation, convection, and clouds. Although the precision of the results depends on the representation of clouds, we suggest that the simple prescription employed is likely to correctly capture essence of cloud change in response to climate change.

We use the Russell model in our paper to show that the tropopause rises in response to the global warming that occurs with larger and larger CO_2 amounts (Fig. 7 in our paper[4]), and cloud cover decreases with increasing CO_2. In consequence climate sensitivity initially increases as CO_2 increases, consistent with the upturn of sensitivity found in more complex global climate models[11]. With the more realistic physics in the Russell model the runaway water vapor feedback that exists with idealized concepts[12] does not occur. However, the high climate sensitivity has implications for the habitability of the planet, should all fossil fuels actually be burned. Furthermore, we show that the calculated climate sensitivity is consistent with global temperature and CO_2 amounts that are estimated to have existed at earlier times in Earth's history when the planet was ice-free.

One implication is that if we should "succeed" in digging up and burning all fossil fuels, some parts of the planet would become literally uninhabitable, with some time in the year having wet bulb temperature exceeding 35°C. At such temperatures, for reasons of physiology and physics, humans cannot survive, because even under ideal conditions of rest and ventilation, it is physically impossible for the environment to carry away the 100 W of metabolic heat that a human body generates when it is at rest[14]. Thus even a person lying quietly naked in hurricane force winds would be unable to survive. Temperatures even several degrees below this extreme limit would be sufficient to make a region practically uninhabitable for living and working.

The picture that emerges for Earth sometime in the distant future, if we should dig up and burn every fossil fuel, is thus consistent with that depicted in "Storms" -- an ice-free Antarctica and a desolate planet without human inhabitants. Although temperatures in the Himalayas may have become seductive, it is doubtful that the many would allow the wealthy few to appropriate this territory to themselves or that humans would survive with the extermination of most other species on the planet. At least one sentence in "Storms" will need to be corrected in the next edition: even with burning of all fossil fuels the tropical ocean does not "boil". But it is not an exaggeration to suggest, based on best available scientific evidence, that burning all fossil fuels could result in the planet being not only ice-free but human-free.

4. Summary Discussion

The inertia of the climate system is not our friend. Because climate responds slowly, we have felt so far only about half of the effect of gases already in the air. This limited response makes it easier for people to believe that we are exaggerating the climate threat.

Climate system inertia means that it will take several centuries for the eventual extreme global warming mentioned above to occur, if we are so foolish as to burn all of the fossil fuel resources. Unfortunately, despite the ocean's thermal inertia, the transient climate phase this century, if we continue business-as-usual fossil fuel burning, is likely to cause an extended phase of extreme climate chaos. As ice sheets begin to shed ice more and more rapidly, our climate simulations indicate that a point will be reached when the high latitude ocean surface cools while low latitudes surfaces are warming. An increased temperature gradient, i.e., larger temperature contrast between low and high latitudes, will drive more powerful storms, as discussed in "Storms of My Grandchildren".[10]

The science of climate change, especially because of the unprecedented human-made climate forcing, includes many complex aspects. This complexity conspires with the nature of reporting and the scientific method itself, with its inherent emphasis of caveats and continual reassessment of conclusions, to make communications with the public difficult, even when the overall picture is reasonably clear.

My principal objective in "retiring", i.e., in leaving government service, is to create more time that will allow me to try to contribute more effectively to this communications effort. I also had concluded that the future of the Goddard Institute for Space Studies and its people would be better served by a younger person who could be focused on leading GISS. My own heart is turning more and more toward trying to make the science and its implications for policy clearer.

I appreciate very much the well wishes I have received from many of you. I am not good at keeping up with e-mail correspondence, so I apologize to anyone who I may have failed to respond to. I also realize that the interview I gave regarding my retirement[3] may have left the impression that I would now be working mainly on specific actions to stem fossil fuel extraction and use. I believe all the individual actions occurring at many places are very important and the sum of them may help turn the tide to clean energies. But I must keep up with and contribute to climate science or I cannot be effective, so I hope to be doing more science rather than less -- and science requires more than 40 hours a week -- so it is not practical for me to respond to all the requests that I am receiving. I also want to support two or three people working with me, so I need to spend time in fund raising - and I am finding that it is not easy to get foundation support. I hope that papers and testimony that I provide for cases of Our Children's Trust, or cases regarding coal exports, tar sands and other unconventional fossil fuels, can find wider use with little modification. I will continue to support the growing 350.org movement. I support CitizensClimateLobby.org especially, because of their focus on fee-and-dividend, which I believe is the sine qua non for phase out of fossil fuels. I hope you noticed the op-ed supporting fee-and-dividend in the Wall Street Journal by George Shultz and Gary Becker[15], who point out that fee-and-dividend plus removal of energy subsidies would provide a level playing field and be good for the economy and jobs. There is also a Democratic (Boxer/Sanders) bill in Congress, but as usual they cannot keep their hands off our wallets, proposing to take 40% of the money to make government bigger, including congressional specification of how 15% of the money is to be spent. Washington seems likely to remain dysfunctional on climate policy, so when we get a bit closer to 2016 I will argue why I think we need a third party. In the meantime we must try to do what we can with what we have. Somebody with access to the President should wake him up to the implications of going down the unconventional fossil fuels route (I have tried, but failed to get access). He will have a heck of a lousy legacy if he takes the big step down that road with the Keystone pipeline. This is an area where he could reach across the aisle, suggesting that he is open to the idea of a revenue neutral carbon fee, which would save much more carbon than the Keystone pipeline would carry, but he would have to give up the Democratic penchant for telling us how to spend our money.

Finally, I recognize that in this Summary Discussion I failed to answer the question "How can we pass from "jumping the gun" to unavoidable deleterious consequences without passing through demands for common sense policy actions?" Delving into that matter requires getting into how our government functions and fails to function. That is a big subject and, as you can see, I am running out of steam for this present communication.

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[1] Hansen, J, D Johnson, A Lacis, S Lebedeff, P Lee, D Rind, G Russell, 1981: Climate impact of increasing atmospheric carbon dioxide. *Science*, **213**, 957-966.

[2] Kerr, RA, 1989: Hansen *vs*. the World on the Greenhouse Threat. *Science*, **244**, 1041-1043.

[3] http://www.nytimes.com/2013/04/02/science/james-e-hansen-retiring-from-nasa-to-fight-global-warming.html?ref=science&_r=1&

[4] Hansen J, M Sato, G Russell, P Kharecha, 2013: Climate sensitivity, sea level, and atmospheric CO_2,to appear in Phil Trans Roy Soc, near-final preprint available at arXiv:1211.4846

[5] Hansen, JE, 2007: Scientific reticence and sea level rise. *Environ. Res. Lett.*, **2**, 024002, doi:10.1088/1748-9326/2/2/024002.

[6] Hansen, J, M Sato, P Kharecha, G Russell, DW Lea, M Siddall, 2007: Climate change and trace gases. *Phil. Trans. R. Soc. A*, **365**, 1925-1954, doi:10.1098/rsta.2007.2052.

[7] APS (2011) Direct Air Capture of CO_2 with Chemicals: A Technology Assessment for the APS Panel on Public Affairs. American Physical Society. http://www.aps.org/policy/reports/assessments/upload/dac2011.pdf.

[8] Hansen, J et al., 2013: Scientific prescription to avoid dangerous climate change to protect young people, future generations, and nature (submitted for publication).

[9] House KZ, Baclig AC, Ranjan M, van Nierop EA, Wilcox J, Herzog HJ, 2011: Economic and energetic analysis of capturing CO_2 from ambient air. Proc. Natl. Acad. Sci. 108, 20428-20433.

[10] Hansen J, 2009: Storms of My Grandchildren, 304 pp., Bloomsbury USA, New York.

[11] Lunt DJ et al., 2012: A model-data comparison for a multi-model ensemble of early Eocene atmosphere-ocean simulations: EoMIP. *Clim. Past* **8**, 1717-1736.

[12] Ingersoll AP, 1969: Runaway greenhouse - a history of water on Venus. *J. Atmos. Sci.* **26**, 1191-1198.

[13] Goldblatt C, Watson AJ, 2012: The runaway greenhouse: implications for future climate change, geoengineering and planetary atmospheres. Phil. Trans. R. Soc. A 370, 4197-4216.

[14] Sherwood, SC, and Huber, M. An adaptability limit to climate change due to heat stress. *Proc Natl Acad Sci USA* 2010, 107:9552-9555.

[15] Schultz G, Becker G, 2013: 8 April Wall Street Journal. http://online.wsj.com/article/SB10001424127887323611604578396401965799658.html?mod=hp_opinion