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Interactive Comment

# *Interactive comment on* "Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming is highly dangerous" *by* J. Hansen et al.

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Title: Reducing the risks from devastating sea level rise through an improved understanding of Earth System operation in past and present

This seminal paper by Hansen et al. has made an important contribution to the current debate about a huge potential risk to humanity from rapid ice-sheet melt, but is not convincing on how to reduce this risk.

Because the impact of SLR of several metres over coming decades would indeed have “incalculable cost”, the probability has to be reduced to an extremely small value, for the risk to be acceptable. It is the duty of scientists to write, and journals to publish, on a subject of such societal concern. One might simply conclude that “we are in great danger from devastating sea level rise”, yet it is important to understand the problem properly, identify possible solutions, and not to evoke panic.

Can such a risk be reduced? The authors’ implied argument that a reduction of CO2 to 350 ppm, keeping global warming below 1.5°C, could prevent catastrophic SLR this century seems tenuous in the extreme - especially basing the argument on SLR coming from the Antarctic. Albedo loss in the Arctic continues, as the sea ice declines, snow retreats and GIS surface melts. The trend in Arctic sea ice, established over at least two decades, is for exponential decrease in volume. The apparent recovery since 2012 can not be taken as a reassurance that the long term trend has ceased, and some experts consider that the minimum extent will fall below the 1 million km2 mark by 2020. In this circumstance, there seems to be no possible mechanism for how a reduction in CO2 could cause a cessation in the exponential trends of sea ice retreat, Arctic warming and, consequentially, GIS melt rising to a dangerous level.

Thus one is forced to consider other measures to reduce risk, based on how the Earth System is behaving, how it reacts to natural stimuli (such as volcanic eruptions and meltwater pulses) and how it would react to contrived stimuli. The albedo loss from sea ice retreat has to be countered, which will require considerable cooling power. It has been proposed that a drastic reduction in short-lived climate forcing agents, particularly methane and black carbon, would have a cooling effect, but this would not be on the required scale. One is inevitably drawn to the stark conclusion that a geoengineering technique, or combination of techniques, must be deployed to cool the Arctic and save the sea ice, in order to reduce risk to an acceptable level.

Now consider Peter Thorne’s four major concerns. My response is initialled ‘JN’.



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1. Sea-level and storminess indicators in the palaeo-record

[PT] The authors present strong evidence that both the chevrons and the boulders' movement and deposition are marine mediated. Indeed, it is hard to envisage a non-marine mediated deposition mechanism in this location. However, I am unconvinced that the sole possible source of either feature is very substantial storms. It is entirely plausible that the rocks and chevrons could have been deposited by one or more tsunamis. It is well known that several Atlantic islands are prone to large landslides that may mediate tsunamis with a fetch from the north east at the location. I disagree with reviewers who have pointed to an ice sheet calving mediated tsunami as the direction is likely wrong and also the Greenland ice-sheet at present day (and therefore presumably 5e) is unlikely to collapse directly into the ocean in sufficiently large chunks as it is largely land-bound with glacial outflow.

[JN] Thorne is right that tsunamis are a likely cause of the Bahama boulder phenomenon, but he should not dismiss GIS as a possible source, by arguing either (i) that the direction is wrong, or (ii) that GIS glaciers are land-bound and thus unable to produce icebergs of the necessary size. The tsunami waves from GIS would have been reflected off the mid-Atlantic ridge and arrived at Eleuthera from the north-east; and the terminations of GIS glaciers are well below sea-level because of valleys recently discovered below the ice.

Nevertheless, as a risk reduction exercise and precautionary measure, countries bordering on the North Atlantic should ensure that nuclear installations are secure against tsunamis of a magnitude that could move giant boulders high above sea level on Eleuthera.

2. Use of a single coarse resolution model and a single set of hosing experiments

[PT] Because of gross inadequacies in the cryospheric components and assumptions of the model, hosing experiments are required. These hosing experiments spread freshwater over large domains of the North Atlantic and the Southern Ocean in the



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model. It is unclear how representative of what would happen in the real-world such experiments are and I am not convinced that this aspect has been adequately covered in the submitted draft. In the real-world freshwater inputs will tend to occur as almost point sources from outlet glaciers or at worst regional inputs from floating ice shelves. It is unclear to what extent the real-world oceanic mixing processes would then result in a freshwater surface plume spreading over the oceans' polar gyres leading to a widespread and persistent local cold SST anomaly. Given the import of the SST anomaly fields and sea-ice response in driving the atmospheric circulation and storminess response posited in the analysis I see this as a potential weak link in the causal chain.

If the model is instead forced with more local fresh water hosing does it yield a distinct response? Is this response more or less consistent with the available palaeo-evidence? These and other questions could and possibly should be answered both by further experimentation with the current model and the use of at least one additional model. Such further experimentation would help to build confidence in the authors' findings.

[JN] Thorne has doubts about the modelling used by the authors, but instead of using an independent model for verification, as Thorne suggests, one could look at what is happening now: validation by observation.

For several years there has been evidence of GIS meltwater spreading across North Atlantic resulting in a cold anomaly. There is also evidence of freshwater build-up in the Beaufort Gyre. Yet neither of these processes has caused a regional cooling, because the albedo loss effect dominates in the Arctic Ocean, and greenhouse effects dominate at lower latitudes.

With Arctic amplification and a reduction in tropic-polar temperature gradient, we observe the very opposite of the increase in gradient which the authors claim could produce extreme storminess in the future.

However, although the meltwater cooling effect is currently dominated by the albedo heating effect in the Arctic Ocean, the situation could change with giant icebergs from the east coast of Greenland. Such giant icebergs floating on the surface of the Arctic Ocean would posit copious freshwater on the surface, allowing sea ice to readily form at the end of summer. Such a mechanism could explain how periods of rapid sea level rise were ended in the past, e.g. at the end of the great meltwater pulses, 1a, 1b, and 1c, which followed the last glacial maximum. Ice-rafted detritus (IRD), such as recorded for Heinrich events, could provide evidence for such a mechanism, if the dating were to coincide with the end of rapid Arctic warming. (The conventional dating of Heinrich events to precede the D-O "rapid warming and slow cooling" events appears anomalous in this context.)

3. The physical basis for ice sheet melt-doubling rates

[PT] The authors make some simplified assumptions that the rate of ice sheet mass loss can be approximated by a doubling every [so many] years. While this may indeed be possible there is no robust underlying physical basis given at the outset (the justification is left to a few lines in Section 3.2 with no forward reference to Section 7.3). Specifically it would be useful to know from where on the great ice sheets and how such a melt could, plausibly, occur at this point to justify the assertion. The stopping melt at a certain point is also unrealistic as the authors themselves admit.

[JN] The rate of melting of GIS could be increasing exponentially simply because Arctic warming has been increasing exponentially (although there is a threshold effect, with non-linear melt rate as temperature rises). Ultimately the Arctic will become seasonally sea ice free, with steady high heating – and GIS melt could then be expected to become linear again. This seems to have happened in the past, when great meltwater pulses contributed 5 cm per year for hundreds of years – e.g. 20 metres in 400 years, about 14000 years ago (Hansen and Sato, 2011, "Paleoclimate Implications for Human-Made Climate Change".

4. Modern instrumental evidence

[PT] There is certainly robust evidence for an increase in mass loss from the Greenland and Antarctic ice sheets. This aspect of the discussion of modern era records is almost certain to be correct.

Evidence, however, becomes more ambiguous with respect to locally decreased SST and expanding Antarctic sea-ice and arguably sub-surface ocean measurement is sparse and should be treated with caution.

Since the paper was submitted Antarctic sea-ice anomalies have turned negative after a period of four years around +1 million square kilometres extent anomalies. This may simply be temporary. However, it does yield questions as to whether the recently observed increase in Antarctic sea-ice coverage has been indicative of a long-term trend process or simply natural variability. At the very least the record is too short and arguably the mechanisms too poorly understood to place much credence in it. At a minimum therefore the discussion needs to be recast so as to be less certain of the observational support for the posited sea-ice mechanism until it is much clearer whether there is in fact a long-term trend to increase underway in the real world climate system.

Similarly, the seas south of Greenland are anomalously cool relative to a mid-to-late 20th Century climatology. However, as shown in the recent ERSSTv4 analysis by Huang et al (caveat emptor applies) virtually the whole instrumental record is anomalously cold relative to this period. Certainly the recent anomalies are not unusual or unprecedented in the context of the record as a whole. Rather it is the climatology period which is unusual in the longer-term context. I therefore see little observational support that the SSTs south of Greenland are truly anomalous relative to 1880 to date.

[JN] The evidence from observations is indeed critical in obtaining a correct understanding of the processes at work in the planet's control of temperature, climate and sea level rise. The Arctic sea ice appears to take a crucial role. There appears to be a switch in progress from an ice-covered Arctic Ocean to an ocean seasonally free of ice.



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Most alarming are the observations of sea ice thickness over thirty years, confirming an exponential decline in sea ice, which if continued for a few years would lead to the low ice state. This shows that the Arctic is capable of providing the heat source necessary for rapid melting of GIS to produce up to a half metre per decade of sea level rise.

The Arctic is also implicated in climate change, since the rapid warming in comparison with lower latitudes has reduced the temperature gradient.

Conclusions

Some conclusions can be drawn from the paper, using observations of past and present workings of the Earth System, as follows:

1. The Eemian analogue provides a new argument, and throws fresh light on the situation. It is clear now that sea level change of several metres is very likely. 2. The timing of this SLR is in doubt. The authors put it "by the end of the century" whereas it can be argued that, with the Arctic Ocean liable to become seasonally free of sea ice within a few years, several metres of SLR from Greenland is possible by 2050. 3. Severely disruptive climate change is also very likely following significant sea level rise. Hansen argues for polar cooling and warm tropics, with increased storminess due to increased tropic-pole temperature gradient, whereas continued polar heating seems likely in current circumstances, with more severe climate extremes due to a further decreased gradient. 4. The authors have insight on the importance of sub-surface heat storage in saline water, and its effect on iceberg calving. 5. This effect is important in the modelling of sea ice. Conventional models fail to take account of how, as sea ice retreats, extra solar energy is stored below the surface, causing further sea ice retreat in future years. Thus the models have grossly underestimate speed of sea ice retreat and its non-linear character. 6. The authors have insight on the importance of AMOC and possible effects of a slowdown or turnoff as regards gross heat transfer to and from the Arctic. 7. Their argument that dangerous SLR and climate change can be avoided simply by emissions reduction is very tenuous. 8. The possibility of North

Atlantic mega-tsunamis producing the Bahama boulders remains, so precautions must be taken. 9. The highest priority must be to cool the Arctic and save the sea ice, because if this is not done quickly, there is an extremely high risk of devastating sea level rise and climate change to follow inevitably. 10. The long term goal must be to restore the Earth System to a state which is hospitable to humanity and capable of supporting a growing population. This goal must include reducing the CO2 level below 350 ppm (as the authors argue) as well as restoring the sea ice and restabilising the ice sheets.

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