Comments on Assertions of Pat Michaels at Grover Norquist's "Wednesday" Meeting, 5 September 2012

Topic 1. The Rate of Sea Level Rise.

1993-2012 data. Michaels uses the sea level data of Nerem et al. (2006), which is the most accurate available record of global sea level change. It is based on satellite altimetry measurements beginning in 1993, which are updated every few months and made available on a Univ. Colorado web site. The entire data set is shown here in Fig. 1a, which is an update of Fig. 12 of Hansen et al. (2011). The oscillations of the 1-year running mean sea level (red curve in Fig. 1a) are to a substantial extent a consequence of El Nino/La Nina oscillations of tropical ocean temperatures, which affect ocean heat uptake and the vertical temperature distribution in the ocean (and thus ocean thermal expansion or contraction) and also affect the storage of water on continents during La Ninas as a consequence of heavy rainfall and floods (Llovel et al., 2011). The transfer of ocean mass to continents during La Nina flooding was detected by the gravity satellite (GRACE), which measures changes of Earth's mass distribution.

Fig. 1b is a measure of tropical Pacific temperature anomalies (Nino 3.4 index), which is based on satellite measurements (ERSST) of sea surface temperature (Smith et al., 2008). The strong correlation of sea level oscillations about the trend line with the Nino index is confirmed by data for longer time scales. The sea level fall in 2011 is largely a consequence of the strong 2010-2011 La Nina, especially resulting extreme continental flooding (Llovel et al., 2011).

Tropical ocean temperatures returned to El Nino/La Nina neutral conditions by mid 2012, and sea level rose to a level above the 3.1 mm/year trend line (Fig. 1a). Fig. 1 makes it clear that

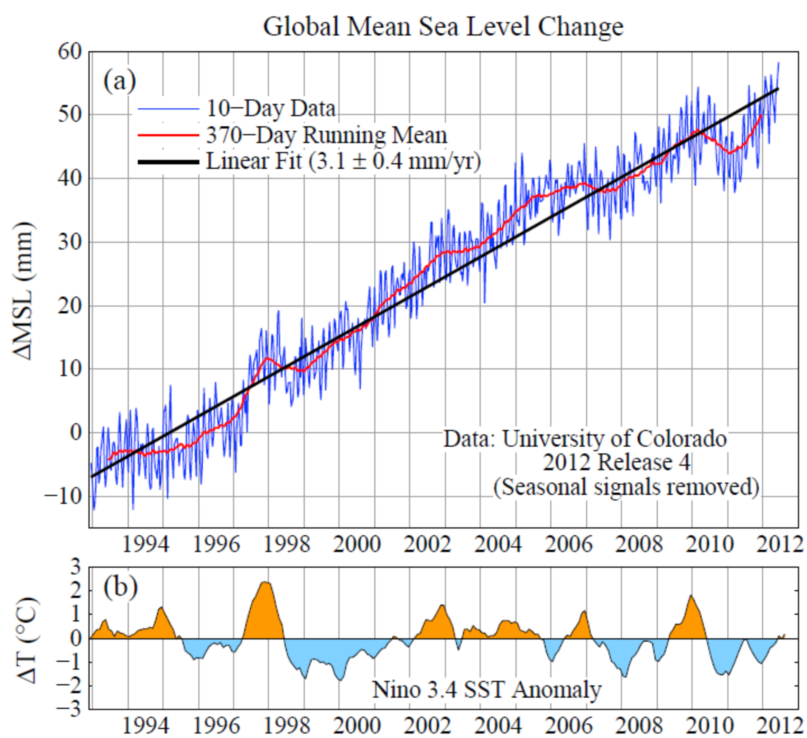

Fig. 1. (a) Sea level change based on satellite altimeter measurements calibrated with tide-gauge measurements (Nerem et al., 2006; data updates at http://sealevel.colorado.edu/), (b) Nino 3.4 index as defined at http://www.cpc.ncep.noaa.gov/data/indices/ersst3b.nino.mth.81-10.ascii. Generally El Nino conditions exist when the 3.4 index exceeds +0.5°C and La Nina conditions when the index is less than □0.5°C.

there has been no slowdown in the rate of sea level rise. ***The data shown in Fig. 1a are the data that were available in the few weeks preceding Michaels' presentation to the Norquist meeting, yet Michaels chose not to show the actual data -- perhaps because the data reveal that his claim (that the rate of sea level rise is declining) is false.***

Michaels instead used a trick to create an illusion that sea level rise is declining. He chose to calculate a sliding 10-year trend of sea level, so that the relatively warm tropical sea surface temperatures in 2002-2006 would cause the early 10-year trend to have a large sea level rise while the late 10-year trend would have a declining rate of sea level rise. The apparent decline in the rate of sea level rise is a figment of the chosen averaging period and the specific variability within the total period of data. Michaels titles his chart "Observed Decadal Rates of Sea Level Rise", but the 10 decadal bars that he creates (for 1993-2002, 1994-2003, etc.) are all constructed from 19 years of data. The variation of this "decadal" rate of sea level rise from one of his decades to another is necessarily smooth, as successive "decadal" trends are not independent, 9 of the 10 years being identical.

A further effect of Michaels' method of smoothing the data is to create the impression that we are not dealing with a noisy data set. Yet in reality it is the noise, the oscillations of the red curve in Fig. 1a about the average sea level rise (black line), that creates the "decadal" change that Michaels plots.

Michaels also uses only calendar year annual means, which allows him to avoid showing any 2012 data. Michaels uses the Univ. Colorado data updates, so he was aware that 2012 data exist and are available. ***A simple honest presentation of all the data, as in our Fig. 1a, would have made clear that the rate of sea level rise is not declining. A professor likely would give Michaels an "F" for his analysis of the rate of sea level rise. If the professor were Machiavelli, perhaps the grade would be elevated, but not much.***

Longer periods. Examination of the change of decadal rates of sea level rise requires a data set longer than 19 years. Fig. 2 combines the satellite era data with the longer tide gauge record (Church and White, 2006). Tide gauge sea level is based on a finite number of shoreline points, so local variability limits accuracy in a single year, but the trend over a long period is meaningful. At the turn of the 19th to the 20th century sea level was rising about 1 mm/year.

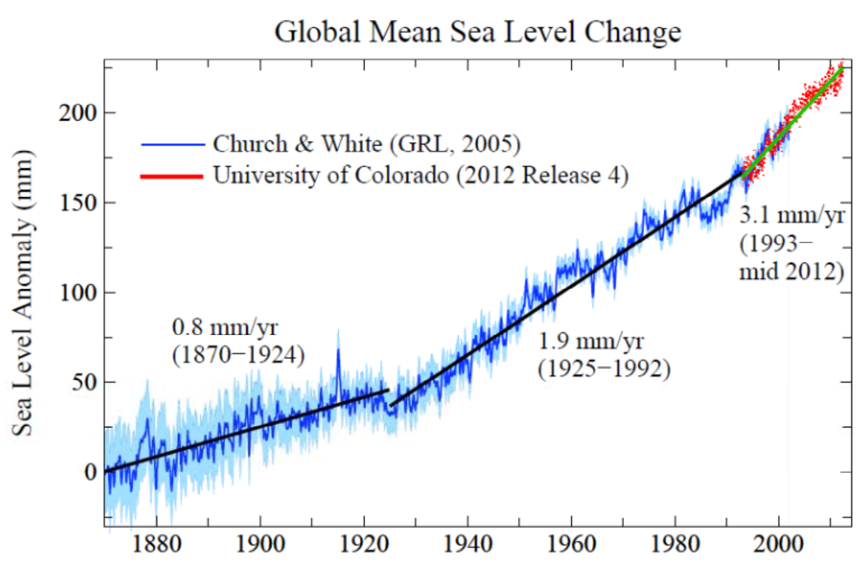

Fig. 2. Sea level change for 1870-2001 based on tide gauge measurements (Church and White, 2006) and recent satellite era data (Nerem et al., 2006) from Fig. 1.

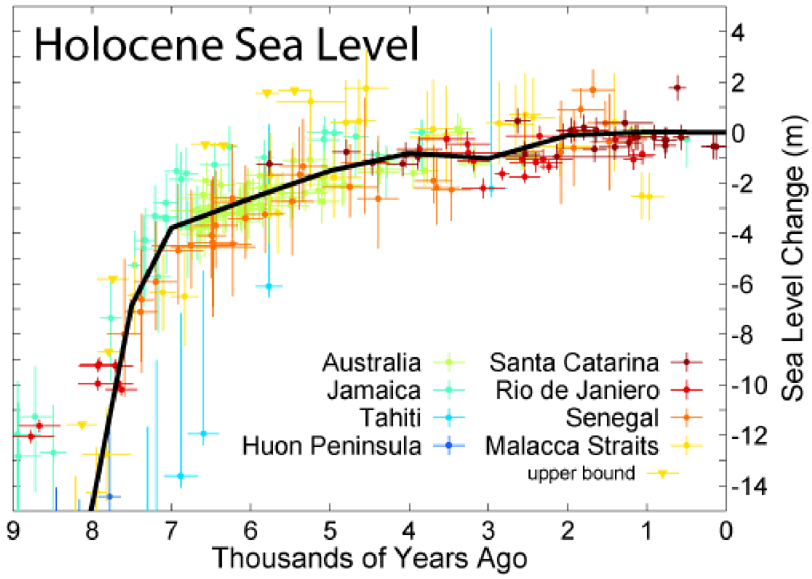

Fig. 3. Sea level during the past 9000 years relative to the present, based on data of Fleming et al. (1998), Fleming (2000) and Milne et al. (2005), as compiled by Robert Rodhe (http://commons.wikimedia.org/wiki/File:Holocene_Sea_Level.png)

The average in the 20th century rise was about 2 mm/year. In the last two decades the average rate of rise has been 3.1 mm/year.

The recent rate of sea level rise corresponds to 3.1 meters per millennium, which is at least an order of magnitude faster than sea level rise during the past 5000 years of the Holocene, when sea level rose by only 1-2 m (Fig. 3).

Discussion. Clearly the rate of sea level rise is not declining. There is general agreement in the scientific community that continued global warming is likely to cause the rate of sea level rise to increase, and that burning all the fossil fuels would cause eventual sea level rise of many meters perhaps tens of meters. The uncertainty and disagreement concern how rapidly the rate will grow. Because of its potential importance, this topic warrants discussion.

We have suggested (Hansen, 2005, 2007, 2009) that multi-meter sea level rise is likely on the century time scale, if humanity follows a "business-as-usual" greenhouse gas emissions path. If fossil fuel emissions continue to increase rapidly through this century the climate forcing will exceed any known forcing in the paleoclimate record, yet that record includes instances in which warming climate caused sea level rise as great as 4-5 meters in a century.

The West Antarctic ice sheet is the ice sheet most vulnerable to possible collapse. It rests on bedrock well below sea level, so is potentially capable of rapid escape to the ocean, raising sea level several meters. Michaels provides several citations of papers in the literature that argue for relative ice sheet stability. All of his citations refer to Greenland, not Antarctica.

Nevertheless, our opinion about the near-term vulnerability of the ice sheets is certainly at the high end of what the scientific community has discussed. We have suggested (Hansen, 2005, 2007, 2009) that the deliberate pace at which the scientific community has moved its estimates of future sea level rise to higher values could be related to a phenomenon that we describe as "scientific reticence". We continue this sea level discussion in Appendix A.

Topic 2. Surface Temperature Anomalies.

Michaels asserts that there must be a flaw in our analysis indicating nearly 10% land area covered by +3-sigma heat anomaly in Jun-Jul-Aug 2003; he states that 2003 was a cool year and the heat anomaly over Europe was very small in area. Surface temperature anomalies are shown in Fig. 4 for each Jun-Jul-Aug for the first 12 years of the 21st century. The global temperature anomaly in 2003 (+0.45°C) is in the middle of the range (0.32-0.54°C) for years 2001-2012. Thus Michaels' assertion that 2003 was globally an unusually cool year is wrong. The temperature anomalies here are from the well-documented analysis of Hansen et al. (2010).

The surface temperature anomalies for Jun-Jul-Aug of 2003 are converted to units of the local surface temperature standard deviation in Fig. 5. The portion of this land area covered by temperature anomalies of +3 standard deviations or more is 9% in agreement with Fig. 5 of Hansen et al. (2012). Thus Michaels' assertion that there must be an error in that figure is also wrong. ***Michaels' confusion may be a result of the fact that he looked at anomalies relative to a base period 1979-2003. We made the point in our paper that shifting the base period toward the present makes it easy to fool oneself into thinking that climate is not changing much. Perhaps Michaels understood and is trying to fool someone else.***

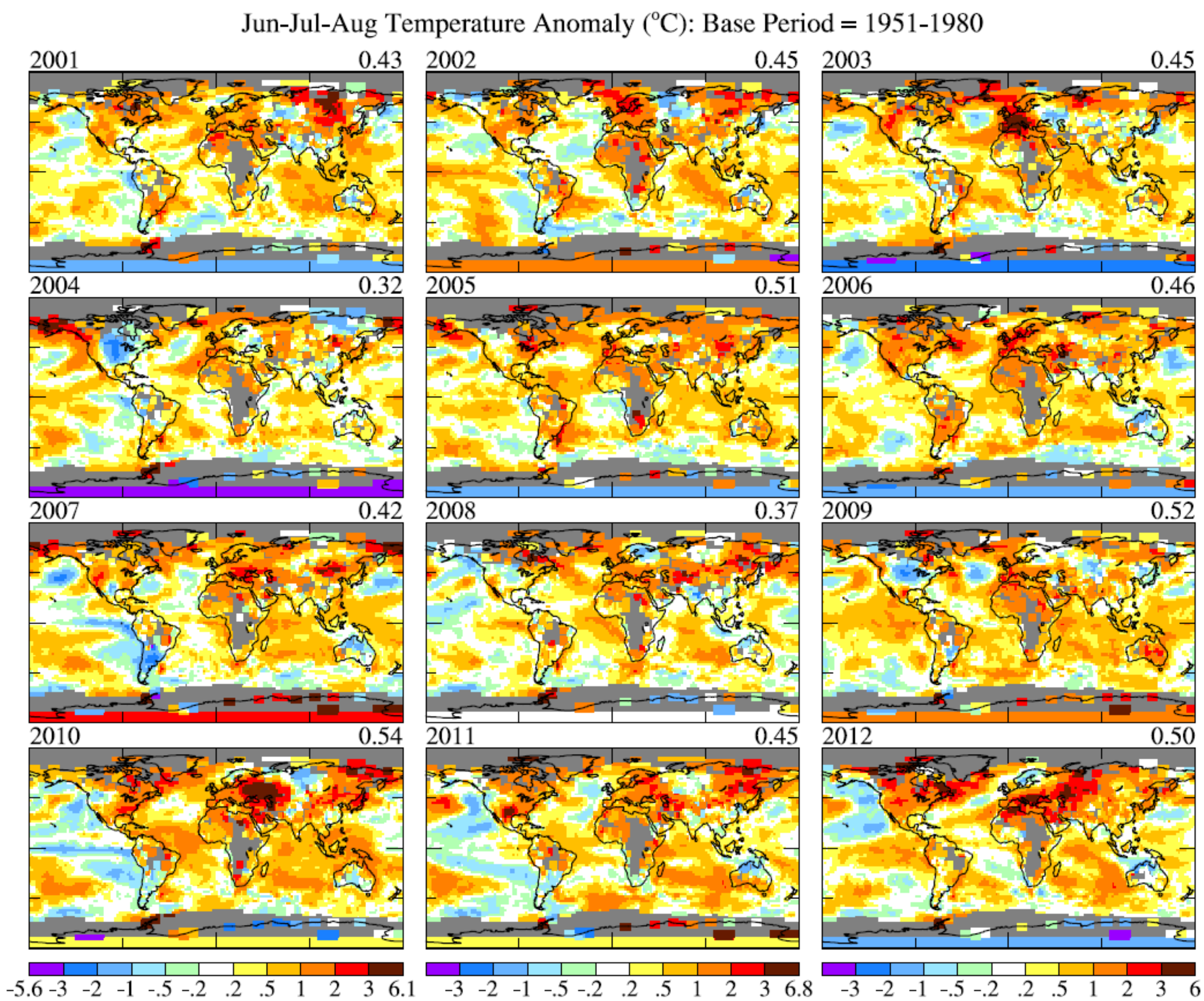

Fig. 4. June-July-August surface temperature anomalies in the first 12 years of the 21st century relative to mean 1951-1980 temperature. Number on upper right is the global mean (average over all area with data).

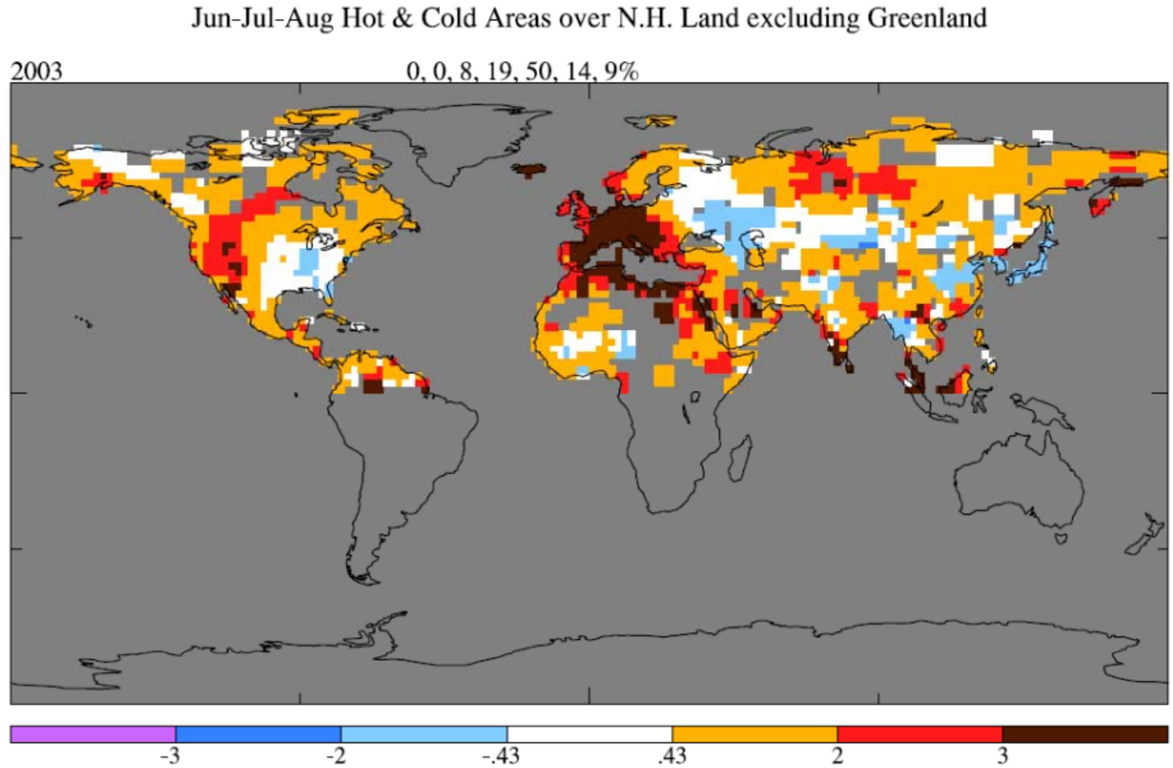

Fig. 5. June-July-August surface temperature anomalies over the Northern Hemisphere land in 2003 relative to 1951-1980 base period in units of the local 1951-1980 standard deviation. Numbers above the map are percent of surface area covered by each category in the color bar.

We have always kept the base period fixed at 1951-1980, which is a good choice for base period because it was a time of relative climate stability prior to the rapid global warming of the past three decades. Most important, the global temperature of 1951-1980 was probably still within the Holocene temperature range, i.e., the climate that existed during the period when civilization developed and to which humanity and other life on the planet are adapted. In contrast, the past two decades and in all likelihood the period 1979-2003 that Michaels employs are already outside the range of the earlier Holocene. Confirmation that global temperature is now above the prior Holocene range is provided by the fact that ice is melting all over the planet, with both Greenland and Antarctica shedding ice at substantial rates. The current rate of sea level rise, more than 3 meters per millennium is far above the rate of sea level rise in the past several thousand years.

Finally we note that the conclusion of Hansen et al. (2012) that global warming has increased the typical area of extreme summer heat anomalies (defined as +3 standard deviations or more warmer than the mean climate of the base period 1951-1980), from a few tenths of a percent of the land area several decades ago to about 10 percent now, does not depend substantially on the length of the base period. Specifically we have shown (http://www.columbia.edu/~jeh1/mailings/2012/20120811_DiceDataDiscussion.pdf) that use of a longer base period that includes the 1930s has only a moderate effect on global surface temperature standard deviations and the frequency of +3 standard deviation anomalies.

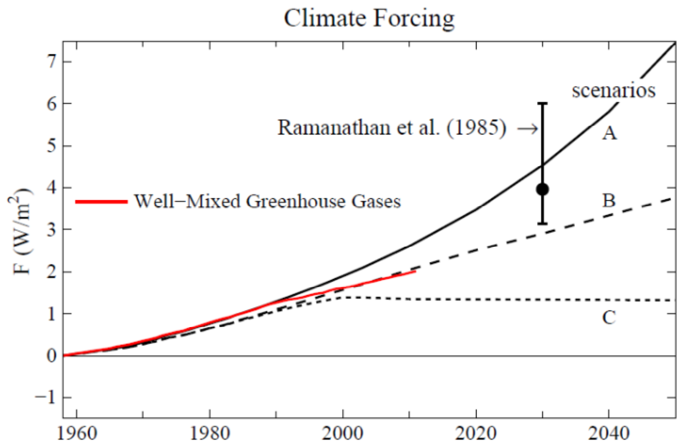

Fig. 6. Greenhouse gas climate forcing scenarios (A, B, C) used by Hansen et al. (1988) to drive climate simulations, compared with the actual greenhouse gas climate forcing (red curve).

Topic 3. Observed Warming: Comparison to Models.

Hansen's congressional testimony in 1988 was based on a paper (Hansen et al., 1988) that made global temperature projections with a climate model driven by three alternative greenhouse gas (GHG) scenarios (A, B, C), which were used to bracket likely possibilities (Fig. 6). Scenario A was described as "on the high side of reality". Intermediate scenario B was described as "the most plausible" and scenario C as "a more drastic curtailment of emissions than has generally been imagined", specifically GHGs were assumed to stop increasing after 2000.

Actual GHG climate forcing (red line in Fig. 6) has been intermediate, close to but slightly smaller than scenario B. Fossil fuel CO_2 emissions have moderately exceeded IPCC projections, but net growth of GHG climate forcing has been slightly less than in IPCC scenarios (Fig. 7), because growth of CH_4 and chlorofluorocarbons slowed sharply and because the "airborne fraction" of CO_2 emissions (the portion remaining in the air as opposed to being soaked up by the ocean, soil or biosphere) declined moderately (Hansen and Sato, 2004).

Observed global temperature change is compared in Fig. 8 with the climate simulations carried out in 1988. The red curve is an update of the observational analysis made in 1988, which is based on meteorological station records, so much of the ocean is excluded. The heavy black curve is a land-ocean temperature analysis Hansen et al. (2010) that incorporates satellite

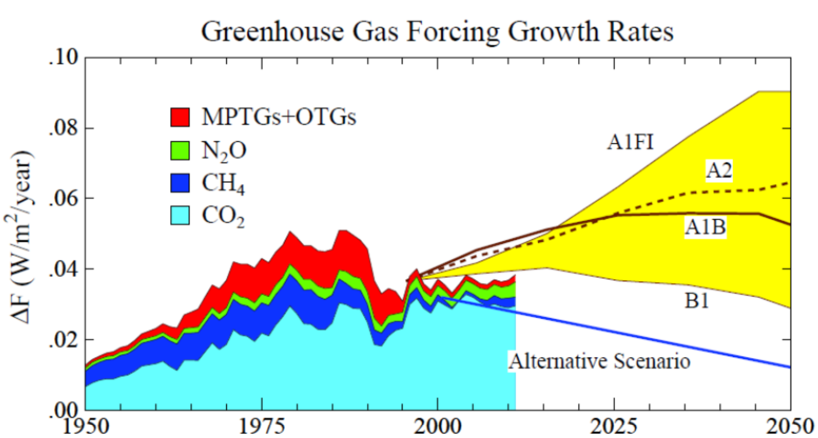

Fig. 7. Five-year running-mean of the growth rate of climate forcing by well-mixed GHGs (CO_2, CH_4, N_2O, Montreal Protocol trace gases and other trace gases (update of Hansen and Sato, 2004).

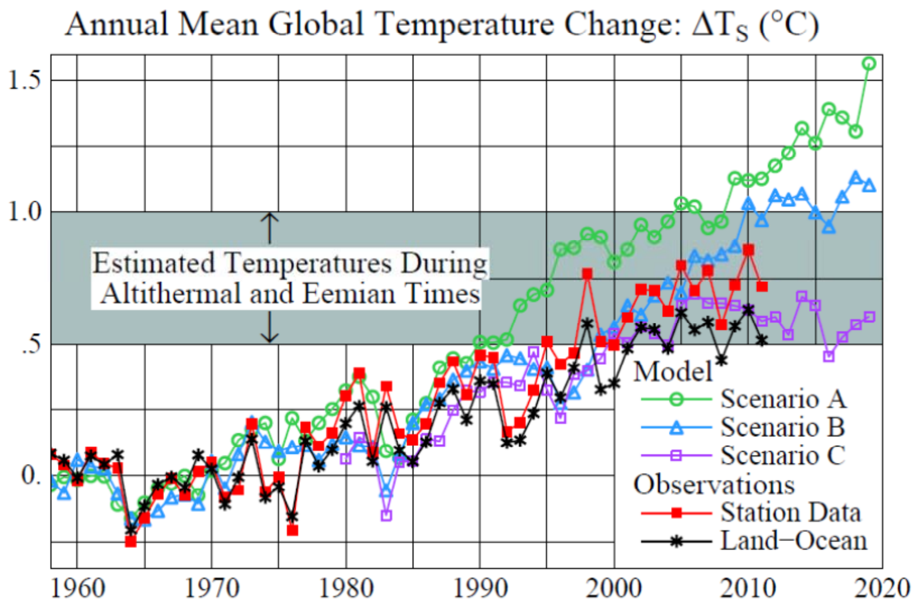

Fig. 8. Global surface temperature computed for scenarios A, B, and C, compared with two analyses of observational data. The 0.5°C and 1°C temperature levels, relative to 1951-1980, were estimated (Hansen et al., 1988) to be the maximum global temperature in the Holocene (also called Altithermal) and the prior interglacial

and ship observations thus providing practically full global coverage. The heavy black curve is therefore the most appropriate one for comparison with the global model results.

It is apparent that the real world has become warmer, as predicted by the model, but the observed warming is less than that in the climate model. Michaels is correct in saying that the observed temperature trend for 1988-2011 is substantially less than that calculated for scenario B (the 1988-2011 temperature changes based on linear fits are 0.28°C/decade for the model and 0.17°C/decade for observations). Michaels then makes no effort to explain why the modeled and observed temperatures differ, perhaps hoping the audience will leap to some conclusion such as: "wow, climate models are really over-estimating actual global warming!"

Would that were true. Unfortunately, climate models are pretty much on the mark. One should first ask obvious questions, why did this specific model run differ from observations over this period, how does it compare with other models, and what is expected as time goes on?

The most important factor is climate sensitivity, usually expressed as the model equilibrium response to doubled CO_2. The model used by Hansen et al. (1988) had sensitivity 4.2°C for doubled CO_2. The (1-D) model used by Hansen et al. (1981) had sensitivity 2.8°C for doubled CO_2. The 3-D model used for GISS contributions to the 2007 IPCC reports and dozens of climate studies over the past 6-8 years has sensitivity 2.9°C for doubled CO_2 (Hansen et al., 2005, 2007). At the time of the 1981 and 1988 studies, the scientific communities estimate of actual climate sensitivity was 3±1.5°C. More recently we (Hansen and Sato, 2012) have used paleoclimate data to conclude that climate sensitivity is more tightly constrained to 3±0.5°C.

Why did we use a model with sensitivity 4.2°C for our 1988 simulations (the first simulations of the transient climate response to time-dependent climate forcing scenario) even though the central estimate for climate sensitivity was 3°C? The climate sensitivity of such a model is not an adjustable parameter per se; instead it depends on the representations of all physical processes in the model. The physics in the GISS model resulted in a high climate sensitivity, making the GISS model a useful complement to another (GFDL) leading climate model. Charney et al. (1979) found that the GFDL model in use at that time (which had deficient sea ice and specified fixed cloud cover) yielded sensitivity ~2°C while the first GISS model (which had excessive sea ice and an amplifying cloud feedback) yielded ~4°C. It required one and half years for us to make the simulations for Fig. 8 (our computer was a used Amdahl that had been excessed by the Census Bureau), so it was not practical for us to make simulations for alternative models.

Why did Michaels choose our 1988 simulations for comparison to the real world rather than say the 1981 or 2007 Hansen et al. simulations? Hint: it probably has something to do with a fruit. The 1981 and 2007 simulations, both covering longer periods including the period shown in Fig. 8, both yielded global warming somewhat <u>less</u> than observations. Cherry-picking is unscientific and misleading; it allows a person preferring a predetermined answer to find the sweetest fruit for his purpose.

Climate sensitivity is only one of the factors affecting the ability of the climate model to accurately simulate the real world. The other most important factor is the accuracy of the climate forcings that drive the model. Although the history of atmospheric CO_2 in the past century is known with high precision, the same is not true for all forcings, especially the forcing by atmospheric aerosols (small particles), which has not been measured accurately even though the capability to do so has been proven (Mishchenko et al., 2007).

The Hansen et al. (1981) study assumed that CO_2 change was the dominant human-made forcing, which amounted to a presumption that warming by non-CO_2 human-made GHGs was approximately balanced by cooling by human-made aerosols over the period of simulation (1880-2020). By the time of the 1988 study, data was available showing that non-CO_2 GHGs substantially enhanced the GHG forcing (see Fig. 7), so their positive forcing was included. However, the aerosol forcing remained unmeasured, and there were substantial efforts in the United States and Europe to reduce aerosol pollution that may have partially balanced increasing aerosols in developing countries for the post-1958 period considered. Therefore, in the absence of measurements, no human-made aerosol forcing was included in the climate simulations. Present efforts to model tropospheric aerosol formation suggest that there probably was some global increase of human-made aerosols during 1958-present, which aerosols probably produced a moderate negative climate forcing over that period. Thus the net forcing in the Hansen et al. (1988) simulations may have been somewhat too large. The 2007 GISS simulations include aerosol changes, but these are based on aerosol models that are primitive and uncertain. Thus until aerosols are measured there will be a range of assumed climate forcings, which will leave uncertainty and encourage cherry-picking by people who have preferred answers.

<u>**Discussion**</u>**.** Global temperature simulated by climate models depends upon a number of factors, especially the model's climate sensitivity and the forcings used to drive climate change. Scientific understanding about climate sensitivity and about climate forcings have improved substantially over the past few decades, but enough uncertainty remains to allow cherry-picking among many different climate model results. However, ***an important point is that climate models are not the principal basis of our concerns about future climate change, as made clear in my presentation (Appendix B), which relied on observations, not climate models.***

Topic 4. PNAS Review Procedures.

Michaels charges that the Proceedings of the National Academy of Sciences (PNAS) has loose editorial review procedures, which he terms "pal review", citing the fact that members of the National Academy of Sciences are allowed to submit papers to PNAS accompanied by reviews of two relevant experts and copies of the correspondence between the author and those experts. This assertion is made with regard to our 2012 paper on the changing frequency of extreme seasonal climate "Perception of Climate Change".

The reality is that the PNAS procedures for approving papers can be more strict and arduous than most peer-reviewed journals. The paper in question was reviewed in detail with open constructive reviews by two of the top relevant experts in the world, Andrew Weaver and Tom Karl. It then went through two rounds of review by anonymous editorial board member(s). Finally, the editor himself became involved in the reviewing, requiring the deletion of "The New Climate Dice" from the title of our paper (the paper was originally submitted as "Public Perception of Climate Change: The New Climate Dice").

Topic 5. Key Science Issues.

My presentation (Appendix B) at the Norquist meeting did not employ climate models. Instead it was based on observations of on-going climate change in the real world. Recent advances in our understanding of climate change have come primarily from climate observations, including paleoclimate data.

1. <u>Extreme Weather</u>. Local weather fluctuations are always large, even with weather averaged over a season. Yet weather extremes are affected by global warming, and weather extremes have the largest practical impacts. Based only on observational data, we showed that the variability of local summer-average temperature is increasing and the global distribution of summer-average temperature anomalies is shifting noticeably hotter (Hansen et al., 2012). ***The land area with extreme high summer temperature anomalies, of a degree that covered only a few tenths of one percent of the land 50 years ago, now covers about 10 percent of the land each summer. Such extreme heat anomalies occurred in Texas-Oklahoma in 2011 and in the Central Rockies and Great Plains in 2012.*** The steady decade-by-decade march of global seasonal-mean temperature anomalies toward higher temperatures is a graphical representation of global warming. Thus ***based on observational data alone we can conclude that the increased frequency of hot extremes is caused by global warming.*** These increased hot extremes occur preferentially in areas where weather patterns create sustained high atmospheric pressure, thus leading to more extreme droughts as well as more wildfires that cover greater area, burn hotter, and are more damaging.

2. <u>Earth's Energy Imbalance</u>. We showed that ***Earth is out of energy balance, more energy coming in than going out, i.e., the amount of solar energy absorbed by Earth exceeds the heat energy that Earth is radiating to space*** (Hansen et al., 2011). The imbalance is a consequence of increasing greenhouse gases, mainly CO_2 from fossil fuel burning, which act like a blanket, reducing heat radiation to space. Knowledge of the imbalance is based on measurements. The imbalance occurs even during a period when the sun is at its dimmest level in the period of accurate solar monitoring, confirming that the human-made forcing overwhelms the principal natural climate forcing. ***An important implication of the energy imbalance is that there is additional global warming "in the pipeline" comparable in magnitude to the warming that already has occurred.***

3. <u>Paleoclimate Implications</u>. Earth's history reveals that climate is highly sensitive to climate forcings, i.e., perturbations of Earth's energy balance that alter global temperature. Climate sensitivity, beginning from today's climate state, is about 3°C for doubled atmospheric CO_2, including only feedback processes such as changes of water vapor, clouds and sea ice that respond rapidly as climate changes. However, paleoclimate data also show that the dominant feedback processes on time scales of centuries and millennia, such as changes of ice sheet size, are amplifying feedbacks, increasing the expected long-term response to a given forcing.

Earth's climate history reveals that global warming of even 1-2°C has important consequences. Climate has been relatively stable during the current interglacial period, the Holocene, which is now more than 10,000 years long. ***The prior interglacial period, the Eemian, was only about 1°C than the Holocene maximum, yet sea level was at least 4-6 meters higher than today.***

Paleoclimate data are less useful for informing us about the speed at which changes will occur as climate warms in the 21st century. There are no paleo cases in which climate forcings increased as rapidly as they will this century if fossil fuel emissions continue to increase. Yet the weaker natural forcings in some cases induced rapid climate response including sea level rise as much as several meters in a century, suggesting that ***real-world ice sheets are not as lethargic as today's primitive ice sheet models suggest.*** However, there is a wide range of opinion among scientists about how rapidly sea level is likely to rise this century.

4. <u>Carbon Budget</u>. ***Carbon dioxide that humans release by burning fossil fuels will determine the future of Earth's climate for the next 100,000 years.*** That carbon will stay in surface carbon reservoirs (atmosphere, ocean, soil, biosphere) for many millennia, until the weathering process eventually removes the CO_2 via carbonate deposition on the ocean floor.

The eventual climate response to a doubling of pre-industrial atmospheric CO_2 would be a global warming of several degrees Celsius, which would probably melt most of the ice on Earth and lead to sea level rise of tens of meters. The science is thus clear: ***we cannot burn all, or even most, of the fossil fuels without unacceptable consequences***. Yet the public and policy-makers seem to be blithely unaware of the situation, as fossil fuel companies are encouraged to continue to pursue every fossil fuel they can find. This widespread ignorance of the carbon budget has created a situation of great urgency -- for ***as we fail to initiate a transition to a low-carbon energy future, the costs of acting will escalate as will the costs of climate impacts -- and many climate consequences may become unavoidable***.

Appendix A: Sea Level Rise

The most recent Intergovernmental Panel on Climate Change report (IPCC, 2007) estimated sea level rise of about one-third to one-half meter this century due to global warming, but they explicitly excluded any sea level contribution from Greenland and Antarctic ice sheet dynamics (disintegration), because understanding of relevant processes was too primitive. Unfortunately, it is the potential ice sheet disintegration that is of greatest concern.

Subsequent to the IPCC (2007) report there have been several studies suggesting that inclusion of ice sheet dynamics raises the estimated sea level rise this century to about one meter. These studies also conclude that sea level rise after 2100 would continue at an even more rapid rate, but this latter conclusion receives little discussion, apparently under the assumption that it is impossible to get politicians or the public to consider any time scale longer than 88 years.[1]

A one-meter sea level rise alone would have enormous economic consequences, but we have argued (e.g., Hansen, 2005, 2007) that ice sheet disintegration is a highly non-linear process spurred by amplifying feedbacks and that the "business-as-usual" human-made climate forcing expected this century is so large that multi-meter sea level rise is likely by the end of the century. We have supported our opinion with evidence from Earth's history, which includes instances of multi-meter sea level rise in a century spurred by climate forcings much smaller than the human-made increase of greenhouse gases. Nevertheless, we do not deny that our expectation of multi-meter sea level rise in this century, if rapid growth of fossil fuel emissions continues, seems to be a distinctly minority opinion within the scientific community.

However, we have noted the phenomenon of "scientific reticence" (Hansen, 2007, 2009), which perhaps plays a role in the sea level rise discussion. Scientific reticence refers to the cautionary movement toward a changed perspective on a given scientific issue, and a reluctance to speak out about an emerging suspicion or tendency [cf. pp. 87-89 of Hansen (2009) and Hansen (2007)]. Caution has its merits and scientific reticence probably has its origin in the scientific method itself: success in science depends on continual objective skepticism. Yet we may rue our reticence if it serves to lock in future ice sheet disintegration.

"Lock-in" is a threat that arises from the inertia of the climate system, especially inertia of the ice sheets and the ocean. Climate inertia is both our best friend and worst enemy. The ocean, on average, is four kilometers deep and ice sheets are three kilometers thick. Because of their huge masses the ocean and ice sheets respond only slowly to the steadily increasing human-made climate forcing caused by increasing greenhouse gases. Thus the climate system has only partly responded to the greenhouse gases that are already in the air.

This climate inertia is our friend because it would allow us to avert, or at least minimize, additional climate change by reducing emissions to a level that allows growth of greenhouse gases to slow, or even reverse, as the Earth system absorbs some of the greenhouse gases. However, climate inertia is also our enemy because it can lead to further change being built in, if we push the system beyond tipping points, so that the dynamics of the climate system takes over.

The basic issue is whether disintegration of an ice sheet is approximated better as a linear or a nonlinear process that can be characterized by a doubling time for the rate of mass loss. We have argued (Hansen, 2005, 2007, 2009) that amplifying feedbacks (e.g., as an ice sheet begins to melt it becomes darker, thus absorbing more sunlight and melting faster) favors a nonlinear

[1] Curiously, humanity becomes increasingly short-sighted with each passing year. For example, in 2005 people were willing to consider time scales up to 95 years. The same phenomenon occurred in the 1900s, when people were uninterested in events beyond year 2000. Amazingly, a new century did arrive, and we are now well into it.

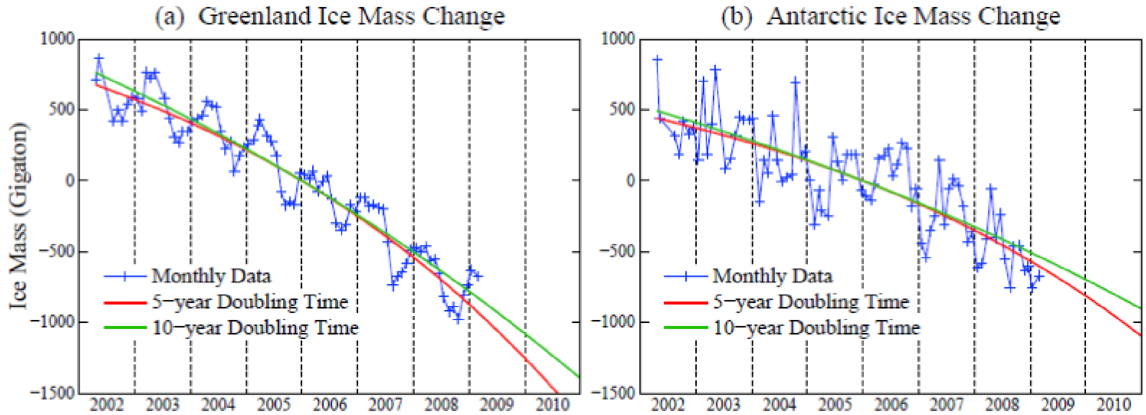

Fig. 4. Greenland and Antarctic mass change deduced by Velicogna (2009) from satellite gravitational field measurements and best-fits with 5-year and 10-yearr doubling times.

process. There are also diminishing feedbacks, e.g., once ice sheet mass loss is fast enough the resulting icebergs cool the ocean, but Earth's paleoclimate history suggests that multi-meter sea level rise can occur before this diminishing feedback becomes an effective brake.

Observed rates of mass loss by the Greenland and Antarctic ice sheets (Fig. 4), based on satellite measurements of Earth's changing gravitational field (Velicogna, 2009) are accelerating. There is uncertainty in actual mass loss rates, primarily because of the difficulty in accounting for isostatic adjustment of Earth's crust as the ice sheet mass changes (Peltier, 2009), but recent evaluations show that the rate of mass loss is continuing to accelerate (Rignot et al., 2011). Continued observations of the ice sheet masses are probably the only way to obtain definitive assessment of the nonlinearity of mass loss. Available data (Rignot et al., 2011) indicate that the rate of change of the mass loss rate is increasing (positive 2nd derivative), but to confirm that the process is exponential and can be characterized by a doubling time we need to know that the 3rd derivative (the rate of change of the rate of change of the mass loss rate!) is positive, which requires a longer record.

The accelerating mass loss from Greenland and Antarctica raises a question: why has the rate of sea level rise been nearly constant during 1993-2012? We have suggested (Hansen et al., 2011) that during the past 20 years the two largest changes to the rate of sea level rise have been ice sheet mass loss and thermal expansion of ocean water, and these two processes have tended to be offsetting.

During the latter part of the 1993-2002 period the major individual contributions to sea level rise can be evaluated from accurate measurements of Earth's gravitational field that began in 2002 and from Argo float measurements of ocean heat that became sufficiently global (about 3000 floats) in 2005. The gravity satellite allows assessment of the mass change not only of the Greenland and Antarctic ice sheets, but also large mountain glaciers and ice caps. The Argo floats measure changes of the ocean vertical temperature profile and thus thermal expansion of ocean water.

These data sources indicate that sea level rise since the middle of the last decade is due primarily to three processes (Fig. 14 of Hansen et al., 2011), with each of them contributing of the order of 1 mm/year to the observed sea level rise of about 3 mm/year: (1) mass loss by Greenland and Antarctic ice sheets, (2) mass loss by mountain glaciers and small ice caps, (3) thermal expansion of ocean water.

Mass loss from the ice sheets probably was near zero (mass balance) at the beginning of the period 1993-2012 (Zwally and Giovinetto, 2011; Zwally et al., 2011), increasing to of the order of 1 mm/year contribution to sea level at the end (1 mm sea level is 360 cubic kilometers of water or 360 billion tons of water). Mass loss from glaciers and small ice caps was reasonably constant through that 20 year period (Meier et al., 2007). Thermal expansion of ocean water would have been largest at the beginning of the 1993-2012 period because of the 1991 Pinatubo volcanic eruption and the resulting ocean cooling during 1991-1993 (Hansen et al. 2011).

Improved understanding of sea level rise depends upon continued precise gravity field observations and Argo float measurements. If our expectation that mass loss from the ice sheets may double over the next decade is borne out, sea level rise is likely to increase to 4 mm/year within about a decade and continue to accelerate thereafter.

Unfortunately if we "wait and see" how sea level rise develops, we may guarantee that even much greater changes occur in the future. Fortunately, there are other very good reasons to begin to reduce emissions of greenhouse gas emissions now and move toward a clean energy future.

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Appendix B: Hansen Charts, Norquist Meeting on 5 September 2012

Global temperature fluctuates, but the world is getting warmer

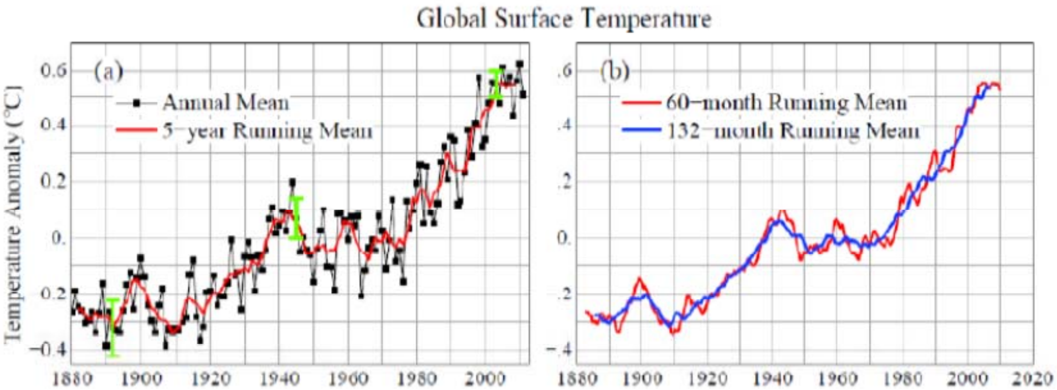
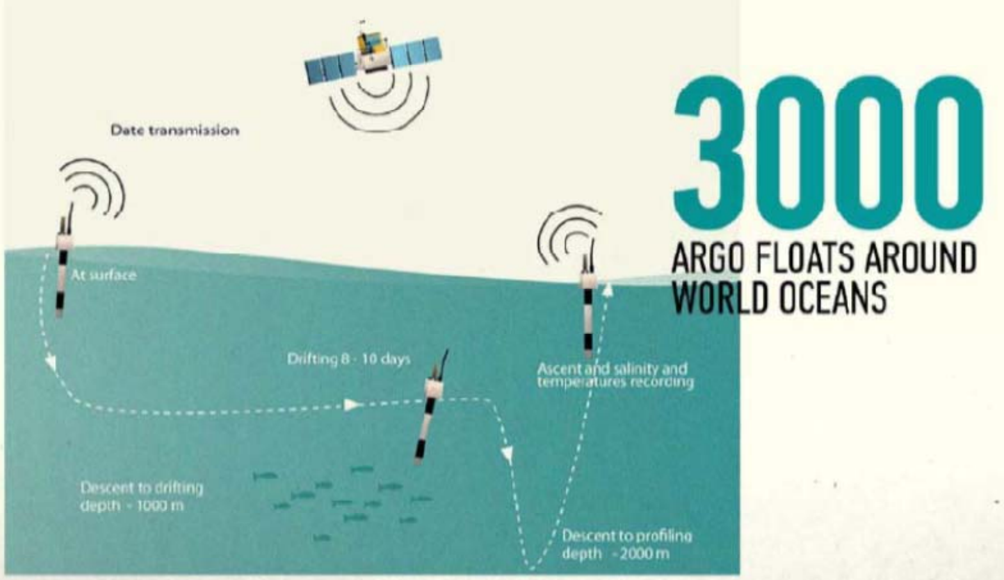


Figure 1. Global surface temperature anomalies relative to 1951-1980 average for (a) annual and 5-year running means through 2010, and (b) 60-month and 132-month running means through July 2012. Green bars are 2-σ error estimates.

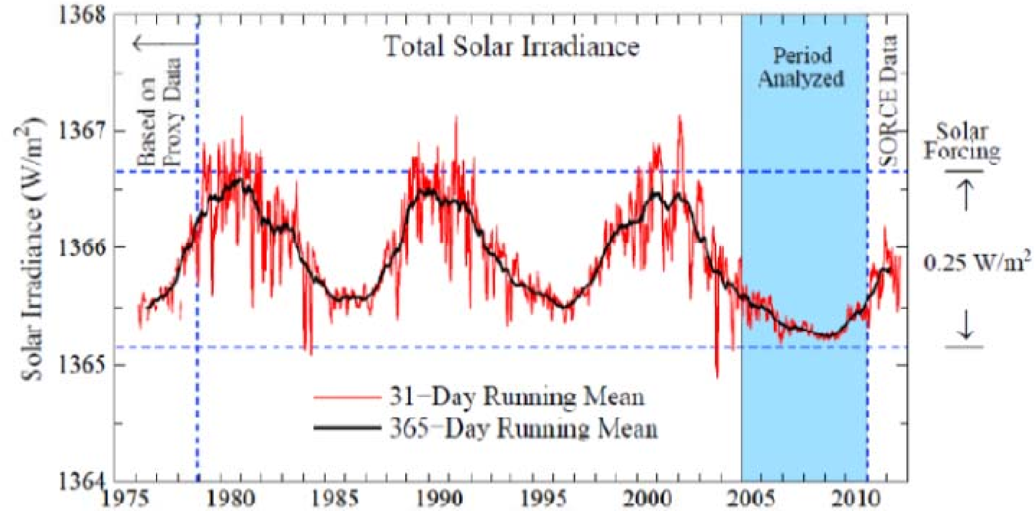
(Hansen. J.. Ruedy. R.. Sato. M.. and Lo. K.. 2010: Global surface temperature change. Rev. Geophys. 48. RG4004.)

Earth's energy imbalance: more energy coming in than going out



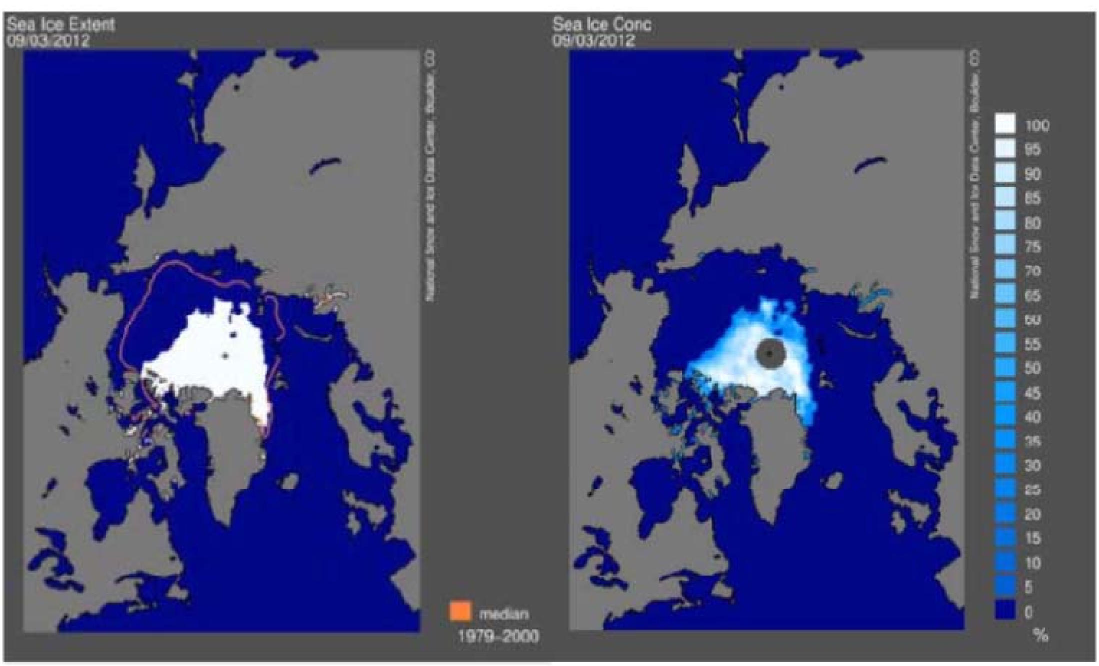
ARGO floats have allowed accurate measurement of ocean heat gain since 2005. Earth is gaining energy at a rate 0.6 W/m², which is 20 times greater than the rate of human energy use. That energy is equivalent to exploding 400,000 Hiroshima atomic bombs per day, 365 days per year.

Earth's energy imbalance, more energy in than out, was measured when the energy from the Sun reaching Earth was at its lowest level in the period of accurate data.
This confirms that solar variability effects are overwhelmed by greenhouse gases.



Solar energy reaching Earth; energy absorbed per m² of Earth's surface is ~240 W, so 0.1% solar variability is a climate forcing of almost 0.25 W/m².

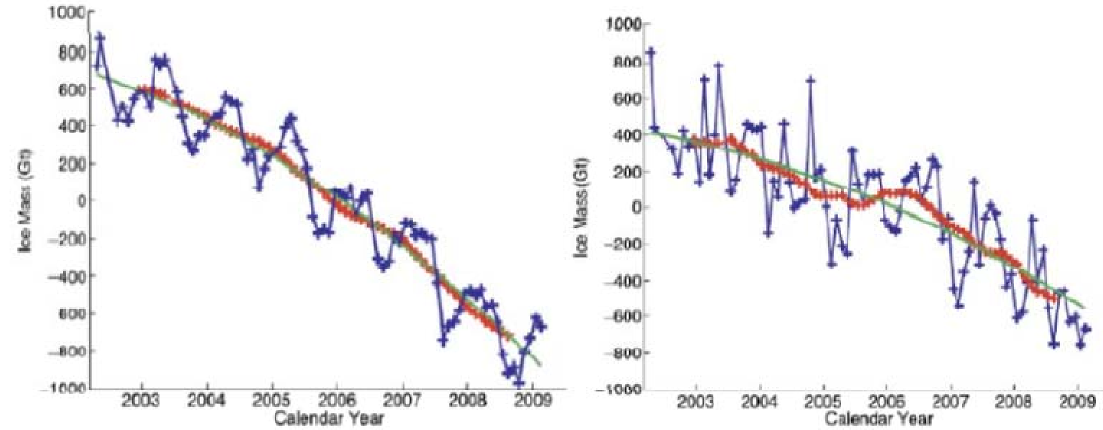
(Update, through Aug. 2012, of Fig. 17 of Hansen et al., Atmos. Chem. Phys., 11, 13421-13449, 2011. Data through 2 Feb. 2011 is from Frohlich and Lean; more recent data from Univ. Colorado, SORCE experiment.)



Left map: sea ice extent (>15% ice). Right: sea ice concentration (%).
Purple line: climatologic extent (1979-2000). Data: 3 September 2012.

Source: National Snow and Ice Data Center, Boulder, Colorado

Gravity Satellite Ice Sheet Mass Measurements



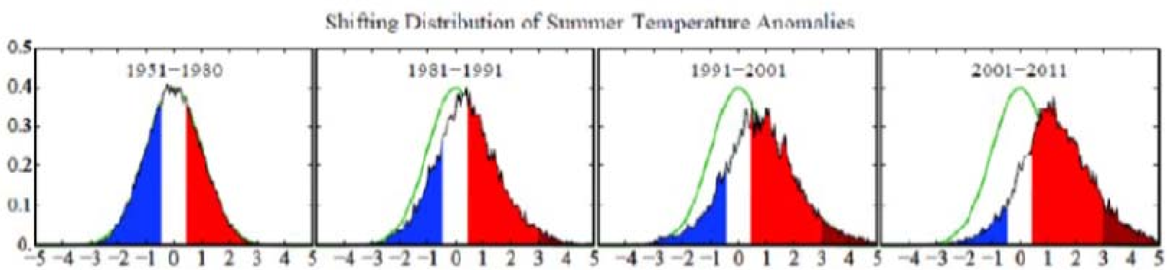
Greenland Ice Sheet **Antarctic Ice Sheet**

Source: Velicogna, I. *Geophys. Res. Lett.*, **36**, L19503, doi:10.1029/2009GL040222, 2009.

Loaded Climate Dice: global warming is increasing extreme weather events.

Extreme summer heat anomalies now cover about 10% of land area, up from 0.2%.

This is based on observations, not models.



Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies (relative to 1951-1980 mean) for Northern Hemisphere land in units of local standard deviation (horizontal axis). Temperature anomalies in the period 1951-1980 match closely the normal distribution ("bell curve", shown in green), which is used to define cold (blue), typical (white) and hot (red) seasons, each with probability 33.3%. The distribution of anomalies has shifted to the right as a consequence of the global warming of the past three decades such that cool summers now cover only half of one side of a six-sided die, white covers one side, red covers four sides, and an extremely hot (red-brown) anomaly covers half of one side.
Source: Hansen, J., Sato, M., and Ruedy, R., Proc. Natl. Acad. Sci., 2012.

Nuclear Power Technology: The Case for U.S. Leadership

Background: The U.S. abandoned its leadership role in advanced nuclear power technology development in 1993 when the President announced that DOE would terminate its development of "unnecessary" 4th generation nuclear technology. Yet the Integral Fast Reactor (IFR) technology that Argonne National Laboratory had developed is still the best approach for solving nuclear power issues and providing an inexhaustible clean energy supply. The U.S. could still lead the implementation of this potential, and derive the benefits, if we move promptly. Principal merits of this technology:

1. Dovetails with current generation (light-water) reactors, "burning" their nuclear waste; solves nuclear "waste" problem, reducing lifetime of remaining waste to a few centuries

2. Utilizes >99% of nuclear fuel (light-water reactors use ~1%, remainder is long-lived "waste")

3. Existing uranium stockpiles + nuclear "waste" are sufficient fuel to last several centuries; sea water provides sufficient nuclear fuel to last as long as the sun (billons of years)

4. Can lead to secure sequestration of virtually all of the world's plutonium

Summary: U.S. leadership is crucial for solving the interrelated issues of: (1) adequate global supply of clean energy, (2) accumulating nuclear "waste" from 2nd and 3rd generation light-water reactors, (3) minimizing dangers of proliferation of weapons-grade nuclear material. If the U.S. does not resume the technologic and geopolitical lead in this area, global development of nuclear technology will be anarchistic and dangerous.

Fee & Dividend

Fee: Collected at Domestic Mine/Port of Entry

Covers all Oil, Gas, Coal → No Leakage

Dividend: Equal Shares to All Legal Residents

Not One Dime to the Government.

Merits:

Transparent. Market-based. Stimulates Innovation.

Does Not Enlarge Government.

Leaves Energy Decisions to Individuals.

A Conservative Energy & Climate Plan.