Climate Change Briefing for Policymakers

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Climate change is already having severe impacts on our world and, going forward, poses a clear and present danger unless we immediately begin to lower global greenhouse gas emissions. It is the emissions between now and 2050 that will largely determine the fate of human civilization.

Basic climate science:

1. **Greenhouse Gases**. Global warming and climate change are caused by an increasing concentration of greenhouse gases ("GHGs") in the atmosphere. While the concentration of GHGs is quite small (the pre-industrial concentration of CO_2 in the atmosphere was 0.028% or 280 parts per million ("ppm")), these GHGs are very effective at trapping heat radiating from the Earth. There are many lines of evidence that confirm that **human activities are the main cause for increased GHG concentrations in the atmosphere** (CO_2 now stands at 0.040% or 400 ppm). You can think about GHGs like a blanket around the Earth keeping it warm. We are in the process of doubling and perhaps tripling the thickness of the blanket this century.

2. **Cumulative Carbon Emissions**. Climate change is unlike all other "environmental" problems in that it is a one-way street. With a polluted river or lake, once you stop polluting it, it will get less polluted over time and eventually will be clean again. However, **the carbon pollution we spew into the atmosphere lasts there for hundreds to thousands of years** and there are currently no practical means to remove it. Theoretical geo-engineering "air capture" methods to remove CO_2 from the atmosphere, if they could be developed, would be difficult to deploy and would cost trillions of dollars a year to operate. Also, the oceans absorb 90% of global warming heat energy and act like a giant flywheel keeping temperatures elevated even after we stop putting greenhouse gases in the atmosphere. Here are a few facts about carbon pollution and climate change from the National Research Council:

- The peak warming is linearly proportional to the *cumulative* carbon emitted
- It doesn't matter much how rapidly the carbon is emitted - it is only the total cumulative amount emitted that matters
- ***The warming you get when you stop emitting carbon is what you are stuck with for the next thousand years***
- The climate recovers only slightly over the next ten thousand years
- At the mid-range of IPCC climate sensitivity, a trillion tonnes cumulative carbon gives you about +2ºC global mean warming above the pre-industrial temperature.

These facts have profound implications for climate policy. It is the emissions between now and 2050 that will largely determine the fate of human civilization. We have already emitted about 580 gigatons of carbon (GtC - not to be confused with gigatons of CO_2), and to have some chance to stay below +2ºC (+3.6ºF) warming we can, ignoring the melting permafrost, emit only about another 630 GtC of carbon, *something we are on track to do later this century*. Therefore, **only policies that result in near-term and significant reductions in *global* greenhouse gases will play a primary role in preserving a livable climate for our children**. Note that the melting permafrost will significantly reduce the allowable carbon we can emit and still stay under +2ºC (see Section 12 below). Also, +2ºC warming is too much (see next section).

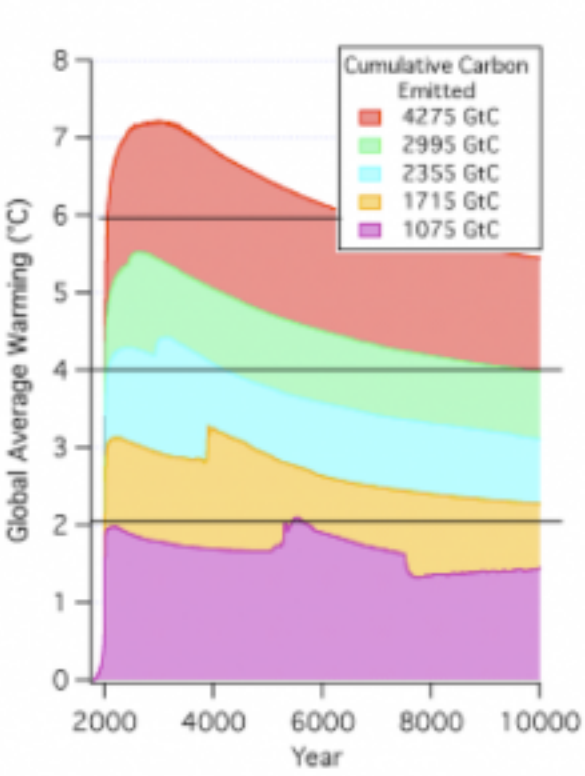

Figure 1. Impact of cumulative carbon emissions (gigatons of carbon "GtC") vs. global average warming. Note that the peak warming decreases only slightly over 10,000 years.

Sources: National Research Council. *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*. Washington, DC: The National Academies Press, 2011. http://dels.nas.edu/materials/booklets/warming-world
Kevin Anderson, Climate Change Going Beyond Dangerous - Brutal Numbers and Tenuous Hope. Development Dialogue, September 2012, What Next Volume III, Climate, Development and Equity http://www.whatnext.org/resources/Publications/Volume-III/Single-articles/wnv3_andersson_144.pdf

3. **+2ºC Warming is Too Much.** Almost every government and scientific academy agrees that we should not exceed +2ºC (+3.6ºF) warming over the pre-industrial average temperature. Since policies are not in place to limit warming to +2ºC, we are, therefore, in the process of voluntarily committing ourselves to a +2ºC and beyond

world. Recent studies suggest that **allowing warming to reach even +2ºC will have catastrophic consequences for the United States and the rest of the world**. The reasons for this are twofold. First, paleoclimate data as well as measured climate impacts over the past decade show that **the assumptions used to come up with the +2ºC "firewall" threshold were too optimistic.** For example, while the IPCC predicted an ice-free Arctic around 2100, the Arctic sea ice minimum has declined about 75% in volume over the past 30 years and the Arctic is expected to be virtually ice-free (for the first time in human history) within this decade or shortly afterwards. Second, paleoclimate data and recent observations suggest that "slow" feedbacks (such as melting of the Arctic sea ice that exposes dark water instead of reflective ice, and the melting of the permafrost that releases greenhouse gases) will not be so slow and, therefore, **a +2ºC warming will cause the world to warm further**.

Sources: Hansen J, Kharecha P, Sato M, Masson-Delmotte V, Ackerman F, et al. (2013) *Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*. PLoS ONE 8(12): e81648. doi:10.1371/journal.pone.0081648, http://www.plosone.org/article/fetchObject.action?uri=info%3Adoi%2F10.1371%2Fjournal.pone.0081648&representation=PDF and summary: http://www.columbia.edu/~jeh1/mailings/2013/20131202_PopularSciencePlosOneE.pdf
UK Met Office: http://www.metoffice.gov.uk/research/news/2014/global-carbon-budget

4. **Coal vs. Natural Gas**. Coal burning for electricity production is one of the main sources of excess CO_2 emissions. In addition to CO_2 emissions, coal burning is also a source of mercury, soot, sulphate, and other forms of pollution. Natural gas ("NG") has been promoted as a "clean" alternative to coal. While it is true that NG does not contain significant amounts of mercury, soot, sulphates, and similar forms of pollution, NG is mostly methane and methane is an extremely powerful greenhouse gas.

From a global warming point-of-view, NG is incorrectly viewed as having a significantly lower warming potential than coal. It is often noted that NG when burned in a power plant produces about half as much CO_2 per unit of energy produced compared with coal but, while that is true, it is not the full story. The lifecycle GHG emissions from NG includes the methane emitted during the exploration, extraction, transportation, and use phases. These "fugitive" emissions, especially when hydraulic fracturing or "fracking" is used, are estimated to be in the range of 1 to 6% of the total NG extracted, though there is much discussion and controversy about these figures. A recent NOAA study measured fugitive emissions from a fracked natural gas field to be approximately 4%, which does not include downstream emissions[1].

A study of recent life cycle assessments of coal and natural gas GHG emissions show that, **at best, natural gas is 25% "less bad" than coal and some assessments show them to be about the same**[2]. Further, over a 10 to 20 year period, NG is worse than coal since methane takes about a decade to degrade to CO_2 in the atmosphere and before it degrades methane is over 100 times more powerful than CO_2 in trapping heat.

Even if NG produces somewhat less net GHG emissions than coal, ***switching from coal to natural gas will raise global temperatures slightly for 100 years***[3]. This is because coal burning produces sulphates that act to reflect sunlight and, the sulphates therefore, cool the Earth. Natural gas burning does not release significant amounts of sulphates and it takes about 100 years for the possible lower GHG benefit of NG to overcome the cooling effect of sulphates from coal.

In addition, studies show that low priced **natural gas** will not only replace some coal use but **will also offset zero-carbon renewable energy and, therefore, results in higher emissions than the case where natural gas use is not expanded.**

Since we need to quickly and dramatically lower our fossil fuel emissions, **switching from coal to natural gas will not help us avoid catastrophic outcomes**. It's a bit like a doctor telling a patient that they must stop smoking 4 packs of cigarettes a day or they will die soon, and the patient says, "Don't worry doc, I'll cut back to 3 packs a day!"

Sources: (1) *Nature* **482,** 139–140 (09 February 2012) doi:10.1038/482139a
http://www.nature.com/news/air-sampling-reveals-high-emissions-from-gas-field-1.9982
(2) Deutsche Bank Group, DB Climate Change Advisors and Worldwatch Institute, *Comparing Life Cycle Greenhouse Gas Emissions from Natual Gas and Coal*, August 25, 2011, Figure ES-1
http://www.worldwatch.org/system/files/pdf/Natural_Gas_LCA_Update_082511.pdf
(3) Tom Wigley, *Coal to gas: The influence of methane leakage,* https://www2.ucar.edu/atmosnews/news/5292/switching-coal-natural-gas-would-do-little-global-climate-study-indicates
(4) Changing the Game?: Emissions and Market Implications of New Natural Supplies, Emissions Modeling Forum Report #26, Volume 1, Stanford University. http://emf.stanford.edu/publications/emf_26_changing_the_game_emissions_and_market_implications_of_new_natural_gas_supplies/

The climate has already changed:

5. **"Extremely Hot Summers"** have already increased by more than a factor of 50 (5000%) in the past 50 years and, therefore, we know with very high confidence (>90%) that certain extreme heat events — such as the recent Texas and Midwest heat waves that caused many billions of dollars in damage and the 2003 European heat wave that killed 70,000 people — were *caused* by global warming.

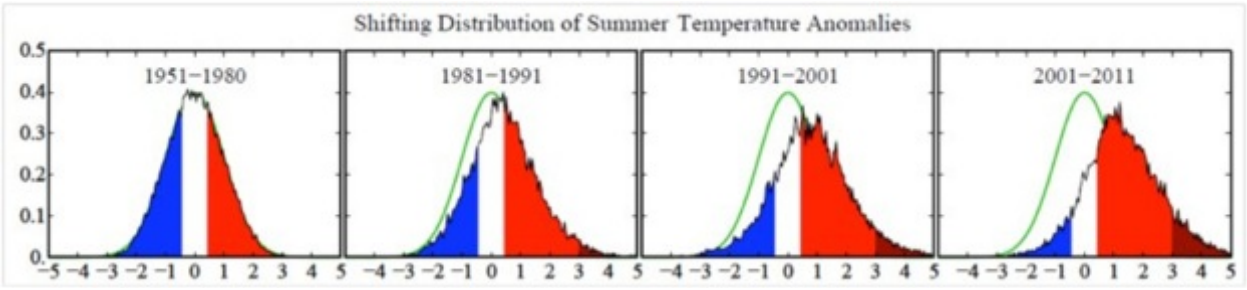

Figure 2. Northern Hemisphere temperature distribution curves for the base period 1951-1980 and the 3 most recent decades. The vertical axis is probability of occurrence (e.g., 0.4 = 40%) and the horizontal axis is temperature variance measured in 'standard deviations'. The shift of the curve to the right IS global warming. Blue is "Cold Summers", Red is "Hot Summers", and Dark Red is "Extremely Hot Summers" — which have increased by over 5000% in 50 years. This is not based on climate models nor is it a prediction — this increase already occurred.

Source: Hansen, J., Mki. Sato, and R. Ruedy, 2012: Perception of climate change. *Proc. Natl. Acad. Sci.*, **109**, 14726-14727, E2415-E2423, doi:10.1073/pnas.1205276109. "Extremely Hot Summer" is *defined* as an average summer (June-August) temperature for a particular place that is 3 'standard deviations' or more above the 1951-1980 mean for that place. See also: http://pubs.giss.nasa.gov/abs/ha00610m.html for links to the paper, a summary, and a science brief. For an explanation of the 5000% and >90% figures, see http://climateplace.org/file/Summary.html.

6. **Arctic sea ice** summer minimum extent has declined by 53% over the past 30 years and the minimum volume has declined by 75%. Based on current trends, the Arctic may be virtually ice-free — for the first time in human history — later this decade.

The latest science suggests that the decline in Arctic sea ice is causing the Jet Stream to become wavier and move slower, which is contributing to the *"weird weather"* (more frequent heat waves and cold spells, more droughts and floods, etc.) we have been experiencing in recent years. With the Arctic becoming ice free in summer later this decade, we can expect this weird weather to continue and intensify and it is likely that we will never return to what we used to consider "normal weather".

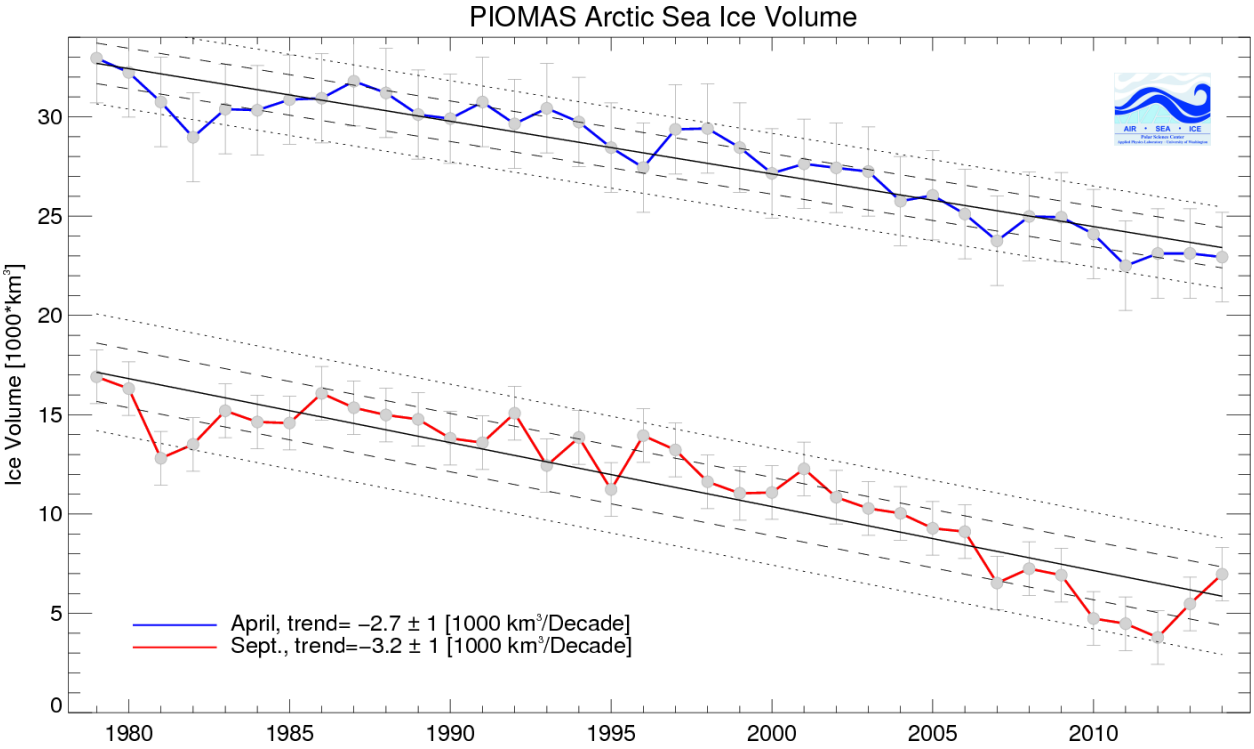

Figure 3. Arctic minimum sea ice *volume* over time. Blue line is April (Winter) and red line is September (Summer). If the trend continues, the Arctic could be virtually ice free, at least a short while, within a decade. Link to graph.

Source: Sea ice extent: National Snow & Ice Data Center (NSIDC). http://nsidc.org/arcticseaicenews/. September ice extent has dropped from about 7.5M km^2 in 1982 to 3.5M km^2 in 2012, a decrease of 53%. Sea ice volume: Polar Science Center of the U. of Washington. http://psc.apl.washington.edu/wordpress/. September 1st volume decreased from 13,561,000 km^3 in 1982 to 3,455,000 km^3 in 2012, a drop of 75%.
Evidence linking Arctic amplification to extreme weather in mid-latitudes, Jennifer A. Francis, Stephen J. Vavrus, Geophysical Research Letters, Volume 39, Issue 6, March 2012:
http://onlinelibrary.wiley.com/doi/10.1029/2012GL051000/abstract
Polar Science Center: http://psc.apl.uw.edu/research/projects/arctic-sea-ice-volume-anomaly/

7. **Antarctic glaciers have past a tipping point.** NASA scientists announced in 2014 that the West Antarctic Ice Sheet (WAIS) has past a tipping point and its loss now appears “unstoppable”. The loss of the WAIS glaciers will contribute about 4 feet to sea level rise directly but those glaciers also hold back the rest of the ice sheet, which contain enough ice to raise sea level by about 20 feet. While it will take a long time to melt all that ice, we should expect about 10 feet of sea level rise from WAIS in the next 100 to 300 years. That is in addition to the sea level rise we will get from ocean thermal expansion and the melting of the Greenland and East Antarctic ice sheets. Speaking of East Antarctica, a recent study (March 2015) shows that the Totten Glacier in East Antarctica is melting in a manner similar to WAIS and that glacier alone could contribute as much sea level rise as the entire WAIS.

Source: Jet Propulsion Laboratory, West Antarctic Glacier Loss Appears Unstoppable, http://www.jpl.nasa.gov/news/news.php?release=2014-148
Live Science, Hidden Channels Beneath East Antarctica Could Cause Massive Melt, http://www.livescience.com/50174-east-antarctica-glacier-melt.html

8. **Every major scientific academy** in the world — without exception — says that global warming is occurring, is mostly caused by human activities, and requires urgent action.

Source: "Joint science academies' statement: Global response to climate change": http://nationalacademies.org/onpi/06072005.pdf

9. **Comparison to Atomic Bombs**. Excess greenhouse gases — mostly CO_2 from the burning of fossil fuels — have already caused an "energy imbalance" (more energy coming into the Earth than is going out) that is equivalent to 400,000 Hiroshima atomic bombs going off every day.

Source: NASA climate scientist James Hansen's TED talk, Feb. 2012: http://www.ted.com/talks/james_hansen_why_i_must_speak_out_about_climate_change.html. Transcript: *"The total energy imbalance now is about six tenths of a watt per square meter. That may not sound like much, but when added up over the whole world, it's enormous. It's about 20 time greater than the rate of energy use by all of humanity. It's equivalent to exploding about 400,000 Hiroshima atomic bombs per day 365 days per year. That's how much extra energy Earth is gaining each day. This imbalance means, if we want to stabilize climate, we must reduce CO2 from 391 ppm (parts per million) back to about 350 ppm. That is the change needed to restore energy balance and prevent further warming."*
Calculation of 400,000 atomic bombs equivalence: Little Boy (Hiroshima bomb) ~ 63 x 10^12 joules. **1 bomb/day =** 63 x 10^12 joules/day ~ **7.3 x 10^8 joules/second (watts)** (86,400 sec/day). Area Earth = 5.1 x 10^14 square meters (m2). **Energy imbalance =** 0.6 watts/m2 x 5.1 x 10^14 m2 = **3 x 10^14 watts**. Ratio = (3 x 10^14)/(7.3 x 10^8) = **400,000 Hiroshima bombs/day**

10. **Current impact on deaths and GDP**. A recent study estimates that climate change already contributes to 400,000 deaths each year and has reduced global GDP by 1.6% ($1.2 trillion) annually.

Source: Climate Vulnerable Forum and DARA: *Climate Vulnerability Monitor: A Guide to the Cold Calculus of a Hot Planet, 2nd Edition*. Executive Summary: https://s3.amazonaws.com/daraint/CVM2ndEd-ExecutiveSummary.pdf.

Future climate change poses a clear and present danger to the United States:

11. **Predicted warming**. MIT researchers have predicted that by the end of this century, under "business-as-usual" emissions, there is a 95% probability that the world will warm +3.5°C (+6.3°F) and a 50% chance that it will warm +5°C (+9°F) — and they are being conservative because they do not include the impacts of the melting permafrost (see Section 11 below). For reference, almost all scientists and policy makers believe we should not cross the +2°C (+3.6°F) "firewall" temperature increase to avoid tipping points and dangerous (or very dangerous) climate change.

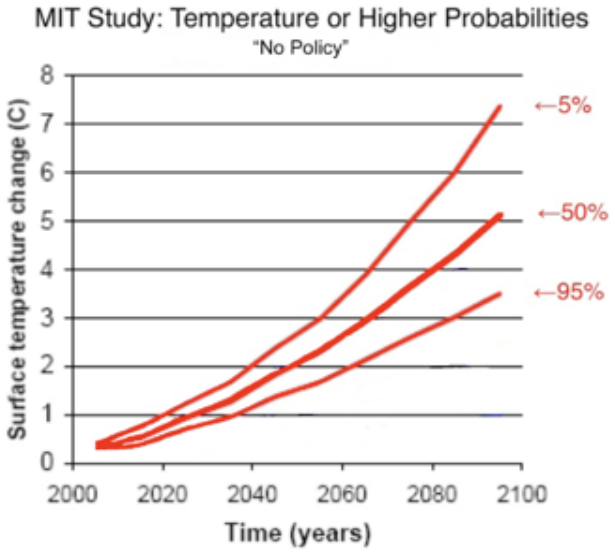

Figure 4. Probabilities of global average temperature increases this century under business-as-usual ("No Policy") emissions scenarios. Effects of melting permafrost are not included. Note that the +2°C "safe" temperature is crossed around mid-century.

Source: A.P. Sokolov, et al. *Probabilistic Forecast for 21st Century Climate Based on Uncertainties in Emissions (without Policy) and Climate Parameters*, MIT Joint Program on the Science and Policy of Global Change: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt169.pdf. For summary and graph, see http://climateplace.org/file/Summary.html.

12. **Permafrost melt impact on temperature**. A 2012 study predicts that the CO_2 released from the melting permafrost will add an additional 0.25 to 1°C (about 0.4 to 1.5°F) to the global average temperature by the end of this century. This is on top of the current predictions such as the MIT study.

Source: Andrew H. MacDougall, et al, *Significant contribution to climate warming from the permafrost carbon feedback*, Nature Geoscience 5, 719–721 (2012) doi:10.1038/ngeo1573. See: http://www.nature.com/ngeo/journal/v5/n10/full/ngeo1573.html.

13. **Permafrost melt impact on allowable carbon emissions.** The permafrost emissions will reduce the "safe" amount of carbon we can emit — from 440 to 270 billion tons of carbon — and still possibly stay under +2°C. And if that wasn't bad enough, the same study predicts that the permafrost emissions will offset the Earth's natural absorption of CO_2 so we will be stuck with whatever CO_2 level we reach when we finally stop emitting CO_2, unless we artificially extract CO_2 from the air and sequester it.

Source: Andrew H. MacDougall, et al, *Significant contribution to climate warming from the permafrost carbon feedback*, Nature Geoscience 5, 719–721 (2012) doi:10.1038/ngeo1573. See: http://www.nature.com/ngeo/journal/v5/n10/full/ngeo1573.html, also http://thinkprogress.org/climate/2012/10/06/970721/carbon-feedback-from-thawing-permafrost-will-add-04f-15f-to-total-global-warming-by-2100/

14. **Going beyond dangerous**. Because the world has not yet taken any significant action to reduce CO_2 emissions (2012 global CO_2 emissions were the highest in history and emissions are accelerating upward), it will be exceedingly difficult to limit warming to +2°C. In fact, if we do not act now, it will be a challenge to limit warming to +4°C (+7.2°F). However, limiting warming to less than +4°C must be done at all costs because, according to climate scientist Kevin Anderson, **"*a +4°C future is incompatible with an organized global community, is likely to be beyond 'adaptation', is devastating to the majority of ecosystems, and has a high probability of not being stable* (i.e., will lead to even higher temperatures)."**

Source: Kevin Anderson is Deputy Director of the Tyndall Centre for Climate Change Research at the U. Of Manchester (UK): http://www.tyndall.ac.uk/people/Kevin-Anderson. Article: http://www.whatnext.org/resources/Publications/Volume-III/Single-articles/wnv3_andersson_144.pdf. Direct link to his talk "*Climate Change: going beyond dangerous*": http://137.205.102.156/Ms%20S%20J%20Pain/20111124/Kevin_Anderson_-_Flash_(Medium)_-_20111124_05.26.31PM.html.
World Meteorological Organization: *Greenhouse Gas Concentrations in Atmosphere Reach New Record*, http://www.wmo.int/pages/mediacentre/press_releases/pr_980_en.html

15. **Droughts**. A recent study by the National Center for Atmospheric Research (NCAR) predicts that under business as usual emissions ***"The United States and many other heavily populated countries face a growing threat of severe and prolonged drought in coming decades"***. By mid-century, much of the contiguous U.S. will be experiencing drought conditions comparable to the 1930's Dust Bowl, with large areas at 2 to 3 times the drought levels of the Dust Bowl.

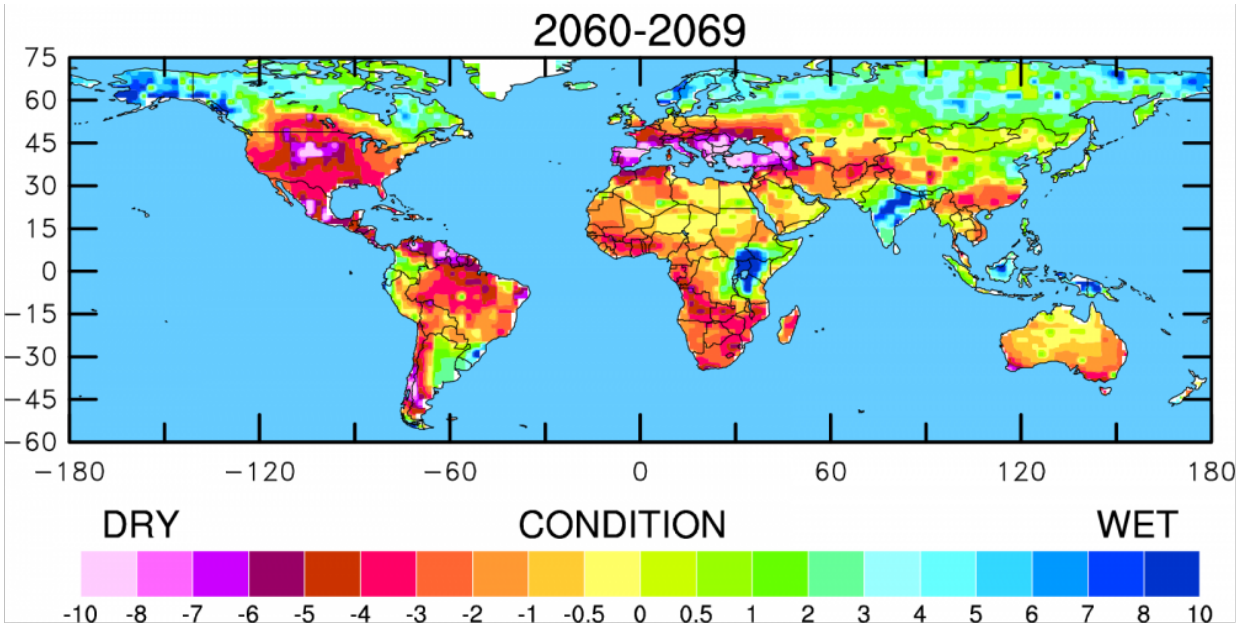

Figure 4. Predicted Drought Conditions in 2060-2069. Value is the "Palmer Drought Index". For reference, the 1930's Dust Bowl was a Palmer Index of -3 (with a brief peak of -6). So pink and red colors are Dust Bowl conditions and purple colors are 2 to 3 times the drought conditions of the Dust Bowl.

Source: Dai Aiguo. Drought under global warming: a review. *WIREs Clim Change* 2011, 2: 45-65. doi: 10.1002/wcc.81. See: https://www2.ucar.edu/atmosnews/news/2904/climate-change-drought-may-threaten-much-globe-within-decades for a summary and images.

16. **Sea level rise**. According to NASA climate scientist James Hansen, under business as usual emissions, sea level rise could reach 6 to 16 feet (2 to 5 meters) at the end of this century or shortly thereafter. Six feet of sea level rise would devastate many coastal cities and eliminate many island nations. At 16 feet, the bottom third of Florida will no longer be on the map.

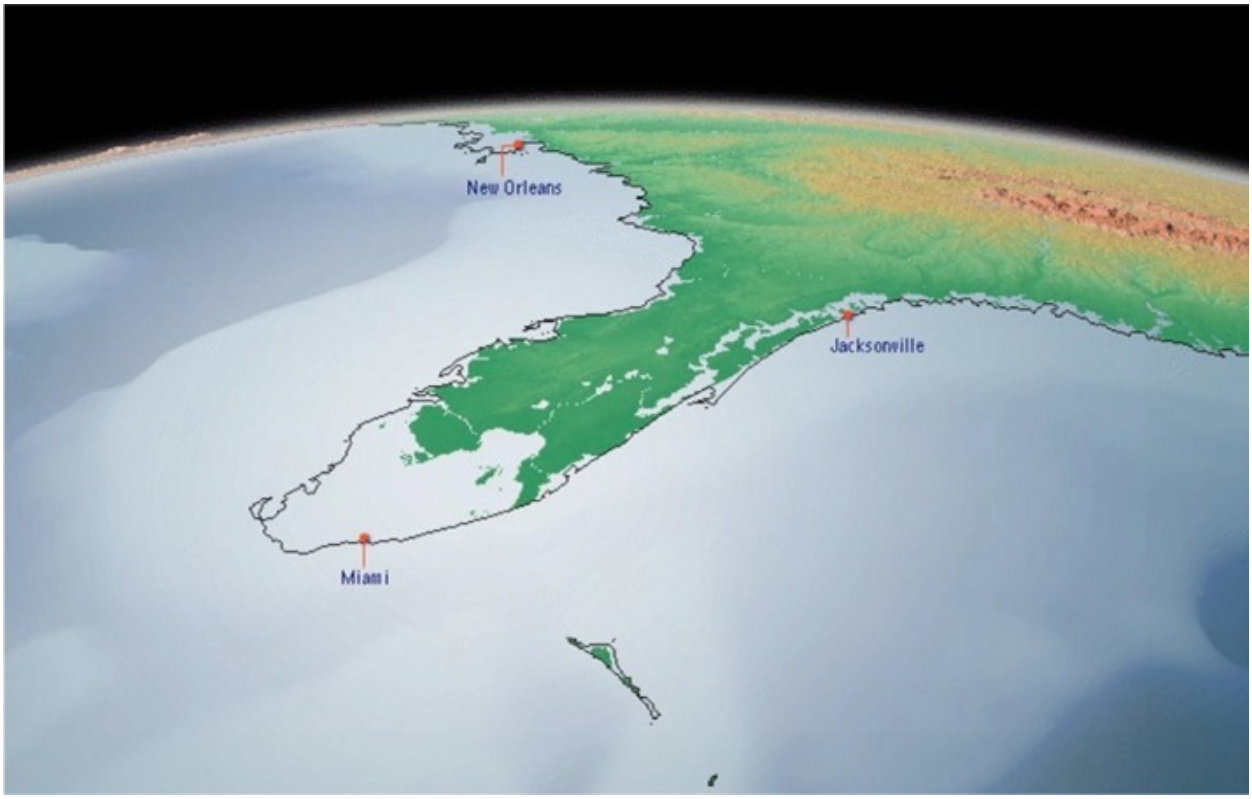

Figure 5. Florida with 5 meters (16 feet) of sea level rise.

Source: James Hansen's TED talk, Feb. 2012: http://www.ted.com/talks/james_hansen_why_i_must_speak_out_about_climate_change.html. Transcript: *"Most estimates are that, this century, we will get at least 1 meter. I think it will be more if few keep burning fossil fuels, perhaps even 5 meters -- 18 feet (sic: 5m=16.4 ft) -- this century or shortly thereafter. The important point is that we will have started a process that is out of humanity's control. Ice sheets would continue to disintegrate for centuries -- there would be no stable shoreline. The economic consequences are almost unthinkable -- hundreds of New Orleans-like devastations around the world."*

Suggested policy initiatives:

17. **Correct the market failure**. Climate change is the biggest "market failure" in history because the external costs of CO_2 are not included in the price of fossil fuels. **To use market forces to reduce greenhouse gas emissions, it is necessary to put a price on carbon.** Recent efforts to put a "Cap and Trade" system in place have failed, and there is some doubt that such a policy, even if implemented, would limit greenhouse gas emissions sufficiently.

Source: Sir Nicholas Stern, 2007 Royal Economic Society public lecture: *"Climate change is a result of the greatest market failure the world has seen. The evidence on the seriousness of the risks from inaction or delayed action is now overwhelming. We risk damages on a scale larger than the two world wars of the last century. The problem is global and the response must be a collaboration on a global scale."* See: http://www.guardian.co.uk/environment/2007/nov/29/climatechange.carbonemissions.

18. **Fee and Dividend Policy**. A simpler, more transparent, and likely more effective policy is the *Fee and Dividend* policy ("F&D"). Under F&D, fossil fuel companies pay a rising fee on CO_2 content of fuels when extracted from the ground or when imported into the country. The fee would start out small — $5 to $10/ton — and rise $5 to $10 each year for 10 years. If **100% of the money collected is distributed to every legal resident on a per-capita basis,** the public would accept (and even welcome) the fee. **This would eliminate any issues of regressive indirect taxation and would stimulate the economy and create millions of jobs**, since most people will receive more money than they pay in higher energy and product prices. This policy should be attractive to conservatives because it does not increase the size of government nor does it pick winners and losers — and because they have children too!

A recent economic analysis by Regional Economic Models, Inc. (REMI) and Synapse Energy Economics, Inc. shows that **the Fee and Dividend policy will, over 20 years, cut emissions by more than 50% and create 2.8 million jobs while growing U.S. GDP by $1.4 trillion.**

Source: REMI: *The Economic, Climate, Fiscal, Power, and Demographic Impact of a National Fee-and-Dividend Carbon Tax.* http://citizensclimatelobby.org/remi-report/

19. **Border duty.** Even if the U.S. significantly reduced greenhouse gas emissions but the rest of the world did not, it would be impossible to avoid catastrophic climate change. Therefore, in addition to implementing CEC, the U.S. should also simultaneously implement — in conjunction with the EU and perhaps China — **a tariff on goods coming from countries without their own price on carbon**. Besides protecting American industry against the impacts of U.S. carbon fees, it will also encourage most other countries to implement their own carbon fees and, therefore, reduce emissions. This could be done without the involvement of the UN, which has so far failed to get countries to agree on significant greenhouse gas reductions.

Addendum

"But the climate has changed before!"

When confronted with the fact of climate change, some people say *"But the climate has changed before!"*, implying that people are not responsible for the current changes and/or that the changes will not be harmful. While the climate has changed before, **both implications are false**.

• *"Climate has changed before so people are not responsible for the current changes"* — this is like saying "Wild fires occurred before people were on the planet so people cannot cause wild fires." We know quite accurately how much fossil fuels we burn every year and we know precisely how much CO_2 that generates. The fact that CO_2 helps keep the Earth warm has been known since the 1800's and is now established science. The amount of CO_2 in the atmosphere has increased from 280 parts per million (PPM) in pre-industrial times to about 395 ppm today — an increase of 41%. **There is no other accepted explanation for for the increase in CO_2 in such a short time frame except for human activities.** Every major scientific academy in the world -- without exception -- has stated that global warming is occurring, is mostly caused by humans, and urgent action is required to reduce greenhouse gas emissions.

• *"Climate has changed before so the current changes will not be harmful"*. The climate has indeed changed before. In the past million years, the Earth has gone through a number of ice ages and interglacial periods. These periods were caused by slight changes in the Earth's orbit over periods of tens of thousands of years which in turn lead to changes in the amount of CO_2 in the atmosphere. The Earth was never much warmer than today during the past million years. However, there was a time, about 250 million years ago — the "end-Permian event" — when the Earth was about +6°C (+11°F) warmer than now. **+6°C is about what we should expect to see later this century if we stay of our "business-as-usual" approach to burning fossil fuels. When the world heated up +6°C 250 million years ago, about 70~90% of all life on Earth died**. That warming was probably triggered by massive volcanoes in Siberia causing methane releases from under the oceans. The current warming is mostly caused by mankind's burning of fossil fuels, though it may eventually lead to warming greater than +6°C because of CO_2 and methane releases from permafrost and, eventually, from methane releases from the ocean bottom like what occurred during the end-Permian event.

Source: James Hansen, *Storms of My Grandchildren*, Bloomsbury, 2009

"What about the 'pause' in warming?"

Much has been written recently about a supposed 'pause' in global warming since 1998 and some writers have implied that, therefore, global warming has stopped. **There actually has not been a pause in global warming since 1998**, and even if there was, it would not mean that global warming has stopped.

Short climate variability due to factors such as La Niña and El Niño can cause global temperatures to drop for a number of years. Also, short-lived aerosols (e.g., smoke) from industrial activities and power production can also reduce warming for a short time, (though the related greenhouse gas emissions will cause warming for thousands of years!) — this was seen during the re-industrialization following World War 2 and China's rapid construction of coal-burning power plants in the last decade may have played a role in reducing global temperatures somewhat.

Also, when we talk about 'global temperatures', we are talking about surface air temperatures. **Only about 2% of global warming energy goes into the atmosphere. About 93% goes into the oceans.** So even a small increase in the oceans rate of warming could reduce atmospheric surface temperatures.

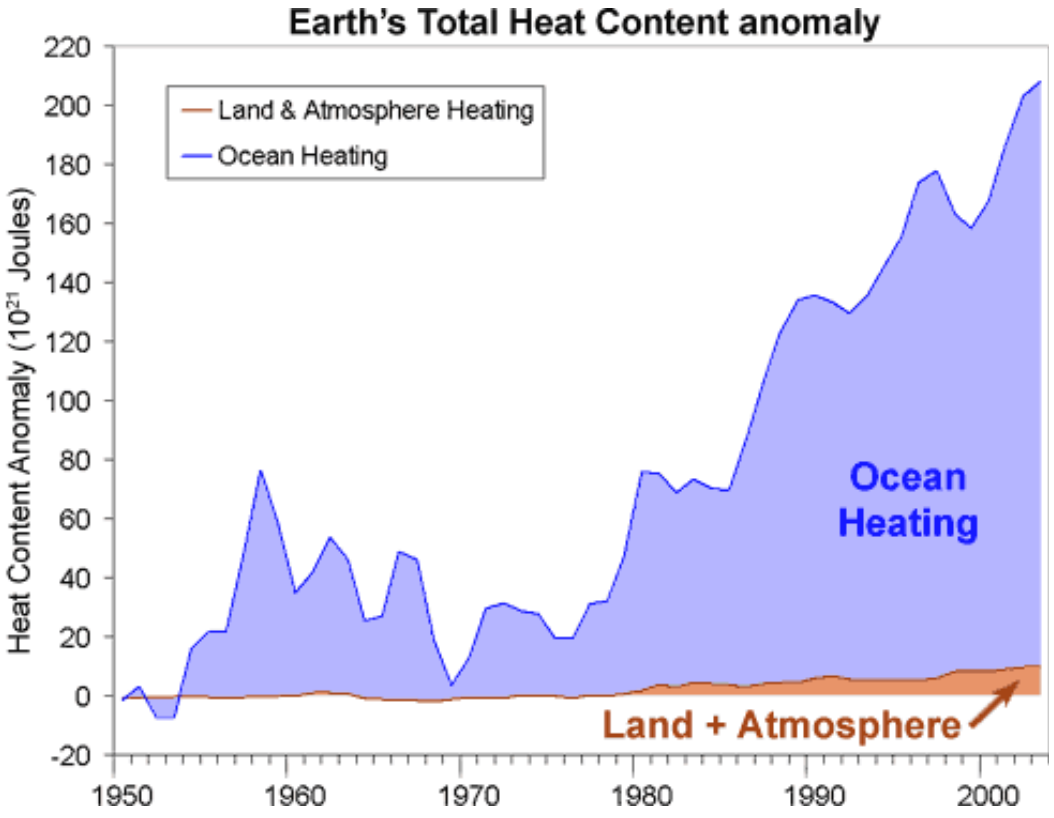

Figure 5: Total Earth Heat Content anomaly from 1950 (Murphy 2009). Ocean data taken from Domingues et al 2008. Land + Atmosphere includes the heat absorbed to melt ice.

The ability of the oceans to affect surface air temperatures is demonstrated every time we get a La Niña (which is a temporary cooling of the Pacific Ocean surface temperatures) or an El Niño (which is a temporary warming of the Pacific Ocean surface temperature). These conditions cause a short-term decrease or increase, respectively, in average global air temperatures when they occur. There has been a number of La Niña events in the past several years and no El Niño events. It is very likely that when an El Niño event occurs in the next year or two, we will experience a record high global average air temperature. The 1998 spike in global temperatures was due to a very strong El Niño event that year. Even with that spike, **new records for global average temperatures were set in 2005, 2010, and 2014.**

But even with the variability caused by the effects described above, there still was no pause in warming since 1998. The reason people believed there was a warming pause was because the UK's Met Office used an overly conservative method to fill in missing temperature data from locations that did not have weather stations. Most of the missing data were, not surprisingly, in the Arctic where the temperatures are increasing 8 times faster than the global average. The Met Office left out missing data from their global temperature calculations so the areas with missing data were effectively considered to have the global average temperature. But since the Arctic is warming 8 times faster than the average, this technique greatly underestimated the Arctic's true temperature. Scientists recently used satellite data to get a better estimate of the "missing" temperature data and, using the corrected temperature data, they found **there was no pause in warming since 1998**.

Source: K. Cowtan, R. G. Way, *Coverage bias in the HadCRUT4 temperature series and its impact on recent temperature trends*, Quarterly Journal of the Royal Meteorological Society. http://onlinelibrary.wiley.com/doi/10.1002/qj.2297/abstract