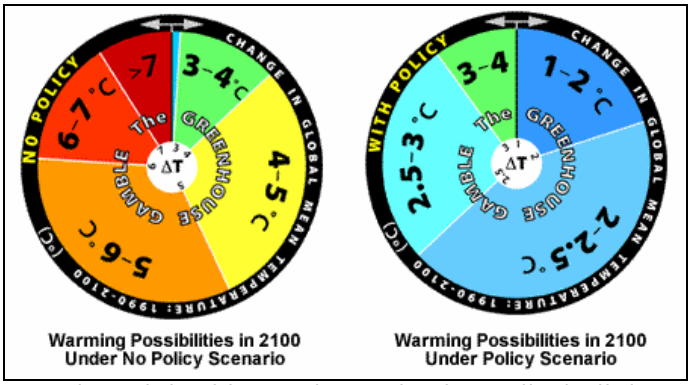
An Illustrated Guide to the Science of Global Warming Impacts

How We Know Inaction Is the Gravest Threat Humanity Faces

Joe Romm, September 28, 2011



Humanity's Choice (via M.I.T.): Inaction ("No Policy") eliminates most of the uncertainty about whether or not future warming will be catastrophic. Aggressive emissions reductions dramatically improves humanity's chances.

In this post, I will summarize what the recent scientific literature says are the key impacts we face in the coming decades if we stay anywhere near our current emissions path. These include:

- Staggeringly high temperature rise, especially over land — some 10°F over much of the United States
- Permanent Dust Bowl conditions over the U.S. Southwest and many other heavily populated regions around the globe
- Sea level rise of around 1 foot by 2050, then 4 to 6 feet (or more) by 2100, rising some 6 to 12 inches (or more) each decade thereafter
- Massive species loss on land and sea — perhaps 50% or more of all biodiversity
- Unexpected impacts — the fearsome "unknown unknowns"
- Much more extreme weather
- Food insecurity — the increasingly difficult task of feeding 7 billion, then 8 billion, and then 9 billion people in a world with an ever-worsening climate.
- Myriad direct health impacts

Remember, these will all be happening simultaneously and getting worse decade after decade. Equally tragic, a 2009 NOAA-led study found the worst impacts would be "largely irreversible for 1000 years."

The single biggest failure of messaging by climate scientists (until very recently) has been the failure to explain to the public, opinion makers, and the media that business-as-usual warming results in simultaneous, ever-worsening impacts that, individually, are each beyond catastrophic, but combined are unimaginablly horrific. For these impacts, terms like "global warming" and "climate change" are essentially euphemisms. That is why I have prefered the term "Hell and High Water."

By virtue of their success in promoting doubt and inaction, the climate science deniers and disinformers have, tragically and ironically, turned the worst-case scenario into business as usual.

Business-as-usual typically means continuing at recent growth rates of carbon dioxide emissions, which we now know would likely take us to atmospheric concentrations of CO2 greater than 850 ppm if not above 1000 ppm (see U.S. media largely ignores latest warning

from climate scientists: "Recent observations confirm … the worst-case IPCC scenario trajectories are being realised"). We are at about 8.5 billion metric tons of carbon a year (31 billions metric tons of CO2) and, until the recent global economic recession, were rising about 3% per year.

What is less well understood is that even a very strong mitigation effort that kept carbon emissions this century to 11 billion tons a year on average would still probably take us to 1000 ppm (A1FI scenario) — a little noted conclusion of the 2007 Intergovernmental Panel on Climate Change (IPCC) report (see "*Nature* publishes my climate analysis and solution").

Until recently, the scientific community has spent little time modeling the impacts of a tripling (~830 ppm) or quadrupling (~1100 ppm) carbon dioxide concentrations from preindustrial levels. In part, I think, that's because they never believed humanity would be so stupid as to ignore the warnings and simply continue on its self-destructive path. In part, they lowballed the difficult-to-model amplifying feedbacks in the carbon cycle.

So I pieced together those impacts from available studies and from discussions with leading climate scientists for my 2006 book, *Hell and High Water*. But now as climate scientists have sobered up to their painful role as modern-day Cassandra's, the scientific literature on what we face is much richer.

In a AAAS presentation last year, the late William R. Freudenburg of UC Santa Barbara discussed his research on "the Asymmetry of Scientific Challenge": New scientific findings since the 2007 IPCC report are found to be more than twenty times as likely to indicate that global climate disruption is "worse than previously expected," rather than "not as bad as previously expected."

This post will review the latest findings. It will be a cornerstone of the Climate Progress archive I promised. Please add links to more studies in the comments.

TEMPERATURE

Three of the best recent analyses of what we are headed towards can be found here:

- M.I.T. doubles its 2095 warming projection to 10°F — with 866 ppm and Arctic warming of 20°F
- Hadley Center: "Catastrophic" 5-7°C warming by 2100 on current emissions path
- Our hellish future: Definitive NOAA-led report on U.S. climate impacts warns of scorching 9 to 11°F warming over most of inland U.S. by 2090 with Kansas above 90°F some 120 days a year — and that isn't the worst case, it's business as usual!

As Dr. Vicky Pope, Head of Climate Change Advice for the Met Office's Hadley Centre has explained:

… where no action is taken to check the rise in Greenhouse gas emissions, temperatures would most likely rise by more than 5 °C by the end of the century. This would lead to significant risks of severe and irreversible impacts.

That likely rise corresponds to roughly 9°F globally and typically 40% higher than that over inland mid-latitudes (i.e. much of this country) — or well over 10°F.

[*Note: The MIT rise is compared to 1980-1999 levels see study here). So you can add at least 0.5 C and 1.0°F for comparison with pre-industrial temperatures.*]

Based on two studies in the last few years:

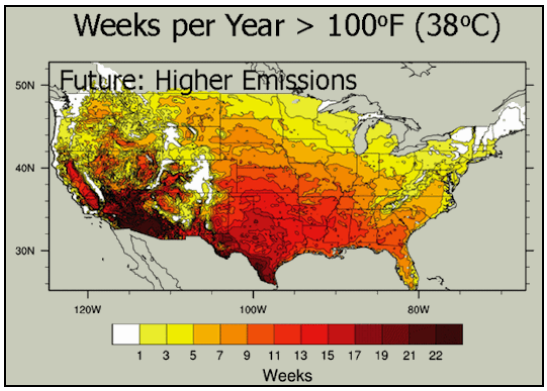
By century's end, extreme temperatures of up to 122°F would threaten most of the central, southern, and western U.S. Even worse, Houston and Washington, DC could experience temperatures exceeding 98°F for some 60 days a year. Much of Arizona would be subjected to temperatures of 105°F or more for 98 days out of the year–14 full weeks.

Yet that conclusion is based on studies of only 700 ppm and 850 ppm, so it could get much hotter than that.

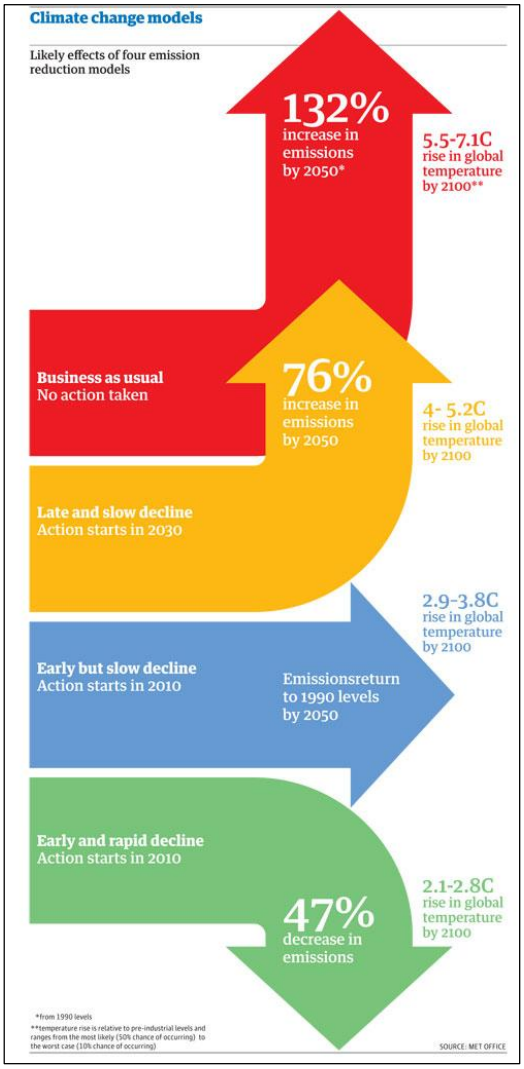
And the Hadley Center adds, "By the 2090s close to one-fifth of the world's population will be exposed to ozone levels well above the World Health Organization recommended safe-health level."

The MIT press release calls for "rapid and massive" action to avoid this. Study co-author Ronald Prinn, the co-director of the Joint Program and director of MIT's Center for Global Change Science, says, it is important "to base our opinions and policies on the peer-reviewed science…. There's no way the world can or should take these risks." Duh!

MIT put together a good figure that compares the temperatures we risk on our current do-nothing path with those we might expect if we took serious action [see figure above]. Note that in the "no policy case" there is an extremely high probability of more than 4°C (7°F) global warming, an about a 25% chance of more than 6°C (11°F) global warming. In a terrific March 2010 presentation, Climate scientist Katherine Hayhoe has a figure of what 1000 ppm would mean (derived from the 2010 NOAA-led report):



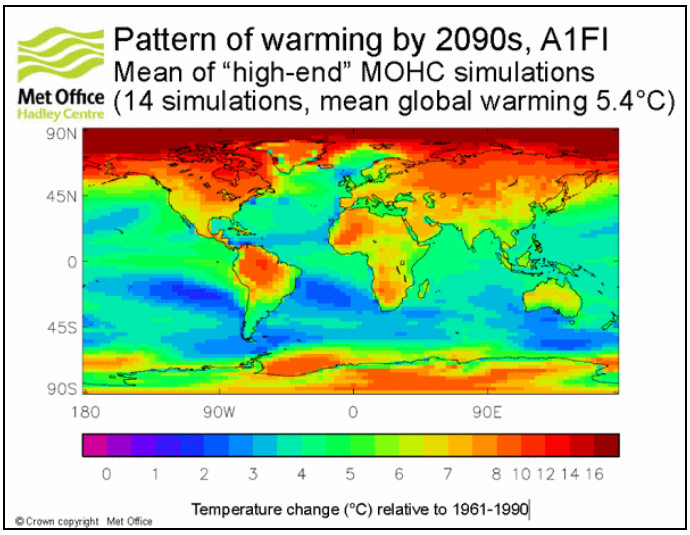
For more of the literature on U.S. warming, see "Mother Nature is Just Getting Warmed Up."
The Hadley Center has a huge but useful figure which I will reproduce here:



Note again that this is not the worst-case scenario. It's just business as usual out to 2100. In the worst case, we get both continuing high levels of emissions and high carbon-cycle feedbacks. That possibility was discussed here:

- Royal Society Special Issue on Global Warming Details 'Hellish Vision' of 7°F (4°C) World — Which We May Face in the 2060s! "In such a 4°C world, the limits for human adaptation are likely to be exceeded in many parts of the world, while the limits for adaptation for natural systems would largely be exceeded throughout the world."

This would be the worst-case for the 2060s, but is in any case, close to business as usual for 2090s:



This is indeed 13-18°F over most of U.S. and 27°F in the Arctic. And there is every reason to believe that the earth would just keep getting hotter and hotter:

- *Science* stunner — On our current emissions path, CO2 levels in 2100 will hit levels last seen when the Earth was 29°F (16°C) hotter: Paleoclimate data suggests CO2 "may have at least twice the effect on global temperatures than currently projected by computer models"

UPDATE: Steve Easterbrook's post "A first glimpse at model results for the next IPCC assessment" shows that for the scenario where there is 9°F warming by 2100, you get another 7°F warming by 2300. Of course, folks that aren't motivated to avoid the civilization-destroying 9°F by 2100 won't be moved by whatever happens after that.

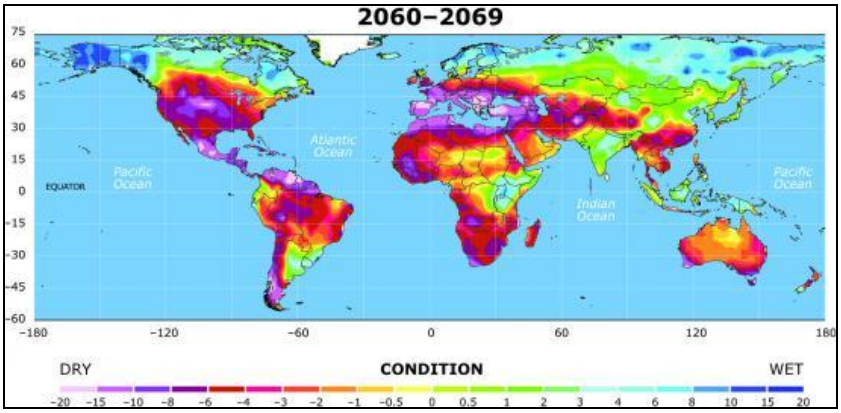
DUST-BOWL-IFICATION

Dust-bowlification — and its impact on food security – may well be the impact that harms the most number of people over the next few decades.

As far back as 1990, scientists at NASA's Goddard Institute of Space Studies projected that severe to extreme drought in the United States, then happening every 20 years, could become an every-other-year phenomenon by mid-century [*Rind et al., 1990*].

A number of major recent studies have confirmed those early findings. They warn that the Southwest, parts of the Midwest, and many other highly populated parts of the globe are likely headed toward sustained — if not near permanent — drought and Dust Bowl-like conditions if we stay anywhere near our current emissions path (see "USGS on Dust-Bowlification").

- Back in October 2010, the National Center for Atmospheric Research published a complete literature review, "Drought under global warming: a review," (See NCAR analysis warns we risk multiple, devastating global droughts even on moderate emissions path). That study makes clear that Dust-Bowlification may be the impact of human-caused climate change that hits the most people by mid-century, as the figure below suggests (click to enlarge, "a reading of -4 or below is considered extreme drought"):



The PDSI [Palmer Drought Severity Index] in the Great Plains during the Dust Bowl apparently spiked very briefly to -6, but otherwise rarely exceeded -3 for the decade (see here).

The large-scale pattern shown in Figure 11 [of which the figure above is part] appears to be a robust response to increased GHGs. This is very alarming because if the drying is anything resembling Figure 11, a very large population will be severely affected in the coming decades over the whole United States, southern Europe, Southeast Asia, Brazil, Chile, Australia, and most of Africa.

The National Center for Atmospheric Research notes "By the end of the century, many populated areas, including parts of the United States, could face readings in the range of -8 to -10, and much of the Mediterranean could fall to -15 to -20. Such readings would be almost unprecedented."

For the record, the NCAR study merely models the IPCC's "moderate" A1B scenario — atmospheric concentrations of CO2 around 520 ppm in 2050 and 700 in 2100. We're currently headed much higher by century's end, but I'm sure with an aggressive program of energy R&D we could keep that to, say 800 ppm.

- The UK Met Office came to a similar view four years ago in their analysis, projecting severe drought over 40% of the Earth's habited landmass by century's end (see "The Century of Drought").

The projection of extended if not endless drought for the US Southwest has been studied a great deal:

- In 2007, *Science* (subs. req'd) published research that "predicted a permanent drought by 2050 throughout the Southwest" "" levels of aridity comparable to the 1930s Dust Bowl would stretch from Kansas to California. And they were also only looking at a 720 ppm case.
- "The unexpectedly rapid expansion of the tropical belt constitutes yet another signal that climate change is occurring sooner than expected," noted one climate researcher in December 2007. A 2008 study led by NOAA noted, "A poleward expansion of the tropics is likely to bring even drier conditions to" the U.S. Southwest, Mexico, Australia and parts of Africa and South America."
- In December 2008, the Bush Administration quietly released a US Geological Survey stunner: SW faces "permanent drying" by 2050, which found:

The serious hydrological changes and impacts known to have occurred in both historic and prehistoric times over North America reflect large-scale changes in the climate system that can develop in a matter of years and, in the case of the more severe past megadroughts, persist for decades. Such hydrological changes fit the definition of abrupt change because they occur faster than the time scales needed for human and natural systems to adapt, leading to substantial disruptions in those systems. In the Southwest, for example, the models project a permanent drying by the mid-21st century that reaches the level of aridity seen in historical droughts, and a quarter of the projections may reach this level of aridity much earlier.

- U.S. southwest could see a 60-year drought like that of 12th century — only hotter — this century:

An unprecedented combination of heat plus decades of drought could be in store for the Southwest sometime this century, suggests new research from a University of Arizona-led team"…. "The bottom line is, we could have a Medieval-style drought with even warmer temperatures," [lead author Connie] Woodhouse said.

The literature makes clear future droughts will be fundamentally different from all previous droughts that humanity has experienced because they will be very hot weather droughts (see Must-have PPT: The "global-change-type drought" and the future of extreme weather).

- A 2011 *Environmental Research Letters* article, "Characterizing changes in drought risk for the United States from climate change," comes to a similar conclusion as the NCAR study, "Drought frequencies and uncertainties in their projection tend to increase considerably over time and show a strong worsening trend along higher greenhouse gas emissions scenarios, suggesting substantial benefits for greenhouse gas emissions reductions." See especially Figure 4C.

Another 2011 study, "The Last Drop: Climate Change and the Southwest Water Crisis," that actually looks in some detail at the scientific literature for just one region, finds that drought and reduced precipitation in the U.S. SW alone could cost up to $1 trillion by century's end.

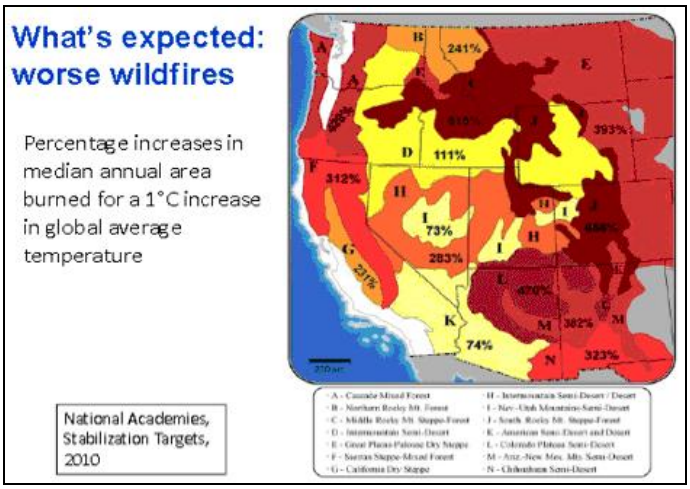
Finally, while the Dust Bowl lasted under a decade, the NOAA-led study found permanent Dust Bowls in Southwest and around the globe on our current emissions trajectory would be irreversible for 1000 years.

- NOAA: Climate change "largely irreversible for 1000 years," with permanent Dust Bowls in Southwest and around the globe. This January 2009 PNAS paper finds

Again, this is all just business as usual.

From a worst-case perspective, Princeton has done an analysis on "Century-scale change in water availability: CO2-quadrupling experiment," which is to say 1100 ppm. The grim result: Most of the South and Southwest ultimately sees a 20% to 50% (!) decline in soil moisture.

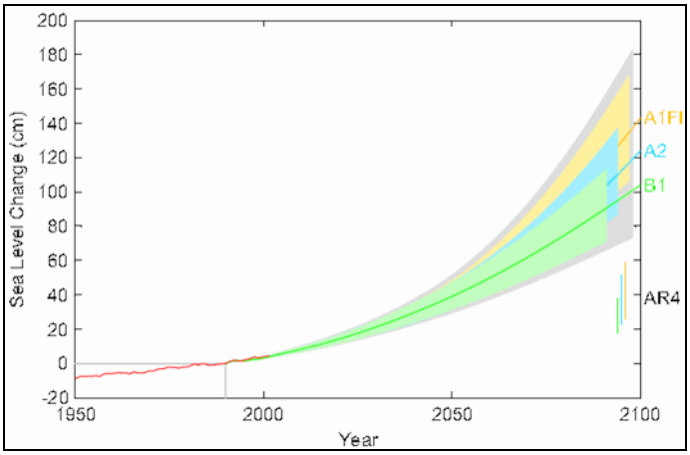
Finally, the heat and drought drives wildfires. Here's a National Academies figure from a presentation made by the President's science adviser Dr. John Holdren in Oslo last year, about conditions projected for mid-century:



SEA LEVEL RISE

The 2007 IPCC Fourth Assessment Report (AR4) report ignored dynamic ice-sheet disintegration, which was already happening (see *Nature*: "Dynamic thinning of Greenland and Antarctic ice-sheet ocean margins is more sensitive, pervasive, enduring and important than previously realized"). The IPCC therefore low-balled sea level rise estimates, suggesting seas might rise "only" a foot or two this century, greatly delighting the anti-science crowd (see here)

Within a year, even a major report signed off on by the Bush administration itself was forced to concede that the IPCC numbers were simply too out of date to be quoted anymore (see US Geological Survey stunner: Sea-level rise in 2100 will likely "substantially exceed" IPCC projections). About half a dozen major studies since the IPCC report concluded that we face much higher sea level rise this century:



- *PNAS* Study (12/09): Sea levels may rise 3 times faster than IPCC estimated, could hit 6 feet by 2100" [see figure above]. Note: We are currently close to the A1F1 emissions trajectoryand thus appear to be on track for 1.4 meters (56 inches) of sea level rise.
- JPL bombshell (3/11): Polar ice sheet mass loss is speeding up, on pace for 1 foot sea level rise by 2050
- Startling new sea level rise research: "Most likely" 0.8 to 2.0 meters by 2100
- High Water: Greenland ice sheet melting faster than expected and could raise East Coast sea levels an extra 20 inches by 2100 — to more than 6 feet.
- West Antarctic ice sheet collapse even more catastrophic for U.S. coasts
- Nature sea level rise shocker: Coral fossils suggest "catastrophic increase of more than 5 centimetres per year over a 50-year stretch is possible." Lead author warns, "This could happen again."
- *NatureGeoscience:* Sea levels may rise 5 feet by 2100

Needless to say, a sea level rise of one meter by 2100 would be an unmitigated catastrophe for the planet, even if sea levels didn't keep rising several inches a decade for centuries, which they inevitably would. The first meter of SLR would flood 17% of Bangladesh, displacing tens of millions of people, and reducing its rice-farming land by 50 percent. Globally, it would create more than 100 million environmental refugees and inundate over 13,000 square miles of this country. Southern Louisiana and South Florida would inevitably be abandoned.

SPECIES LOSS ON LAND AND SEA

In 2007, the IPCC warned that as global average temperature increase exceeds about 3.5°C [relative to 1980 to 1999], model projections suggest significant extinctions (40-70% of species assessed) around the globe. That is a temperature rise over pre-industrial levels of a bit more than 4.0°C. So a 5.5°C rise would likely put extinctions beyond the high end of that range.

Many more studies have raised similar concerns:

- Study finds "mass biodiversity collapse" at 900 ppm, and possibly a "threshold response … to relatively minor increases in CO2 concentration and/or global temperature."

- Last fall, the Royal Society ran a special issue on "Biological diversity in a changing world," concluding "There are very strong indications that the current rate of species extinctions far exceeds anything in the fossil record."

- *Nature Climate Change* (9/11): "The proportion of actual biodiversity loss should quite clearly be revised upwards: by 2080, more than 80% of genetic diversity within species may disappear in certain groups of organisms"

And, of course, "When CO2 levels in the atmosphere reach about 500 parts per million, you put calcification out of business in the oceans." There aren't many studies of what happens to the oceans as we get toward 800 to 1000 ppm, but it appears likely that much of the world's oceans, especially in the southern hemisphere, become inhospitable to many forms of marine life. A 2005 *Nature* study concluded these "detrimental" conditions "could develop within decades, not centuries as suggested previously."

- A 2009 study in *Nature Geoscience* warned that global warming may create expanding "dead zones" in the ocean that would be devoid of fish and seafood and "remain for thousands of years."

- A 2010 *Nature Geoscience* study found that Oceans are acidifying 10 times faster today than 55 million years ago when a mass extinction of marine species occurred.

- "Geological Society (8/10): Acidifying oceans spell marine biological meltdown "by end of century."

As for the worst-case scenario, we have

- *Nature* Stunner — "Global warming blamed for 40% decline in the ocean's phytoplankton": "Microscopic life crucial to the marine food chain is dying out. The consequences could be catastrophic."

Yes, some scientists disputed the analysis, but I have seen no refutation in the scientific literature.

UNEXPECTED IMPACTS

If we go to 800 ppm — let alone 1000 ppm or higher — we are far outside the bounds of simple linear projection. Some of the worst impacts may not be obvious — and there may be unexpected negative synergies. The best evidence that will happen is the fact that it is already happened with even a small amount of warming we have seen to date.

"The pine beetle infestation is the first major climate change crisis in Canada" notes Doug McArthur, a professor at Simon Fraser University in Vancouver. The pests are "projected to kill 80 per cent of merchantable and susceptible lodgepole pine" in parts of British Columbia within 10 years — and that's why the harvest levels in the region have been "increased significantly."

As quantified in the journal *Nature*, "Mountain pine beetle and forest carbon feedback to climate change," (subs. req'd), which just looks at the current and future impact from the beetle's warming-driven devastation in British Columbia:

… the cumulative impact of the beetle outbreak in the affected region during 2000–2020 will be *270 megatonnes (Mt) carbon* (or 36 g carbon m^{-2} yr^{-1} on average over 374,000 km^2 of forest). This impact converted the forest from a small net carbon sink to a large net carbon source.

No wonder the carbon sinks are saturating faster than we thought (see here) — unmodeled impacts of climate change are destroying them:

Insect outbreaks such as this represent an important mechanism by which climate change may undermine the ability of northern forests to take up and store atmospheric carbon, and such impacts should be accounted for in large-scale modelling analyses.

And the bark beetle is slamming the Western U.S. and Alaska, too (see "Oldest Utah newspaper: Bark-beetle driven wildfires are a vicious climate cycle").

The key point is this catastrophic climate change impact and its carbon-cycle feedback were not foreseen even a decade ago — which suggests future climate impacts will bring other equally unpleasant surprises, especially as we continue on our path of no resistance.

EXTREME WEATHER

One of the basic predictions of climate science is that extreme weather will make the hydrological cycle more extreme. I discussed the extensive literature on how dry areas will get drier. But wet areas will also get wetter:

- Two seminal *Nature* papers join growing body of evidence that human emissions fuel extreme weather, flooding that harm humans and the environment:

1) Here we show that human-induced increases in greenhouse gases have contributed to the observed intensification of heavy precipitation events found over approximately two-thirds of data-covered parts of Northern Hemisphere land areas. These results are based on a comparison of observed and multi-model simulated changes in extreme precipitation over the latter half of the twentieth century analysed with an optimal fingerprinting technique.

Changes in extreme precipitation projected by models, and thus the impacts of future changes in extreme precipitation, may be underestimated because models seem to underestimate the observed increase in heavy precipitation with warming.

2) Occurring during the wettest autumn in England and Wales since records began in 1766 these floods damaged nearly 10,000 properties across that region, disrupted services severely, and caused insured losses estimated at £1.3 billion….

… it is very likely that global anthropogenic greenhouse gas emissions substantially increased the risk of flood occurrence in England and Wales in autumn 2000.

That post ended with its own review of the literature on the connection between global warming and extreme weather. Here are a couple more studies:

- Study: Global warming is driving increased frequency of extreme wet or dry summer weather in southeast, so droughts and deluges are likely to get worse

A new study by a Duke University-led team of climate scientists suggests that global warming is the main cause of a significant intensification in the North Atlantic Subtropical High (NASH) that in recent decades has more than doubled the frequency of abnormally wet or dry summer weather in the southeastern United States….

The models – known as Coupled Model Intercomparison Project Phase 3 (CMIP3) models – predict the NASH will continue to intensify and expand as concentrations of carbon dioxide and other greenhouse gases increase in Earth's atmosphere in coming decades."This intensification will further increase the likelihood of extreme summer precipitation variability – periods of drought or deluge – in southeastern states in coming decades," Li says.

- *Nature*: Hurricanes ARE getting fiercer — and it's going to get much worse

The team calculates that a 1 ºC increase in sea-surface temperatures would result in a 31% increase in the global frequency of category 4 and 5 storms per year: from 13 of those storms to 17. Since 1970, the tropical oceans have warmed on average by around 0.5 ºC. Computer models suggest they may warm by a further 2 ºC by 2100.

FOOD INSECURITY

In over two decades of tracking world food prices, the U.N. Food and Agricultural organization index has never stayed so high for so long.

This represents true suffering for hundreds of millions of people who live on the edge, for whom food is a large fraction of their income like, say, North Africa (see Expert consensus grows on contribution of record high food prices to Middle East unrest).

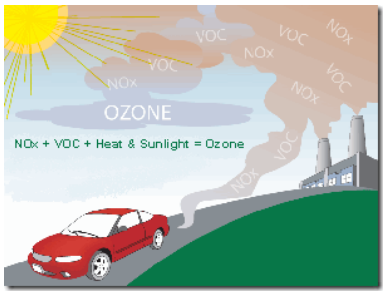
Population growth, dietary shifts, growing use of crops for biofuels, peaking conventional oil production and increases in extreme weather have all played a part.

As the literature above makes clear, on our current emissions path, we face

- Dust-Bowlification's devastating impact on farming;
- Sea level rise and the accompanying salt water infiltration, threatening some of the richest agricultural deltas in the world, such as the Nile and Ganges (see "Rising sea salinates India's Ganges").
- Ocean acidification, warming and overfishing severely depleting the availability of seafood.
- Extreme weather harming crops — see NOAA: Monster crop-destroying Russian heat wave to be once-in-a-decade event by 2060s (or sooner)

One analysis just of the impact of temperature rise on food finds "Half of world's population could face climate-driven food crisis by 2100." And this is just a 700 ppm analysis with no discussion of the impact of soil drying up or other well-understood climate impacts.

DIRECT HEALTH IMPACTS



In April the British Medical Journal warned that climate change "poses an immediate and grave threat, driving ill-health and increasing the risk of conflict, such that each feeds upon the other." The UK's Hadley Center notes that on our current one related impact, "By the 2090s close to one-fifth of the world's population will be exposed to ozone levels well above the World Health Organization recommended safe-health level."

A June 2011 peer-reviewed report released by the Union of Concerned Scientists (UCS) — "Climate Change and Your Health: Rising Temperatures, Worsening Ozone Pollution" — shows that the harm to Americans, especially children, from human-caused warming is upon us now.

A just-released September 2011 report by the European Lung Foundation finds:

Climate change set to increase ozone-related deaths over next 60 years

Scientists are warning that death rates linked to climate change will increase in several European countries over the next 60 yrs.

Earlier this year, Climate Progress reported on what the top medical and health groups warn are the health risks Americans face from climate change:

- More than doubled asthma rates and lengthened asthma season (already 20 days longer)
- Threatened access to clean drinking water
- Increases in airborne and insect borne illnesses (e.g. mosquitos, ticks, tapeworm)
- Increases in diarrheal, respiratory, and heart disease
- Increased risk of salmonella spread as average temperatures rise
- Increase in hospital use results in rising health care costs
- Particular risk among low-income communities, children, the elderly, and the obese

See also The Lancet's landmark Health Commission: "Climate change is the biggest global health threat of the 21st century"

CONCLUSION

The possibility that unrestricted emissions of greenhouse gases would not do unimaginable harm to humanity has become vanishingly small. That's because we remain near the worst-case emissions pathways, there is little prospect of national or global action any times soon (thank you, deniers), many impacts are coming faster than the models projected, and the overwhelming majority of the scientific literature in the past 5 years has been more dire than the 2007 IPCC report, which itself was more than enough motivation for the overwhelming majority of climate scientists and countries to call for urgent action to reduce emissions.

And I haven't even discussed the many, many studies that suggest in fact carbon-cycle feedbacks (like the defrosting tundra) are almost all positive (amplifying) and yet largely ignored in most climate models — see NSIDC bombshell: Thawing permafrost feedback will turn Arctic from carbon sink to source in the 2020s, releasing 100 billion tons of carbon by 2100 and links therein.

We can't let this happen. It is indeed humanity's self-destruction. We must pay any price or bear any burden to stop it.