The Great Climate Experiment

Required Reading

Caldeira, K. (2012). The Great Climate Experiment. *Scientific American, 307*(3), 78-83.

Learning Outcomes and Connections to Course Outcomes

After completing this lesson, you will be able to:

- Examine the relationship between the natural and the social world in order to critique human behaviours and activities.
- Describe how our economic activity impacts the natural world — in particular, climate change — and list responses to this impending crisis.
- Critically evaluate any obligation we might have to try to understand the world accurately.
- Explain the scientific basis and evidence for human-induced global warming.
- Explain the mechanism of the Greenhouse Effect and the role of greenhouse gases. Contrast this to the Runaway Greenhouse Effect.
- Describe the consequences of the current trends of global warming, on a global scale and on your lifestyle.

Main Topics

- The Biosphere: Fragility versus Resilience
- The Greenhouse Effect
- Global Warming: Evidence and Impact
- Economics and the Natural Environment
- Global Warming: Consequences

Introduction to Climate Change

A Matter of Perspective

A Way Forward: Facing Climate Change
(http://video.nationalgeographic.com/video/way-forward-climate)

What was your reaction as you watched the short video? Scared? Indifferent? Angry? Did you shrug and say, 'so what, that's somebody else's problem?' Did you think it a distraction from more important things, like living your life to the fullest and getting the latest, greatest gadget and enjoying the full benefits of a modern society?

Why should *you* care?

You might think that because you live in Canada a warmer climate couldn't hurt. You may even consider buying beachfront property up in Baffin Island if the world gets any hotter and the Arctic waters transform into a tropical paradise.

What could be so wrong in going from this…



Source: By Rear Admiral Harley D. Nygren, NOAA Corps (ret.) [Public domain], via Wikimedia Commons (https://commons.wikimedia.org/wiki/File%3AArctic_ice_melt.jpg)

to this?



Source: By Tim Sackton (Flickr: Tropical Paradise) [CC BY-SA 2.0 (http://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons (https://commons.wikimedia.org/wiki/File%3ATurtle_Cove_Providenciales_Beach.jpg)

On the other hand, you may think that, sure, there's a problem but what's the immediacy? The future is so far away! And if there is this problem, how can one deal with it without damaging the economy or your ability to find a job? How do you balance the idea of making a living versus environmental damage? Some of you have families and have to pay your bills and it's probably an easy decision to take a job with negative environmental effects because you have to put bread on the table. Is it possible to balance these options? Is the choice really so black and white. Climate change is a global phenomenon that will affect you and your descendants; should you make more of an effort? Or for now do you need to focus on surviving in an economically challenging world, and if that means doing the *same-old, same-old*, like driving your car to work every day or working for a company that imports everything from China, so be it!

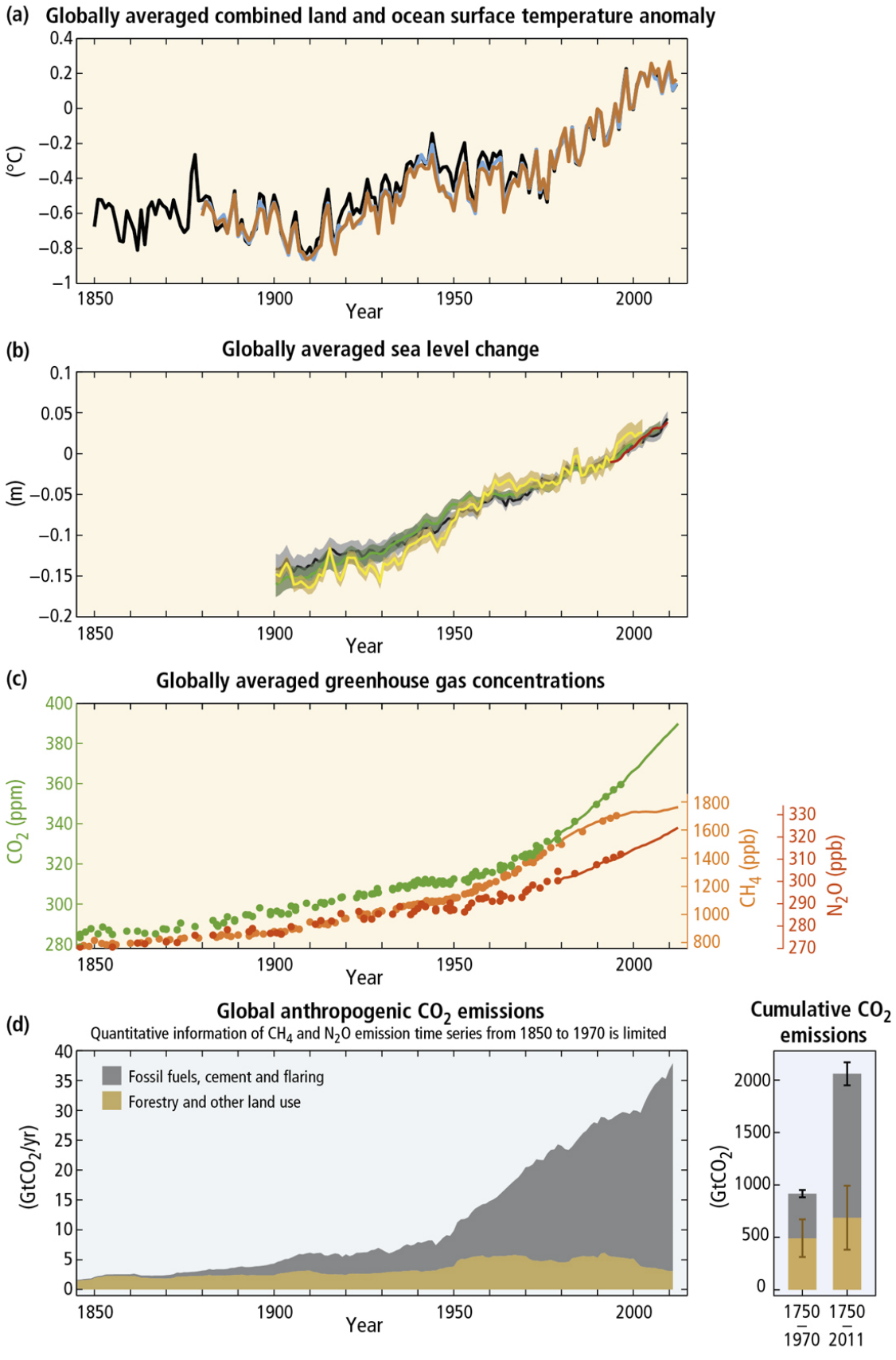
If you remember from the discussion of the scientific method in Unit 1, the differences of "opinion" between scientists and the public on climate change were deep: half of the non-scientists weren't convinced that climate change was the result of human activity, while most scientists saw the evidence for human-induced climate change as compelling. In that gap rest the seeds of hesitancy and doubt, and in that gap those with political and economic agendas try to leverage the public's distrust of science and its experts. If you recall the important aspects of science from Unit 1, you'll know that evidence, testability, reproducibility, and falsifiability must be part of the scientific analysis of the climate. Scientists know that climate can change; the evidence for major changes in the pre-human past is well documented. *But something has changed in the human-dominated age*.

The (probabilistic) scientific statement we can make about climate change is that, given our current evidence, *anthropogenic climate change is the best explanation for global warming in the modern era*. Climate change does occur naturally, but the most recent change to climate is strongly correlated to our global commercial activities. Scientists have observed *long-term trends* in the climate (what is the difference between weather and climate? (http://oceanservice.noaa.gov/facts/weather_climate.html)) and the data demonstrate the linkage between human behaviour and climate modification. Fluctuations, where average temperature, for example, spikes and drops over short periods (weather), are averaged out for long periods in the past (past climate) and projected for longer periods into the future (future climate).

Climate change is real. [1, 2, 3, 4] At least 97% of climate scientists agree that the planet's climate is not only changing, but changing *because of human activity*. [3] It shouldn't be considered that significant if a small minority like 3% hold a dissenting opinion; in science, we can expect some experts to question hypotheses and findings, but the questioning must be framed in context of alternative hypotheses, tests, and falsification, according to the tools of the scientific method. Even accepted theories must undergo constant scrutiny. It has only been in the last few decades, however, that the topic of climate change has moved outside of the realm of academic debates and into the political arena.

According to *The Intergovernmental Panel on Climate Change* (IPCC), "Human influence on the climate system is clear, and recent anthropogenic emissions of green-house gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems," and "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen." [1] The trends are clear:

The complex relationship between the observations (panels a, b, c, yellow background) and the emissions (panel d, light blue background)
Source: IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Retrieved from http://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f=SPM (http://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f=SPM)



The IPCC report discusses an apparent slowdown in the increasing rate of temperature — a "hiatus" — "over the period 1998 to 2012 as compared to the period 1951 to 2012," [5] but a new study from the NOAA (National Oceanic and Atmospheric Administration) concludes,

through the use of improved datasets, that global warming has not slowed down. [6]

There are unintended and unforeseen consequences of our way of life, which do come at the expense of the physical environment. The consequences of global warming will spill over into the social sphere, and, as Caldeira states on page 83 of your reading, “The social response to climate change could produce bigger problems for humanity than the climate change itself.”

When we talk about *what forces shape our world* in this unit and in this article, we will transcend the obvious description of natural forces, such as earthquakes, storms, volcanic activity, or the impact of stray asteroids that can redefine the order of life on this planet (dinosaurs out, mammals in). The force we are discussing here is the power of *humanity* itself, in its technology and its rapid domination of the planet; as biologist E.O Wilson states in his book *Consilience: The Unity of Knowledge*, “we are the first species to become a geophysical force, altering Earth's climate, a role previously reserved for tectonics, sun flares, and glacial cycles.”

This new geophysical force has changed the planet dramatically, and its influence on the environment echoes back and, in turn, impacts the instigators of that change, across all strata of society.

The Biosphere: Fragility versus Resilience

As you begin this lesson, it may be of interest for you to look at a grander scenario, perhaps a more humbling perspective. Think about the earth itself, with or without human beings. Look at the picture of our world below, sometimes described as a blue marble in space:



The Blue Marble
Source: NASA Goddard Space Flight Center Image by Reto Stöckli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation). Data and technical support: MODIS Land Group; MODIS Science Data Support Team; MODIS Atmosphere Group; MODIS Ocean Group Additional data: USGS EROS Data Center (topography); USGS Terrestrial Remote Sensing Flagstaff Field Center (Antarctica); Defense Meteorological Satellite Program (city lights). Retrieved from http://visibleearth.nasa.gov/view.php?id=57723 (http://visibleearth.nasa.gov/view.php?id=57723)

When you look at this image, it's easy to imagine the planet devoid of human life. It's difficult to see the effects of human activity, at least using this particular image, but if you look closely enough, at the edges of the Earth, you can see a wispy, hazy atmosphere, providing a tiny blanket of survivability. You can't miss the blueness of the life-giving water, or the shades of green and brown land. That's the biosphere, home to all living things, from the atmosphere down to the depths of the oceans and deep below the solid surface — a sliver of a life-giving environment that's a tiny fraction of the size of the Earth. You live within that protective shell.

Now you should ask yourself about the *fragility and resilience* of this planet. Before the arrival of human beings, there were natural, cataclysmic events on Earth, from spikes in temperature, to creeping ice ages, to toxic volcanic activity, and even an epic asteroid strike. Species perished and new ones came to prominence. *And the planet survived*.

Look at the picture below and see the glowing handiwork of human civilization (you can go to the NASA website and find a slew of images demonstrating human activity, from large construction projects, biomass burning, atmospheric changes in toxicity, deforestation, *etc.*):



City Lights of the Americas
Source: NASA Earth Observatory image by Robert Simmon, using Suomi NPP VIIRS data provided courtesy of Chris Elvidge (NOAA National Geophysical Data Center). Suomi NPP is the result of a partnership between NASA, NOAA, and the Department of Defense. Caption by Mike Carlowicz. Retrieved from http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=79787 (http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=79787)

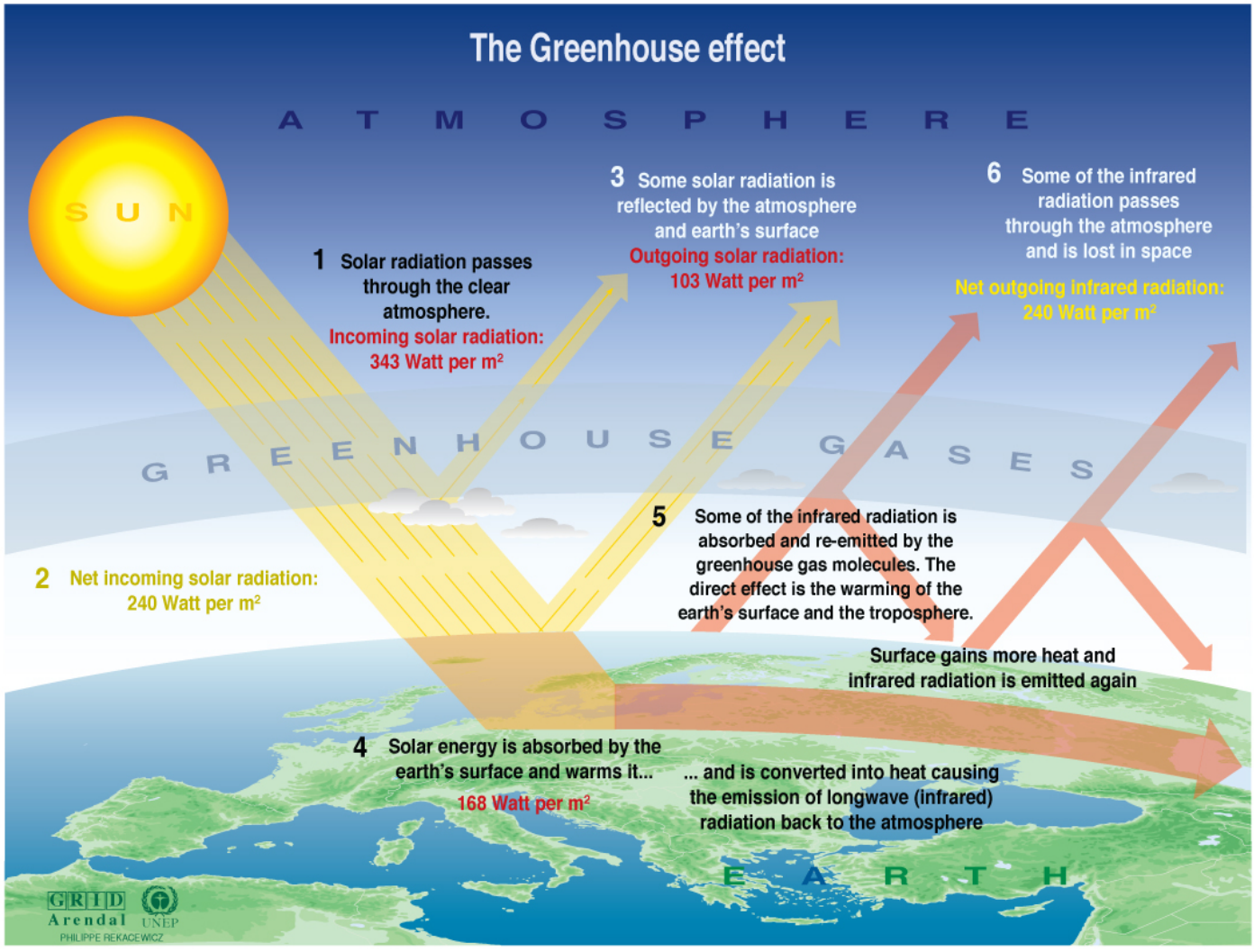
If we had a similar image from a hundred years ago, it would not be so bright, A picture of the Earth 200,000 years ago would only show darkness interrupted by flashes of lightning, some volcanic flare-ups, and forest fires — no hint of a new order of intelligence. The last few hundred years have seen the unprecedented impact of a sole species on its biosphere. This wholesale change is continuing into the immediate future, and global warming is reshaping this living space dramatically. It is difficult for people to escape the results of this bio-restructuring.

Thinking Critically

As we will see in this lesson, the consequences could be dire, with profound effects upon the longevity of the current dominant species. Will the planet survive this phase? Is the Earth resilient enough to withstand whatever we throw at it? And once human beings are gone, will the planet bounce back to its primordial health or will the damage be so severe that a million years from now some alien explorer will study our desiccated planet and wonder what happened?

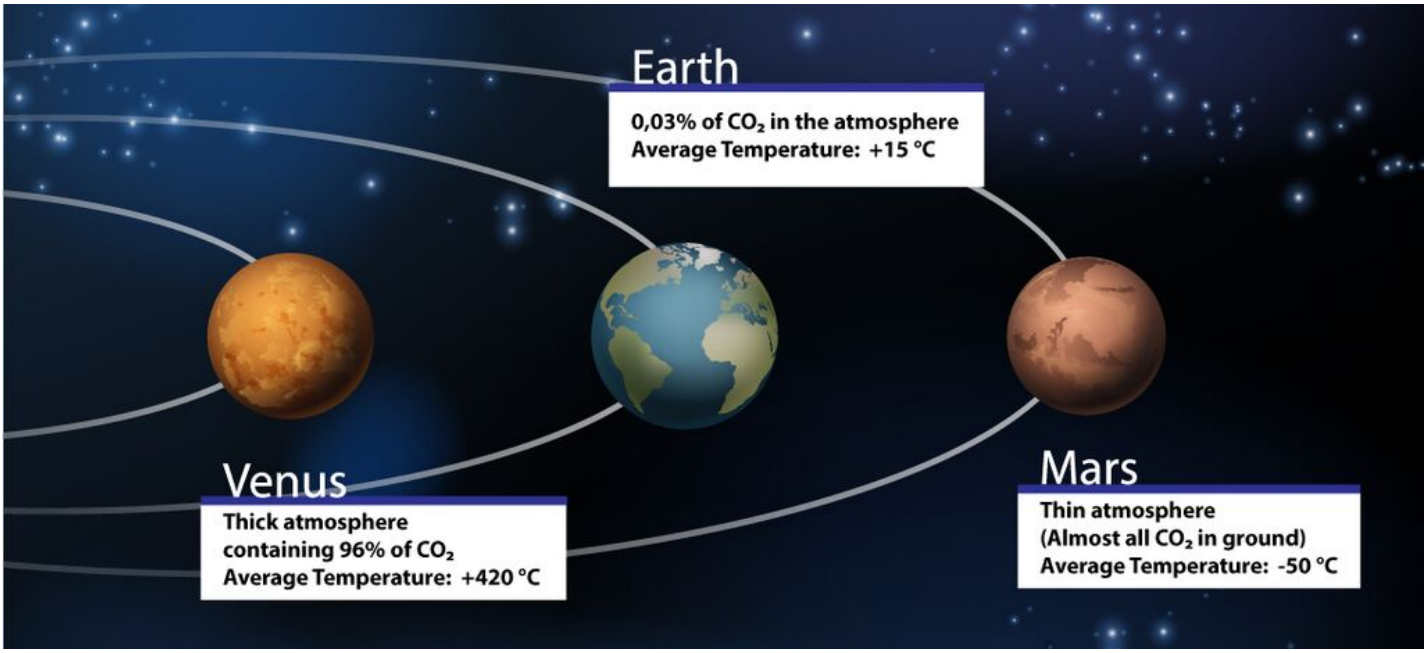
The Greenhouse Effect

Often, in the news, you will hear the term Greenhouse Effect confused with the term Runaway Greenhouse Effect. In itself, the *Greenhouse Effect* is a natural process where the atmosphere of a planet (or the greenhouse gases (GHG), like carbon dioxide, CO2) acts like a blanket, trapping infrared radiation (heat) from the sun for a period of time before the heat eventually leaks out into space. If you've ever been in a greenhouse on a winter day, you'd feel the difference because the sun's heat is trapped inside the greenhouse, with the glass behaving similarly to a GHG (there is an interactive representation of the process, under Additional Resources).



Source:

If this natural process did not exist, the surface of our planet would have a temperature below zero; in other words, we would have a frozen planet and it would much more difficult (though not impossible) for life to flourish. Look at the image below of Earth and its two planetary neighbours, Mars and Venus:



Source: © images courtesy of istockphoto.com
Reference: Calvin J. Hamilton, Views of the solar system, www.planetscapes.com, Bill Arnett, The nine planets, a multimedia tour of the solar system, www.seds.org/billa/tnp/nineplanets.html. Retrieved from http://www.grida.no/publications/vg/climate/page/3056.aspx (http://www.grida.no/publications/vg/climate/page/3056.aspx)

Do you notice the thick, cloudy atmosphere of Venus (sometimes called Earth's twin because of similar size and composition)? It's largely carbon dioxide. Venus is not the closest planet to the sun (Mercury is) but it is the hottest planet in our solar system. Caldeira writes, that after a series of nasty feedback events involving evaporating oceans, increasing carbon dioxide, more water vapour, *etc.*, "Earth's climate would then settle into a state reminiscent of its planetary neighbor Venus." {p. 83) This is the *Runaway Greenhouse Effect*. Current scientific understanding suggests that Earth and Venus may have been similar in atmospheric composition billions of years ago, with Venus cooler than it is today, and perhaps harbouring oceans. A Runaway Greenhouse Effect may have been one of the things that transformed Venus: most of the carbon dioxide locked up in rocks and water somehow was released, making the planet hotter and hotter, boiling away the oceans, spewing water vapour (another GHG) into the atmosphere, and cranking up the heat even more, until you have the hothouse of today.

Would you like to visit Venus? If the lack of oxygen doesn't impair your ability to breathe, the sulphuric acid droplets will do wonders for your complexion. Here's an artist's rendering of Venus today (or future Earth according to some scenarios):



Artist's concept of lightning on Venus
Source: ESA (image by Christophe Carreau) (Artist). (2007). *Artist's concept of lightning on Venus* [Illustration], Retrieved from http://www.esa.int/spaceinimages/Images/2007/11/Artist_s_concept_of_lightning_on_Venus (http://www.esa.int/spaceinimages/Images/2007/11/Artist_s_concept_of_lightning_on_Venus)

We've mentioned carbon dioxide (CO_2), and the main source of carbon dioxide emissions is the burning of fossil fuels (http://www.fe.doe.gov/education/energylessons/coal/gen_howformed.html), but we have some other important greenhouse gases such as water vapour (H_2O), methane (CH_4) and nitrous oxide (N_2O). These gases can also absorb and re-emit heat and they are transparent to visible light (this is why sunlight can penetrate the atmosphere). These particular gases are also natural, but their concentrations have risen dramatically in the human era; some other industry-produced GHGs are perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulphur hexafluoride (SF_6).

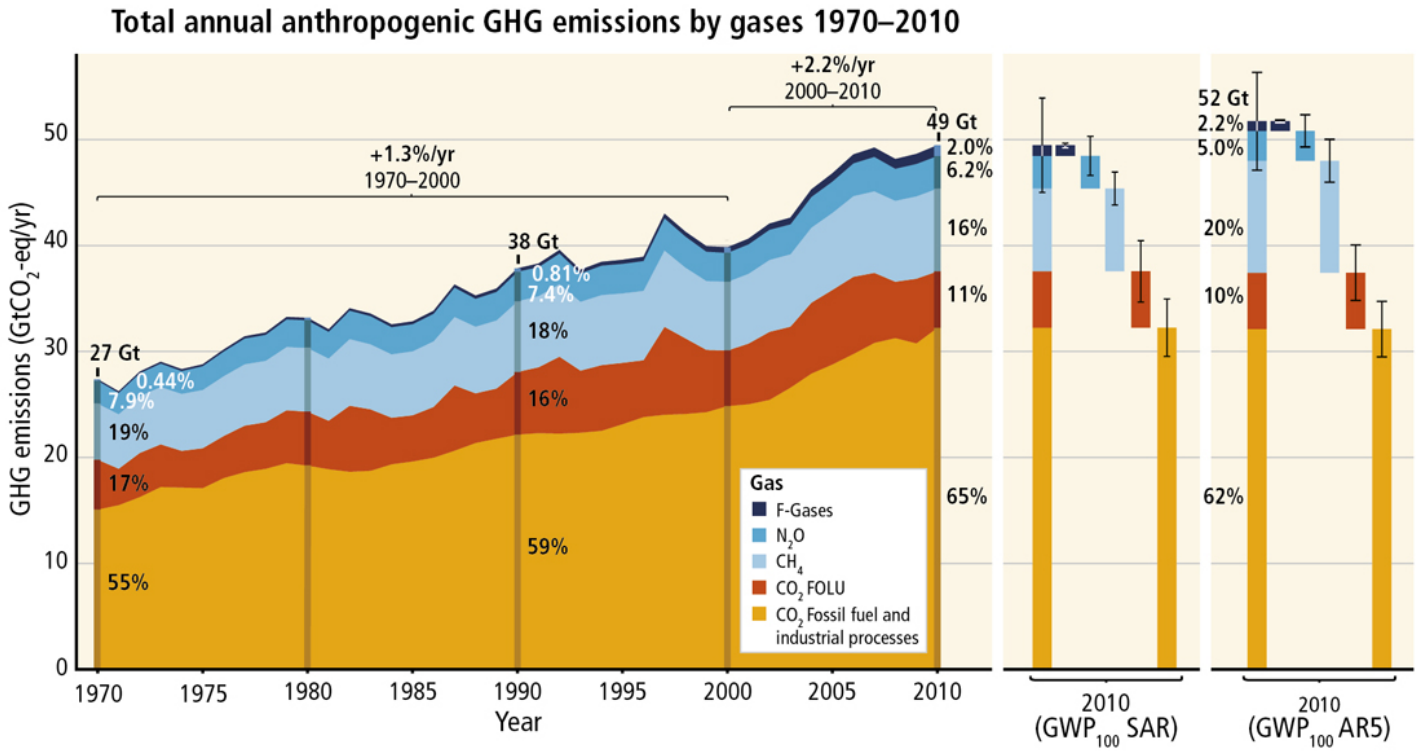
Another point you should note is that some of these gases are more potent than carbon dioxide in heat retention. As Caldeira states, "Arctic warming could cause hundreds of billions of metric tons of methane to rapidly bubble to the atmosphere from Arctic sea beds and soils. Molecule for molecule in the atmosphere, methane is about 37 times better at trapping heat than CO_2." (p. 83) This would be going from bad to worse.

So now we have the recipe for anthropogenic global warming: increasing concentrations of greenhouse gases generated by human industry — the machinery of our modern global economy. The multi-trillion dollar question is, *how does one reduce these emissions without damaging the way we live?*

Global Warming: Evidence and Impact

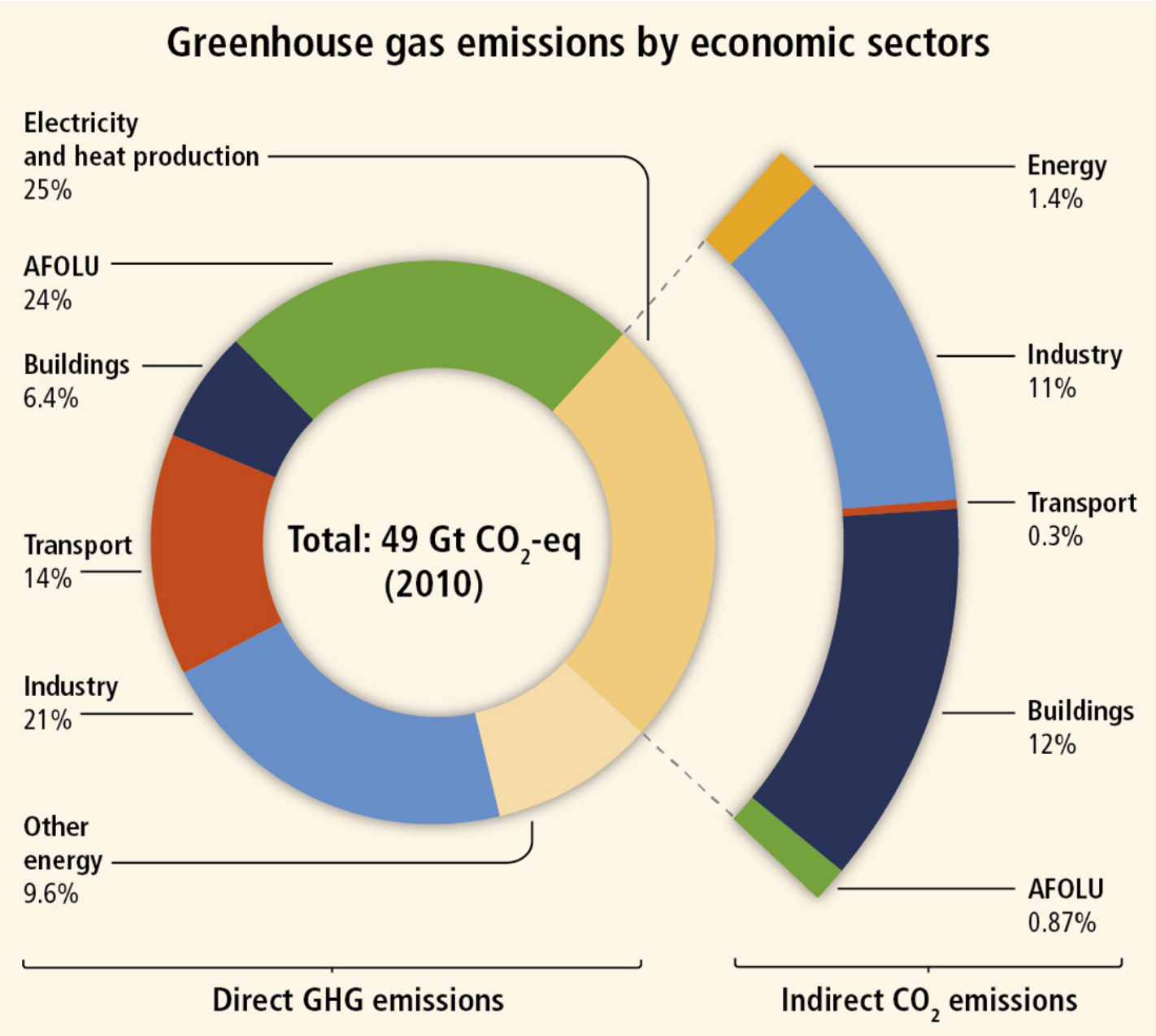
The biosphere is a complex ecosystem composed of living organisms interdependent in a delicate food web (living things have a niche, an evolutionary adaptation), and these living things are bound to environments of a physical and chemical nature (air, water, energy cycles, water cycles, carbon cycles, etc.). It's an intricate mechanism that can be disrupted, and it has been disrupted in the past, before the rise of humanity. But now, as Caldeira states, "Our greenhouse emissions are hitting this complex system with a hammer." (p. 83)

As you see below, CO2 is the biggest contributor so far to GHG emissions:



Source: IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Retrieved from http://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f=SPM (http://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f=SPM)

And where do these gases come from in the modern age?



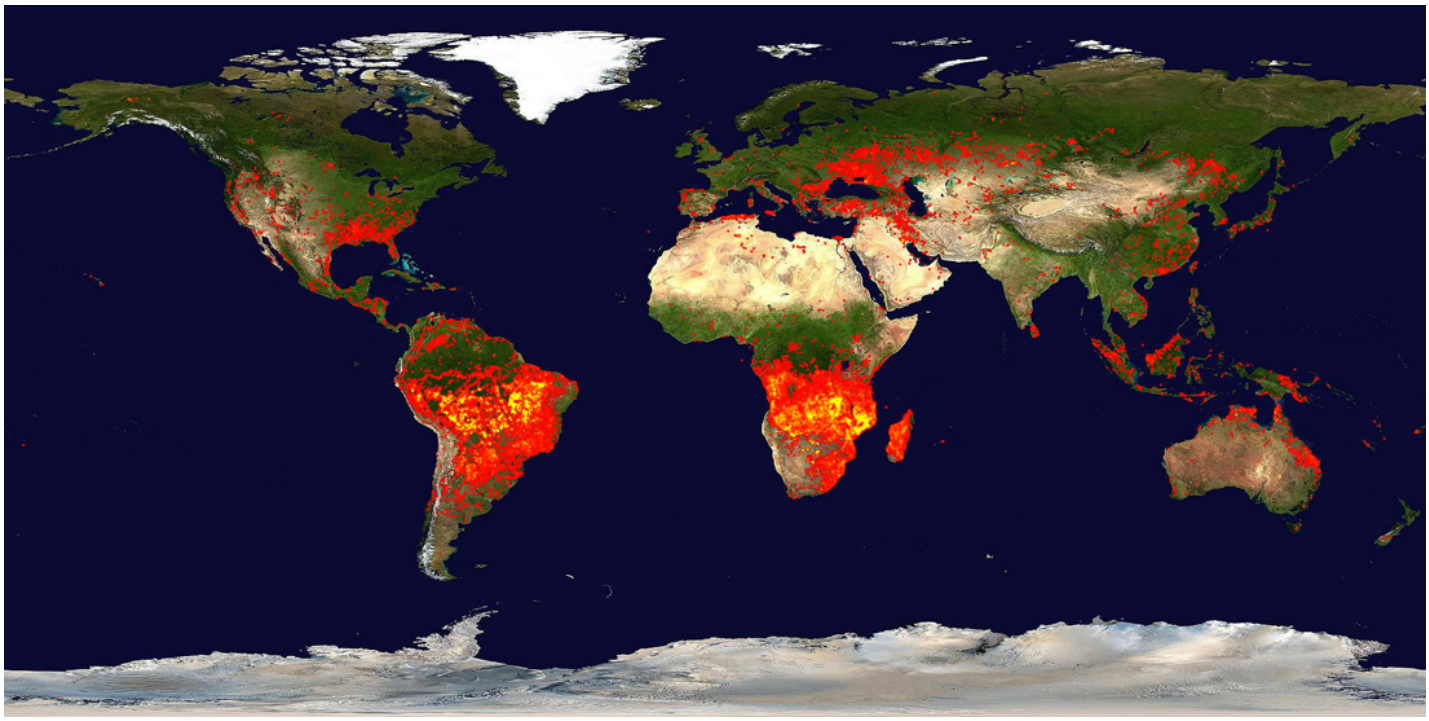
Source: IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Retrieved from http://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f=Topic%201 (http://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f=Topic%201)

GHG emissions from the burning of fossil fuels (coal use, gasoline and diesel fuel) and industrial processes was mentioned in your opening video, but deforestation, according to some climate models, is another net contributor of carbon to the feedback loop of increasing ambient temperature. [7] Deforestation, usually through the burning down of forests and rainforests,

contributes more carbon into the atmosphere, reduces rainfall that cools land, and the land reclaimed for farming can emit even more carbon. Watch this time-lapse imagery of deforestation in the Amazon rainforest, a display of human behaviour that is visible from space:

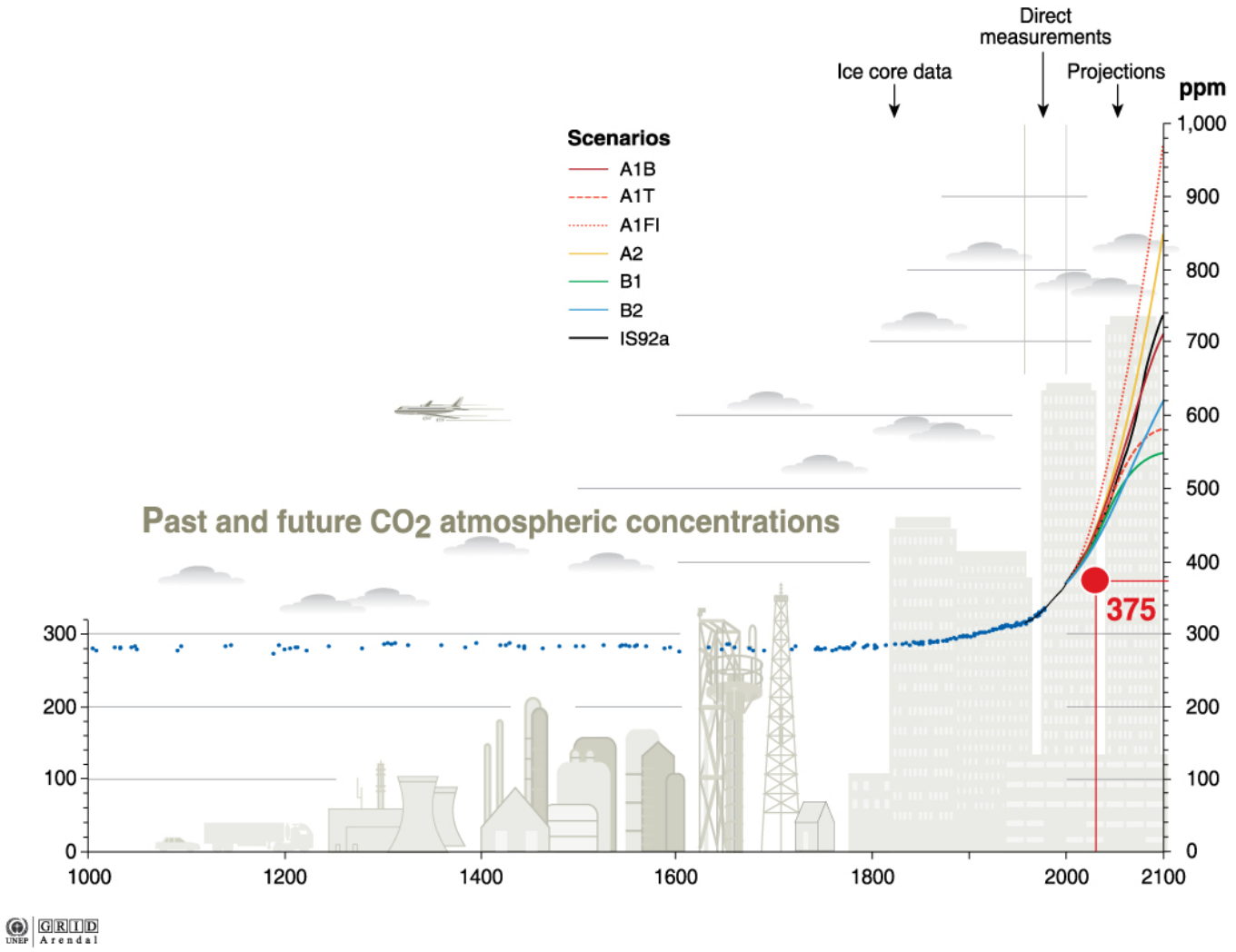
Deforestation in Rondonia, Brazil (http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=3967)

Here is another human activity you can see from space, where 90% of these fires are started by humans and produce 30% of the atmospheric CO_2 [8]:



The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite shows fires around the world. Source: NASA. (2010). *The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite shows fires around the world*, Retrieved from http://www.nasa.gov/topics/earth/features/wildfires.html (http://www.nasa.gov/topics/earth/features/wildfires.html)

We can see a jump in carbon dioxide concentrations with industrialization. The Industrial Revolution (late 18th to mid-19th centuries) brought much in terms of economic growth and improved standards of living, but it also brought the global environment into peril. In the chart below, you can see the atmospheric CO_2 concentrations from then to now (with about a 0.8°C temperature increase over the past 150 years), and the possible projections for the future, based on different estimates and models:



Source: Philippe Rekacewicz, Emmanuelle Bournay, UNEP/GRID-Arendal. (2005). Past and future CO2 concentrations [Illustration], Retrieved from http://www.grida.no/graphicslib/detail/past-and-future-co2-concentrations_a92d (http://www.grida.no/graphicslib/detail/past-and-future-co2-concentrations_a92d)

That's the global change in temperature in modern, industrial times. Let's bring this impact closer to home: according to the Government of Canada's website, Canada's Action on Climate Change (http://www.climatechange.gc.ca/default.asp?lang=En&n=E18C8F2D-1), "Over the period 1948 to 2010, the average annual temperature in Canada has warmed by 1.6°C, a higher rate of warming than in most other regions of the world." [9] If you thought global warming had consequences somewhere far away, think again.

The accumulating, *scientific* evidence reveals large-scale ramifications; in the following NASA interactive presentation, click on each visualization to see the changes to *Sea Ice, Sea Level, Carbon Dioxide, and Global Temperature:*

Climate Time Machine (http://climate.nasa.gov/interactives/climate-time-machine)

In the *Global Temperature* visualization, did you notice which regions of the planet heated up the most? The Arctic has an ominous, crimson hue.

In the *Sea Ice* visualization, the reduction of the Arctic ice cover is dramatic. You would expect freezing and melting (expansion and shrinking) as we go through winters and summers, but on average, the Arctic Ocean is losing its ice cover at a tremendous rate. [10] What happens as we lose more ice cover? Can you see the warming feedback in the animation below?

Multi-year Arctic sea ice 2014 (https://www.youtube.com/watch?v=ApaM_wJ_nE8)

The white ice reflects heat back into space, while the dark ocean absorbs heat. As the ice melts, there is a larger, darker area absorbing more heat and a smaller, whiter, area reflecting less. The temperature goes up. The feedback continues and more ice melts, more heat is absorbed. *End game: no ice*. But think about this: why does melting Arctic Ocean ice not increase sea levels?

Thinking Critically

Did you notice the countries around that ice sheet? It's Canada and four others (name them; a couple of them are superpowers). As the ice melts, there is more ship traffic and international activity (including military) in the once inaccessible Northwest Passage, and what may prove interesting in the future is that a lot of oil has been discovered under the Arctic Ocean. Do you think this may lead to conflict? What can Canada do if some (powerful) countries begin to argue that some of our territory is really international, or belongs to them?

Some of the evidence for global warming was presented in the charts in your introduction, and the references at the end of this lesson hold hundreds of pages of data showing breakdowns or trends, GHG emission, statistical analyses, GHG emission by country (look up Canada's place in the world and you'll find our *per capita* output is rather high), etc. A search for 'climate change' on Google Scholar will yield thousands of journal publications. The evidence paints a dire picture:

- A changing atmosphere, in temperature, toxicity, air flow, jet streams, precipitation, and strange weather events;
- Changes to the temperature and the chemistry of our oceans;
- Altered water cycles;
- Damage to biodiversity and increased extinction rates;
- Diminishment of plant and forest cover;
- Carbon cycle disruption;
- Acidification in the oceans;
- Rising sea levels.

Data show melting of ice in cold environments (the cryosphere, like the Arctic, as mentioned above), diminishing snow cover, and the melting of ice sheets and glaciers. To see these other trends, visit NASA's Global Ice Viewer (http://climate.nasa.gov/interactives/global_ice_viewer) and note the contrast of the Arctic Ocean to Antarctic sea ice in terms of melting. If Antarctica were to experience a runaway warming effect (why does it seem to be an exception? See reference [10]), the resulting melt would prove disastrous for water salinity and sea levels. [11]

A change in global temperature, whether from increased GHG emissions through fossil fuel burning, industry, or from deforestation for farming or settlement, has a ripple effect, possibly building to a tsunami of change on environments across the planet. The biosphere has been undergoing measurable changes; it will continue to suffer incredible stress on all levels, biotic, abiotic, and social: glaciers, snow and ice, permafrost, rivers and lakes, floods, drought, coastal erosion, sea levels, ecosystems and biodiversity, wildfires, food production, health issues, and economics. [12]

Economics and the Natural Environment

A closer look at two examples briefly mentioned in the article should help you see how economics and the natural environment interconnect.

Caldeira claims: “With all the carbon locked in Earth’s crust, we will never run out of fossil fuels.” (p. 80) This may be true in principle, but it is also true that the most common way to extract non-renewable sources of energy from the ground—that is, pumping crude oil out of large oil and gas reservoirs—is slowly becoming less effective. Because of the increasing global demand for non-renewable sources of energy, it is becoming economically attractive to extract oil (bitumen) from the Alberta Oil Sands and natural gas from large shale deposits. These methods, however, are both more difficult than pumping and more detrimental to the environment.



Aerial view of Syncrude Aurora tar sands mine in the Boreal Forest north of Fort McMurray.
Source: Greenpeace/Jiri Rezac. *Aerial view of Syncrude Aurora tar sands mine in the Boreal Forest north of Fort McMurray* [Photograph], Retrieved from http://www.greenpeace.org/canada/en/campaigns/Energy/tarsands/ (http://www.greenpeace.org/canada/en/campaigns/Energy/tarsands/)

The economic viability of the Alberta oil sands project reflects a changing global supply and demand equation for oil — and an increased threat to the environment.

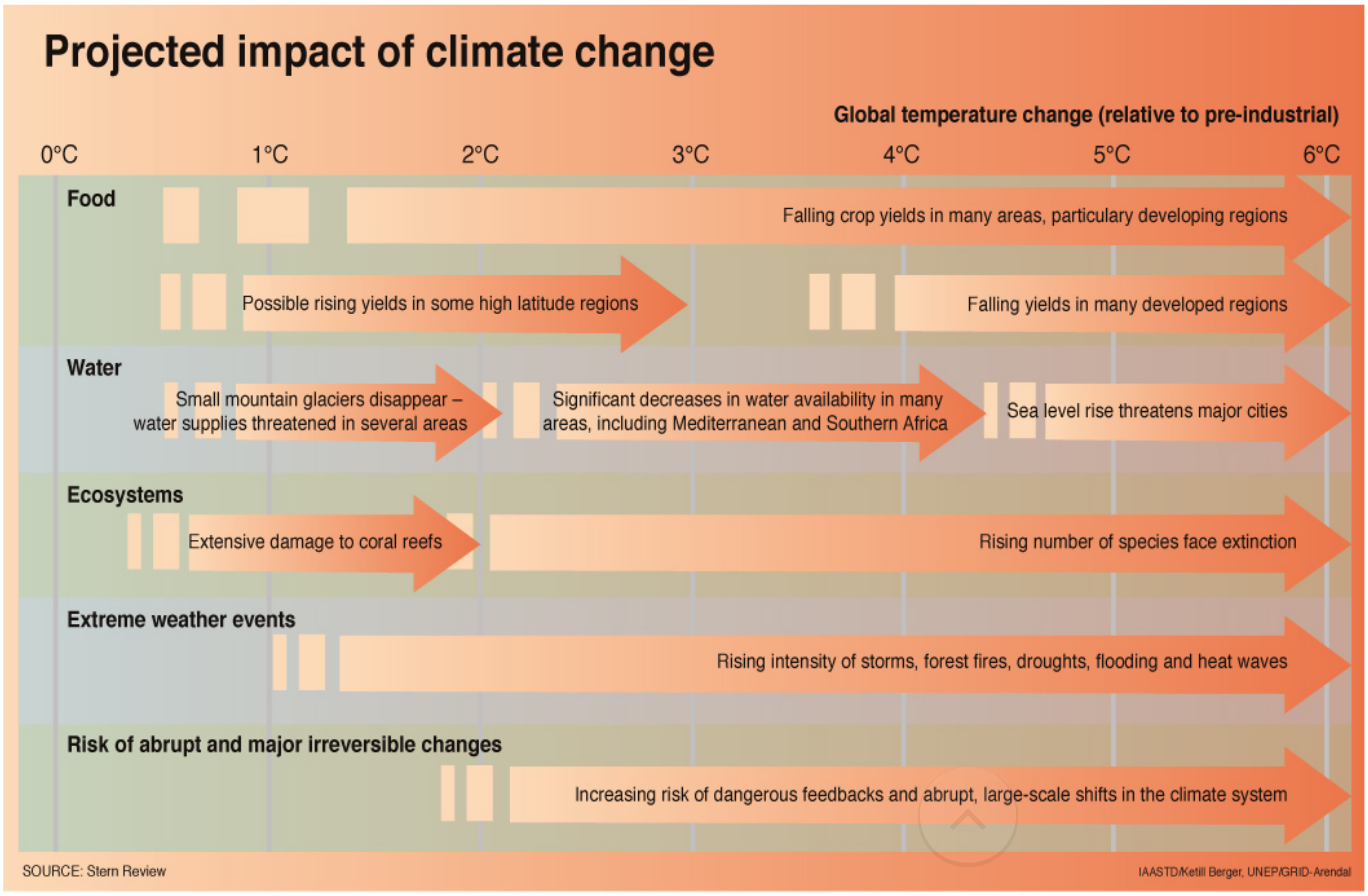
Another more recent form of extracting natural gas from the Earth's crust in North America is hydraulic fracking. Much like extracting bitumen from the Alberta oil sands, hydraulic fracking generates considerable environmental waste. When measured against extracting conventional crude, it is also costly and very harmful to the environment. The process of hydraulic fracking involves pumping water and sand into the ground at a very high pressure in order to creature fractures in large shale deposits. One then extracts the shale gas as it is slowly pumped up through these cracks to the surface. This form of extracting natural gas in the United States, and to a lesser extent in the Western provinces, has become very popular in the last few years and production will certainly continue to increase in the near future. As with the Alberta oil sands, it is also a process that reflects the changing global supply and demand equation for oil. More and more emerging markets mean more demand for coal, oil and natural gas. An increasing global demand for non-renewable sources of energy inevitably means an increasing demand for these non-traditional and environmentally more aggressive methods.

These are just two examples that demonstrate how the force of (capitalist) globalization shapes our world and impacts the physical environment. It would be nice if there were an easy solution to climate change, but because it is a global issue that involves so many intersecting factors, there really is no easy solution to curbing global warming. The most obvious answer would be to curb global demand for non-renewable forms of energy. But in a world where the use of oil, coal and natural gas is so pervasive, solutions on how to curb global demand for these forms of energy are less obvious.

Global Warming: Consequences

It's important to understand that climate change scenarios can only be *speculative*: despite observing trends and understanding causes, climate projections, as anything scientific, are about *probabilities*, not certainties. There is bound to be a certain amount of error in calculations as computer models that simulate the weather and climate are trying to represent incredibly complicated and delicate systems, ranging from cloud dynamics, ocean response to temperature, air and ocean currents, and even solar influences. Initial conditions, slightly altered or buffeted by chaotic forces, can lead to a range of scenarios (you've probably heard of the Butterfly Effect).

Nonetheless, we have a responsibility to understand the trends and try to extend them into the future, and the trends definitely suggest that, even with a margin for error, there will be higher concentrations of atmospheric CO_2, temperatures will rise, and sea levels will continue to rise as well. [13] The effects are global in impact; the greater the rise in temperature, the greater the negative effects:



Source: IAASTD/Ketill Berger, UNEP/GRID-Arendal. (2008). *Projected impact of climate change* [Illustration], Retrieved from http://www.grida.no/graphicslib/detail/projected-impact-of-climate-change_1011 (http://www.grida.no/graphicslib/detail/projected-impact-of-climate-change_1011)

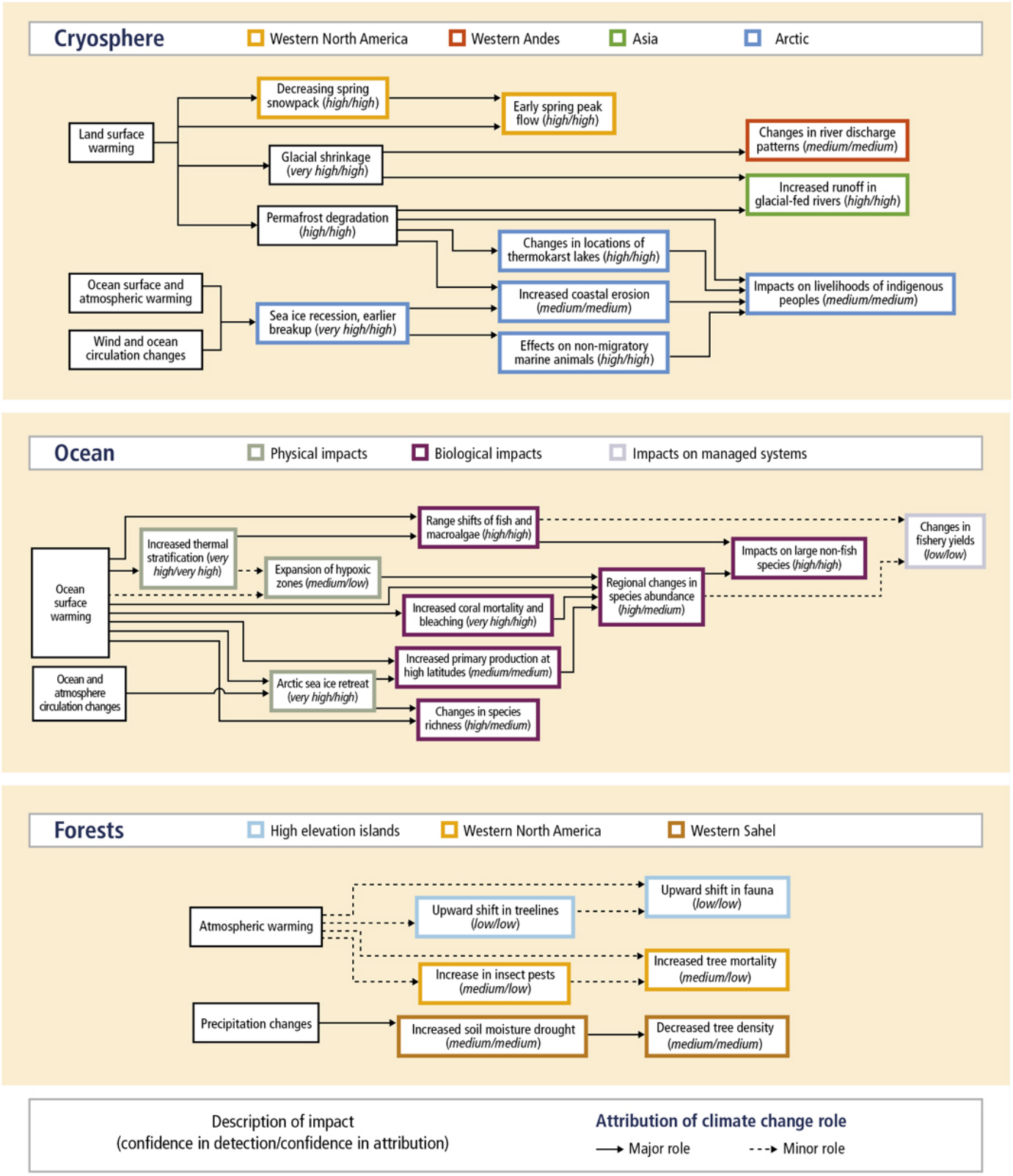
Caldeira discusses some serious consequences if the planet does get warmer as expected. As desert bands creep out from the equator toward the poles (p. 80), there may also be longer growing periods in northern latitude countries — further benefiting what are already in general the richest countries on the planet, while at the same time further stressing tropical climes, the locales of many of the world's poorer countries. Species will likely migrate pole-ward as the climate warms and migrating species will invade and disrupt indigenous species, perhaps bringing new diseases and problems that were once isolated to equatorial environments.

Ocean acidification (p. 82), with its disruptive force on marine ecosystems, will harm marine life (including the very important phytoplankton, a key component of the marine food web [14]), and no doubt threaten the livelihood of people living near water, hand-in-hand with rising sea levels.

Ocean Acidification by the Alliance for Climate Education (https://www.youtube.com/watch?v=Wo-bHt1bOsw)

When we discussed evolution we saw how environmental stresses could effect the adaptation of species. Global warming is a game changer in that many species will not have the tools to survive the rapid changes or the time needed to evolve those tools naturally, and so many species will perish. This will disrupt ecosystems across the planet, and likely fracture various food chains and predator relationships, so that parasites or diseases that were once kept in check by a species that preyed on their carriers may now thrive. Of the five mass extinction events in the earth's past, four are associated with a rapid jump in temperature. A sixth mass extinction may well be developing under human pressure.

The chain of events, of unexpected consequences, will prove difficult to predict, but we can follow the dominoes as they fall:



Major systems where new evidence indicates interconnected, 'cascading' impacts from recent climate change through several natural and human subsystems.

Source: IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Retrieved from http://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f=Topic%201 (http://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f=Topic%201)

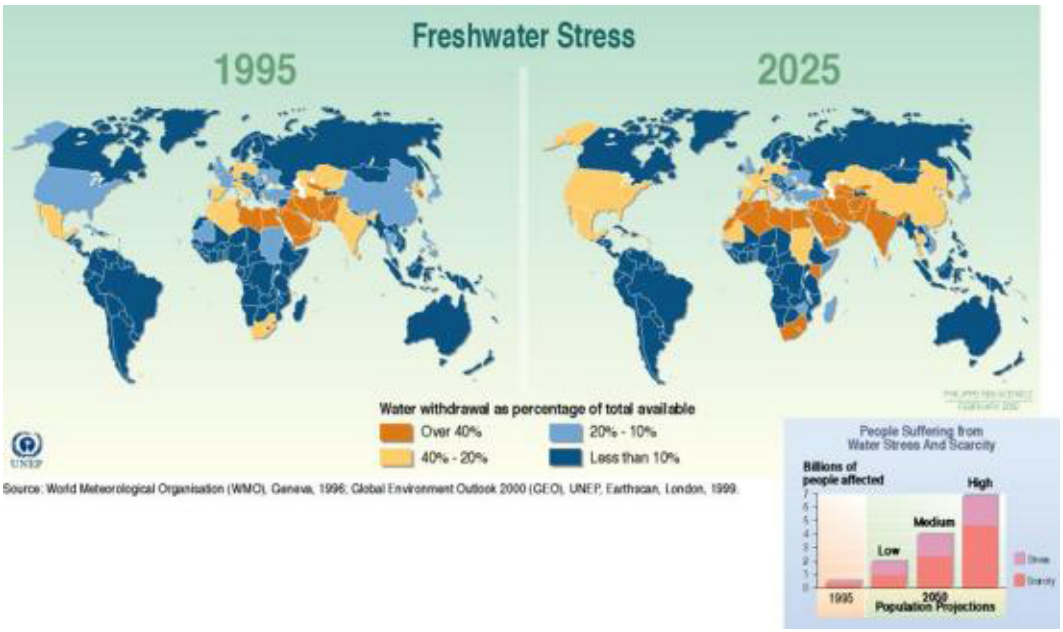
Consequences will go beyond natural systems and will spill over into the world of politics and national power struggles. As the disparity between rich and poor countries grows, so will global tensions. “If the rich get richer and the poor get poorer, could this set in motion mass migrations that challenge political and economic stability?” (Caldeira, p. 83)

The richer countries will not be immune from these consequences, whether from migration stress, increasingly toxic living conditions from greater industrialization, or crops suffering from heat stress and other changing environmental stress factors like precipitation, ultraviolet radiation (UV) exposure, or new competition from encroaching species. The health issues connected to these environmental changes have not yet been fully studied, so we can’t be sure either of the human or of the full *economic* impact of health issues that may arise.

Thinking Critically

Remember when we discussed the discovery of oil beneath the Arctic Ocean? Those countries muscling each other over that watery patch are some of the richest countries on the planet, and that means that any future conflicts will not be described solely as North-South issues.

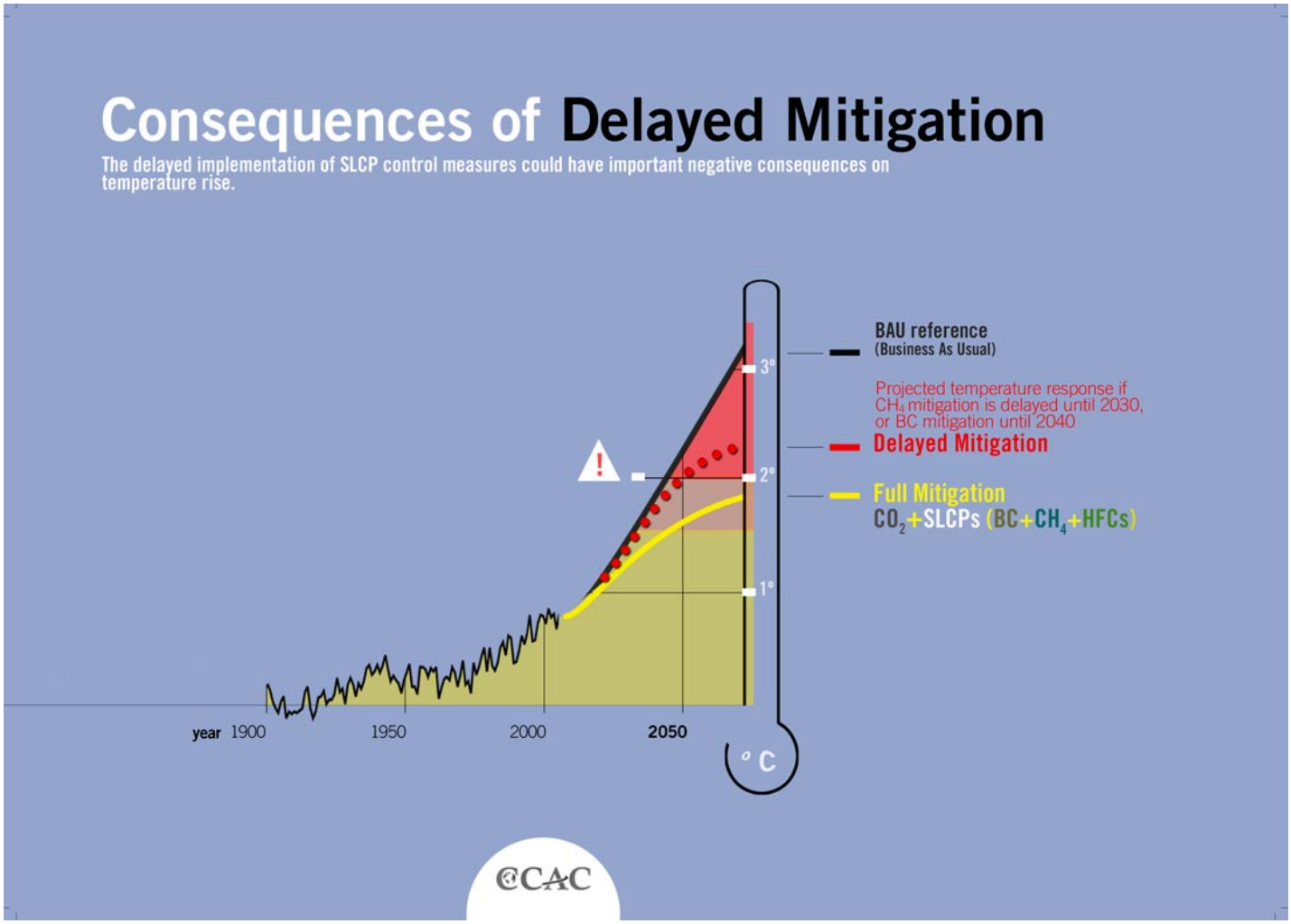
Are there going to be *climate wars* in this century? As the planet gets warmer, it will also get drier and a valuable commodity will be fresh water. Look at the projections below, and note Canada’s healthy reservoir. Are future wars going to be fought over water, much as the oil-inspired conflicts of today?



Global freshwater withdrawal

Source: Philippe Rekacewicz, UNEP/GRID-Arendal. (2005). *Freshwater Stress 1995 and 2025* [Illustration], Retrieved from http://www.grida.no/graphicslib/detail/freshwater-stress-1995-and-2025_6250 (http://www.grida.no/graphicslib/detail/freshwater-stress-1995-and-2025_6250)

There is an earnest debate going on about whether we are near the tipping point — the point of no return in terms of global warming — or may even have passed it. Many scientists suggest that a 2°C warming cap is necessary to stop some of these scary predictions, but from the graph below, that would mean a complete stop in all carbon emissions — as you could guess, that would be highly unlikely. The *Business as Usual* (BAU) projection is grim, taking us to a possible 3° C increase, with all accompanying implications.



Source: GRID-Arendal. (2014). *Consequences of Delayed Mitigation* [Illustration], Retrieved from http://www.grida.no/graphicslib/detail/consequences-of-delayed-mitigation_a32e (http://www.grida.no/graphicslib/detail/consequences-of-delayed-mitigation_a32e)

There are many plans on GHG reduction, from government regulations and actions proposed by various countries, including Canada. [15] These plans can vary from country to country, of course, but there are international treaties as well, such as the Kyoto Protocol (what is the government of Canada's position?), and the work of the United Nations Climate Change Conference (http://unfccc.int/2860.php), but even these treaties and organizations have become hotbeds of political and economic debate. Some developing countries argue that some of these measures are restrictive and will hinder their economic development, especially after the industrialized western world has already profited from environmental exploitation.

Thinking Critically

Will we resolve our impending climate crises through technological innovation? Will incorporating frontier scientific research and better technological innovation into the capitalist system offer us less peril and more promise? Or will the short-term economic rewards and financial incentives lead to our inevitable long-term demise? Is it too late to curtail the unstoppable economic forces that shape our world?

It is easy to not ask these important questions and distance yourself from the impersonal economic and natural forces that shape our world. It is also easy to blame the perils of capitalism and climate change on others. Such a view often leads to inaction and/or self-righteous indignation. Such a view is also irresponsible. So what should or can we do? After this lesson, think about how your action or inaction can, step-by-step, reduce the carbon footprint and perhaps at the same time turn a profit.

Can change begin with *you*?

Summary

On July 12, 2013, from its orbit around Saturn, the *Cassini* spacecraft snapped a picture of our planet, in many ways reminiscent of an earlier picture of Earth taken by *Voyager 1* as it was leaving our solar system. Take a moment to study this picture, and in the lower portion of the image, below the magnificent rings of Saturn, note the speck as seen from 1.5 billion kilometres away, a speck you might have ignored if the arrow did not highlight it.



Pale Blue Dot

Source: NASA/JPL-Caltech/Space Science Institute. (2013). *Pale Blue Dot: Distant Spacecraft Photograph Earth* [Photograph], Retrieved from http://science.nasa.gov/science-news/science-at-nasa/2013/23jul_palebluedot/ (http://science.nasa.gov/science-news/science-at-nasa/2013/23jul_palebluedot/)

That little smudge of light, that *pale blue dot* as elegantly described by astronomer Carl Sagan, is the Earth — *us*. In subtle ways this picture conveys feelings of fragility, isolation, specialness, intellectual accomplishment, loneliness and insignificance. *All we are* is on that dot and humanity's torturous story is mostly confined to that tiny, bright spot.

In describing the sobering perspective that comes with distance, Sagan wrote, "Our posturings, our imagined self-importance, the delusion that we have some privileged position in the Universe, are challenged by this point of pale light. Our planet is a lonely speck in the great enveloping cosmic dark. In our obscurity, in all this vastness, there is no hint that help will come from elsewhere to save us from ourselves." [16]

And if that little dot were to fade away, vanish into oblivion and blend into that dark, cosmic night, who would ever know or notice? Who would care about a nameless clever species in an inconspicuous part of the galaxy? Who would mark this unknown grave in testament to a remarkable intelligence?

Many would argue that humanity has reached a crossroads in the way it negotiates its relationship with the environment and deals with global crises. The evidence that the Earth's climate is changing is considerable, and the claim that it is not anthropogenic is the rationale used by some for not doing anything because, after all, it's a natural event and the Earth will set itself right. Yet, the effects are real and current, and human beings are not invulnerable to the environmental stresses that extinguish life and cripple social structures.

The debate now, for many, is not whether climate change is real but how to prevent the planet from warming at such an accelerated rate. Some argue that there still is time to undo *some* damage, others, perhaps pessimistically, state that the point of no return is quickly shrinking in humanity's rearview mirror. Humanity, as a geophysical force, has altered the environment, and the open question is whether those changes are not only reversible, but if there is the capability to do so — if we have the will to notice that pale blue dot we inhabit.

This new geophysical force of nature is unlike any other living thing that came before it. Even the dinosaurs, titleholders of a two-hundred-million-year reign, didn't modify the planet to the same degree as humankind's brief tenure on this world. These extinct creatures may not have left behind remnants of culture and stone monuments praising themselves, but they lasted a long, long time without paper, pen, and the machinations of higher thought.

But human beings have technological capability and intelligence. When we talk about our technology in addressing problems like global warming, we sometimes frame the question in terms of the promise of technology — the promise of our intelligence — as saviour: no worries, if there is a problem we're smart enough to figure it out.

If there is time.

A chilling thought that you should reflect on is something else E.O. Wilson said: "Perhaps a law of evolution is that intelligence usually extinguishes itself." [17]

One wonders if we really are smarter than the dinosaurs.

Additional Resources

Optional material:

- The Intergovernmental Panel on Climate Change (IPCC) (http://www.ipcc.ch/)
- Global Climate Change: Vital Signs of the Planet (http://climate.nasa.gov/)
- NASA: Tropical 'Runaway Greenhouse' Provides Insight to Venus (http://www.nasa.gov/centers/ames/news/releases/2002/02_60AR.html)
- Global Climate Change: Home Frontier (http://climate.nasa.gov/climate-reel/)
- The Greenhouse Effect (https://phet.colorado.edu/en/simulation/greenhouse)
- David Suzuki Foundation: What is a carbon tax or carbon fee? (http://www.davidsuzuki.org/issues/climate-change/science/climate-solutions/carbon-tax-or-cap-and-trade/)
- The Carbon Cycle (http://earthobservatory.nasa.gov/Features/CarbonCycle/carbon_cycle3a.php)

- 🔗 Arctic Ecosystem (http://www.pbslearningmedia.org/resource/ipy07.sci.life.eco.arcticecosys/arctic-ecosystem/)
- 🔗 The Breathing Earth (http://www.breathingearth.net/)
- 🔗 Blue Marble Navigator (http://www.blue-marble.de/)
- 🔗 National Oceanic and Atmospheric Administration (NOAA) (http://www.nesdis.noaa.gov/)
- 🔗 National Snow & Ice Data Center (http://nsidc.org/arcticseaicenews/)
- 📹 Global Warming 101 (http://video.nationalgeographic.com/video/101-videos/global-warming-101)
- 📹 Climate Change 101 With Bill Nye the Science Guy (http://www.smithsonianmag.com/videos/category/3play_1/climate-change-101-with-bill-nye-the-science/?no-ist)
- 📰 Fact or Fiction?: We Can Push the Planet into a Runaway Greenhouse Apocalypse (http://www.scientificamerican.com/article/fact-or-fiction-runaway-greenhouse/)
- 🔗 A Student's Guide to Global Climate Change (http://www.epa.gov/climatestudents/)
- 📰 What are Phytoplankton? (http://earthobservatory.nasa.gov/Features/Phytoplankton/)
- 📰 Ocean Acidification (http://ocean.si.edu/ocean-acidification)
- 📰 These Are the Planets We Could Move to Once We're Done Completely Destroying Earth (http://www.motherjones.com/environment/2015/06/video-exoplanets-climate-change)
- 📰 Learning to do the math on climate change (http://www.chroniclejournal.com/opinion/columns/jason_maclean/learning-to-do-the-math-on-climate-change/article_5f6e5602-0872-11e5-a57d-

23ca1d7eb21e.html)

- 🗞 Nature Studies: The world's nations have one last chance to slow climate change (http://www.independent.co.uk/voices/comment/the-worlds-nations-have-one-last-chance-to-slow-climate-change-10291342.html)
- 🗞 Nasa 'climate change' test chamber to simulate Venus' toxic conditions (http://www.telegraph.co.uk/news/science/space/9024912/Nasa-climate-change-test-chamber-to-simulate-Venus-toxic-conditions.html)
- 🗞 Media failing on climate-change coverage (http://www.thestar.com/opinion/commentary/2015/05/31/media-failing-on-climate-change-coverage.html)
- 🗞 Climate-change sceptics are more ambivalent than once believed (http://phys.org/news/2015-06-climate-change-sceptics-ambivalent-believed.html)
- 🗞 Edward O. Wilson's New Take on Human Nature (http://www.smithsonianmag.com/science-nature/edward-o-wilsons-new-take-on-human-nature-160810520/?no-ist)

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