Climate Change Overview

- Perspective: Long-term Trends in Temperature
- The Biosphere
- The Greenhouse Effect
- Climate Change: Past, Present, Future
- Mitigation

Lesson based on the reading:
Davidson, D. (2021). Climate Change. In *The Canadian Encyclopedia*. Retrieved from https://www.thecanadianencyclopedia.ca/en/article/climate-change

Please make sure you read this.

Introduction

Video:

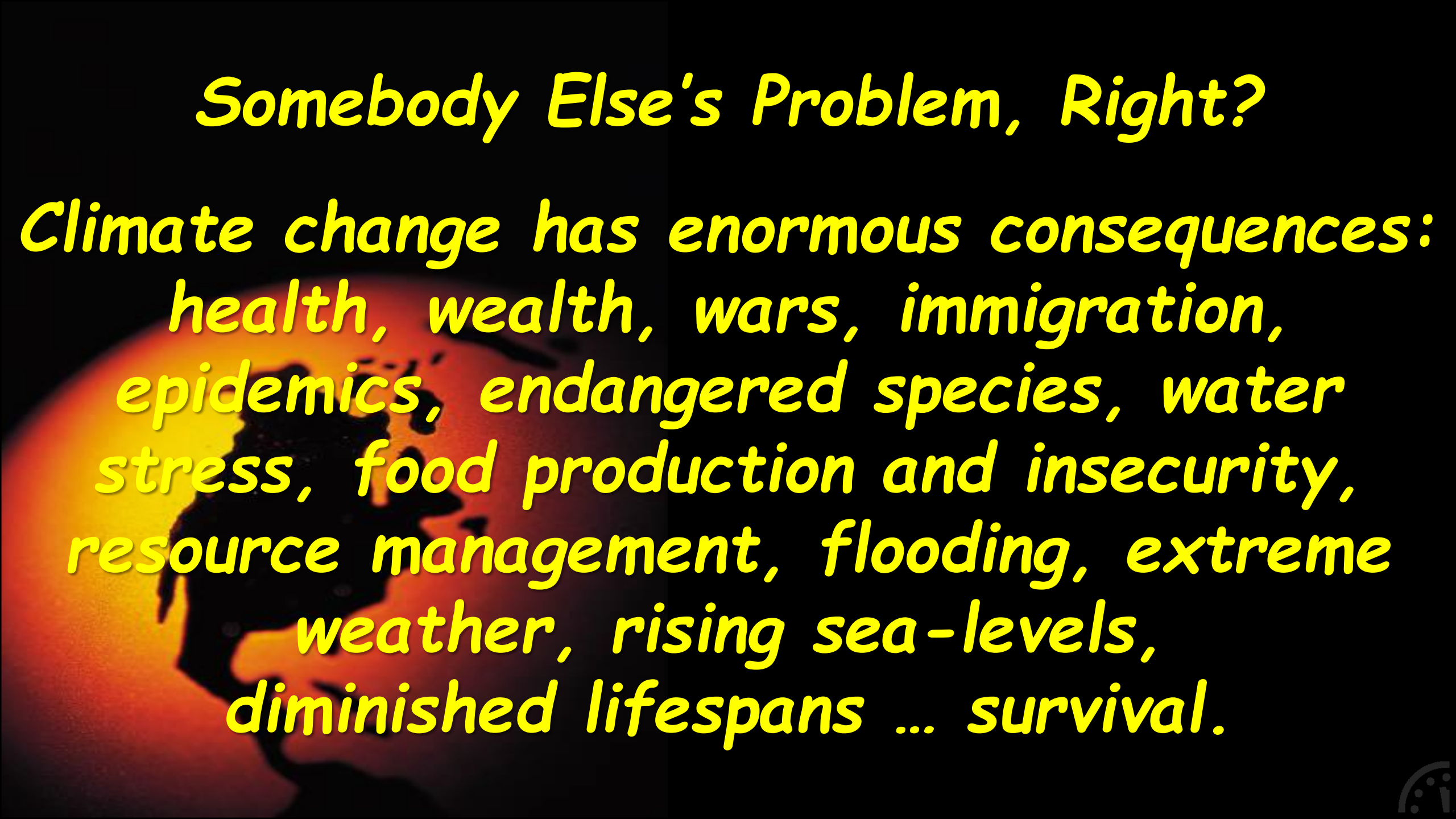
This is Earth in the next 100 years if we don't act on climate change

Why should you care?

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?' That's in the distant future, so sure, even it's a problem, 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?

It isn't easy.

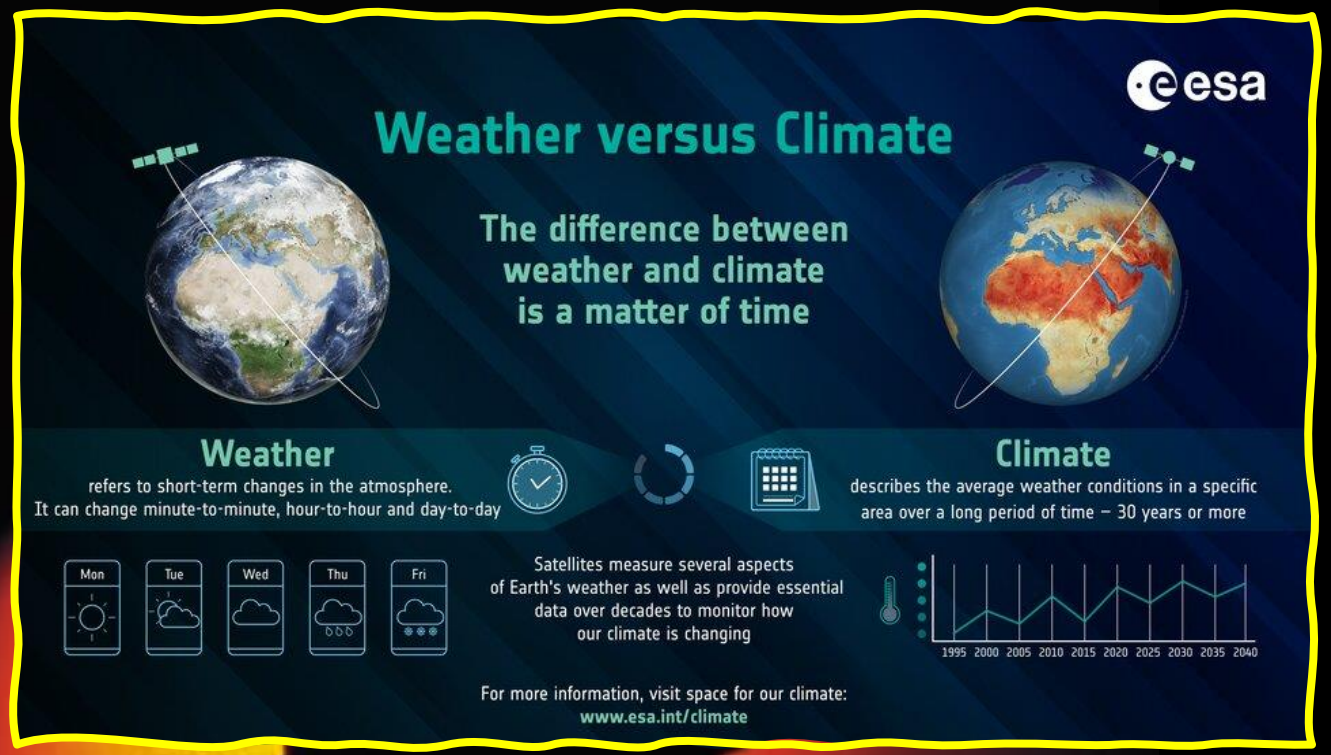

Somebody Else's Problem, Right?
Climate change has enormous consequences: health, wealth, wars, immigration, epidemics, endangered species, water stress, food production and insecurity, resource management, flooding, extreme weather, rising sea-levels, diminished lifespans … survival.

Somebody Else's Problem, Right?

Climate change is the result of human activity (anthropogenic)

The (probabilistic; high-level of confidence) scientific statement we can make about climate change is that, given our current evidence,

ANTHROPOGENIC CLIMATE CHANGE IS THE BEST EXPLANATION FOR GLOBAL WARMING/CLIMATE CHANGE IN THE MODERN ERA.



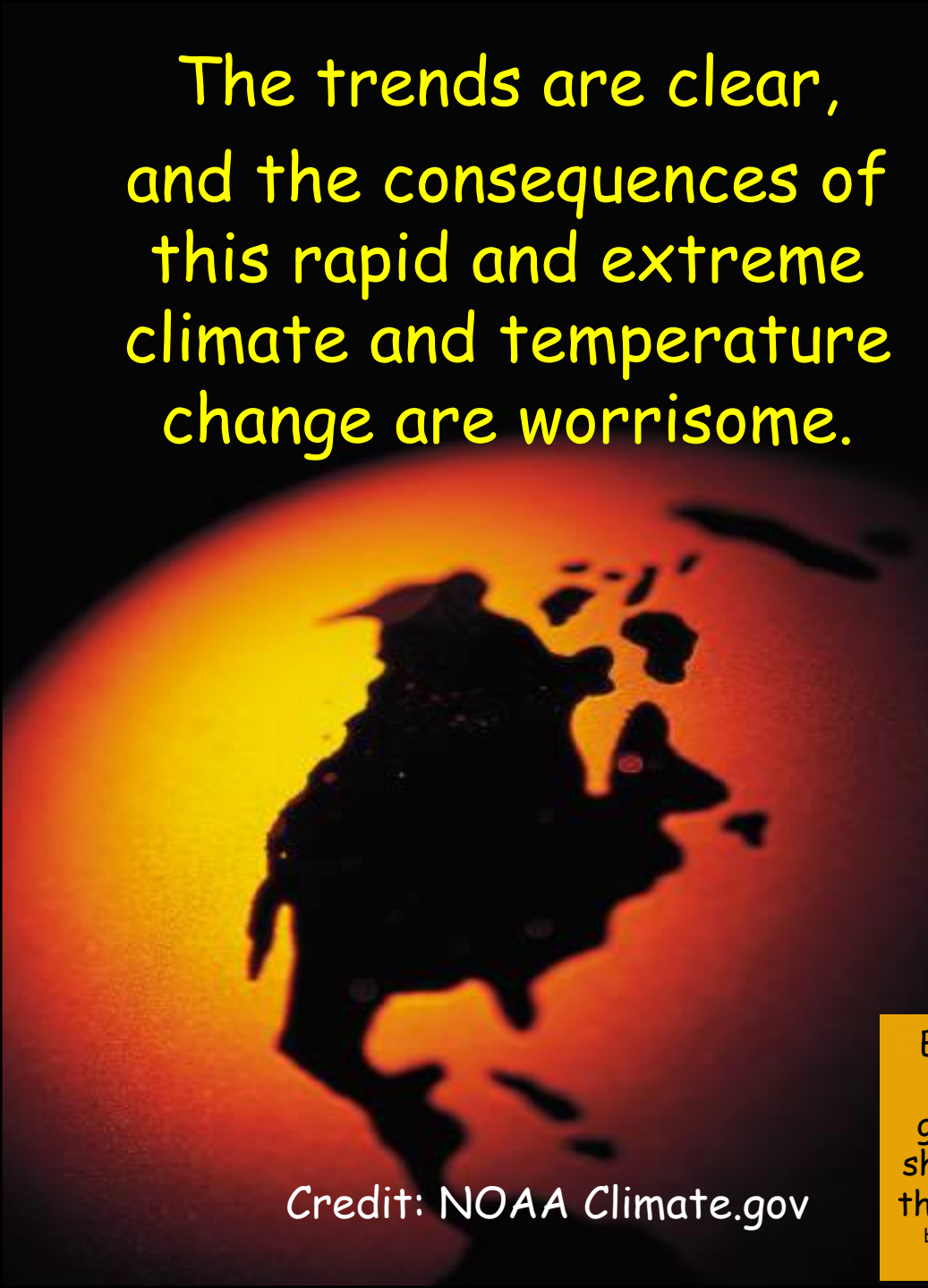
Credit: ESA;
https://www.esa.int/Applications/Observing_the_Earth/Space_for_our_climate/Weather_vs_climate_What_s_the_difference

Climate change does occur naturally, but the most recent change to climate is strongly correlated to our global economic activity.

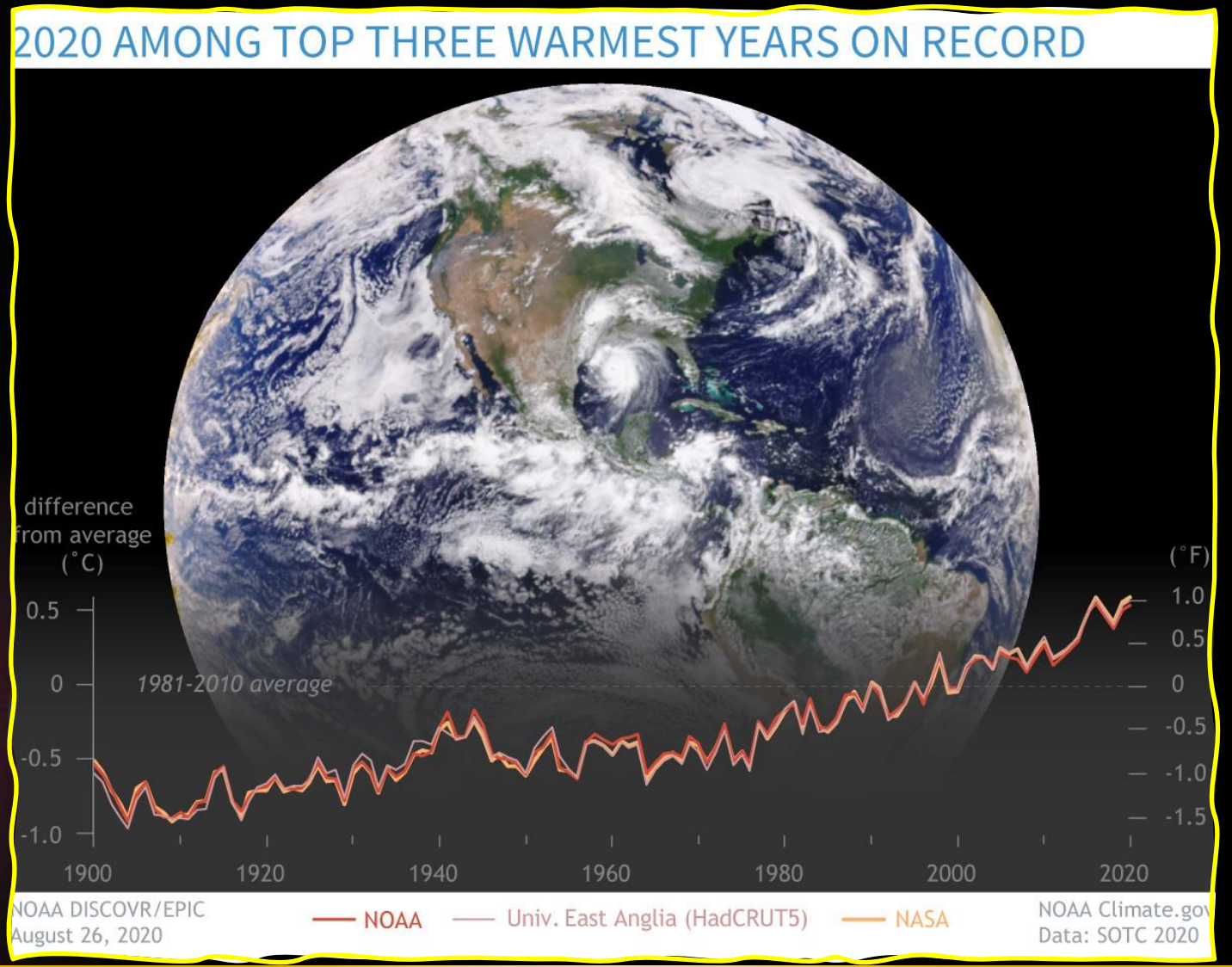
Scientists have observed *long-term trends* in the climate (what is the difference between weather and climate?) and the data demonstrate the linkage between human behaviour and climate modification (greater detail can be found at *The Intergovernmental Panel on Climate Change* (IPCC) https://www.ipcc.ch/)

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).

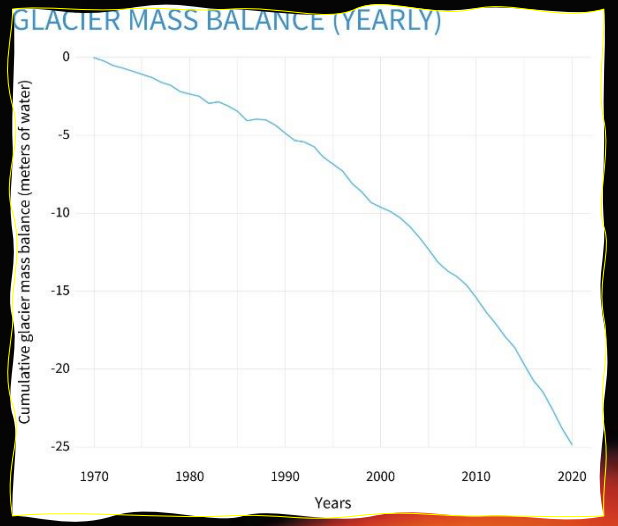
The trends are clear, and the consequences of this rapid and extreme climate and temperature change are worrisome.

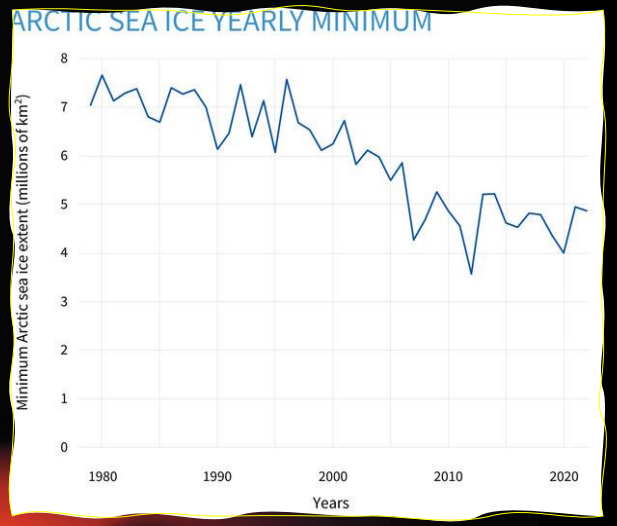


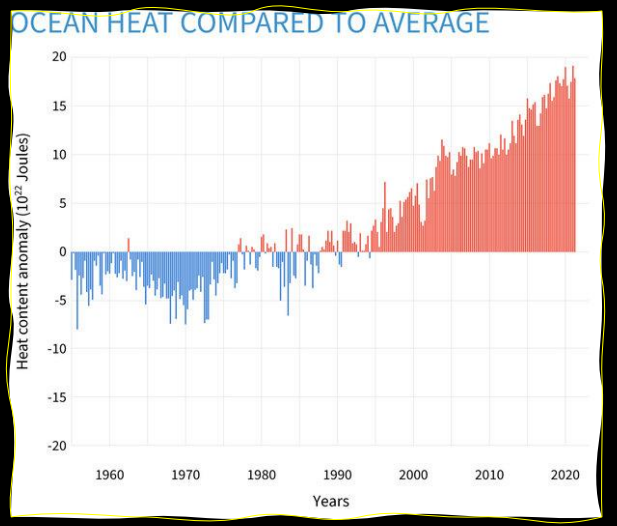
Credit: NOAA Climate.gov

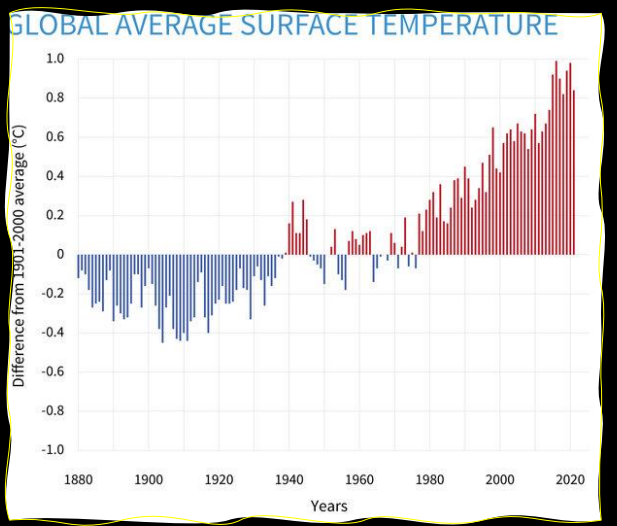


Earth's surface temperature each year from 1900–2020 compared to the 1981-2020 average, based on temperature histories put together by three different research groups: NOAA (red), University of East Anglia (pink line), and NASA (orange line). All show Earth is warming. (The latest multi-dataset comparison comes out each summer in the Bulletin of the American Meteorological Society's *State of the Climate* reports.) The background image from the NOAA DISCOVR/EPIC mission shows Hurricane Laura coming ashore in Louisiana on August 26, 2020. Image by NOAA Climate.gov, adapted from *State of the Climate 2020*.









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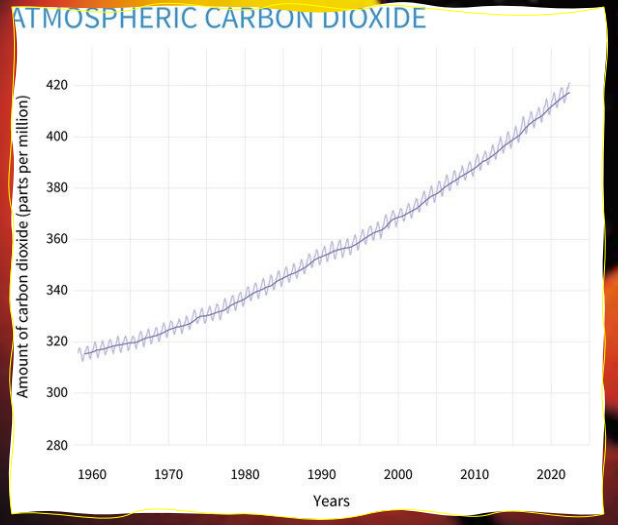
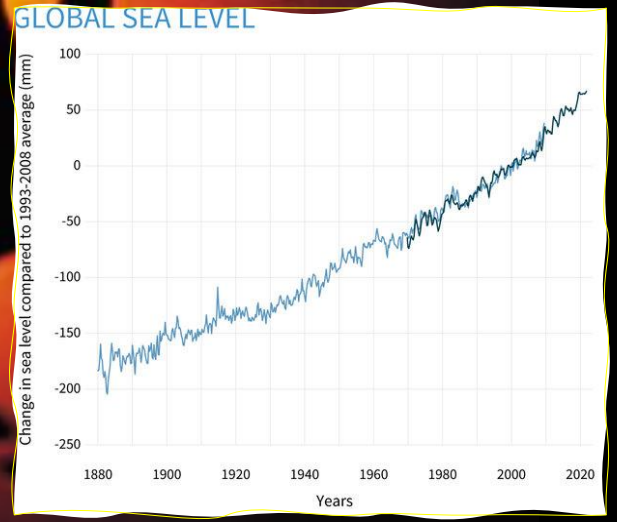
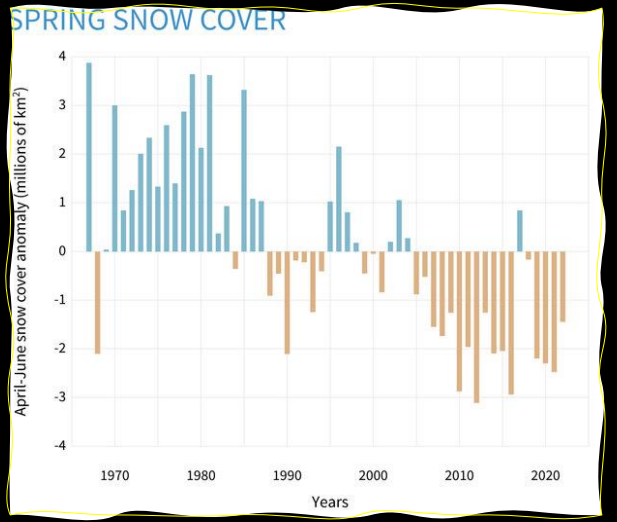
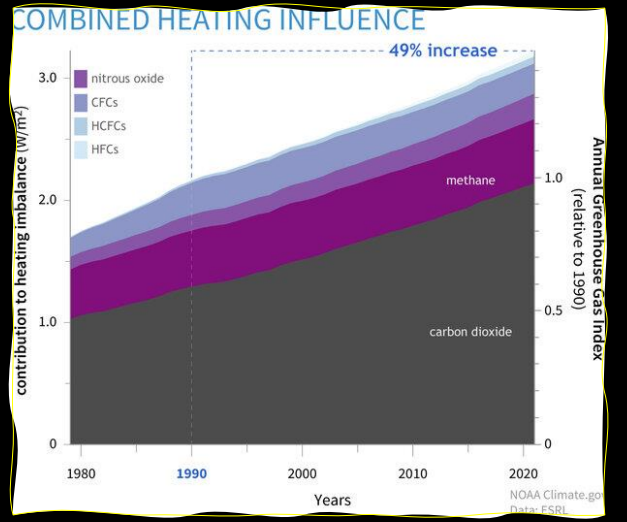








Credit: NOAA Climate.gov

Home Sweet Home

The Biosphere

- Biosphere: all the parts of the Earth where there is life, from the deepest ocean to a few kilometers above the surface into the atmosphere. ~ 20 km thick
- Ecology: Natural living systems
- Ecosystems range in size, but are localized geographically, composed of two interdependent components, living and nonliving:
  - Biotic (living organisms, all interacting individuals)
  - Abiotic (chemical and physical environment)
- Biodiversity: variation of life within an ecosystem.
- An ecosystem is a community in balance, with producers, consumers, decomposers. Resources are limited.
- Each organism occupies an ecological niche (or role).
- Ecosystems are not permanent as balance can be changed.

Fragility versus Resilience

The Blue Marble
Retrieved from http://eoimages.gsfc.nasa.gov/images/imagerecords/57000/57723/globe_west_540.jpg
(Credit: NASA Goddard Space Flight Center Image by Reto Stöckli

Home Sweet Home

The Biosphere

- 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.).

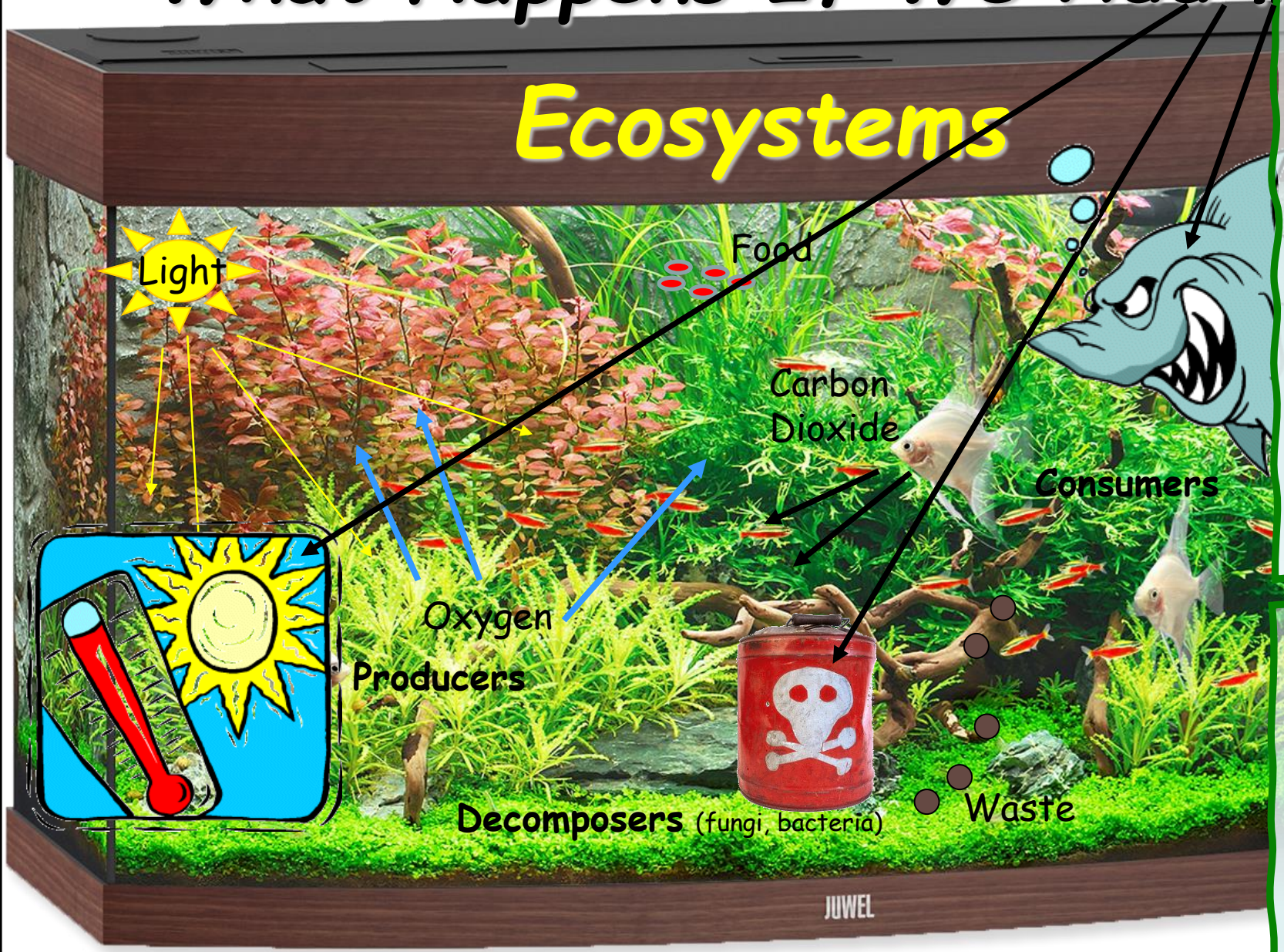
- It's an intricate mechanism that can be disrupted, and it has been disrupted in the past, before the rise of humanity. But now, we have humanity as a new force with planet-wide impact.

Fragility versus Resilience

The Blue Marble
Retrieved from http://eoimages.gsfc.nasa.gov/images/imagerecords/57000/57723/globe_west_540.jpg
(Credit: NASA Goddard Space Flight Center Image by Reto Stöckli

What Happens If We Add ...

Ecosystems



https://www.pngegg.com/en/png-mvqjq/download

***Interdependent* Community**

- plants absorb light, water, carbon dioxide, and nutrients from the soil to ***produce*** oxygen,
- fish ***consume*** food (plants or smaller animals) and oxygen, releasing waste and carbon dioxide, and
- fungi and bacteria in the soil take this waste and ***decompose*** it into nutrients for the plants … and the cycle continues …

The "Law" of Unintended Consequences

"It is virtually impossible to change one aspect of a complex system without affecting other parts of the system, often in as-yet unpredictable ways."

Page 432, Trefil & Hazen; *The Sciences*, 8th edition

Home Sweet Home

The Biosphere: It's Complicated

How Fragile is this System?

- The Earth is surrounded by a thin envelope of gas, its *atmosphere (78% Nitrogen, 21% Oxygen, .9% argon, .1% Carbon Dioxide + Methane + Water Vapour + Neon)*
- Mass of the atmosphere is only one millionth of the total mass of the Earth
- If the Earth were the size of an apple, the atmosphere would be thinner than the apple's skin!
- More than 70% of the Earth's surface is covered by water. Water also acts as a carbon sink (storage) for carbon dioxide, a greenhouse gas (GHG)

The Blue Marble
Retrieved from http://eoimages.gsfc.nasa.gov/images/imagerecords/57000/57723/globe_west_540.jpg
(Credit: NASA Goddard Space Flight Center Image by Reto Stöckli

Home Messy Home

Add Humans: It's More Complicated

How Fragile is this System?

- In our evolution lesson, we learned
  - about selective environmental pressures on a population => some live, some die … typically because of random, natural events.
  - that most species that have ever existed on Earth have perished … because of changing environments, from climate to food sources to cataclysmic events.
  - that we're a very young species, only been around for 200,000 years.
- But we've also learned that we're quite clever at creating technologies that begin to affect who we are: how we think and how we live… and even when we know something is bad for us, we keep doing it.

A key question for this lesson would be this: if we don't change our behaviour, are we clever enough to invent some new technology that can get us out of this global (existential) crisis? Is there enough time to do so?

The Black Marble/Earth at Night 2012; NASA

Home Unstable Home

Unnatural Selection: Human-Driven Evolution

How Fragile is this System?

- In our evolution lesson, it was mentioned that aside from the processes of Natural Selection (with random changes in genetics and environment) and Artificial Selection (purposeful changes to a species via human technology), there is also Unnatural Selection, where humanity's changes to ecosystems (intentional and unintentional) can change the path of evolution for living things.

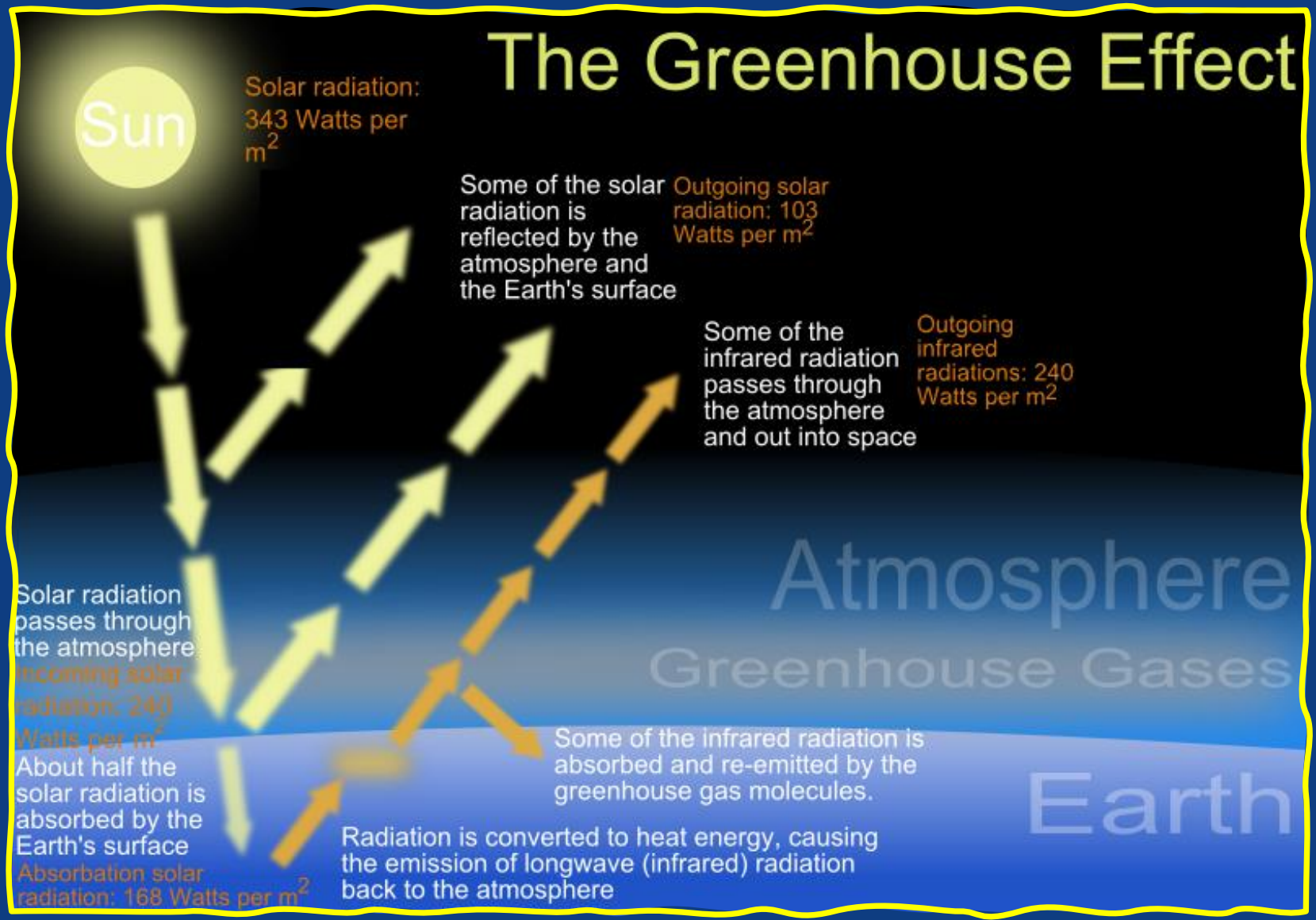
- E.g., size of fishing nets allowing smaller specimens to survive, pollution affecting camouflage, antibiotic resistance, food sources for rodents inside natural domains and within cities, desalination and temperature changes of ocean currents, deforestation and nesting patterns, chemicals in air and water, mosquitos in human habitats, agricultural fertilization, etc.

- Our meddling with the environment, our effect on biotic and abiotic components, is "selecting" some species to live and others to die … without understanding our full interdependences within the food web, and the boomerang effect of changes coming back to harm us.
  We are not independent of nature and our environment.

Anthropogenic Climate Change is changing the process of evolution on our planet.

Climate Past & Present

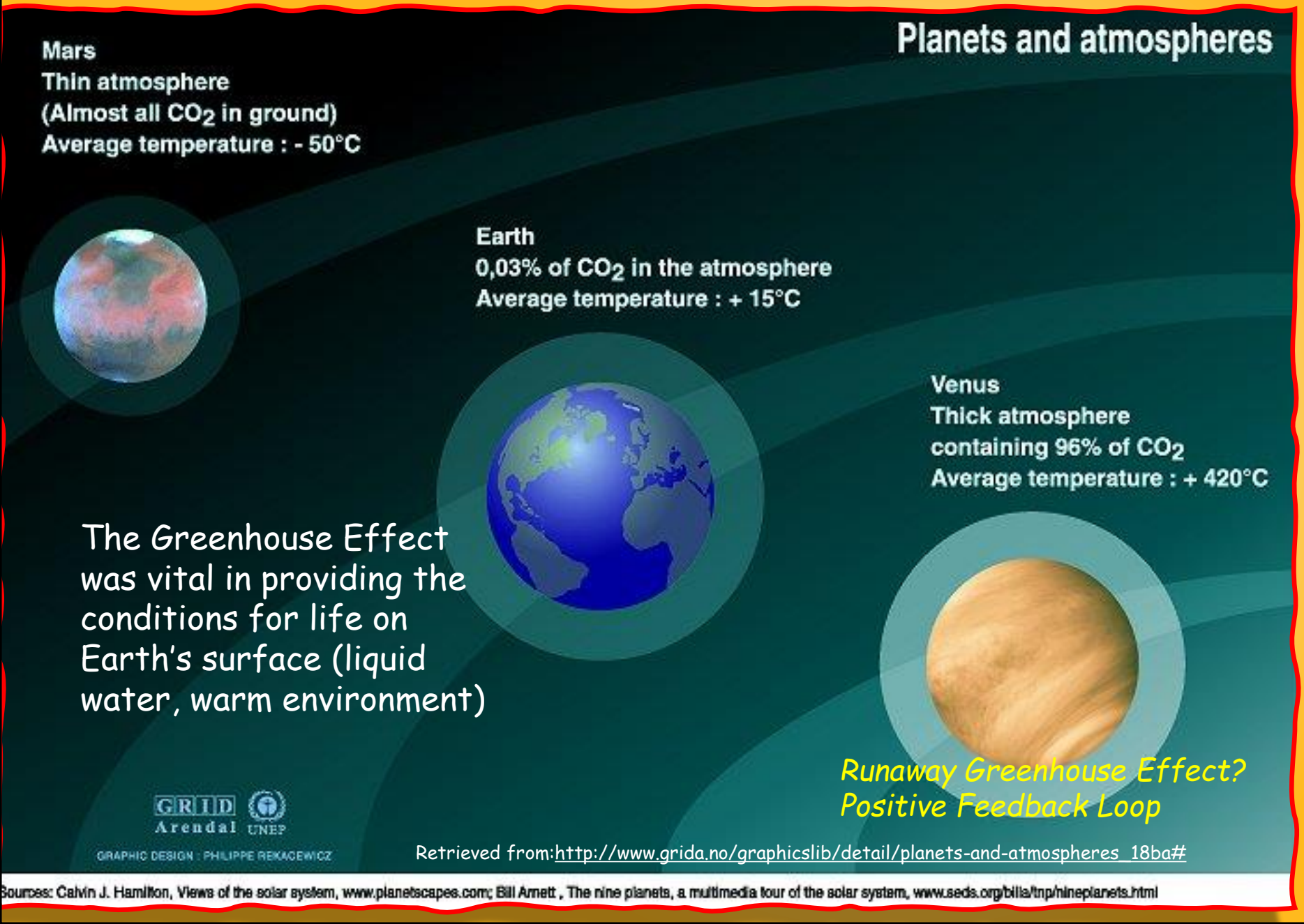
- Greenhouse Effect is a natural process, but it can fall into an accelerated (uncontrollable?) pace called the Runaway Greenhouse Effect (may have happened to Venus; Positive Feedback Loop).
- Planetary atmospheres act like thermal blankets, trapping the Sun's heat for extended periods; important for liquid water and the evolution of life on Earth.
- Greenhouse Effect: "traps" heat on earth (keeps infrared radiation (IR) from rapidly escaping into space).
- Global Warming/Climate change; Main points to keep in mind:
  - CO_2 is a greenhouse gas (GHG)
  - Burning fossil fuels increases CO_2
  - Average global temperature has significantly increased
  - Climate can change



Greenhouse gases (H_20, CO_2, CH_4, others) absorb different wavelengths of light. They absorb and re-emit infrared (IR, heat), and are transparent to visible light

Credit: https://commons.wikimedia.org/wiki/File:The_green_house_effect.svg

Climate Past & Present



The Greenhouse Effect was vital in providing the conditions for life on Earth's surface (liquid water, warm environment)

Runaway Greenhouse Effect?
Positive Feedback Loop

Retrieved from:http://www.grida.no/graphicslib/detail/planets-and-atmospheres_18ba#

After the birth of the Earth, the sun was 30% dimmer: the surface of the Earth could have been frozen solid if not for a GHG like CO_2 (and some extra warming from asteroid bombardment and the moon's effect).

This provided the conditions for liquid water and life (at least it made things easier).

And after that, life itself changed the Earth's atmosphere over billions of years, as well as life's role in the creation of fossil fuels!

The main greenhouse gases

Name	Pre-industrial concentration (ppmv *)	Concentration in 1998 (ppmv)	Atmospheric lifetime (years)	Main human activity source	GWP **
Water vapour	1 to 3	1 to 3	a few days	-	-
Carbon dioxide (CO_2)	280	365	variable	fossil fuels, cement production, land use change	1
Methane (CH_4)	0,7	1,75	12	fossil fuels, rice paddies waste dumps, livestock	23
Nitrous oxide (N_2O)	0,27	0,31	114	fertilizers, combustion industrial processes	296
HFC 23 (CHF_3)	0	0,000014	260	electronics, refrigerants	12 000
HFC 134 a (CF_3CH_2F)	0	0,0000075	13,8	refrigerants	1 300
HFC 152 a (CH_3CHF_2)	0	0,0000005	1,4	industrial processes	120
Perfluoromethane (CF_4)	0,00004	0,00008	> 50 000	aluminium production	5 700
Perfluoroethane (C_2F_6)	0	0,000003	10 000	aluminium production	11 900
Sulphur hexafluoride (SF_6)	0	0,0000042	3 200	dielectric fluid	22 200

* ppmv = parts per million by volume, ** GWP = Global warming potential (for 100 year time horizon).

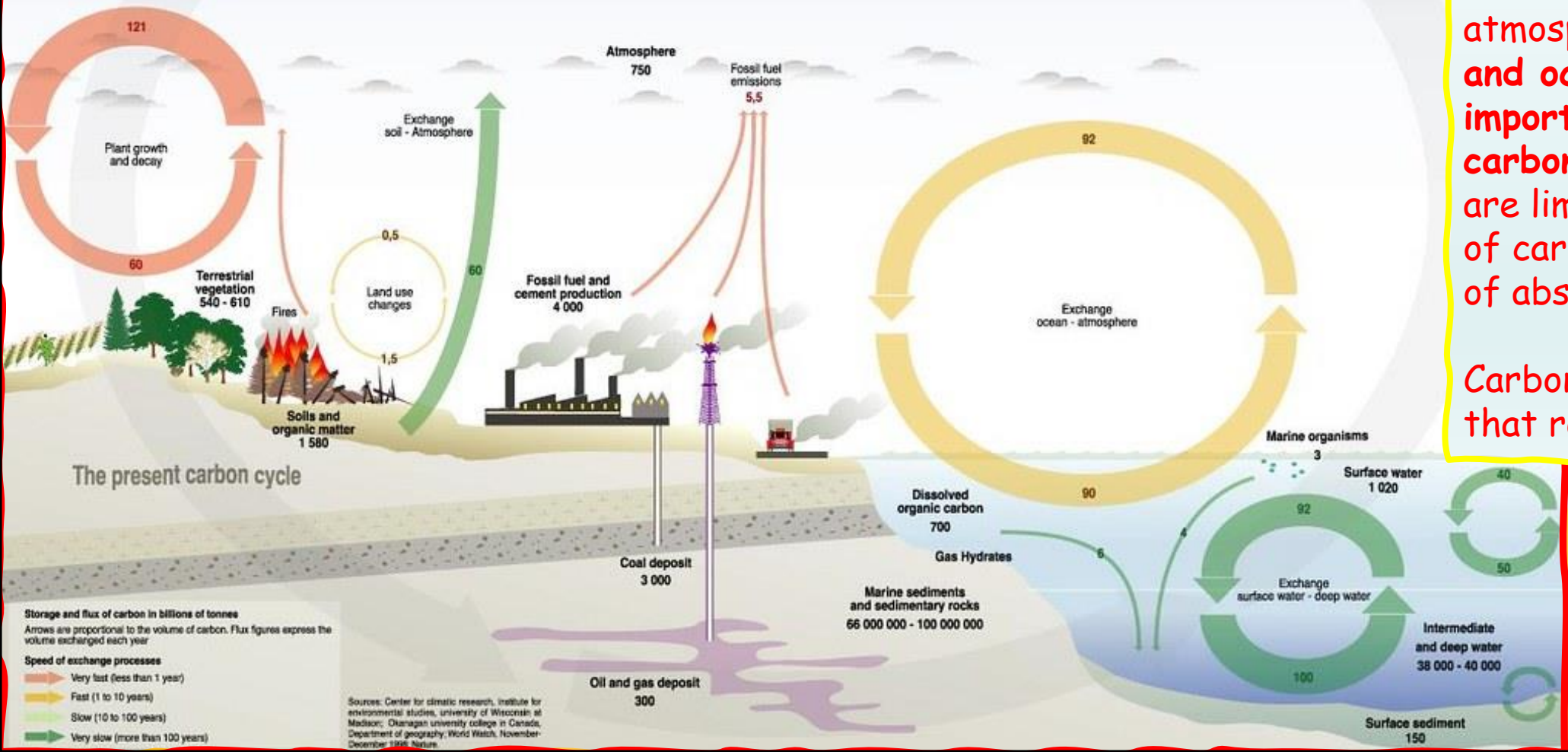
UNEP | GRID Arendal

United Nations Environment Programme / GRID-Arendal

- Greenhouse gases (H_20, CO_2, CH_4, others) absorb different wavelengths of light. They absorb and re-emit infrared (IR, heat), and are transparent to visible light.
- These first four are naturally occurring but their concentrations have been increased dramatically with human activity.

Retrieved from: https://www.grida.no/resources/6467
Graphics by United Nations Environment Programme & GRID-Arendal

Carbon Cycle (Balance)



Carbon Sinks

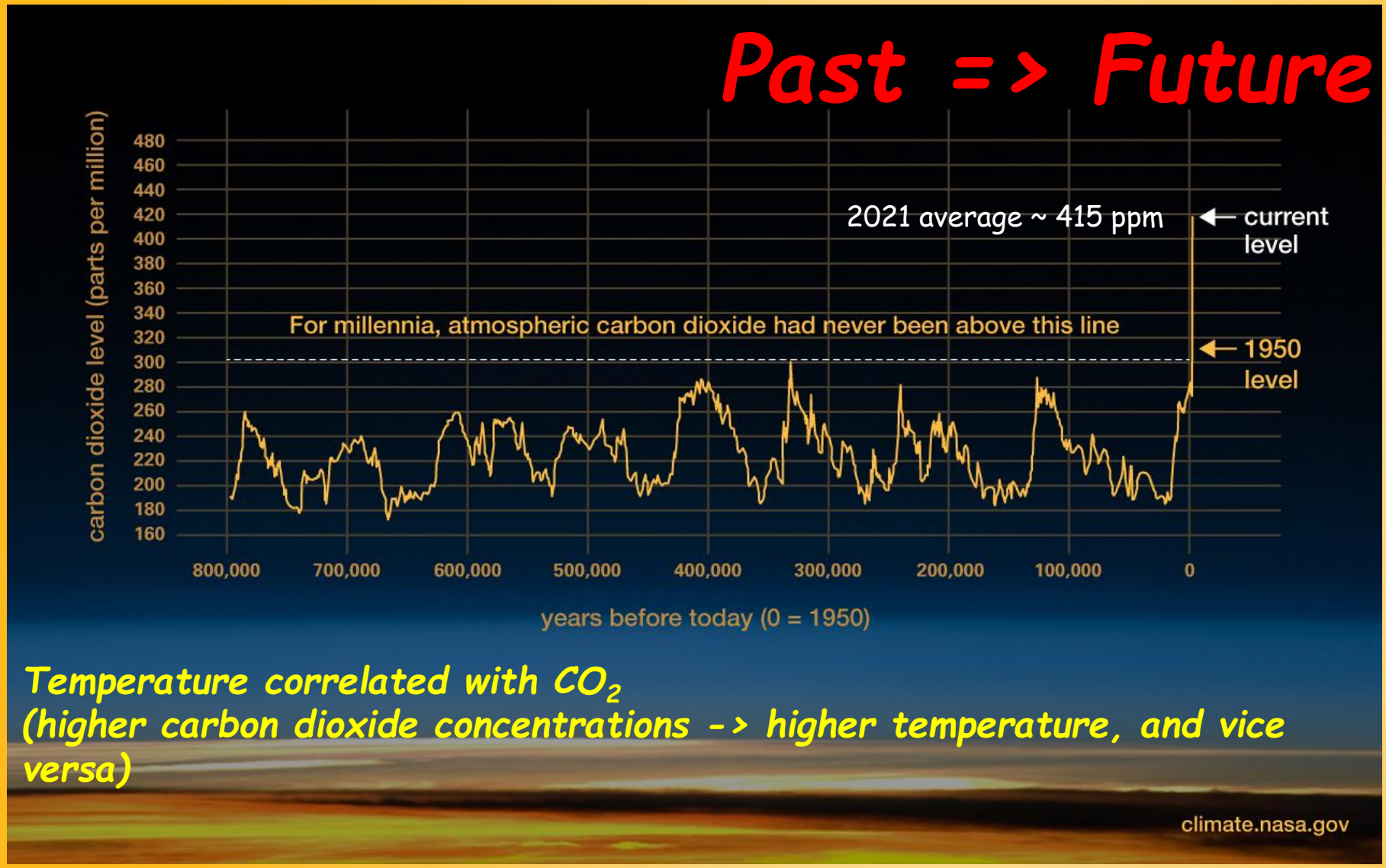
From our Davidson reading:

"*A carbon sink is any natural or technological process that absorbs carbon from the atmosphere.* **Trees, soils and oceans are the most important natural carbon sinks**, but all three are limited in the amount of carbon they are capable of absorbing."

Carbon Source: process that releases CO_2

https://www.grida.no/resources/6885

Temperature and Carbon Dioxide

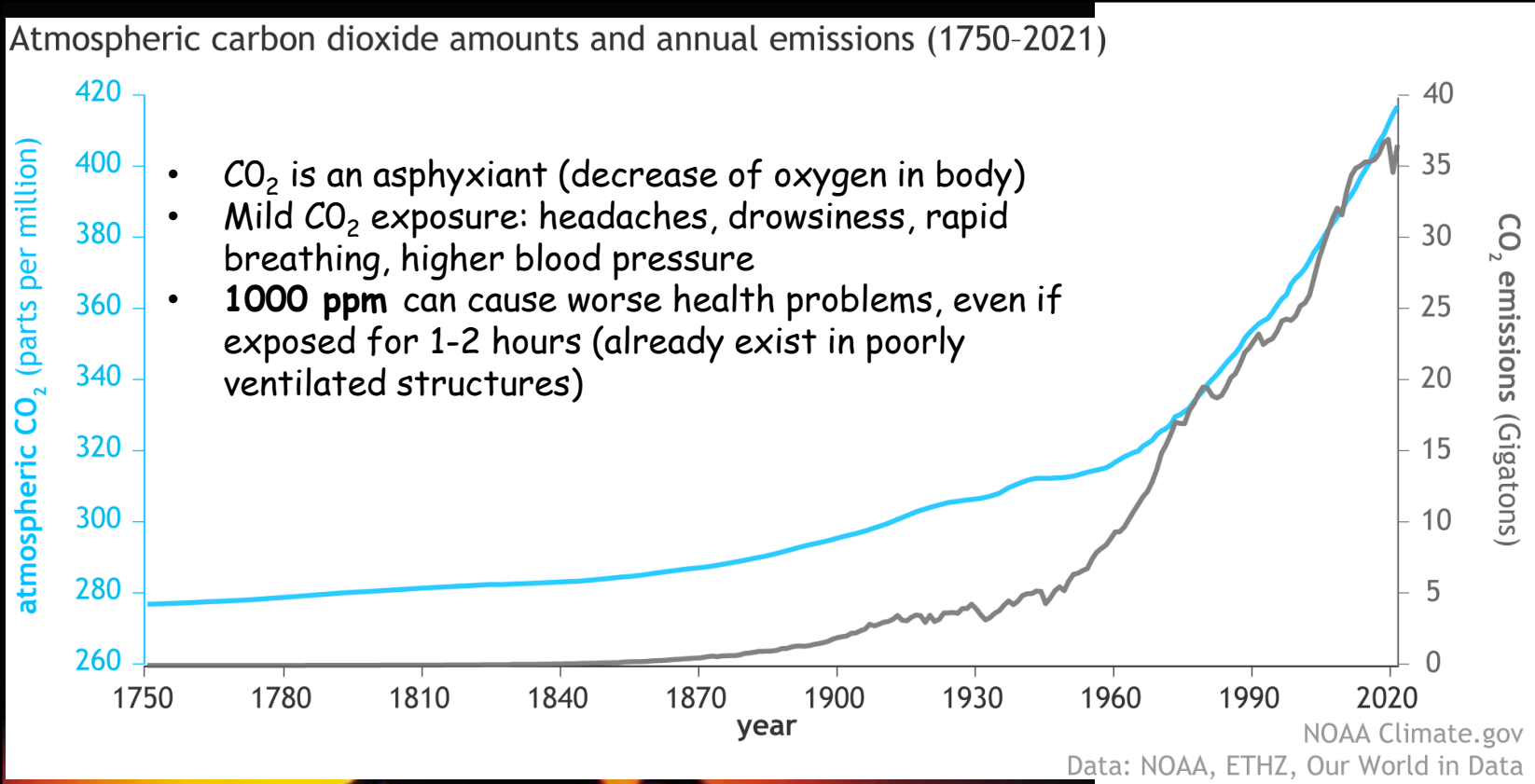


In the far distant past, it took 5000 years for temp to jump 5 degrees.

In the next century, the rate is predicted at 20x faster.

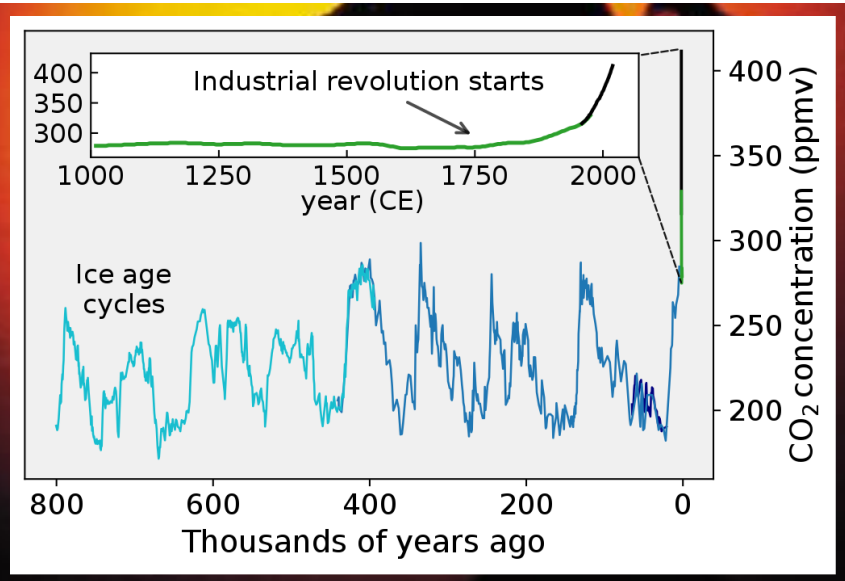
Go to https://climate.nasa.gov/interactives/climate-time-machine and click on 'Carbon Dioxide' to see the change of carbon dioxide concentration in our atmosphere over the last few years.

https://climate.nasa.gov/climate_resources/24/graphic-the-relentless-rise-of-carbon-dioxide/



"The amount of carbon dioxide in the atmosphere (blue line) has increased along with human emissions (gray line) since the start of the Industrial Revolution in 1750. Emissions rose slowly to about 5 billion tons per year in the mid-20th century before skyrocketing to more than 35 billion tons per year by the end of the century."

NOAA Climate.gov graph, adapted from original by Dr. Howard Diamond (NOAA ARL). Atmospheric CO_2 data from NOAA and ETHZ. CO_2 emissions data from Our World in Data and the Global Carbon Project.



We can see a jump in carbon dioxide concentrations with industrialization. The Industrial Revolution brought much in terms of economic promises, but it also brought about great environmental peril.

A Closer Look

Credit: https://www.climate.gov/media/14596
https://commons.wikimedia.org/wiki/File:Carbon_Dioxide_800kyr.svg

Methane

Human sources:

- Fossil fuels
- Cattle
- Landfills
- Rice paddies

Natural sources:

- Wetlands
- Oceans
- Freshwater bodies
- Non-wetland soils
- Permafrost in Arctic (usually defined as "permanently" frozen layer of soil, gravel, sand, and ice), has carbon dioxide and methane previously frozen-in by the cold … as temperature increases, gasses get released into the atmosphere, increasing the temperature further, which in turn releases more methane, … and so on in a positive feedback loop.

National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Search NOAA sites

Home / News & Features

Increase in atmospheric methane set another record during 2021

Carbon dioxide levels also record a big jump

Focus areas: Research Topics: greenhouse gases

April 7, 2022

JOURNALS | COVID-19 Science

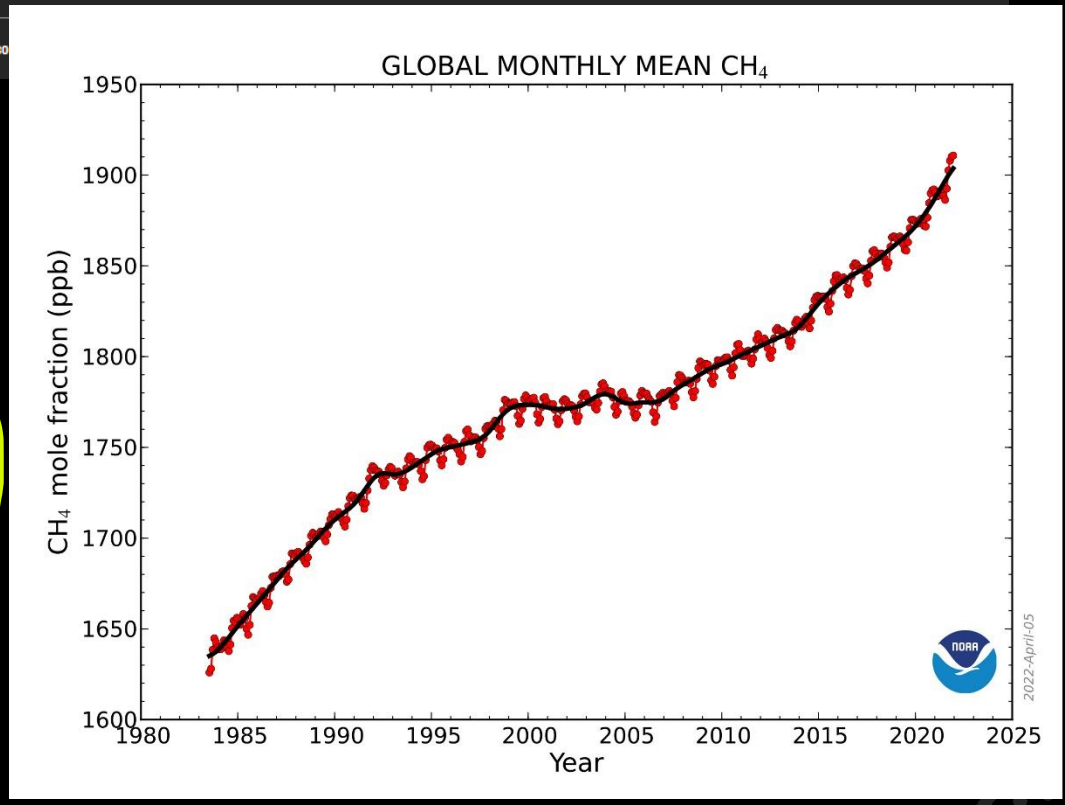
HOME > NEWS > ALL NEWS > IN OMINOUS SIGN FOR GLOBAL WARMING, FEEDBACK LOOP MAY BE ACCELERATING METHANE EMISSIONS

NEWS | CLIMATE

In ominous sign for global warming, feedback loop may be accelerating methane emissions

Tropical wetlands, getting wetter with climate change, emerge as hot spots for heat-trapping gas

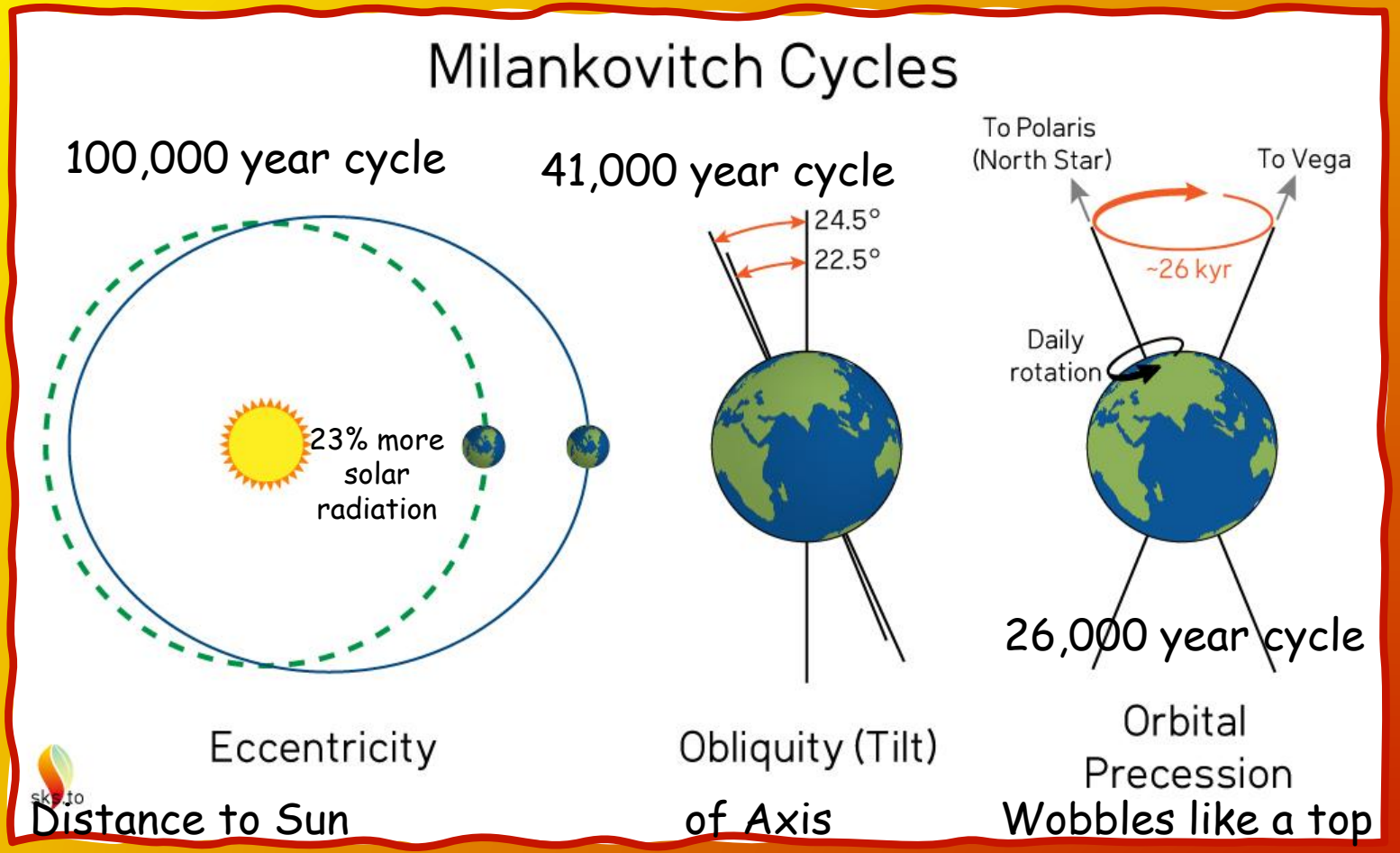
13 JUL 2022 · 2:30



Credit: https://www.noaa.gov/news-release/increase-in-atmospheric-methane-set-another-record-during-2021

Forces of Nature: Causes of Climate Change in the Past

- Orbital Wobbles (Milankovitch Cycles; affects how much solar energy (heat) Earth receives)
- Changes in
  - distance of Earth to the Sun;
  - angle of our axis; why we have seasons. Greater the tilt, more extreme our seasons
  - which way the axis points; affects seasonal contrast between North and South hemisphere.
- Although there is some debate on how large an effect this was in the past, cannot explain current era of rapid warming (it's people).



From: How Earth's Climate Changes Naturally (and Why Things Are Different Now);

Forces of Nature: Causes of Climate Change in the Past

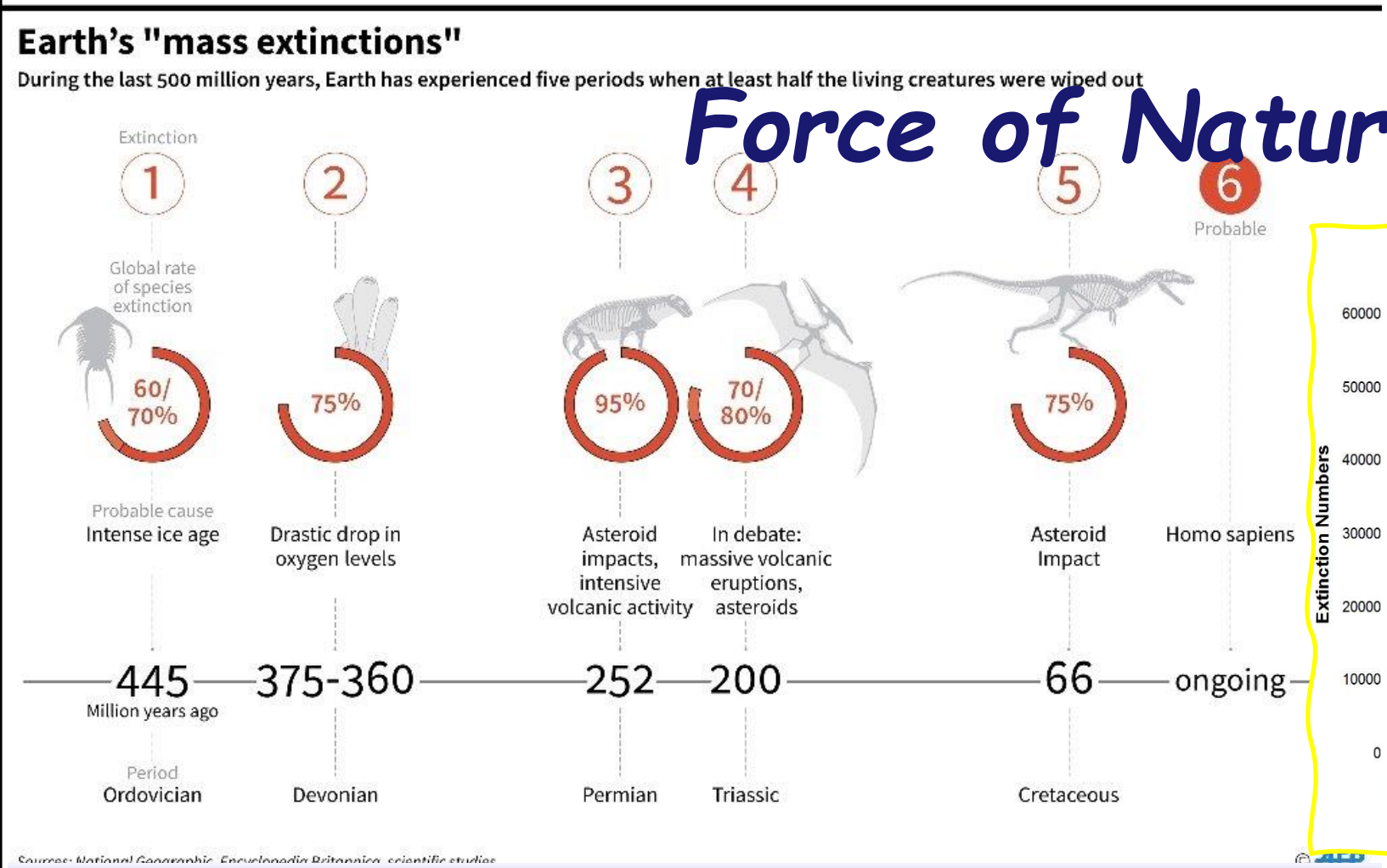
- Seismic activity: Volcanic Sulfur, Plate Tectonics
- Solar Cycles/Sun's brightness
- Atmospheric CO_2
- Asteroids (wiped out the dinosaurs 65 million years ago; global temperature rose ~ 5 degrees)
- Evolution/Life
- Lava Floods

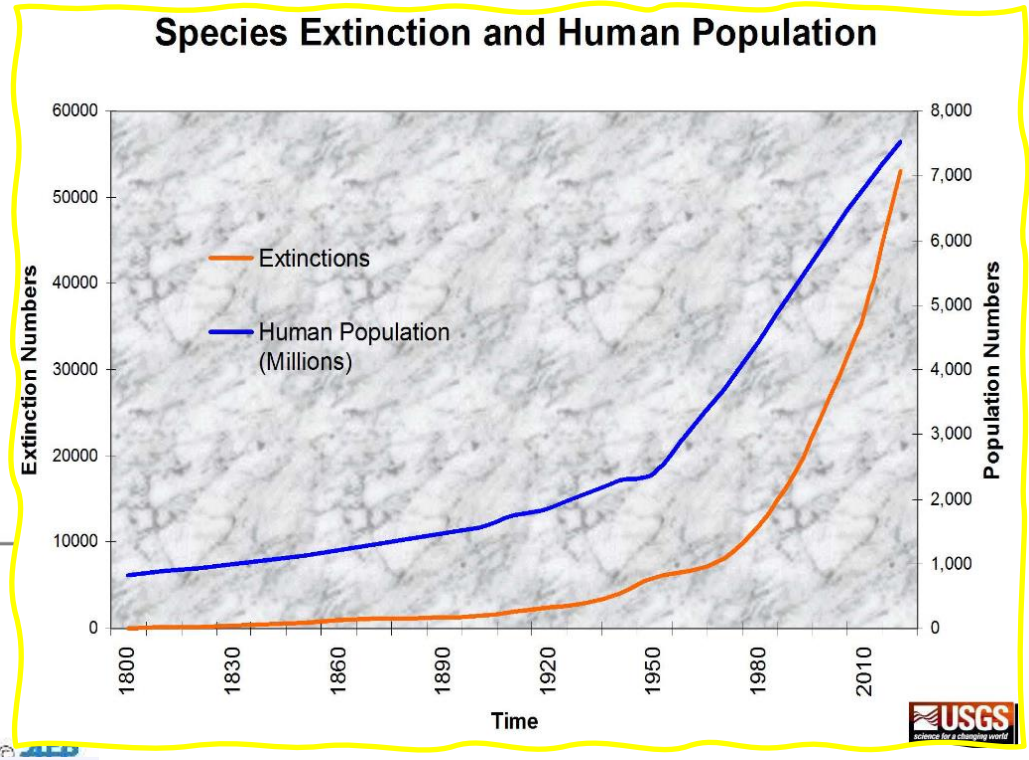
Some of these events are associated with mass extinction events.

From: How Earth's Climate Changes Naturally (and Why Things Are Different Now);

https://commons.wikimedia.org/wiki/File:Etna_volcano_in_eruption.jpg

Force of Nature: Human Beings



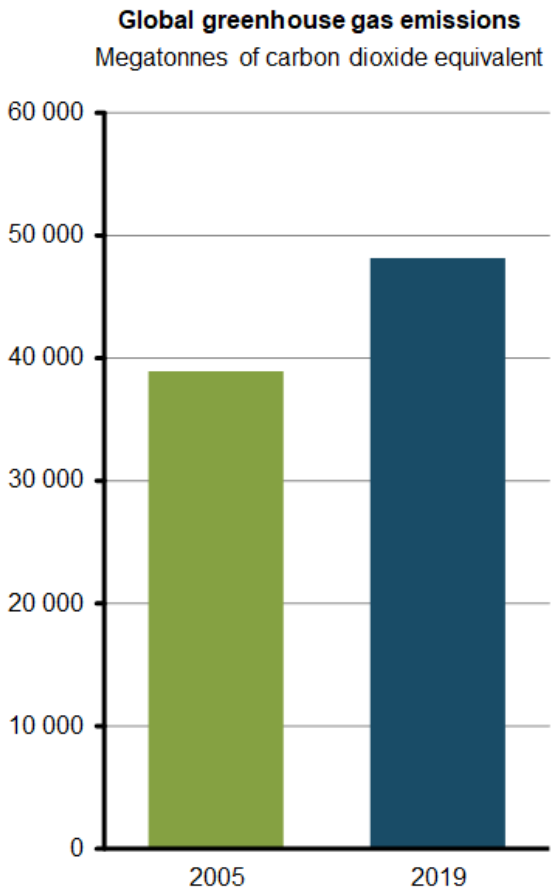


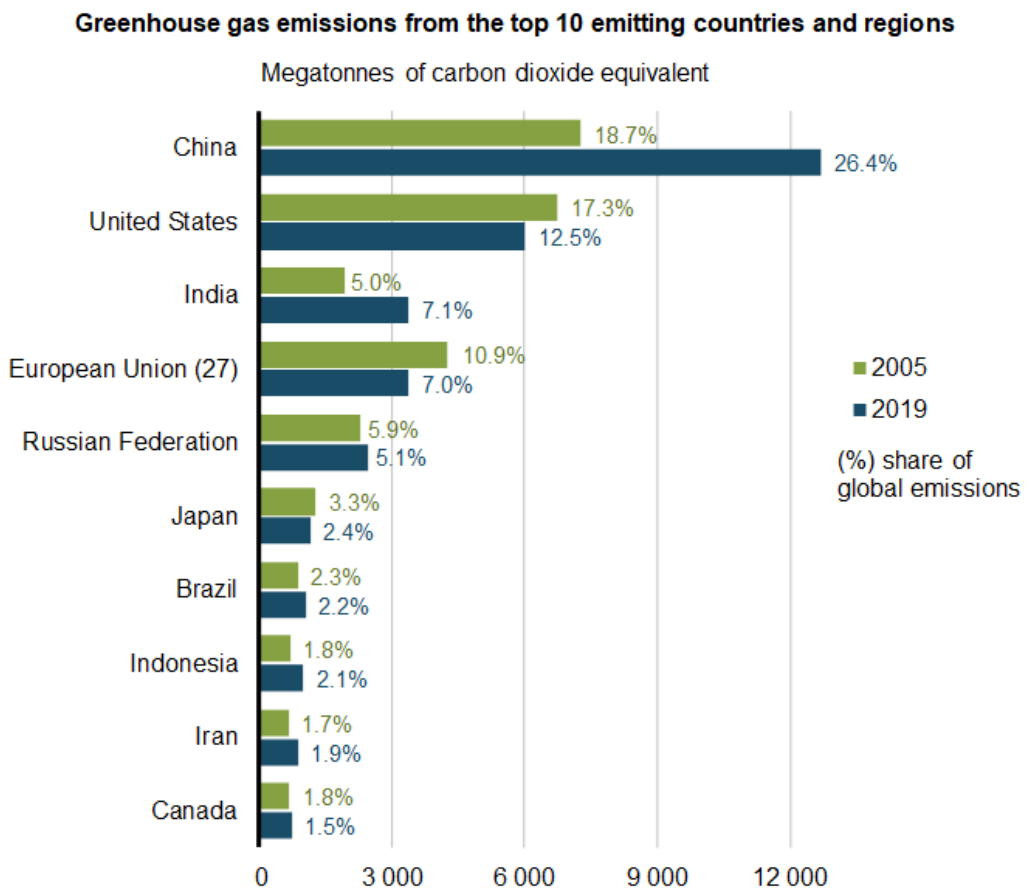
Temperature compared to today: 6^0 higher 5^0 higher

"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."

—E.O. Wilson, *Consilience: The Unity of Knowledge*

Greenhouse gas emissions for the world and the top 10 emitting countries and regions, 2005 and 2019





GHGs Today

Global Anthropogenic Emissions

- Carbon Dioxide from fossil fuel & industry ~ 64%
- Carbon Dioxide from land use ~ 11%
- Methane ~ 18%
- Nitrous Oxide ~ 4%
- Fluorinated gasses ~ 2%

Reference: https://www.ipcc.ch/report/ar6/wg3/figures/summary-for-policymakers/IPCC_AR6_WGIII_FigureSPM1.png

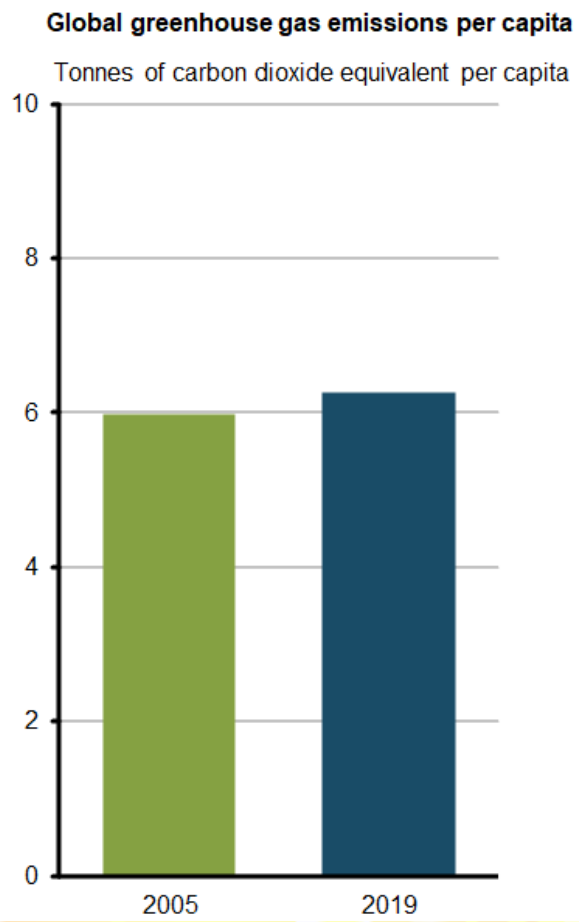
"Key results

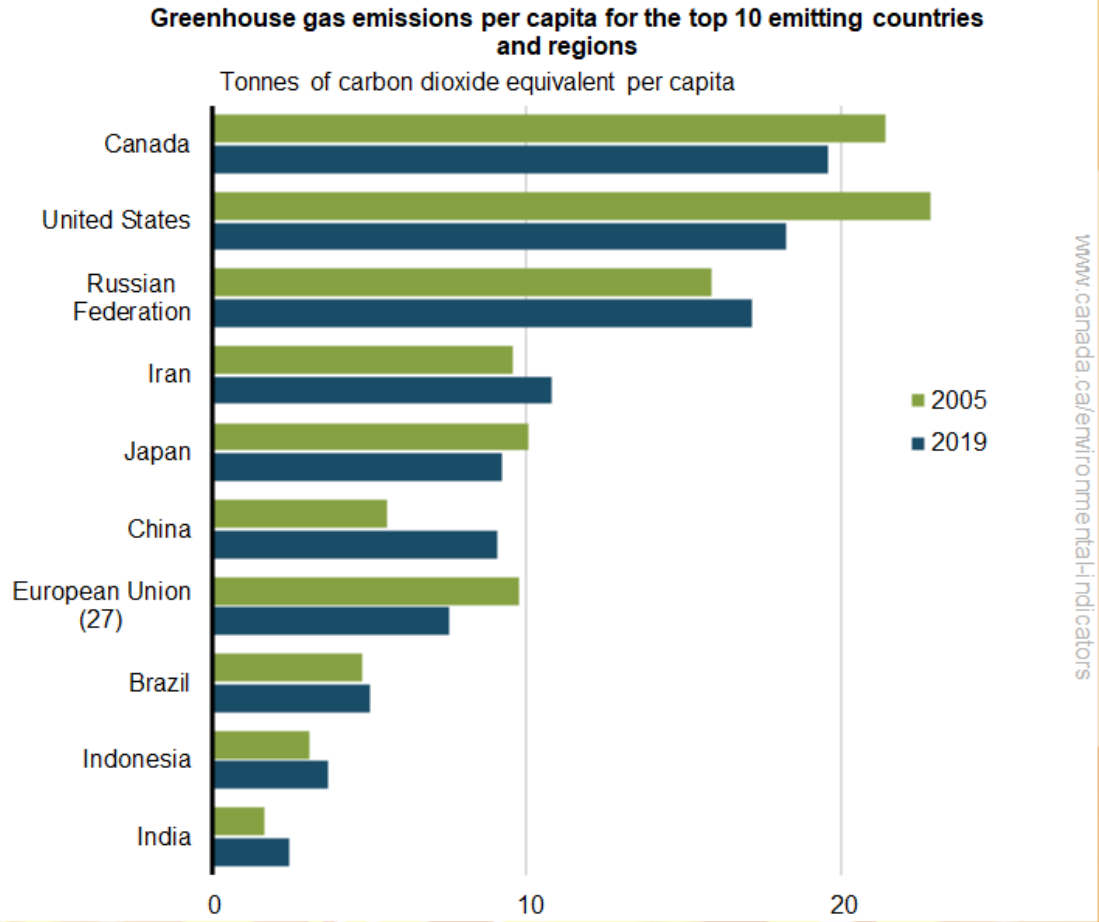
- Between 2005 and 2019, global GHG emissions increased by 23.6%, from 38 669 to 48 117 megatonnes of carbon dioxide equivalent (Mt CO_2 eq)
- In 2019, the highest emitting country was China with 12 705 Mt CO_2 eq, or 26.4% of global GHG emissions. Since 2005, emissions from China increased by 74.8%
- Canada's emissions in 2019 reached 737 Mt CO_2 eq, which made up 1.5% of global GHG emissions"

Retrieved from: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/global-greenhouse-gas-emissions.html

Force of Nature: Human Beings

Greenhouse gas emissions per capita for the world and the top 10 emitting countries and regions, 2005 and 2019





"Key results

- Between 2005 and 2019, global GHG emissions per capita increased 5%, from 6.0 to 6.3 tonnes of carbon dioxide equivalent (t CO_2 eq)
- In 2019, Canada was the highest GHG emitting country per capita among the top 10 emitting countries with 19.6 t CO_2 eq
- Canada's GHG emissions per capita has decreased 8.5% since 2005, from 21.42 t CO_2 eq to 19.6 t CO_2 eq"

Retrieved from: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/global-greenhouse-gas-emissions.html

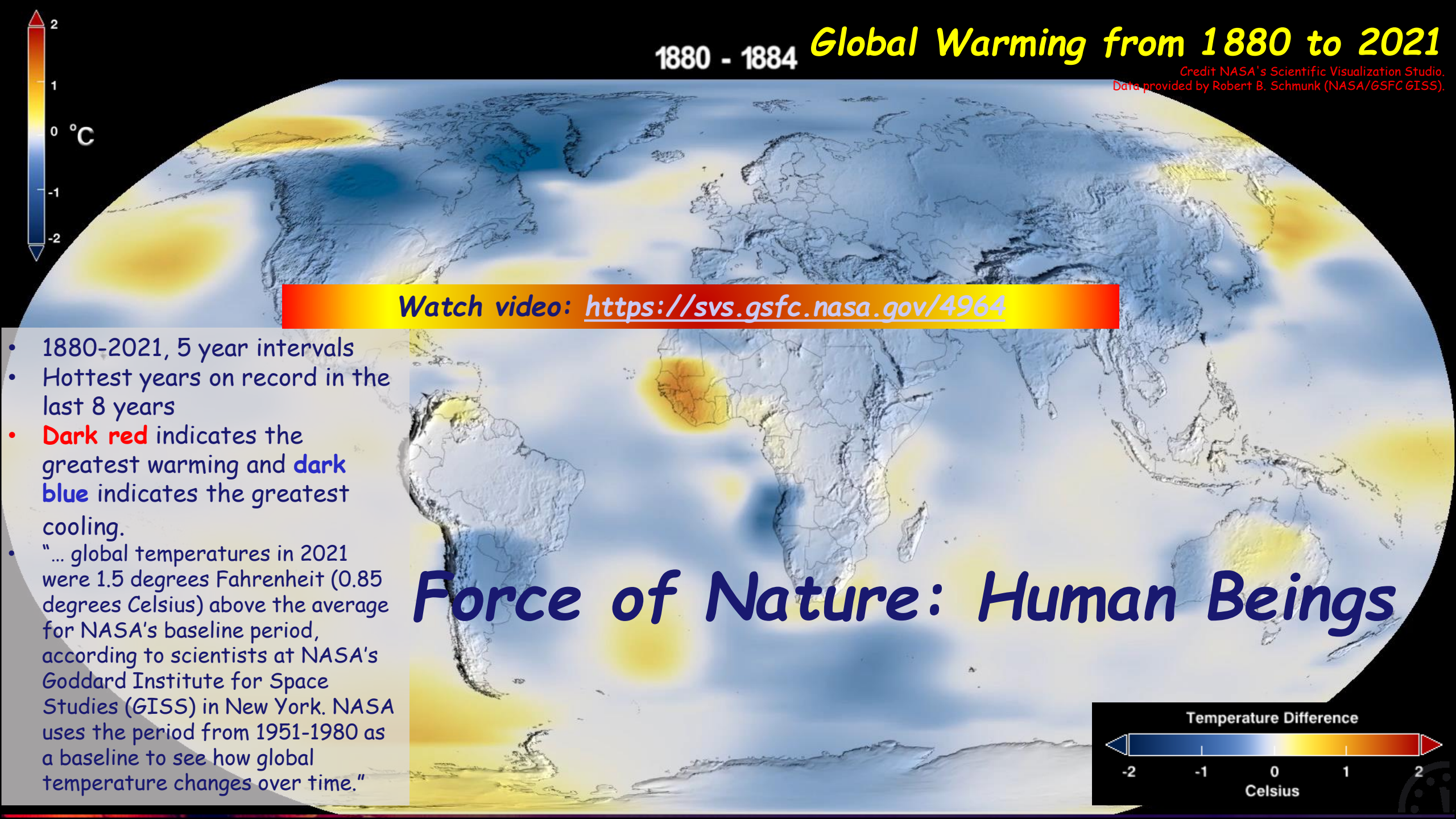
Force of Nature: Human Beings

Oh, Canada

"Although Canada is ranked 10th in the world for total GHG emissions, Canada has the highest GHG emission per capita rate from the top 10 emitting countries and regions. If Canada's GHG emissions per year were shared equally per each person in Canada, each person would emit 19.6 t CO2 eq per year – which is just over **3 times the global rate**. That is the same amount of GHG emissions released as someone driving around the world in a gasoline-powered car twice per year (about 78 296 km total)."

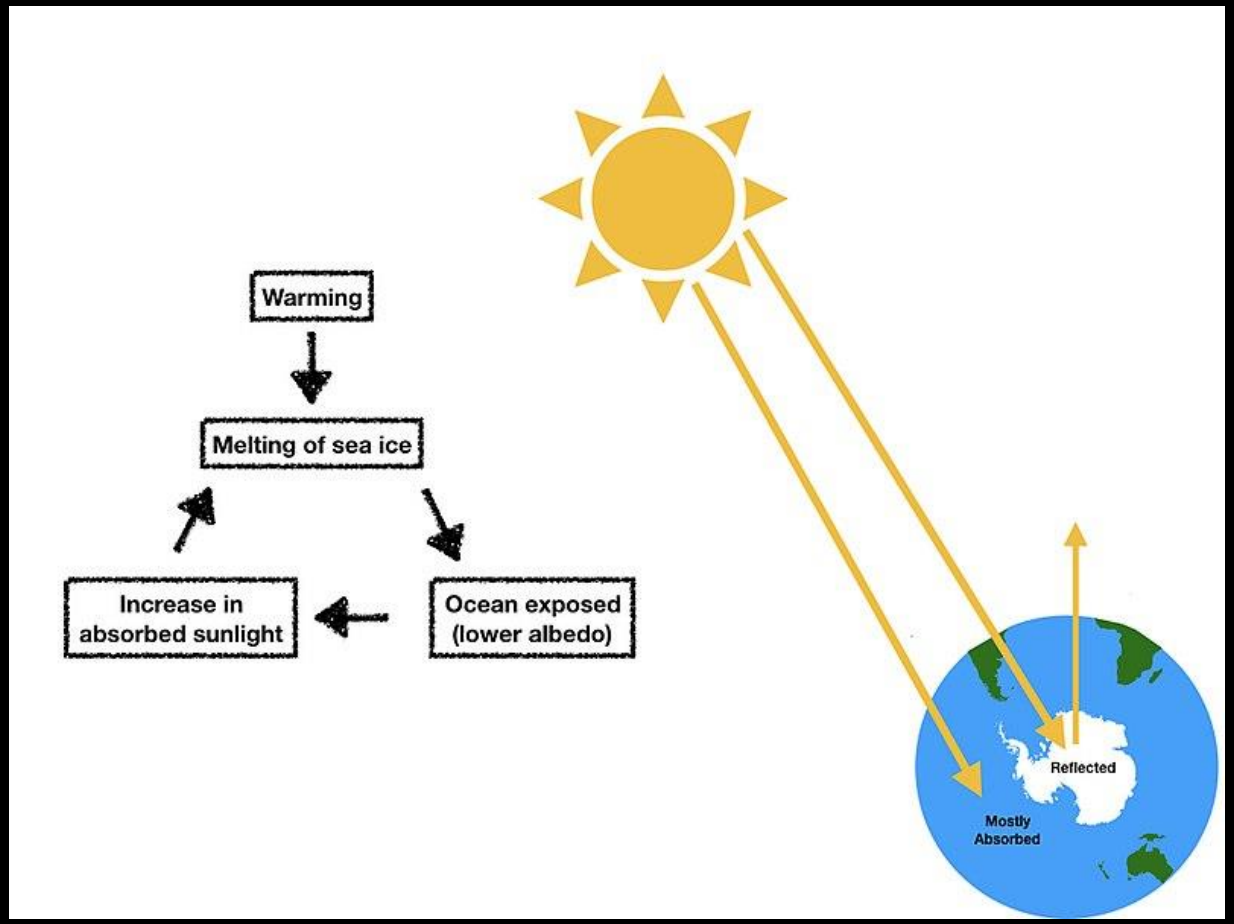
Retrieved from https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/global-greenhouse-gas-emissions.html

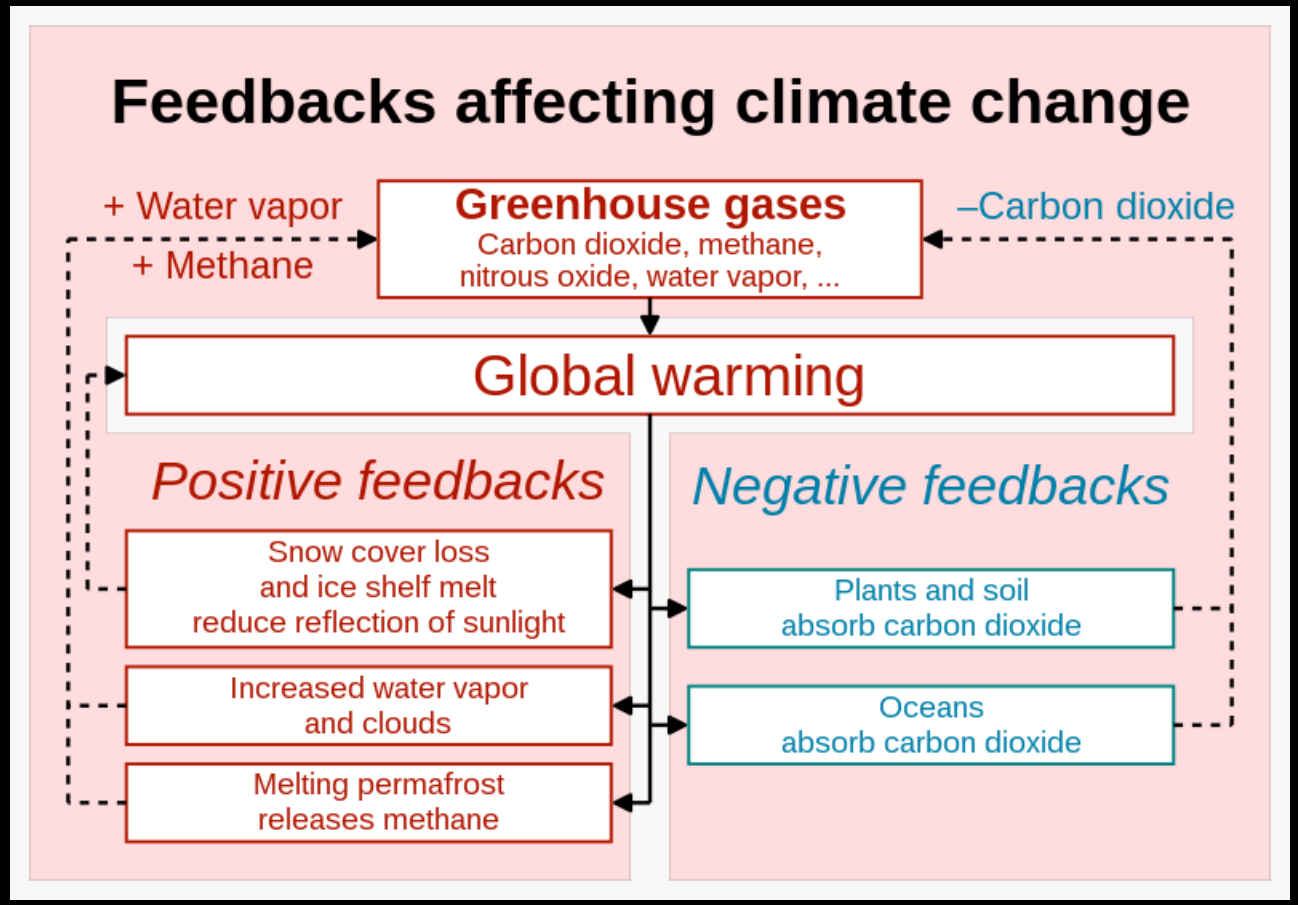
Global Warming from 1880 to 2021



- 1880-2021, 5 year intervals
- Hottest years on record in the last 8 years
- **Dark red** indicates the greatest warming and **dark blue** indicates the greatest cooling.
- "… global temperatures in 2021 were 1.5 degrees Fahrenheit (0.85 degrees Celsius) above the average for NASA's baseline period, according to scientists at NASA's Goddard Institute for Space Studies (GISS) in New York. NASA uses the period from 1951-1980 as a baseline to see how global temperature changes over time."

Positive (+) Feedback Loop



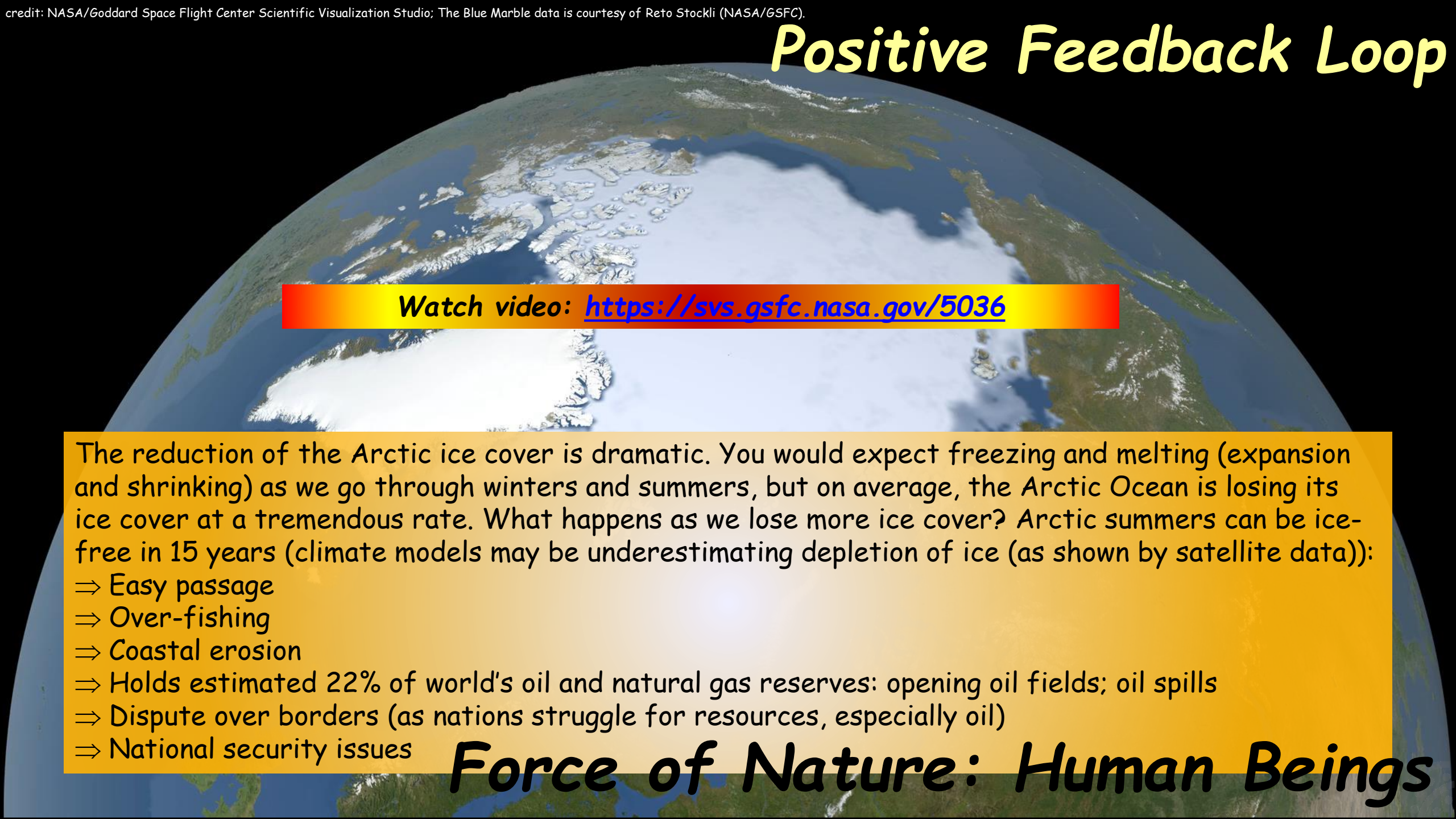


Albedo: the whiter surface (snow) reflects more light back; the darker surface (ocean) absorbs more light/heat)

https://commons.wikimedia.org/wiki/File:Ice_albedo_feedback.jpg
https://commons.wikimedia.org/wiki/File:20220726_Feedbacks_affecting_global_warming_and_climate_change_-_block_diagram.svg

credit: NASA/Goddard Space Flight Center Scientific Visualization Studio; The Blue Marble data is courtesy of Reto Stockli (NASA/GSFC).

Positive Feedback Loop



Watch video: https://svs.gsfc.nasa.gov/5036

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. What happens as we lose more ice cover? Arctic summers can be ice-free in 15 years (climate models may be underestimating depletion of ice (as shown by satellite data)):

⇒ Easy passage
⇒ Over-fishing
⇒ Coastal erosion
⇒ Holds estimated 22% of world's oil and natural gas reserves: opening oil fields; oil spills
⇒ Dispute over borders (as nations struggle for resources, especially oil)
⇒ National security issues

Force of Nature: Human Beings

Active Fires, September 2022

Positive Feedback Loop

Deforestation, usually through the burning down of forests and rainforests (removal of carbon sink), contributes more carbon into the atmosphere, reduces rainfall that cools land, and the land reclaimed for farming can emit even more carbon => temperature rises, which can cause more fires, and so on.

Here is another human activity you can see from space, where >80% of these fires are started by humans

Credit: NASA: for legend on colour of pixels, see https://neo.gsfc.nasa.gov/view.php?datasetId=MOD14A1_M_FIRE

Climate Time Machine: Sea Levels

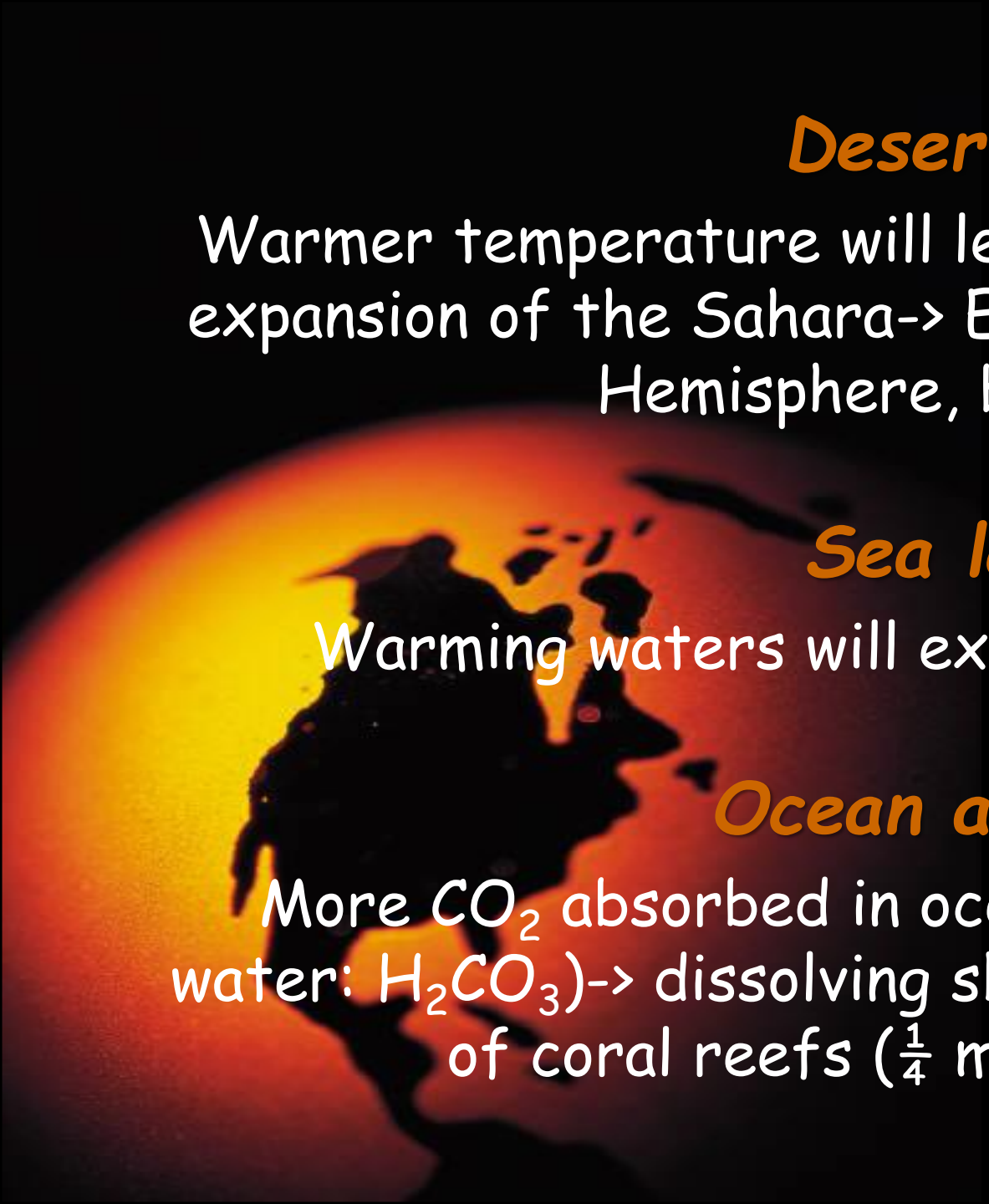
- A melting Arctic may not increase sea levels (have you ever seen an ice cube melt in water? The level won't change), but melting snow and glaciers (on land, such as Greenland and Antarctica) can result in a devastating effect world wide.

- In the following NASA interactive, click on '*Sea Level*' to see the changes to levels around the world, and the coastal flooding: http://climate.nasa.gov/interactives/climate-time-machine

a dire picture

Desertification:

Warmer temperature will lead to desert creep northward (eg, expansion of the Sahara-> Europe. Similar process in Southern Hemisphere, but southward creep.



Sea level rise:

Warming waters will expand and rise/ melting glaciers

Ocean acidification:

More CO_2 absorbed in oceans-> carbonic acid (carbonated water: H_2CO_3)-> dissolving shells of sea creatures-> destruction of coral reefs ($\frac{1}{4}$ marine creatures live here)

a dire picture

Growing seasons altered/crops affected:

Worse for poorer, warmer countries

Disparity between rich and poor nations will grow

Health:

Pollutants such as CFCs deplete ozone, but now a connection to climate change (water vapour in stratosphere destroys ozone): more UV radiation and skin cancer and crop destruction/mutations. Unbreathable air; carcinogenic exposure.

a dire picture

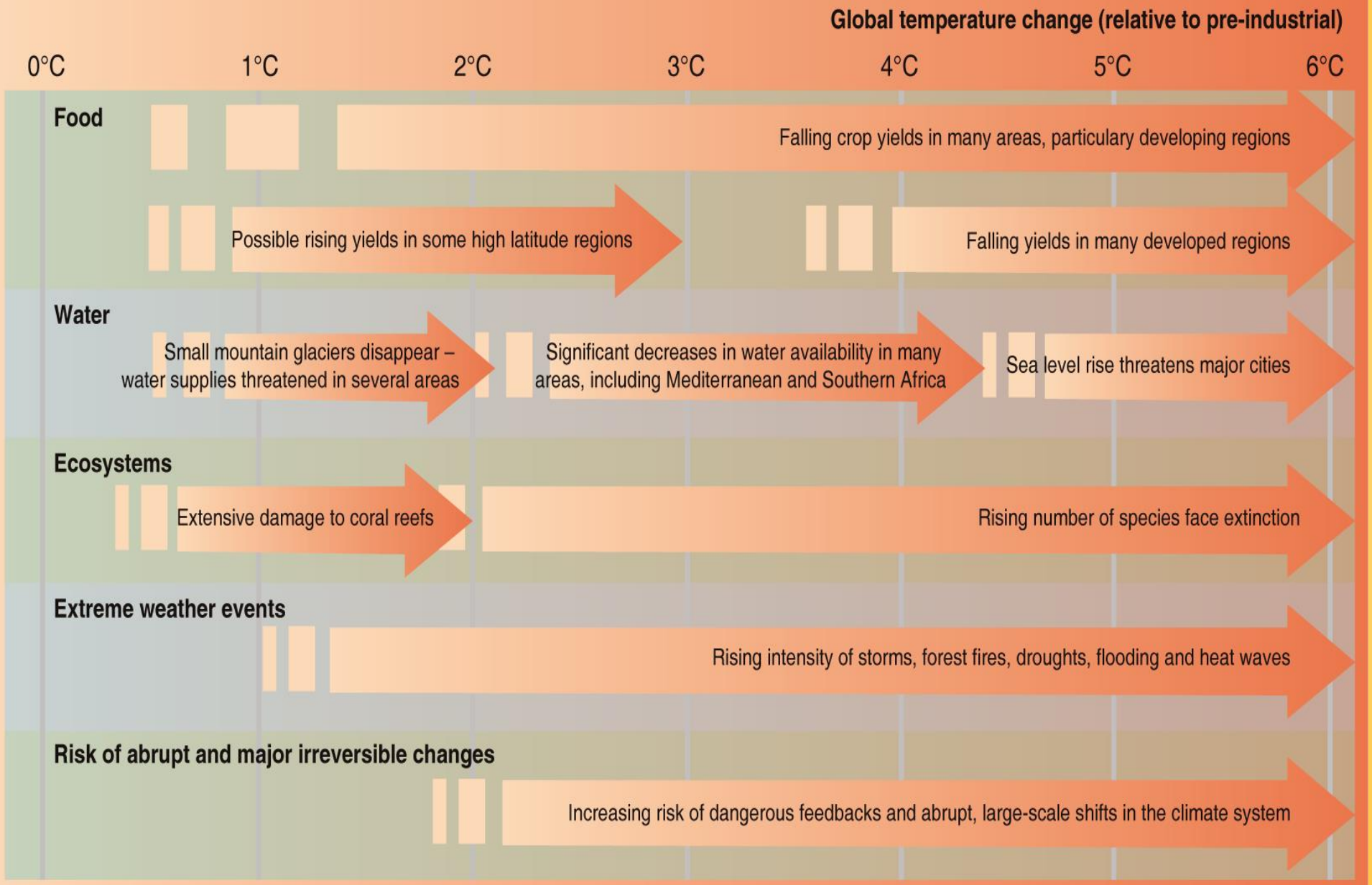
A change in global temperature, whether from increased GHG emissions through fossil fuel burning, industry, or from deforestation for farming or settlement, has a ripple effect, possibly building to a tsunami of change on environments across the planet.

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 and extinction, wildfires, food production, health issues, **struggle for resources**, and economics.

And more …

- *Atmospheric toxicity*
- *Extreme weather events*
- *Carbon cycle disruption*
- *Diminishment of plant and forest cover*
- *Fresh water shortage*
- *Climate Refugees*
- *Climate Wars?*

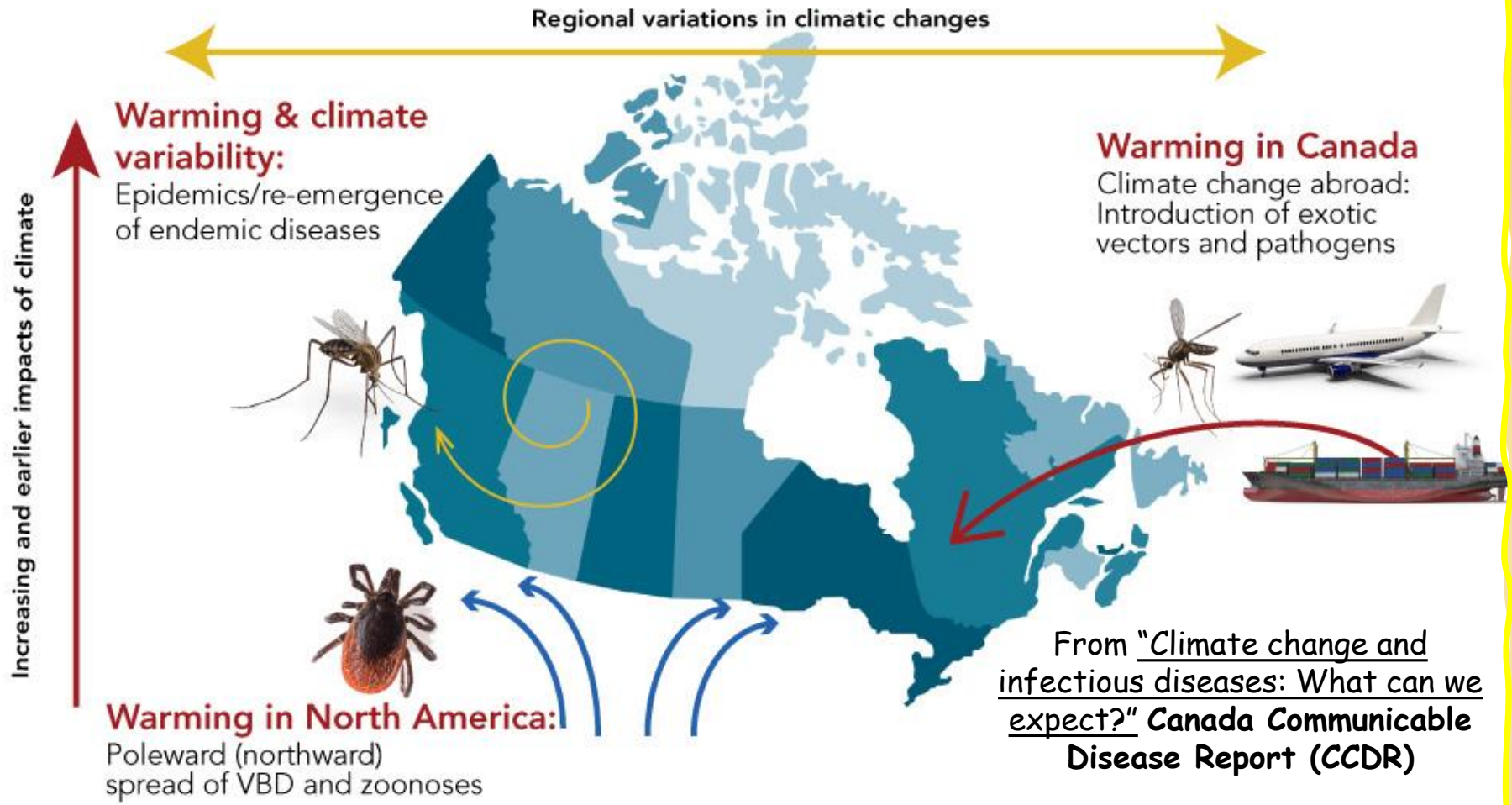
Projected impact of climate change



SOURCE: Stern Review

retrieved from http://www.grida.no/graphicslib/detail/projected-impact-of-climate-change_1011

IAASTD/Ketill Berger, UNEP/GRID-Arendal



"Figure 3: A summary of climate change effects on infectious disease risks for Canada This figure is a graphical illustration that summarizes the climate change effects on infectious disease risks for Canada. The long-term climate changes and increased climate variability will affect the different infectious disease risks:

- Warming & climate variability will cause the Epidemics/re-emergence of endemic diseases
- Warming in Canada and climate change abroad will introduce exotic vectors and pathogens
- Warming in North America: Poleward (northward) will lead to the spread of VBD [vector-borne disease; bacteria, viruses] and zoonoses [jump to humans from animals]."

Disease

- The increasing temperature will also affect the conditions that may create and spread disease, drastically changing the environment for epidemics and pandemics, increasing the potential of outbreaks.
- Mora, C., McKenzie, T., Gaw, I.M. *et al.* **Over half of known human pathogenic diseases can be aggravated by climate change.** *Nat. Clim. Chang.* **12**, 869–875 (2022). https://doi.org/10.1038/s41558-022-01426-1

Image credit: https://www.canada.ca/en/public-health/services/reports-publications/canada-communicable-disease-report-ccdr/monthly-issue/2019-45/issue-4-april-4-2019/article-1-climate-change-infectious-diseases.html

Mitigation

(From our Davidson reading)

"**Mitigation includes three basic strategies**:

- First, the **amount of greenhouse gases being emitted by human activities can be reduced**. This is what is called conventional mitigation, and it generally implies making changes in the ways energy is consumed, either by using less, or switching to alternative fuels that emit little or no carbon.
- Second, **emitted carbon can be captured before it is released into the atmosphere** and stored underground. This is called carbon capture and storage (CCS), and has started to be implemented in a handful of power plants to date, one of which is in Saskatchewan. However, carbon capture is expensive, and governments are a long way from implementing CCS at a scale that would be necessary to influence change.
- Third, certain approaches are capable of removing the carbon that currently exists in the atmosphere. This can include simple strategies like **reforestation**, since trees absorb carbon, as well as more technologically advanced mechanisms.
- A fourth strategy, still only at the sidelines of discussion, involves "geo-engineering," which entails efforts to control the climate by manipulating the Earth's systems in various ways. An example of this is the process of cloud seeding, an attempt to increase precipitation from clouds by dispersing substances, primarily solid carbon dioxide (dry ice) and silver iodide, into them. Geo-engineering techniques are still considered highly speculative, and are associated with significant risks of unintended negative impacts.

How Much Mitigation is Needed?

- With the global lack of progress on reducing greenhouse gas emissions since the establishment of the United Nations Framework Convention on Climate Change, the need for rapid mitigation has become more urgent than ever. In 2018, the Intergovernmental Panel on Climate Change released a report that confirmed that **limiting global warming to 1.5°C could substantially reduce the impacts of climate change. However, the report also indicated that in order to accomplish this net greenhouse gas emissions would need to be reduced to zero by 2040**."