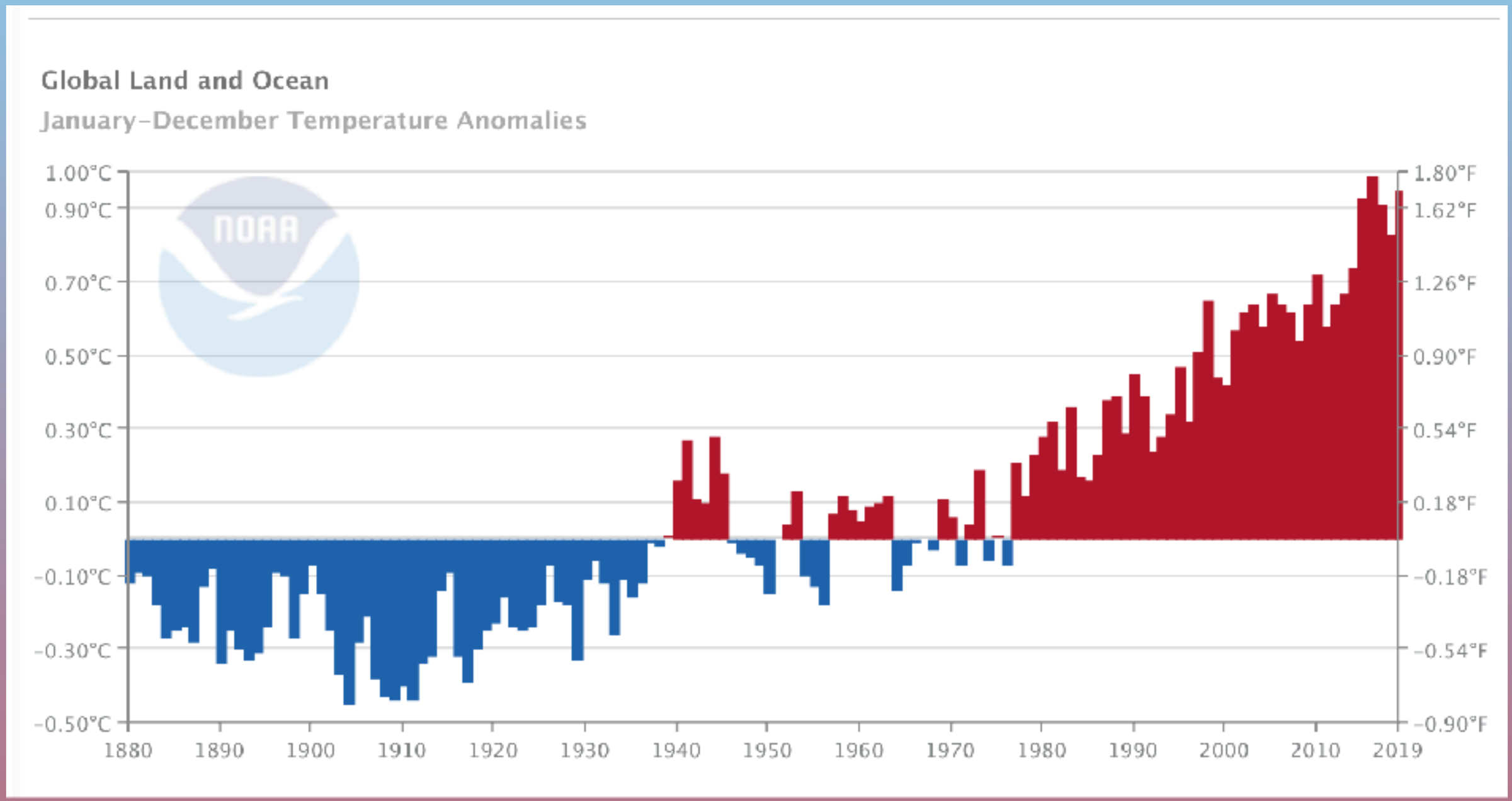
Spring 2020
Math 595MP

Climate Change
Overview

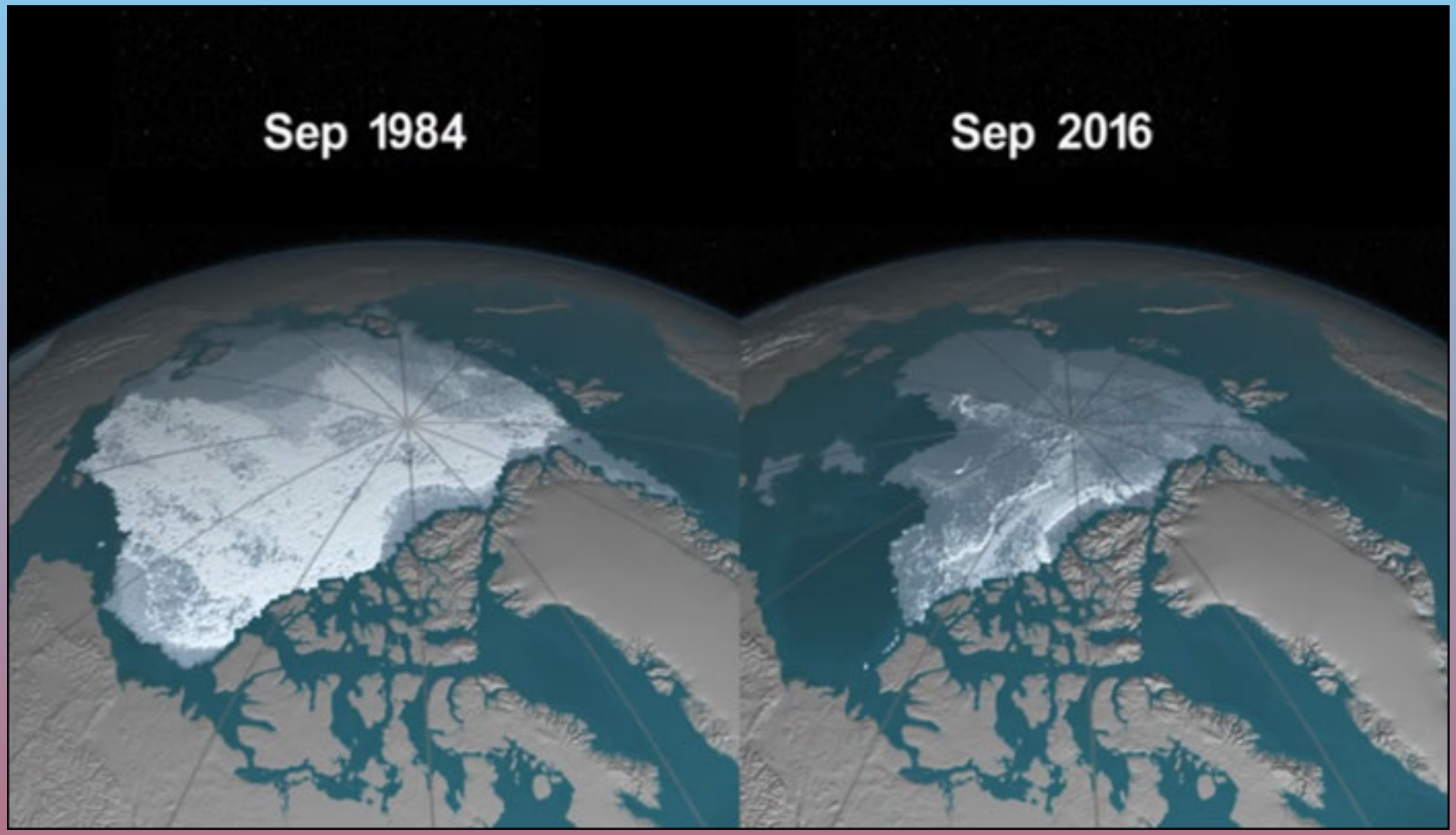
Some Vocabulary

- **Temp:** Celsius vs Fahrenheit, change of 1°C is 1.8° F
- **Temp:** Kelvin vs Celsius, change of 1°C is 1 K
- **Absolute zero:** 0 K = -273.15°C = -459.67°F
- **Length:** 1 meter = 39 in (or 3 ft, 3 in)

Temperature Anomalies
Relative to 20th Century Average



Disappearance of Arctic Sea Ice



Greenland

A study published in *Geophysical Research Letters*, (July 2016) found that Greenland lost a trillion tons of ice between the years 2011 and 2014 alone.

If all ice in Greenland melted, sea level would increase 20 feet worldwide.

Greenland Lost 12.5 Billion Tons of Ice in a Single Day

The amount of ice collectively lost last Wednesday and Thursday would be enough to cover Florida in almost five inches of water

An aerial view of meltwater rivers carving into the Greenland ice sheet on August 04, 2019. (Sean Gallup/Getty Images)

By **Meilan Solly**
SMITHSONIAN.COM
AUGUST 5, 2019

Antarctica

In just 3 years (2014 to 2017) Antarctica lost the same amount of sea ice the Arctic lost in 30 years.

Glacial ice is also thinning and almost a quarter of the West Antarctic Ice Sheet is now unstable.

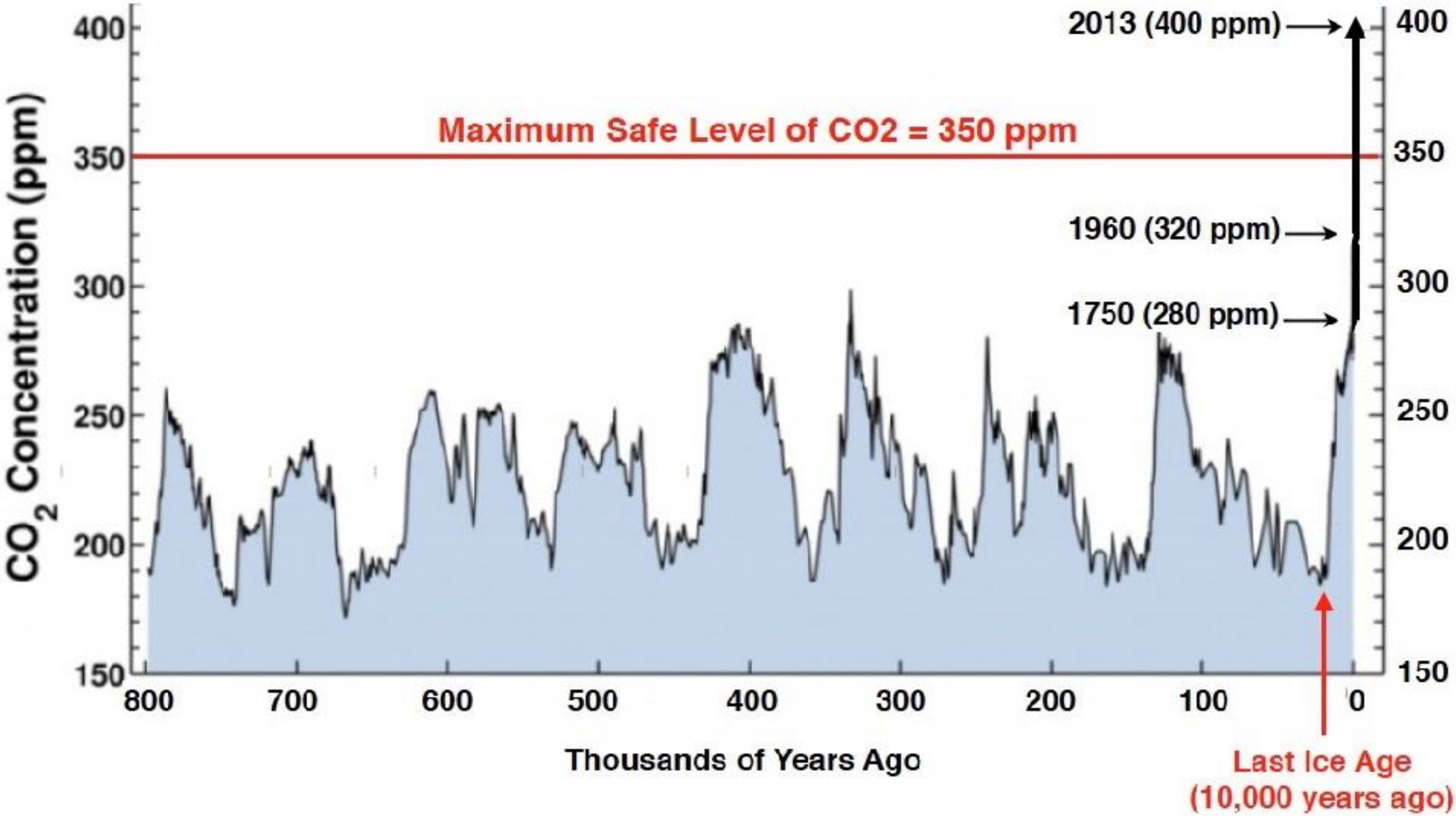
Main Cause of Global Warming

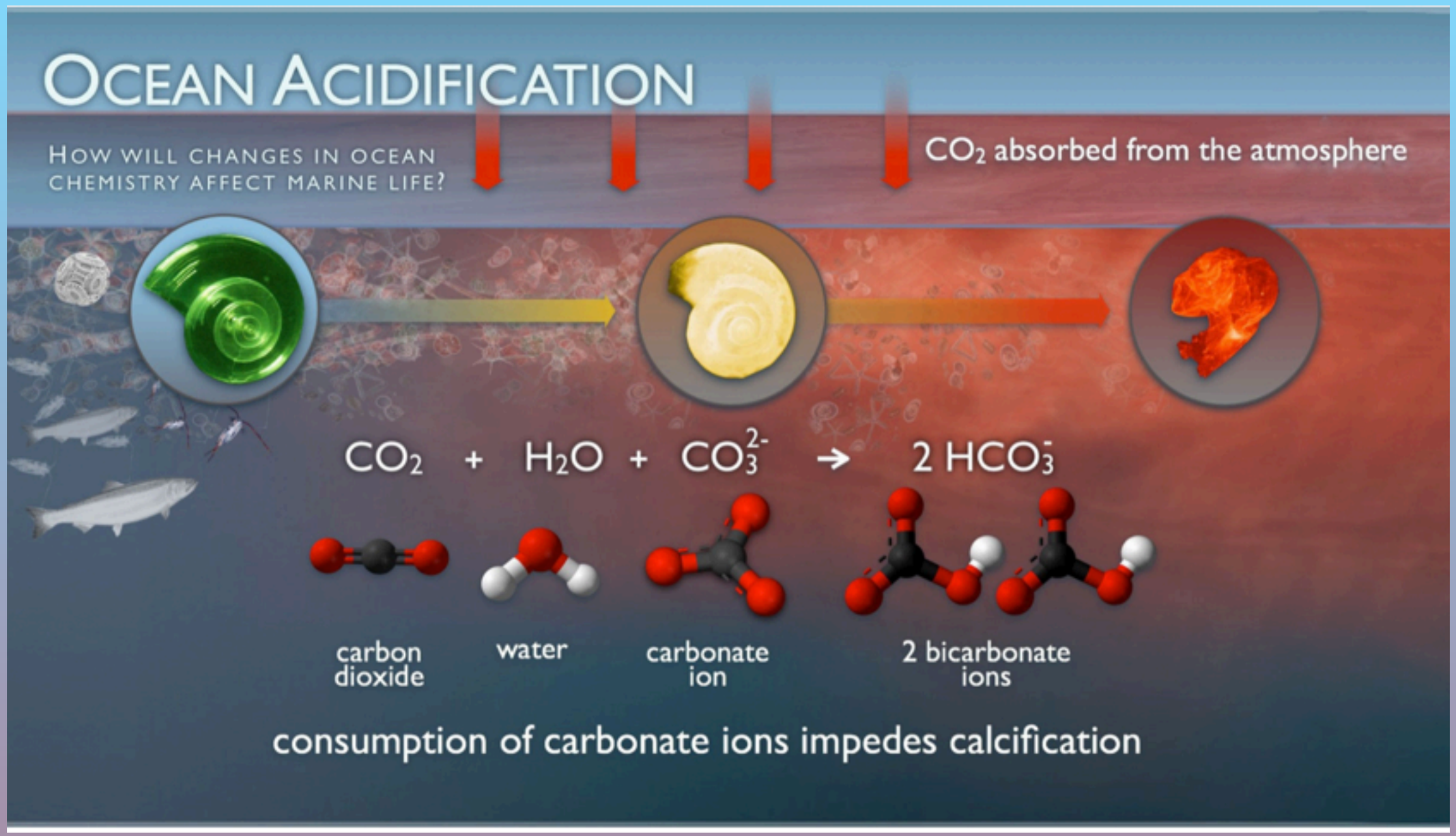
Greenhouse Effect

Greenhouse gases:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- ozone (O_3)
- fluorinated gases (F-gases)
- water vapor (H_2O)

CO_2 levels: 800,000 years ago to present





Carbonate ions are needed for shells by oysters, clams, sea urchins, shallow water corals, deep sea corals, calcareous plankton, and pteropods or "sea butterflies”

Global Climate Model

Atmosphere

Cryosphere

Oceans

Land Surface

Global Climate Model

Fundamental Physical Equations:

- Conservation of momentum

$$\frac{\partial \vec{V}}{\partial t} = -(\vec{V} \cdot \nabla)\vec{V} - \frac{1}{\rho}\nabla p - \vec{g} - 2\vec{\Omega} \times \vec{V} + \nabla \cdot (k_m \nabla \vec{V}) - \vec{F}_d$$

- Conservation of energy

$$\rho c_{\vec{v}} \frac{\partial T}{\partial t} = -\rho c_{\vec{v}} (\vec{V} \cdot \nabla) T - \nabla \cdot \vec{R} + \nabla \cdot (k_T \nabla T) + C + S$$

- Conservation of mass

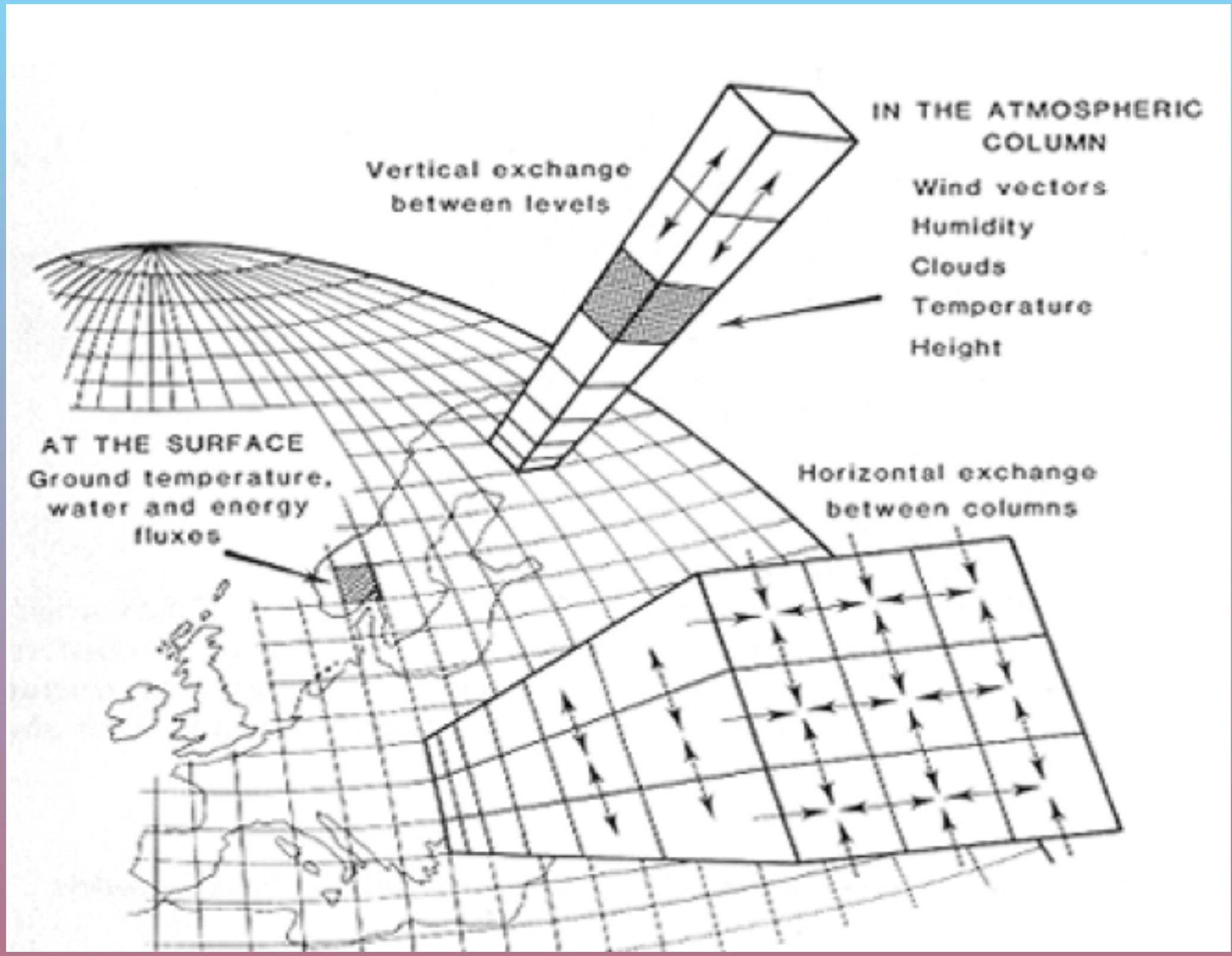
$$\frac{\partial \rho}{\partial t} = -(\vec{V} \cdot \nabla)\rho - \rho(\nabla \cdot \vec{V})$$

- Conservation of H_2O (vapor, liquid, solid)

$$\frac{\partial q}{\partial t} = -(\vec{V} \cdot \nabla) q + \nabla \cdot (k_q \nabla q) + S_q + E$$

- Equation of state

$$p = \rho R_d T$$


IN THE ATMOSPHERIC COLUMN
Wind vectors
Humidity
Clouds
Temperature
Height
Vertical exchange between levels
AT THE SURFACE
Ground temperature, water and energy fluxes
Horizontal exchange between columns

Global Temperature predictions for 2100

Expect 1.5°C to 7°C increase in global average temperature (depending on emissions)

How would that affect us?

Last Glacial Maximum
20,000 years ago

Ice sheets covered Canada, northern U.S

New York City a mile under ice

Sea level: 120 meters (394 feet) lower

How much colder was the global average temperature than now? (Guess!)

Last Glacial Maximum
20,000 years ago

Answer: Global average temperature was 3°C to 6°C cooler than now.

A change of only a few degrees has world-altering consequences.

So, what would a 3°C to 6°C hotter world look like?

3°C to 6°C Warmer World

🔴**In a 3°C warmer world, Brazilian rainforest could burn down, turn to savanna or desert. Hundreds of millions suffer from drought and famine.**

🔴**In a 4°C warmer world, the hot climates of North Africa will likely jump across the Mediterranean and spread into the heart of Europe with typical searing summer temperatures of 120°F. Central America turns to desert creating climate refugees.**

🔴**With 5°C of global warming, the world will be almost unrecognizable. Average inland temperatures would be 18°F higher. Southern U.S. likely becomes a desert, along with Australia, Southern Europe, Central America. Zones of habitability for humans would contract drastically toward the poles. Warming of the oceans would decrease oxygen levels and lead to mass extinctions of ocean species. Billions of people would die.**

🔴**A 6°C warmer world might lead to the extinction of humanity.**

Amazon forest cover

As of 2018, the Brazilian Amazon had 82.7% as much forest cover as it did in 1970.

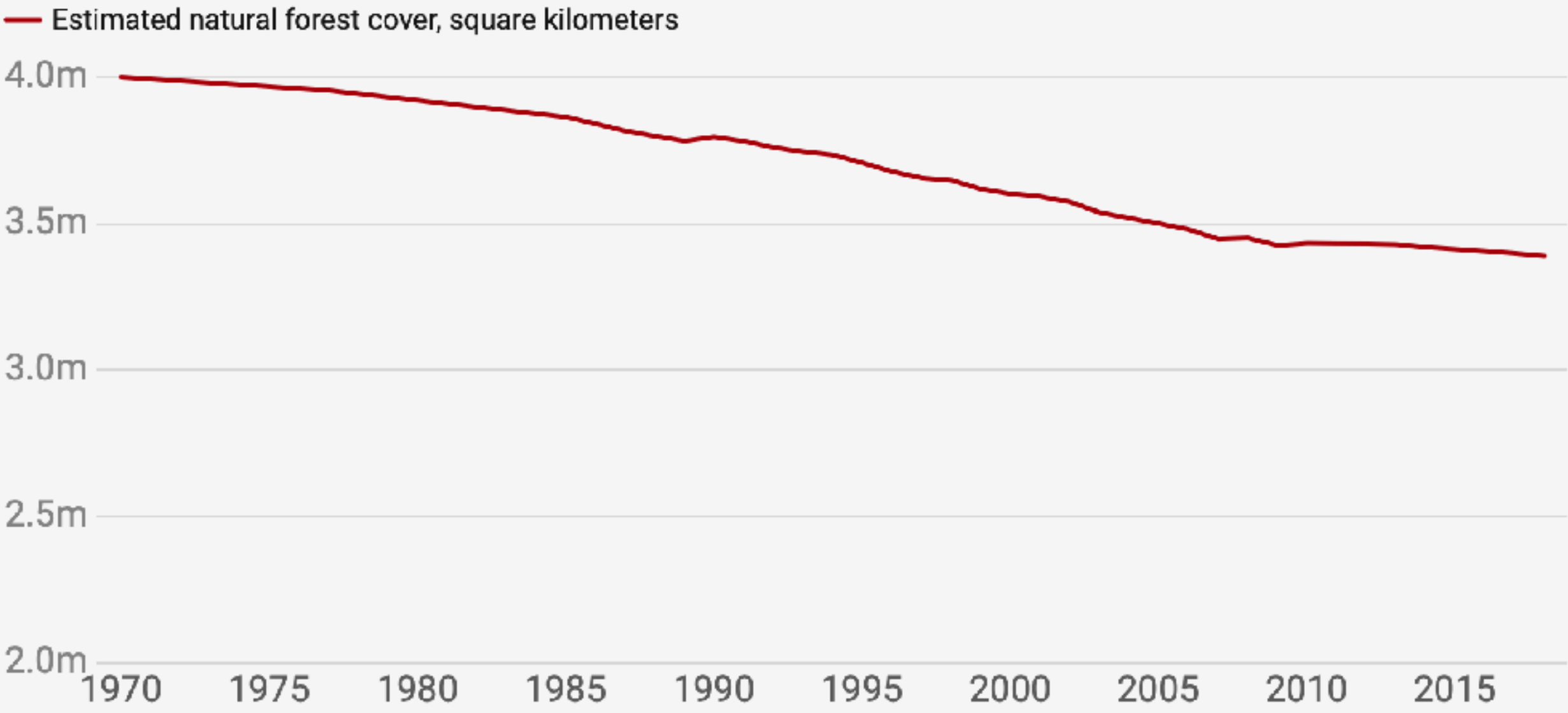


Chart: The Conversation, CC-BY-ND • Source: Mongabay • Get the data

nature climate change

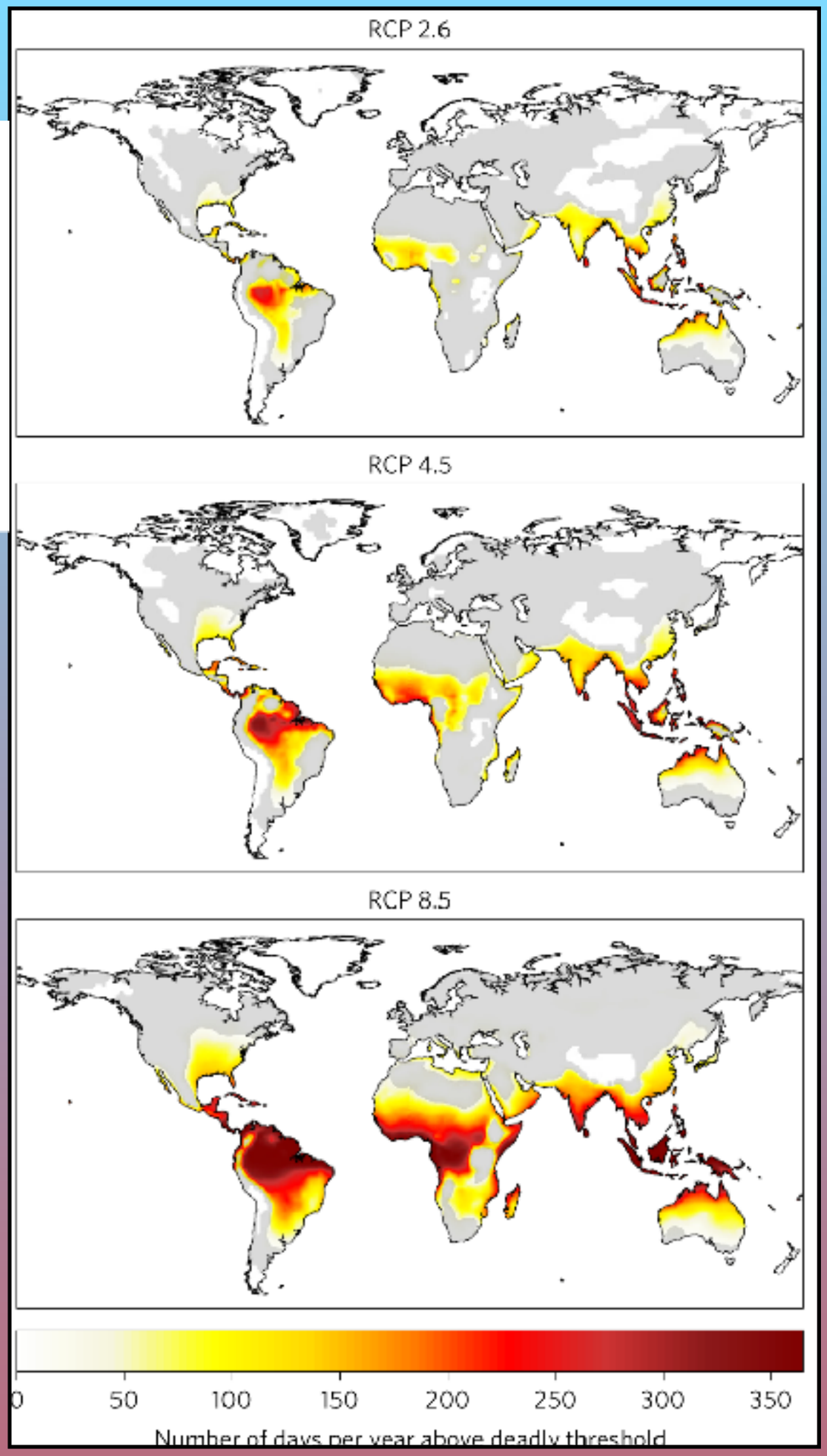
LETTERS

PUBLISHED ONLINE: 19 JUNE 2017 | DOI: 10.1038/NCLIMATE3322

Global risk of deadly heat

Camilo Mora[1*], Bénédicte Dousset[2], Iain R. Caldwell[3], Farrah E. Powell[1], Rollan C. Geronimo[1], Coral R. Bielecki[4], Chelsie W. W. Counsell[3], Bonnie S. Dietrich[5], Emily T. Johnston[4], Leo V. Louis[4], Matthew P. Lucas[6], Marie M. McKenzie[1], Alessandra G. Shea[1], Han Tseng[1], Thomas W. Giambelluca[1], Lisa R. Leon[7], Ed Hawkins[8] and Clay Trauernicht[6]

"We conducted a global analysis of documented lethal heat events to identify the climatic conditions associated with human death and then quantify the current and projected occurrence of such deadly climatic conditions worldwide."



Climate Change and Hurricane Katrina: What Have We Learned?

Monday, 24 August 2015 00:00
By Kerry Emanuel, The Conversation | Report

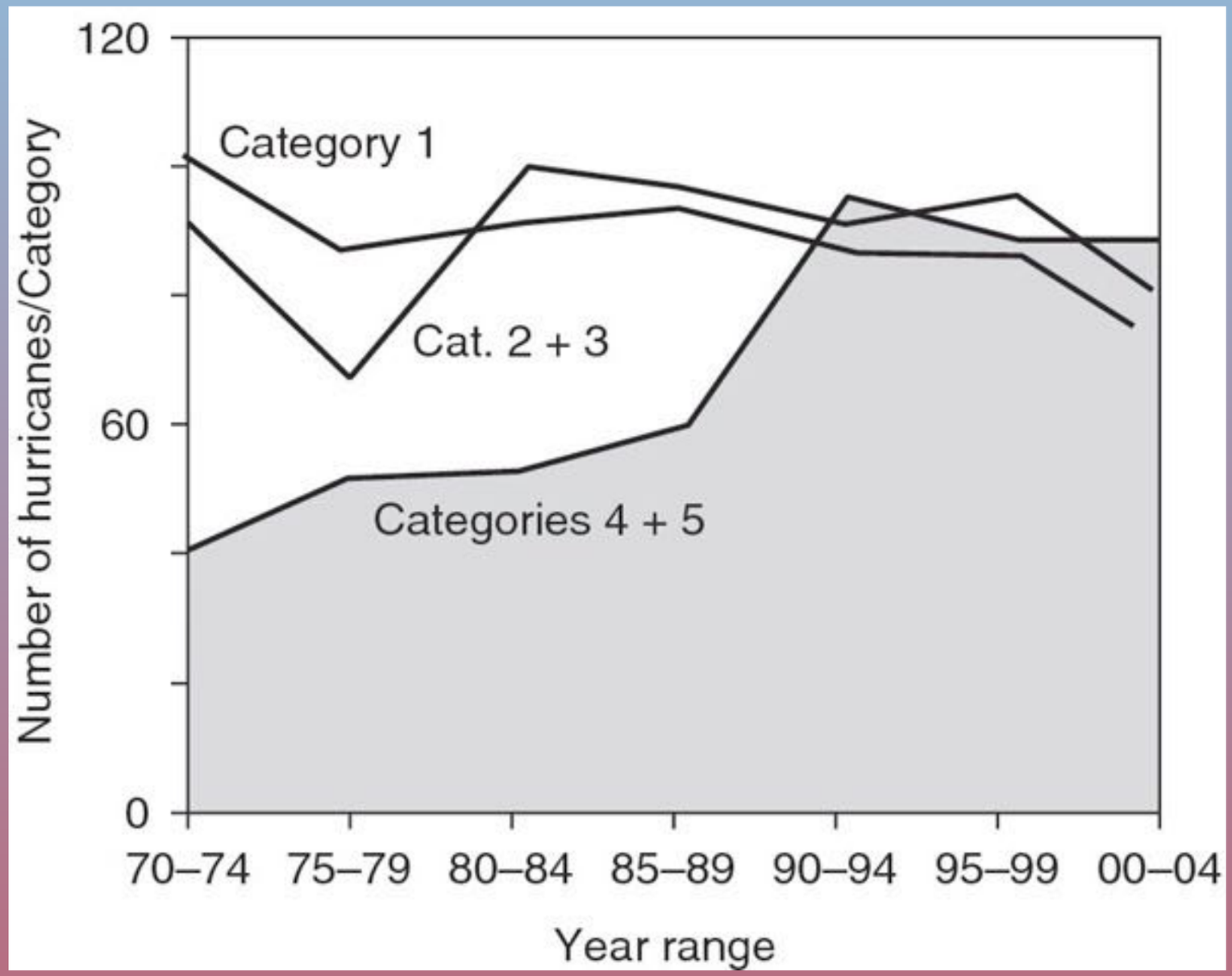
Kerry Emanuel is professor of Atmospheric Science at Massachusetts Institute of Technology.

1.

Theory and computer models show that the incidence of the strongest hurricanes – those that come closest to achieving their potential intensity – will increase as the climate warms, and there is some indication that this is happening.

Satellite data also show that storms are reaching their peak at higher latitudes, consistent with theories and models.

Reduced risk in the deep tropics but increased risk in mid-latitudes.



Understanding Global Warming of 1.5°C

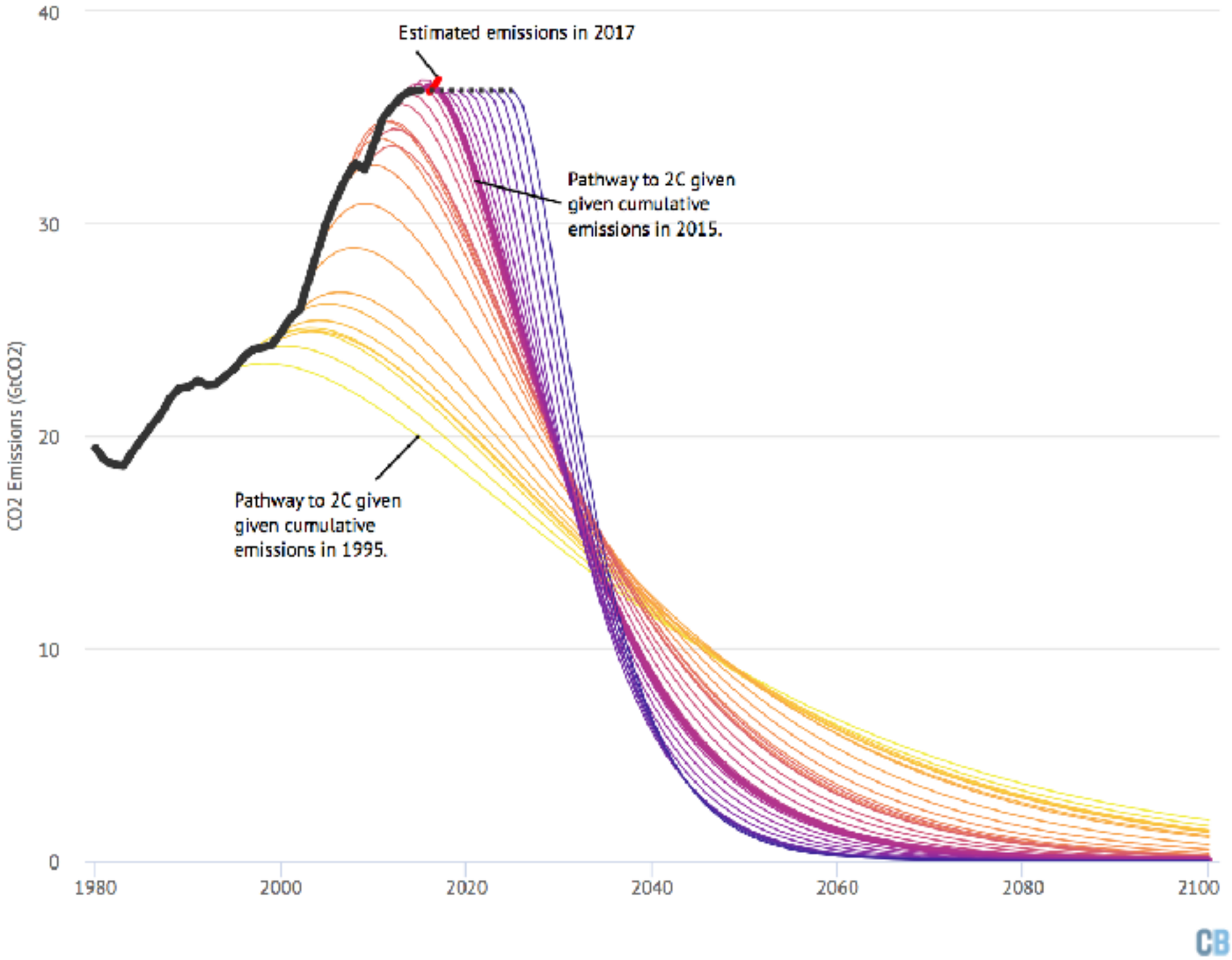
IPCC Special Report, Oct. 2018

Report analyzed the difference between 1.5°C and 2°C of warming.

Half a degree means the difference between a world with coral reefs and Arctic summer sea ice and a world without them.

To stay below 1.5 C requires GHG emissions reduction worldwide of 45% by 2030 and net zero emissions by 2050.

To limit warming to 2C, global emissions must fall more quickly if they peak later



Emission reduction trajectories associated with a 66% chance of avoiding more than 2C warming by starting year, with new 2017 emissions added. Solid black line shows historical emissions, while dashed black line shows emissions constant at 2016 levels. Data and chart design from Robbie Andrew at CICERO and the Global Carbon Project. Chart by Carbon Brief using Highcharts.

4°C Warmer World

"the difference between two and four degrees is human civilisation"

Hans Joachim Schellnhuber,

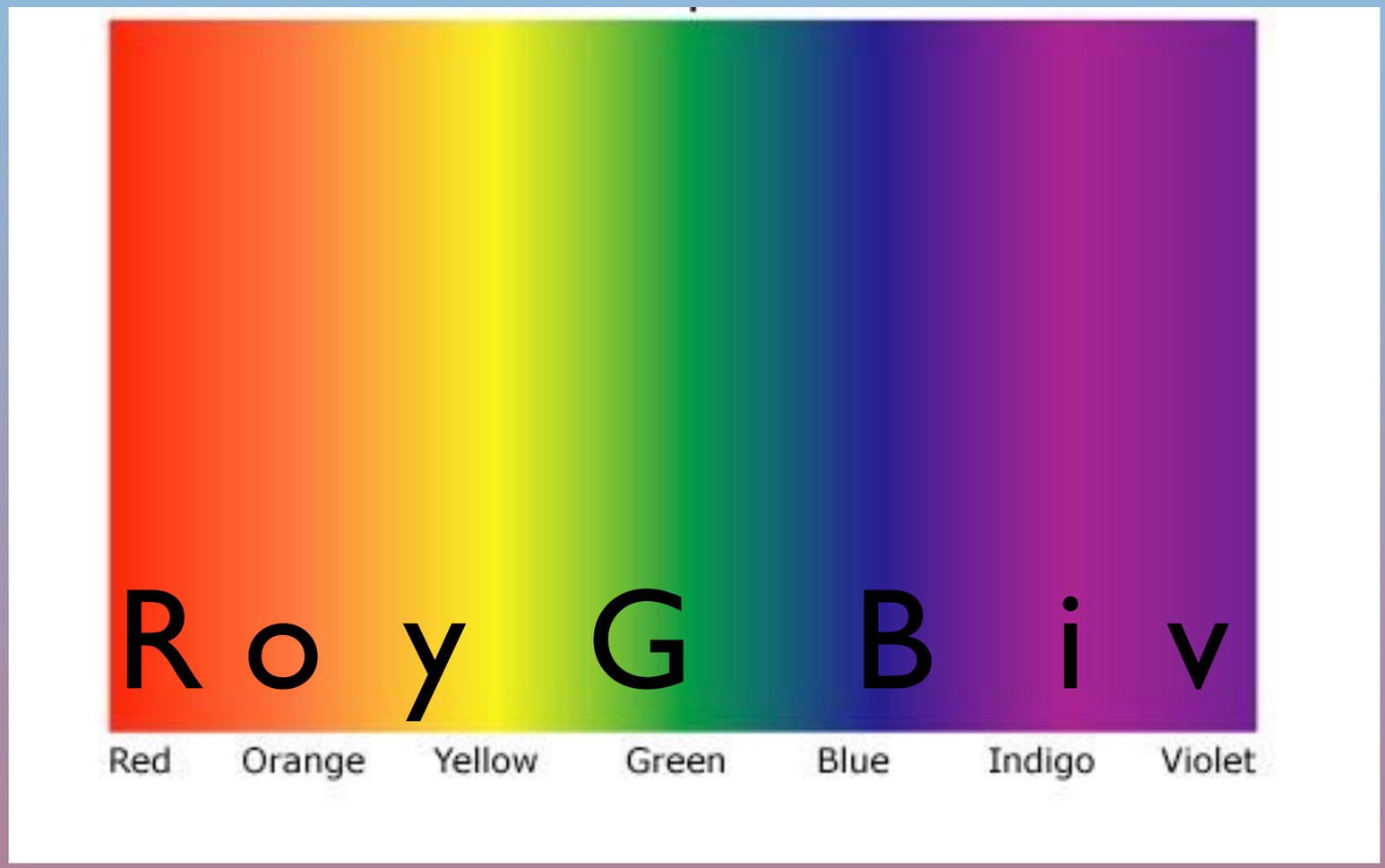
Director, Potsdam Institute for Climate Impact Research

Professor of Theoretical Physics, University of Potsdam

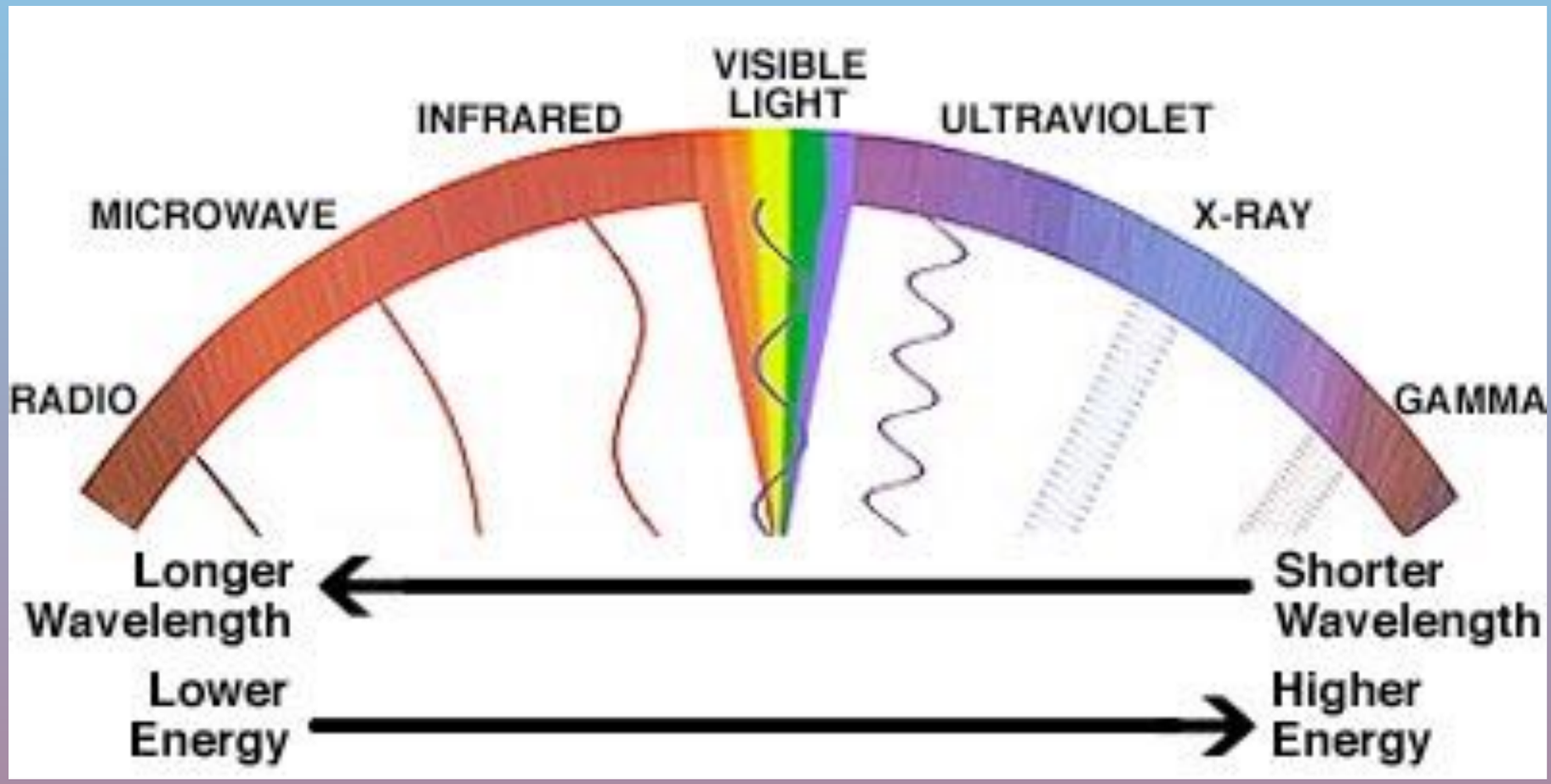
Co-Chair of the German Advisory Council on Global Change

Visible Spectrum

Low Frequency → High Frequency

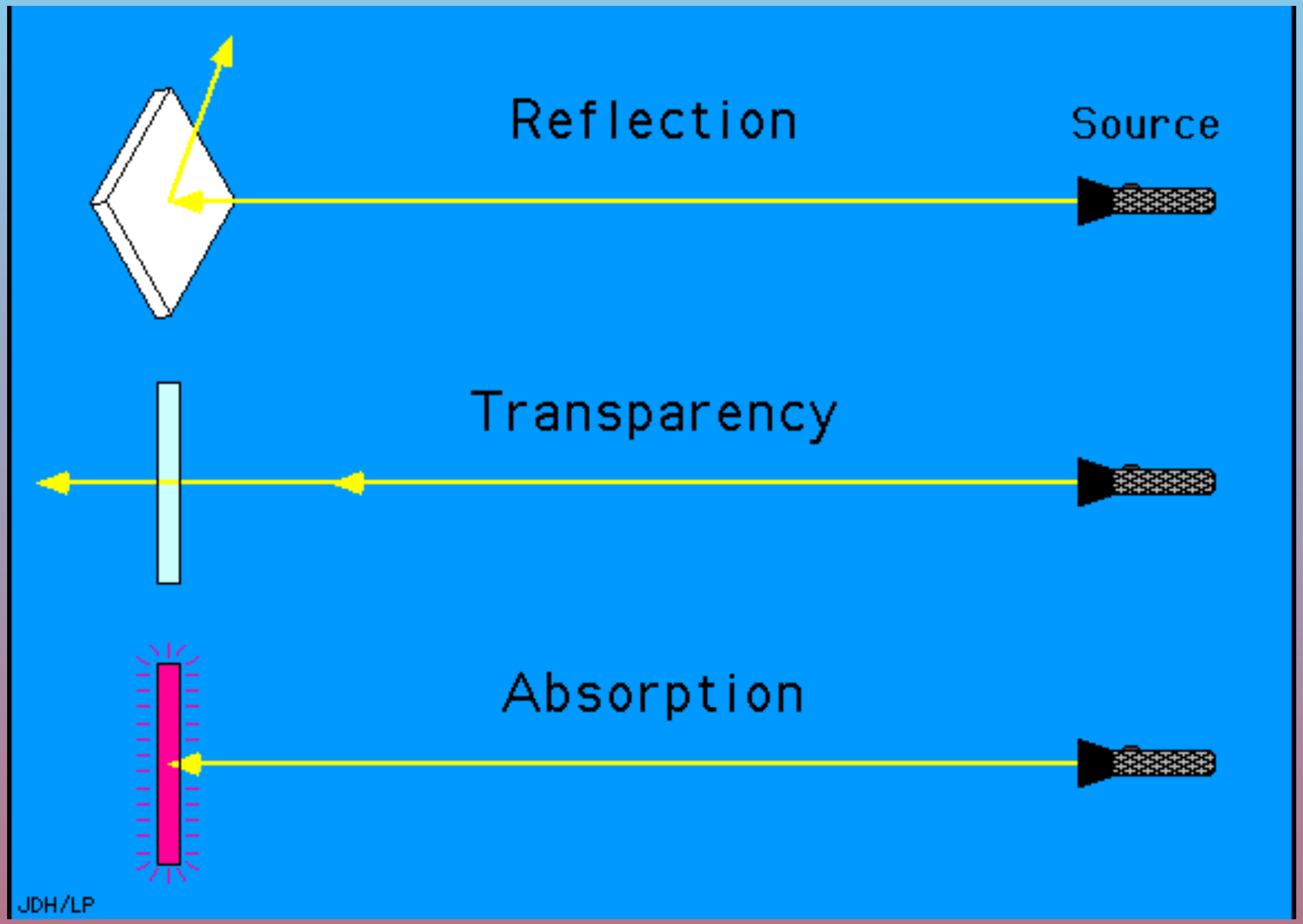


Electromagnetic Spectrum



Infra**red** → Ultra**violet**

Radiation and Matter

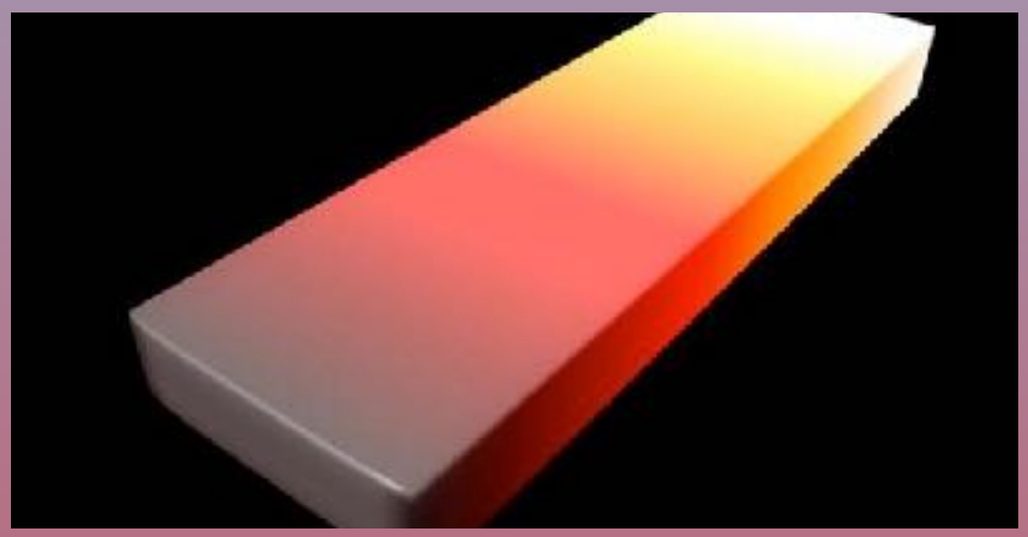


Earth's Planetary Albedo ≈ 0.3

The albedo of snow-covered ice is close to 1 (larger than 0.8); the albedo of sea water is close to zero (less than 0.1).

Heat and Light

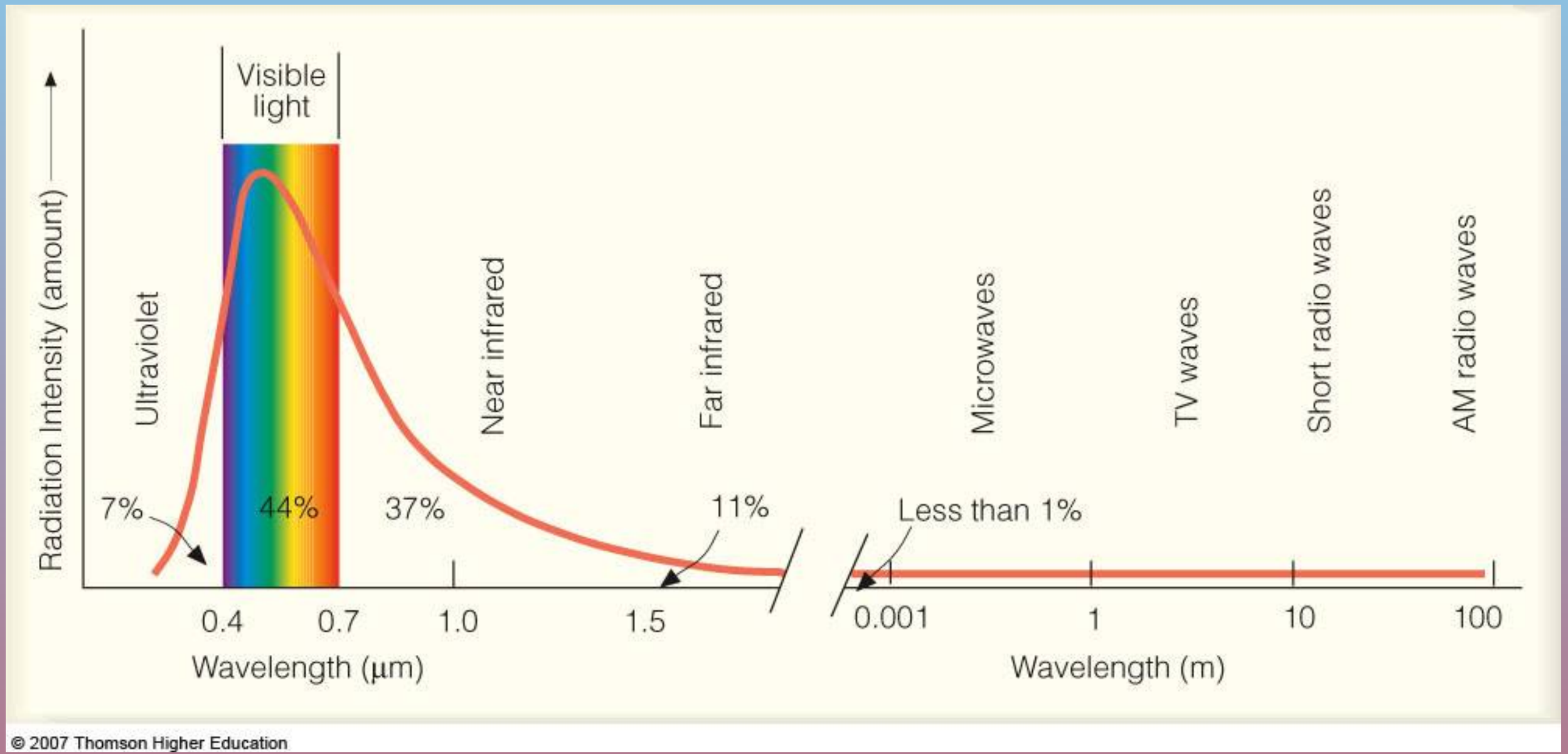
The temperature of an object determines the frequency of radiation it emits.



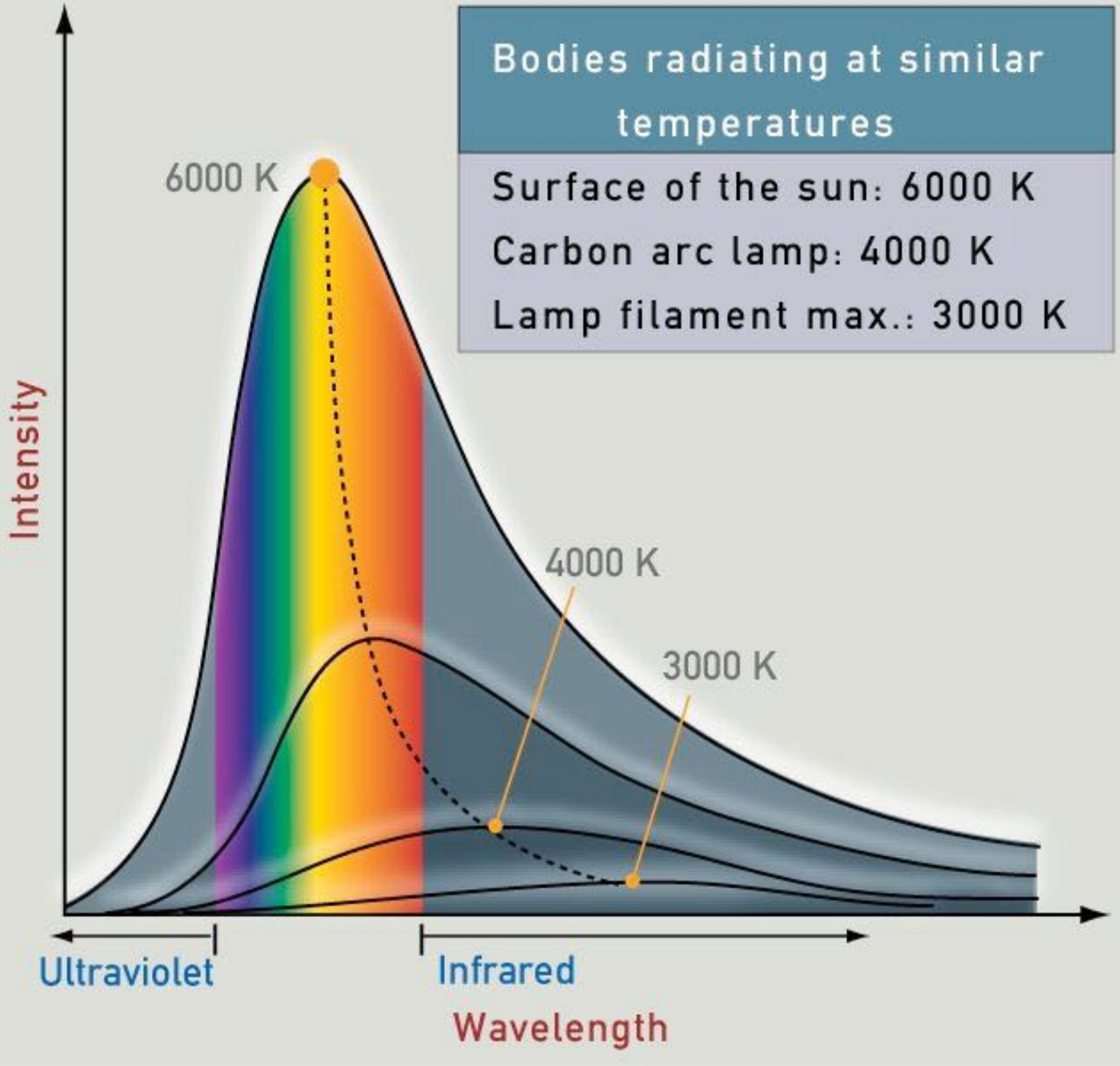
Some Vocabulary

- **Energy:** 1 Joule = 0.74 foot-pounds
- **Power:** 1 Watt = 1 Joule/second
- **Power from Sun** (top of atm) 1370 W/m^2
- Average power **Earth surface**: 240 W/m^2 (approx 1000 W/m^2 at noon)

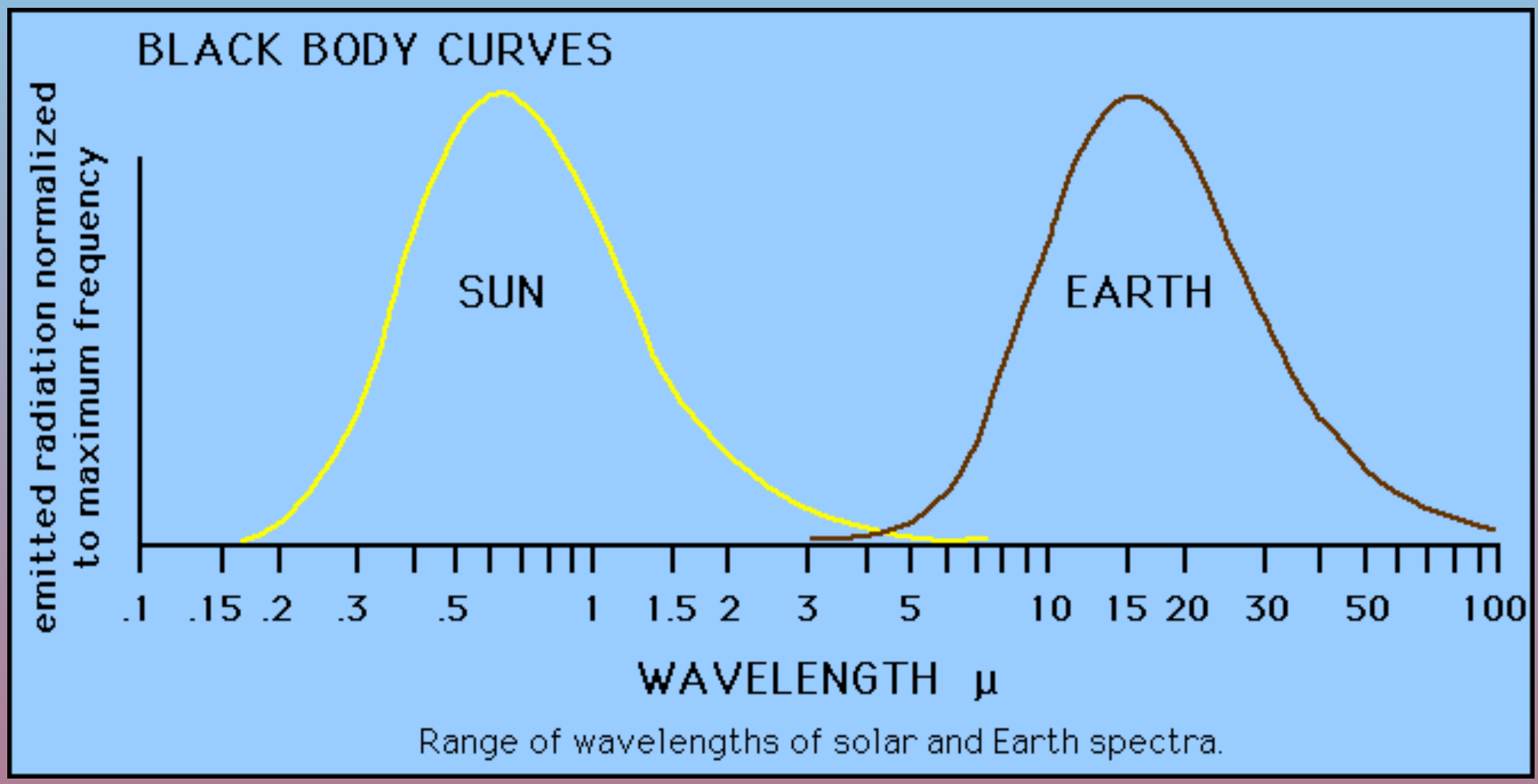
Light from the Sun
Photosphere: ~ 6000° K



Blackbody Radiation Curves

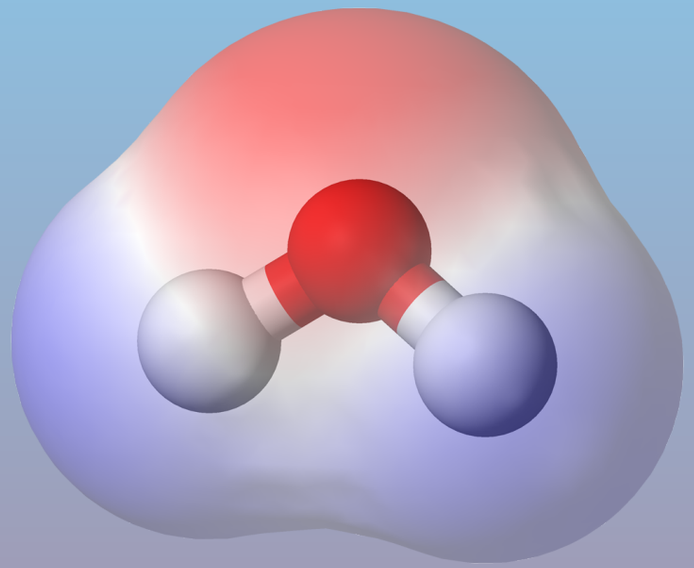


Radiation Spectrum: Sun vs Earth

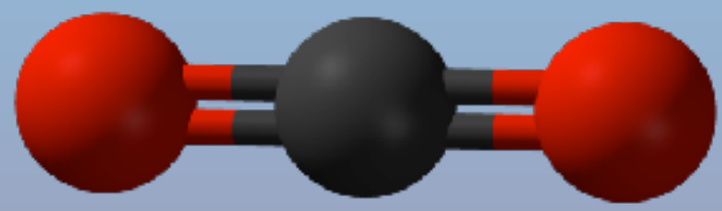


Range of wavelengths of solar and Earth spectra.

Green house gases and radiation



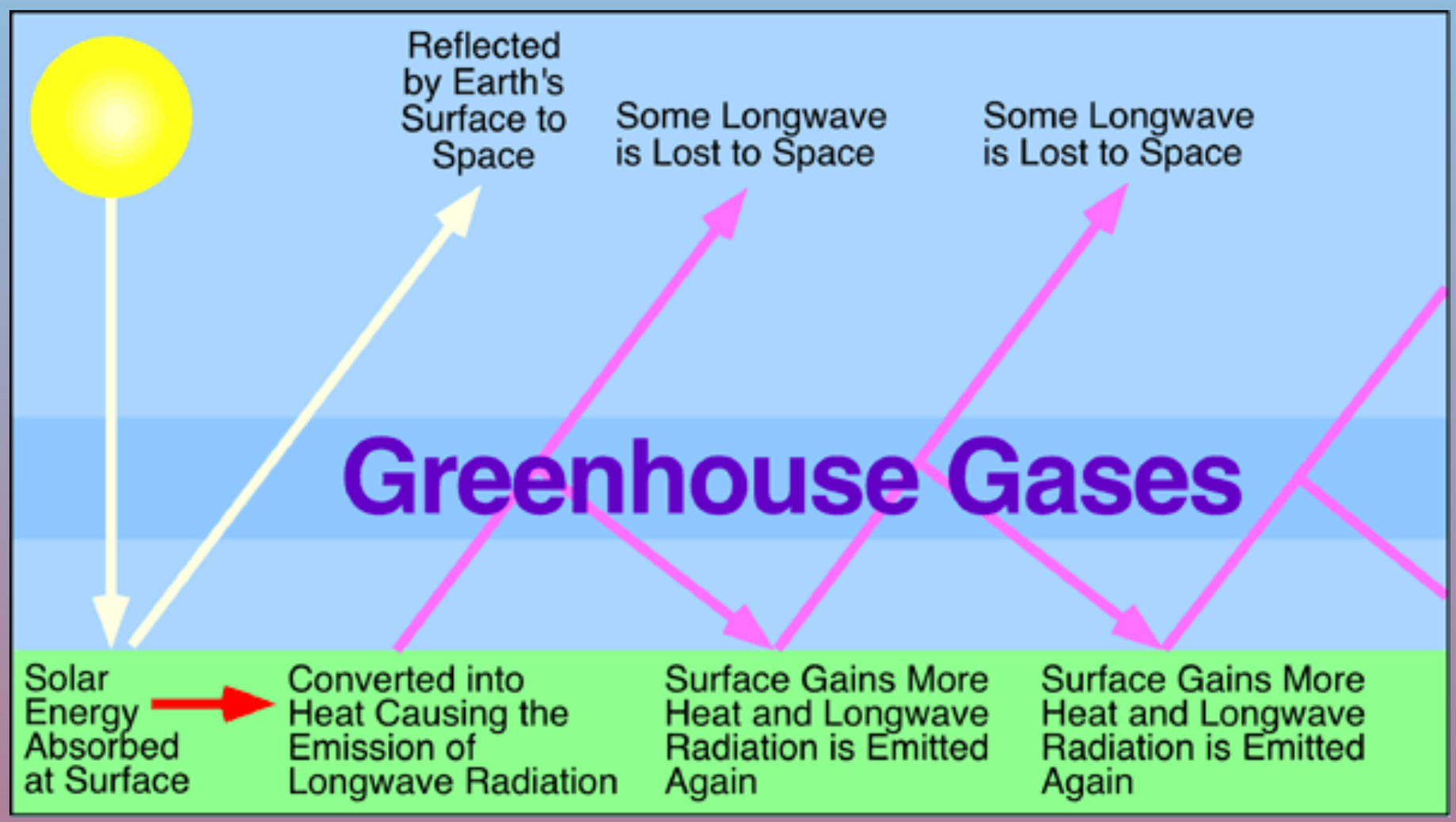
H_2O



CO_2

Molecular structure and quantum mechanical properties determine which frequencies can be absorbed. Green house gases absorb infrared light.

Green House Effect

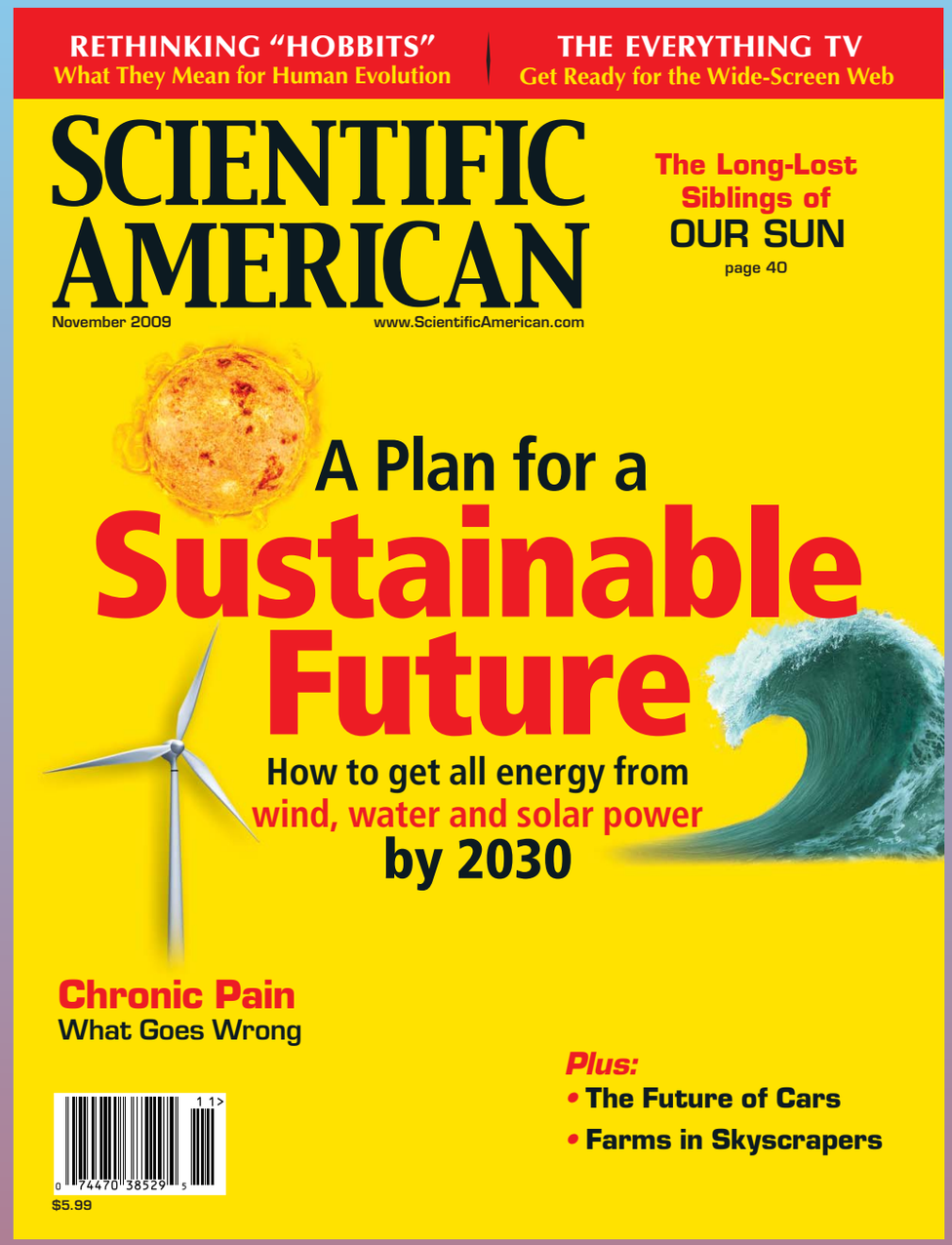


A sustainable global civilization is possible, but just barely.

The technology is already here

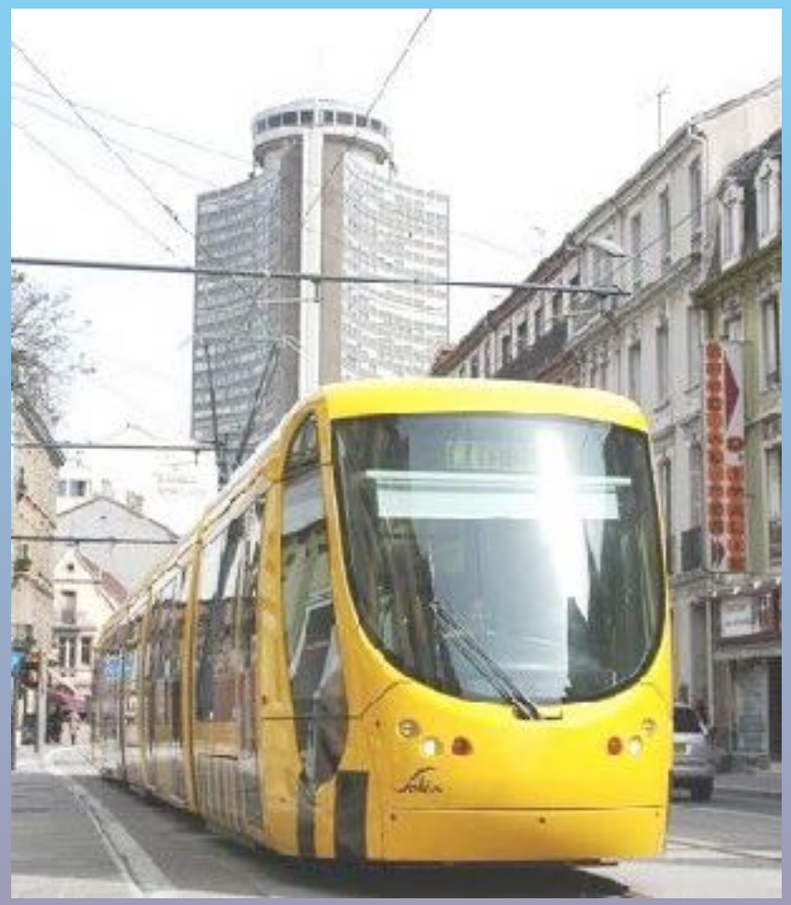
In 2009 *Scientific American* published an article, by leading researchers at Stanford University and UC Davis, that explains how 100% of the world's energy needs, for all purposes, including transportation, could be supplied by wind, solar, geothermal, tidal and hydroelectric power systems (without nuclear power) by as early as 2030.

Their plan calls for 3.8 million large wind turbines, 90,000 solar plants, and numerous geothermal, tidal and rooftop photovoltaic installations worldwide.



Transportation

Electrified mass transportation.



Manufacturing cars that last longer would help, but the last thing auto makers want to do is build cars that can last for decades.

It is more profitable to increase the rate of consumption and entice customers to buy new cars every three or four year

Agriculture

Land use under capitalism is not sustainable.

Industrial agriculture and deforestation are responsible for nearly a quarter of all global greenhouse emissions.

Petroleum based fertilizers, pesticides, and herbicides emit greenhouse gases. Runoff of fertilizers causes pollution of streams, rivers, ponds, lakes and coastal waters, often leaving "dead zones" depleted of oxygen.

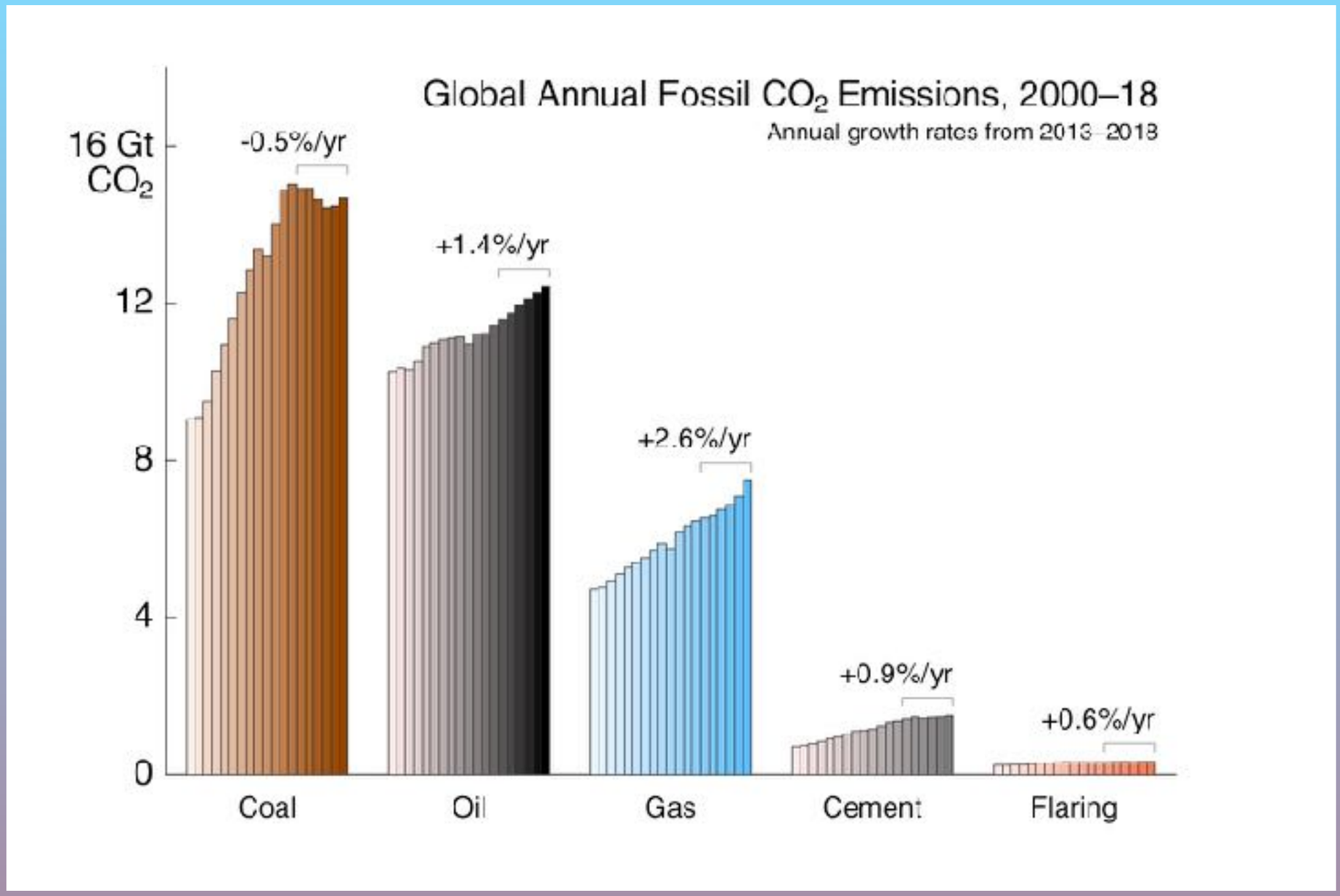
What we now call "organic farming" sustained humanity for thousands of years, and ecological practices continue in many parts of the world. Cuba is an important example, where large monocultural farms have been replaced by small plots with crop rotation, organic composting, crop interplanting, use of bio pesticides and oxen instead of tractors. The results have been remarkable. Urban farms provide more than 70% of all the fresh vegetables consumed in cities such as Havana and Villa Clara.

We can do this too!

So, what is stopping us?

Capitalism's fundamental contradiction with nature

- **Perpetual economic growth of capitalism**
- **Finite limits of the planet**



Global carbon dioxide emissions by fuel type (coal, oil and natural gas) plus emissions from cement production and flaring. Brackets show average annual growth rate for 2013 to 2018. Units are in metric gigatons. (Image credit: Jackson, et al. 2019 Environ Res Lett; https://doi.org/10.1088/1748-9326/ab57b3)

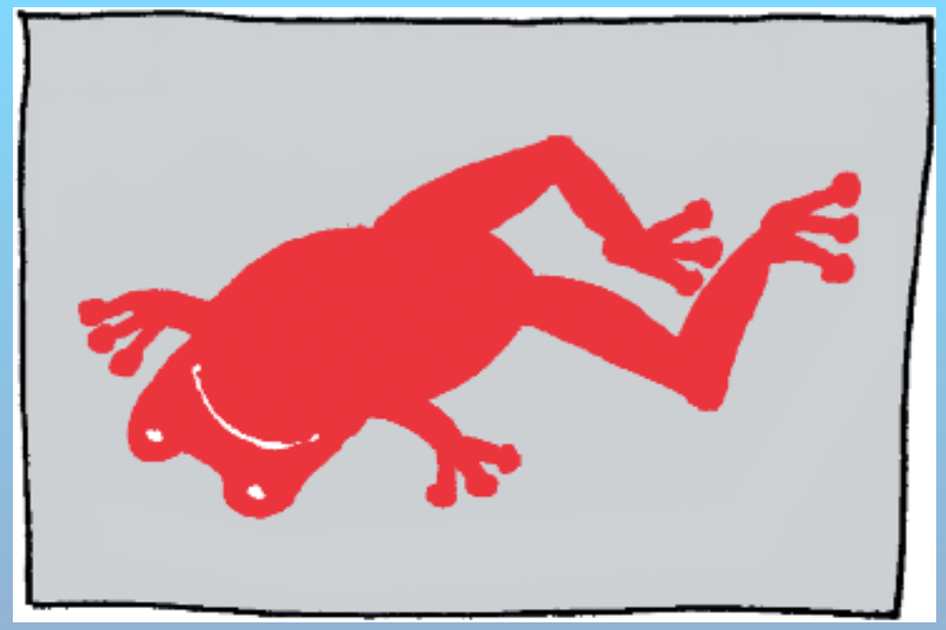
Planetary Limits

The World Wildlife Fund reported in 2018:

Humanity uses the equivalent of 1.7 Earths to provide the natural resources we use, and absorb our waste. It now takes the Earth one year and six months to regenerate what we use in a year.

We use more ecological resources than nature can regenerate because of overfishing, deforestation, and GHG emissions into the atmosphere.

Vanishing Biosphere



One million species at risk of extinction, 2019 UN report warns

Based on a review of about 15,000 scientific and government sources and compiled by 145 expert authors from 50 countries, the global report is the first comprehensive look in 15 years at the state of the planet's biodiversity.