Geo 873 – 001: Seminar in Human-Environment Geography

12:40 am – 3:30 pm; Geo 120

Global [Climate] Change: Today and Tomorrow

Reading Materials

1) AR6 report video, IPCC, 3/20/2023 (https://www.youtube.com/watch?v=5vJJTE9V7EA)
2) 10 Big Findings from the 2023 IPCC Report on Climate Change (https://www.wri.org/insights/2023-ipcc-ar6-synthesis-report-climate-change-findings)
3) IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press. (as a reference, not required to read this 3949-page document)

Homework 3: Based the lectures, reading materials and your knowledge (from your own research) on global climate change and impacts, select a topic of own interest and provide your vision on the research needs for addressing 1-2 major challenges in global climate changes.

Due: 5:00 pm, 4/3/2023

Mar 22-29, 2023

GEO873-001, MSU

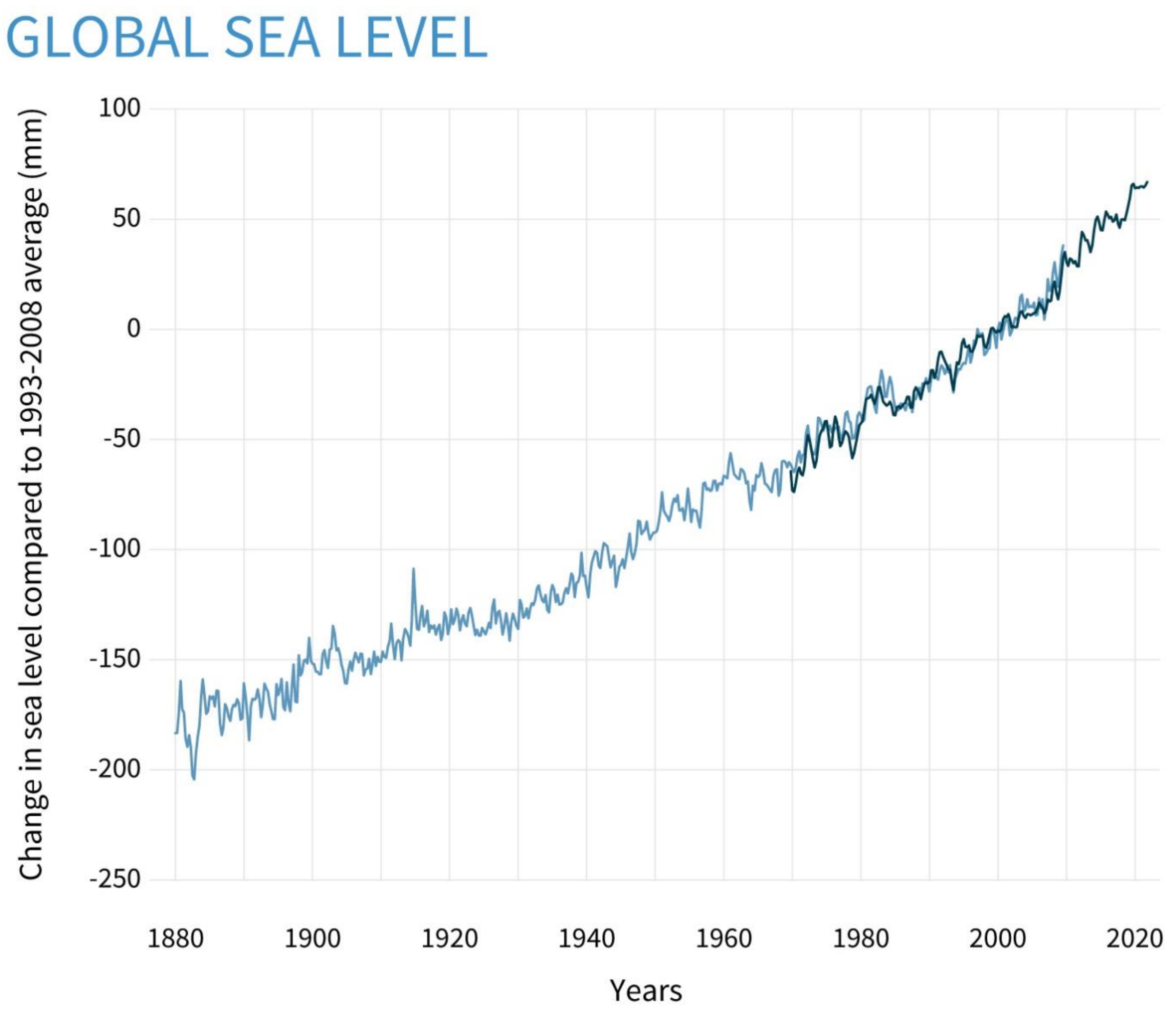
https://www.wri.org/insights/2023-ipcc-ar6-synthesis-report-climate-change-findings

https://www.youtube.com/watch?v=5vJJTE9V7EA

GEO 873: Global Change: Today and Tomorrow

Jiquan Chen

https://youtu.be/aneFRsbMRzg?t=11



Climate Change & Seas

- **Sea Level Rise**
- **Severe Storms**
- **Changing Currents**
- **Shrinking Ice Cover (polar bears)**
- **Bleaching Effect (loss of coral reef)**
- **Hotter Sands**
- **…**

Reading: **10 Big Findings from the 2023 IPCC Report on Climate Change**
AR6 updating

https://climate.nasa.gov/vital-signs/sea-level/

Climate Change: Global Sea Level

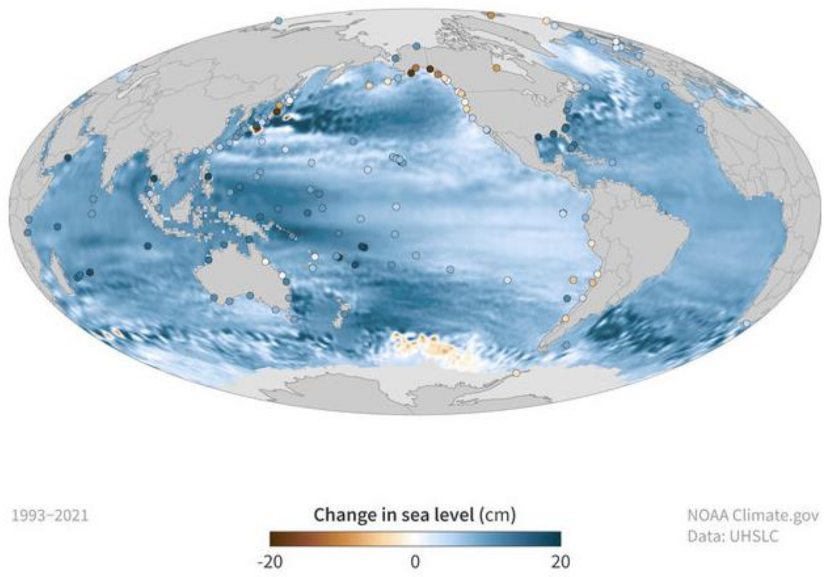
(https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level#:~:text=Global%20average%20sea%20level%20has,3.8%20inches)%20above%201993%20levels.)

HIGHLIGHTS

- Global average sea level has risen 8–9 inches (21–24 cm) since 1880.
- In 2022, global sea level set a new record high—96.7 mm above 1993 levels.
- The rate of global sea level rise is accelerating: it has more than doubled from 0.06 inches (1.4 mm) per year throughout most of the twentieth century to 0.14 inches (3.6 mm) per year from 2006–2015.
- In many locations along the U.S. coastline, the rate of local sea level rise is greater than the global average due to land processes like erosion, oil and groundwater pumping, and subsidence.
- High-tide flooding is now 300% to more than 900% more frequent than it was 50 years ago.
- If we are able to significantly reduce greenhouse gas emissions, U.S. sea level in 2100 is projected to be around 0.6 m (2 ft) higher on average than it was in 2000.
- On a pathway with high greenhouse gas emissions and rapid ice sheet collapse, models project that average sea level rise for the contiguous United States could be 2.2 m (7.2 ft) by 2100 and 3.9 m (13 ft) by 2150.

Amid some variations across the globe!

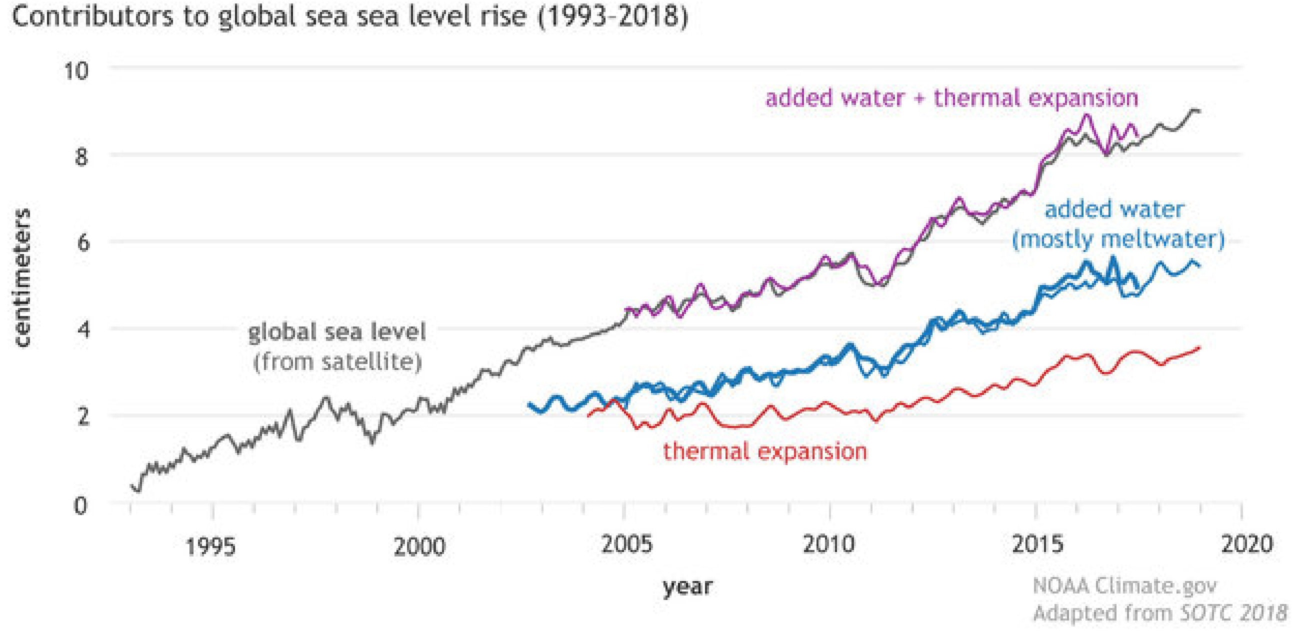
SEA LEVEL CHANGE (1993-2021)



Between 1993 and 2021 mean sea level has risen across most of the world ocean (blue colors). In some ocean basins, sea level has risen 6-8 inches (15-20 centimeters). Rates of *local* sea level (dots) on the coast can be larger than the global average due to geological processes like ground settling or smaller than the global average due to processes like the centuries-long rebound of land masses from the loss of ice-age glaciers. Map by NOAA Climate.gov based on data provided by Philip Thompson, University of Hawaii.

What's causing sea level to rise?

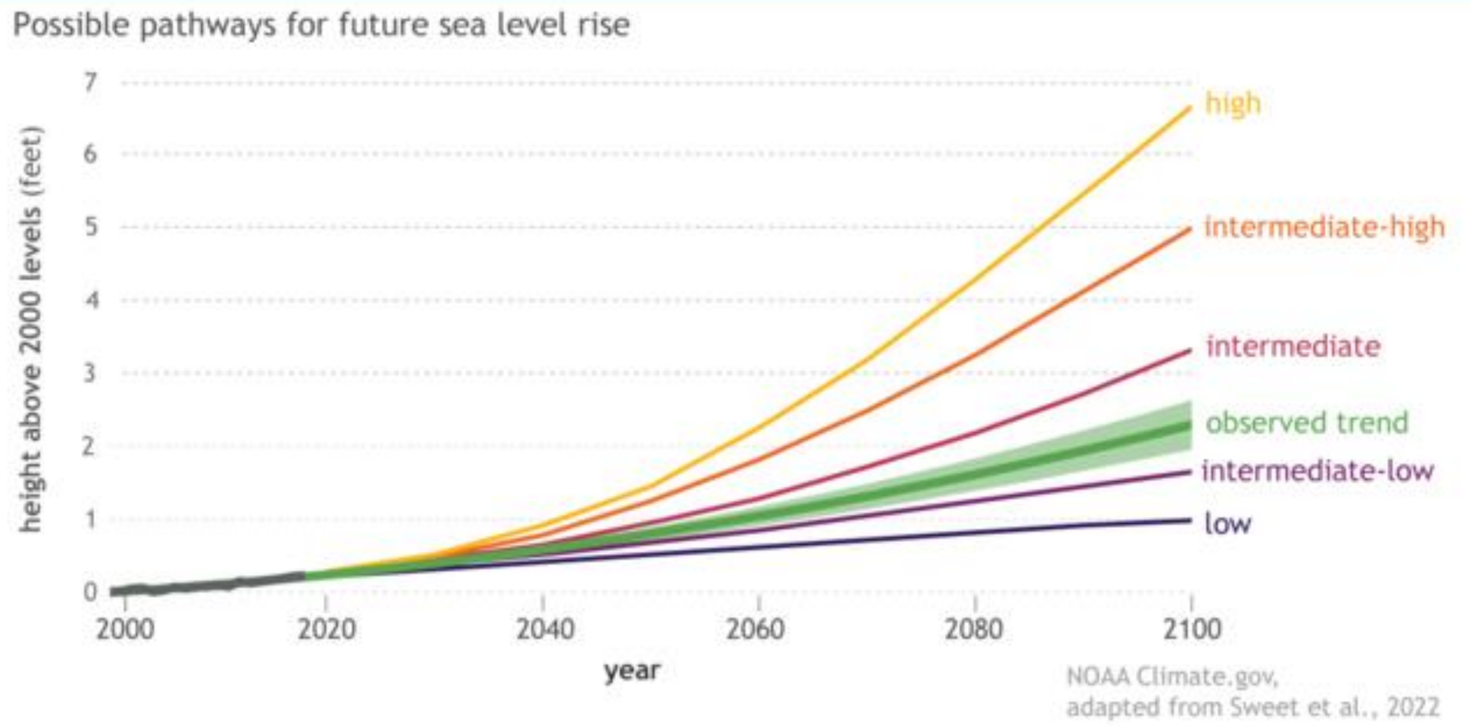
Global warming is causing global mean sea level to rise in two ways. First, glaciers and ice sheets worldwide [are melting](#) and adding water to the ocean. Second, the volume of the ocean is expanding as the water warms. A third, much smaller contributor to sea level rise is a decline in the amount of liquid water on land—aquifers, lakes and reservoirs, rivers, soil moisture. This shift of liquid water from land to ocean is largely due to groundwater pumping.



Observed sea level since the start of the satellite altimeter record in 1993 (black line), plus independent estimates of the different contributions to sea level rise: thermal expansion (red) and added water, mostly due to glacier melt (blue). Added together (purple line), these separate estimates match the observed sea level very well. NOAA Climate.gov graphic, adapted from Figure 3.15a in *State of the Climate in 2018*.

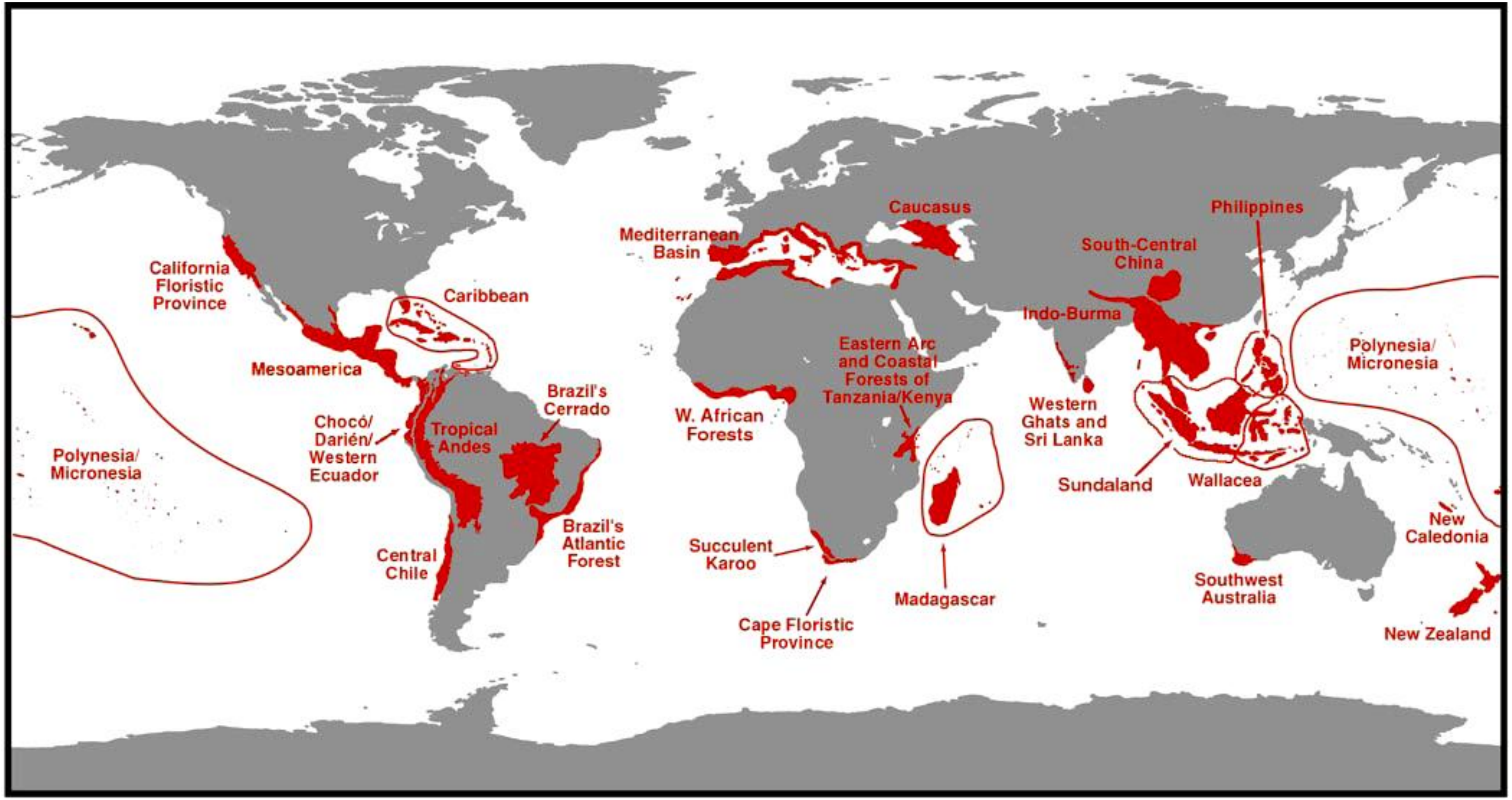
Future sea level rise

As global temperatures continue to warm, additional sea level rise is inevitable. How much and by when depends mostly on the future rate of greenhouse gas emissions. But another source of uncertainty is whether big ice sheets in Antarctica and Greenland will melt in a steady, predictable way as the Earth gets warmer, or whether they will reach a tipping point and rapidly collapse.



Observed sea level from 2000-2018, with future sea level through 2100 for six future pathways (colored lines) The pathways differ based on future rates of greenhouse gas emissions and global warming and differences in the plausible rates of glacier and ice sheet loss. NOAA Climate.gov graph, adapted from Sweet et al., 2022.

The 25 hotspots, most in coastal areas that will be hit first by the rising seas



Myers *et al*. 2000

Temperature-Dependent Sex Determination -- TSD

https://oceanservice.noaa.gov/facts/temperature-dependent.html

What causes a sea turtle to be born male or female?

Most turtles are subject to **temperature-dependent sex determination**.

A Green turtle hatchling heads to sea in the northwest Hawaiian islands. Credit: Mark Sullivan, NOAA Permit 10137-07

In most species, gender is determined during fertilization. However, the sex of most turtles, alligators, and crocodiles is determined after fertilization. The temperature of the developing eggs is what decides whether the offspring will be male or female. This is called temperature-dependent sex determination, or TSD.

Research shows that if a turtle's eggs incubate below 27.7° Celsius (81.86° Fahrenheit), the turtle hatchlings will be male. If the eggs incubate above 31° Celsius (88.8° Fahrenheit), however, the hatchlings will be female. Temperatures that fluctuate between the two extremes will produce a mix of male and female baby turtles.

Researchers have also noted that the warmer the sand, the higher the ratio of female turtles. As the Earth experiences climate change, increased temperatures could result in skewed and even lethal incubation conditions, which would impact turtle species and other reptiles.

Did you know?

Current research suggests that warming trends due to climate change may result in more female turtles being born!

More Information

How do sea turtles hatch? (video)

What do you know about the sea turtle?

What makes the green turtle...green?

What is the largest sea turtle?

Sea turtles: NOAA Fisheries resources

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search

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Brief History:

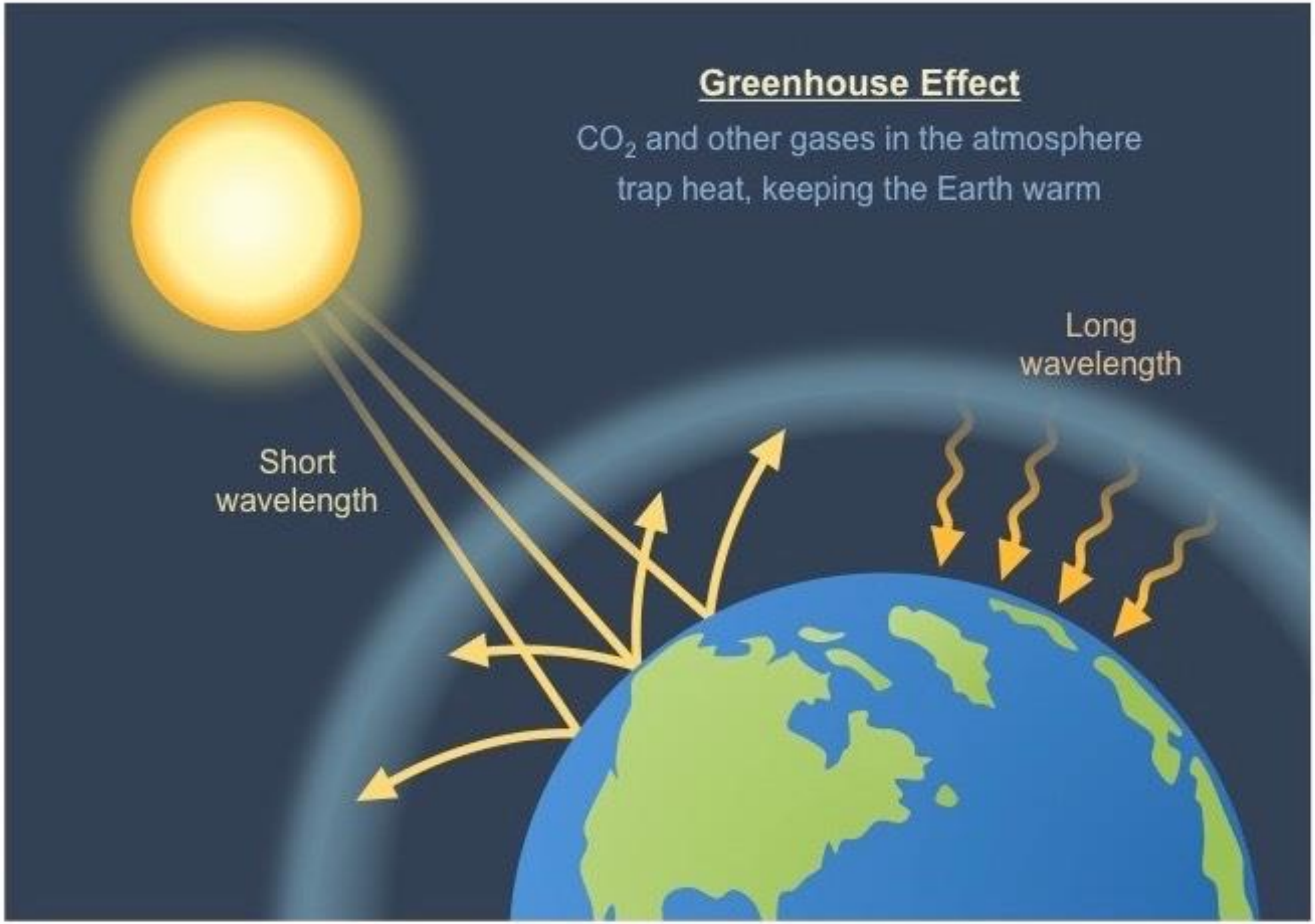
In 1896 Swedish scholar Svante Arrhenius concluded that fossil fuel combustion may eventually result in enhanced global warming. He predicted that a doubling of CO_2 concentration would lead to a 5 ^{o}C increase in global temperature. His warning was mostly ignored until the late 1950s.

Roger R.D. Revelle and other pioneering scholars started scientific investigations on anthropogenic influences on global warming (see more detailed history in Archer & Pierrehumbert 2011). However, they hypothesized that oceans would absorb all the CO_2.

In late 1980s, there was a general hypothesis that terrestrial ecosystems can be managed effectively to reduce GHG to slow down global warming.

Since 1990s, IPCC and other organizations have been calling for reductions in greenhouse gases (GHG).

Why is temperature increasing?



https://ib.bioninja.com.au/standard-level/topic-4-ecology/44-climate-change/greenhouse-effect.html

Blackbody Theory

Any object with a temperature higher than absolute zero (-273.15 ^{o}C) emits energy.

Stefan–Boltzmann Law

The total energy (E) radiated from an object is proportional to the 4th power of its temperature (T), with σ as the emissivity (i.e., Stefan–Boltzmann constant):

$$E = \sigma \cdot T^4$$

Grey Body: actual emissivity

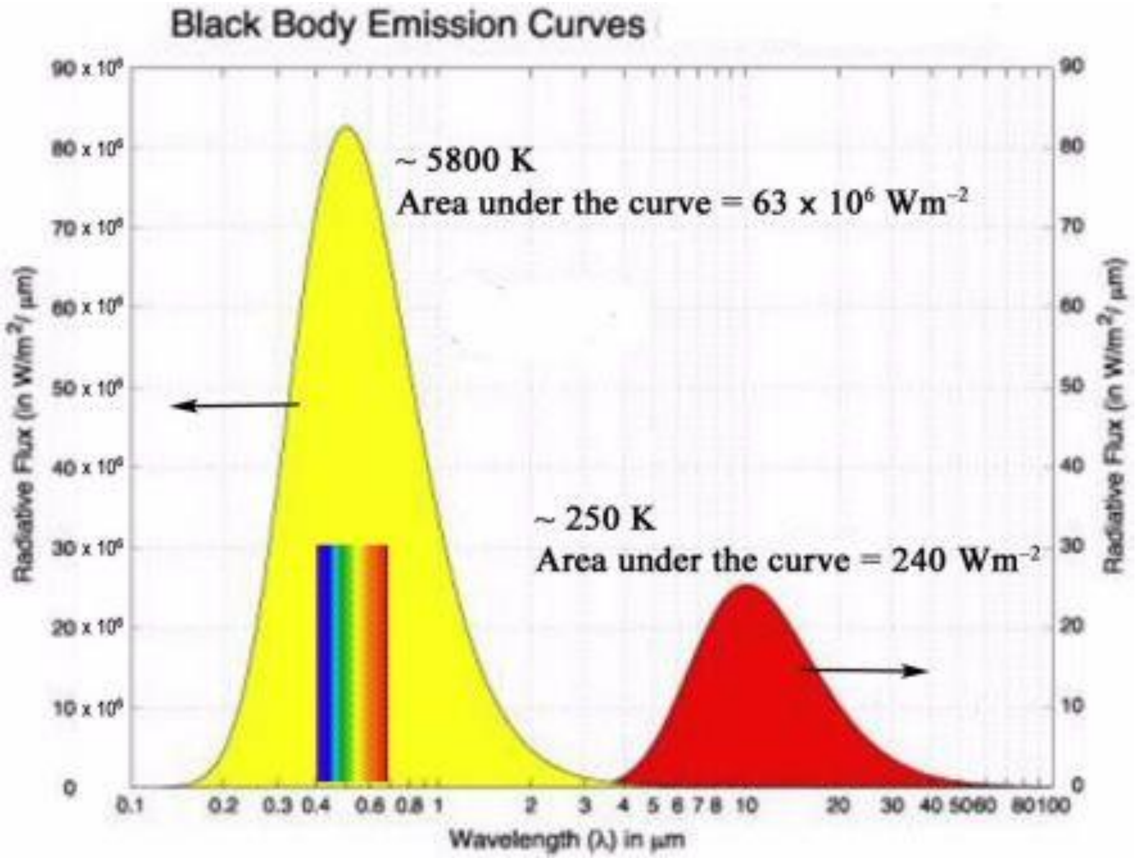
$$E = \varepsilon \cdot \sigma \cdot T^4$$

The energy is transported through photons at the speed of light (c = 3 x 10^{10} m s^{-1}) and behave as particles and waves. This is described by **Plank's Law:**

$$E = \frac{h \cdot c}{\lambda}$$

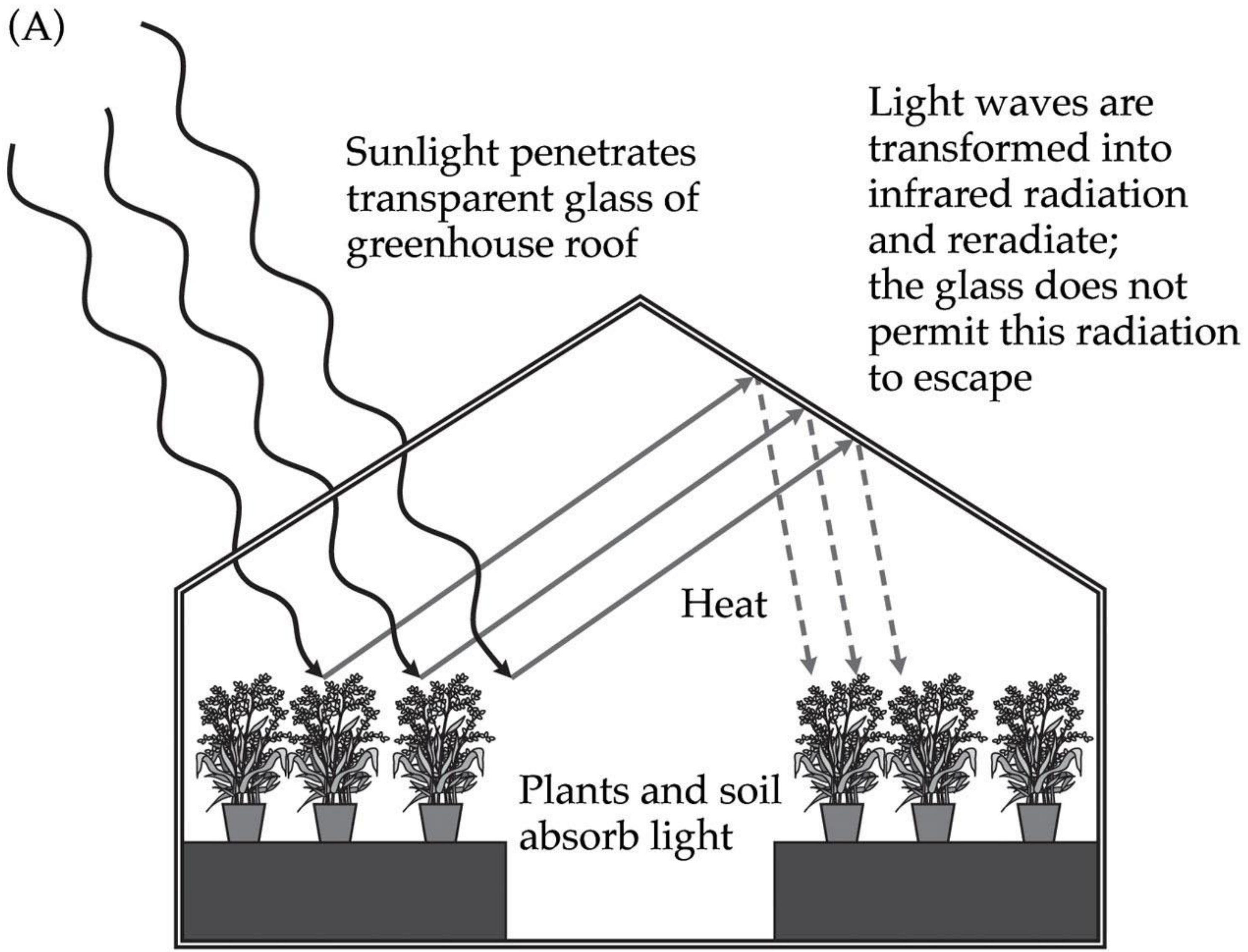
1) Radiant emittance from the sun (T = 6000 ºK) varies from 0.2 nm to 3.0 nm and peaks at spectra of ~0.55 nm, with most energy coming from a wavelength of 0.3-0.7 nm (>50%). These wavelengths are loosely called "shortwave radiation" or "visible light").

2) The Earth's (T = 288 ºK) peak emittance is 9.5-10.0 nm. In sum, Earth's temperature is mostly maintained by the balance of incoming shortwave radiation from the sun and outgoing longwave radiation from the Earth.

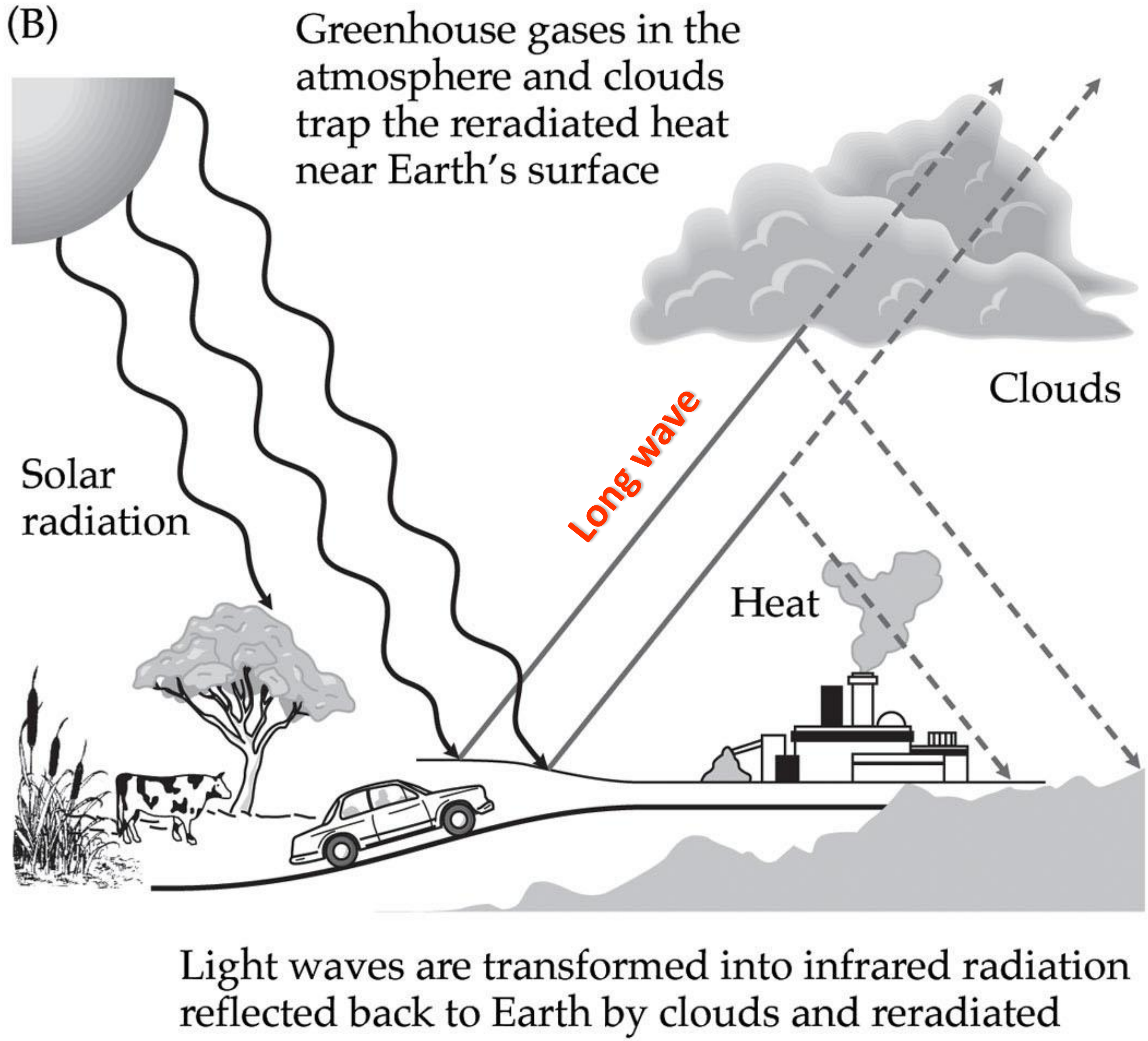


https://www.pinterest.com/pin/561964859722645297/

Nature of Climate Change

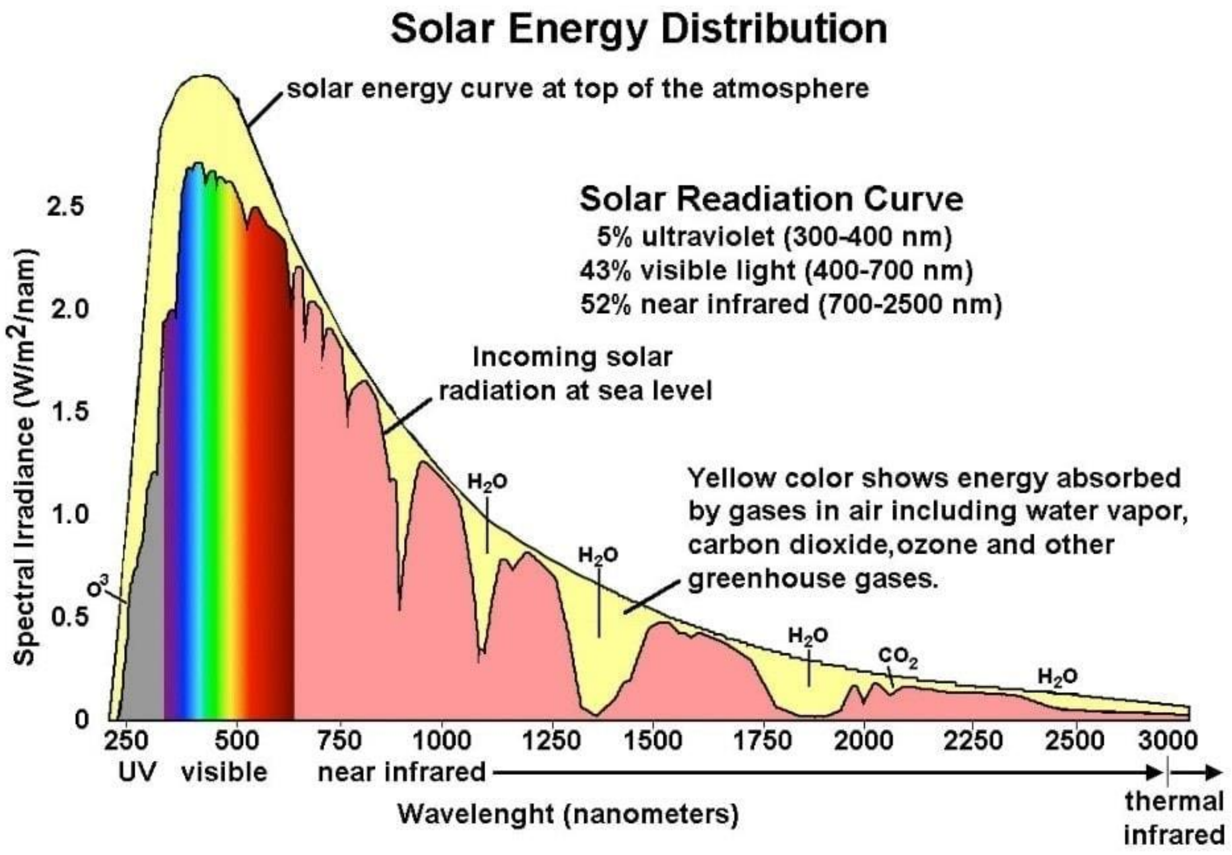


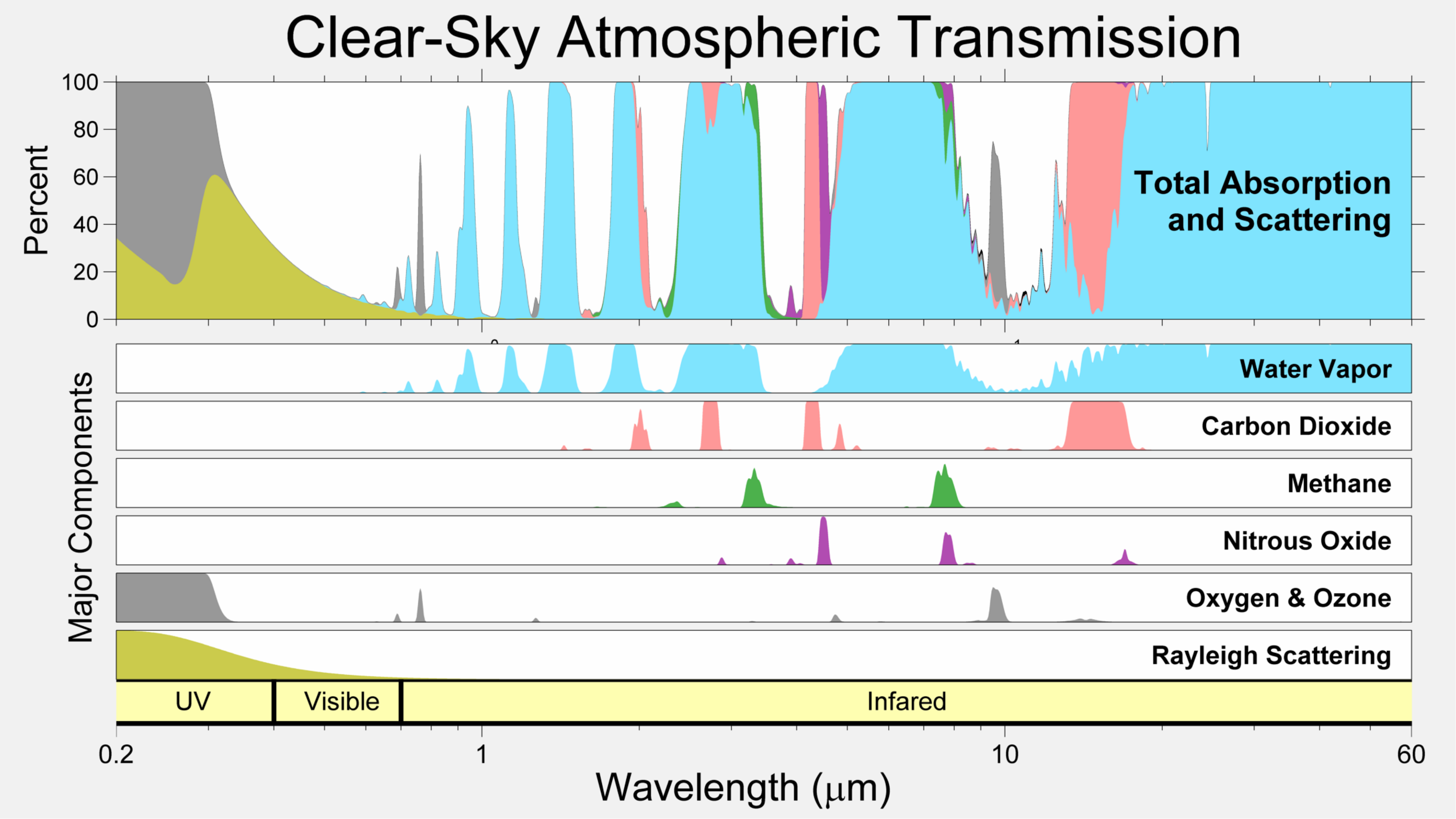
PRINCIPLES OF CONSERVATION BIOLOGY, Third Edition, Figure 10.1 (Part 1)



PRINCIPLES OF CONSERVATION BIOLOGY, Third Edition, Figure 10.1 (Part 2) © 2005 Sinauer Associates, Inc.

- Earth's atmosphere is composed of many gases and particles. Nitrogen (~78%) and oxygen (~21%) are the two major chemical species. Other species, including water, argon, carbon dioxide, neon, helium, methane, krypton, hydrogen, nitrous oxide, xenon, ozone, carbon monoxide, and ammonia, account for <1%.
- The atmosphere also contains a large amount of particulate matters and biological materials that can affect the energy balance of the Earth. For example, an increase in the amount of aerosol deposition on snow and glacier surfaces will reduce and, consequently, keep more energy within the Earth system. Volcanic eruptions, large-scale fires, and industrial production are major sources of aerosols at global scale.




Clear-Sky Atmospheric Transmission
Percent
100
80
60
40
20
0
Total Absorption and Scattering
Major Components
Water Vapor
Carbon Dioxide
Methane
Nitrous Oxide
Oxygen & Ozone
Rayleigh Scattering
UV
Visible
Infared
0.2
1
10
60
Wavelength (μm)

Chen, J. 2020

Some greenhouse gases such as carbon dioxide occur naturally and are emitted to the atmosphere through natural processes and human activities. Other greenhouse gases (e.g., fluorinated gases) are created and emitted solely through human activities. The principal greenhouse gases that enter the atmosphere because of human activities are:

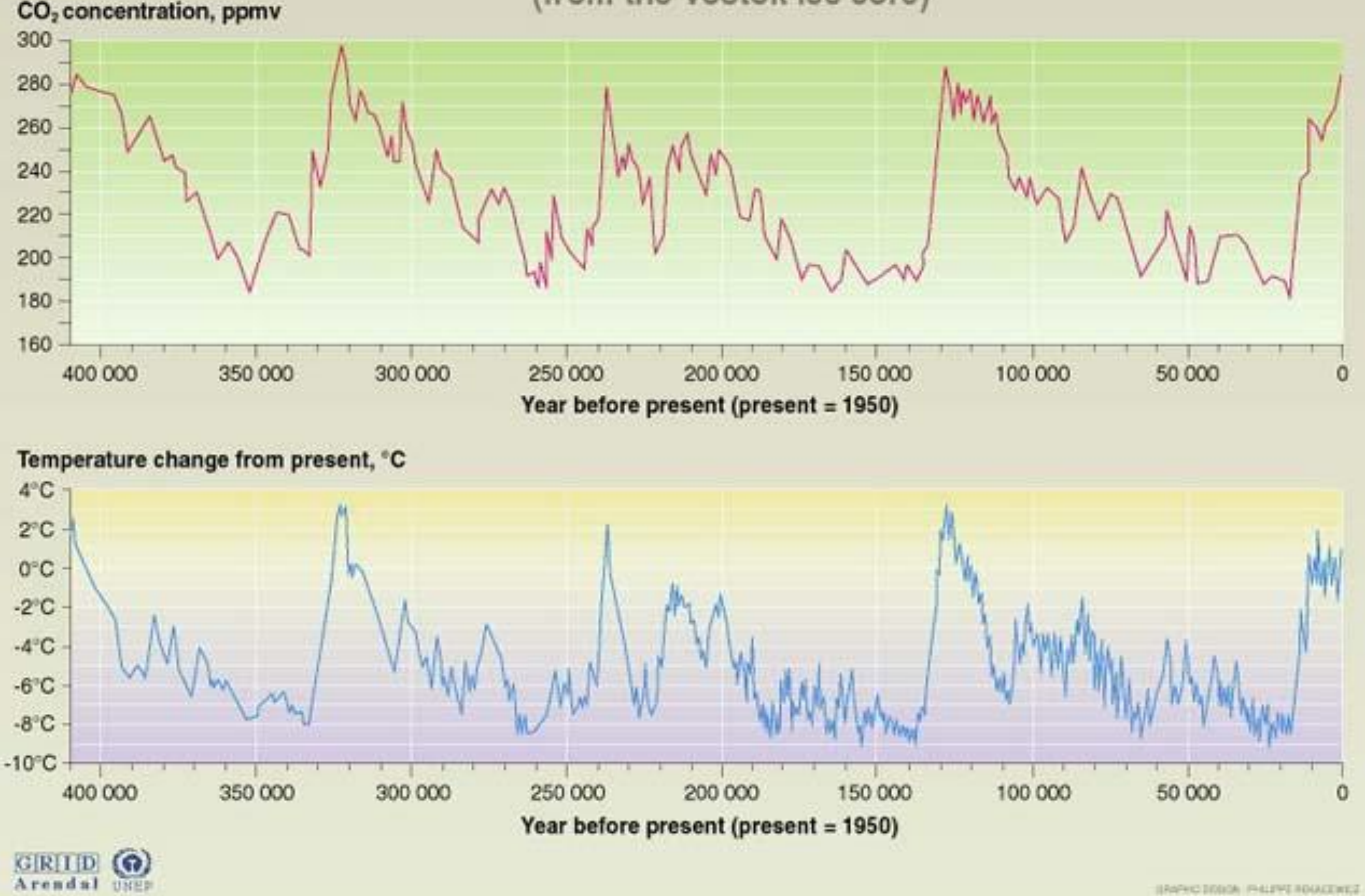
- **Carbon Dioxide (CO_2)**: CO_2 enters the atmosphere through the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees and wood products, and also as a result of other chemical reactions (e.g., manufacture of cement). CO_2 is also removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle.
- **Methane (CH_4)**: Methane is emitted during the production and transport of coal, natural gas, and oil. CH_4 emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills.
- **Nitrous Oxide (N_2O)**: Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.
- **Fluorinated Gases**: Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone-depleting substances (i.e., CFCs, HCFCs, and halons). These gases are typically emitted in smaller quantities, but because they are potent greenhouse gases, they are sometimes referred to as High Global Warming Potential gases ("High GWP gases").

GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases. Other than H_2O, these are the major greenhouse gases (GHG):

- CO_2, by definition, has a GWP of 1 regardless of the time period used, because it is the gas being used as the reference. CO_2 remains in the climate system for a very long time: CO_2 emissions cause increases in atmospheric concentrations of CO_2 that will last thousands of years.
- Methane (CH_4) is estimated to have a GWP of 28–36 over 100 years (Learn why EPA's U.S. Inventory of Greenhouse Gas Emissions and Sinks uses a different value.). CH_4 emitted today lasts about a decade on average, which is much less time than CO_2. But CH_4 also absorbs much more energy than CO_2. The net effect of the shorter lifetime and higher energy absorption is reflected in the GWP. The CH_4 GWP also accounts for some indirect effects, such as the fact that CH_4 is a precursor to ozone, and ozone is itself a GHG.
- Nitrous Oxide (N_2O) has a GWP 265–298 times that of CO_2 for a 100-year timescale. N_2O emitted today remains in the atmosphere for more than 100 years, on average.
- Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are sometimes called high-GWP gases because, for a given amount of mass, they trap substantially more heat than CO_2. (The GWPs for these gases can be in the thousands or tens of thousands.)

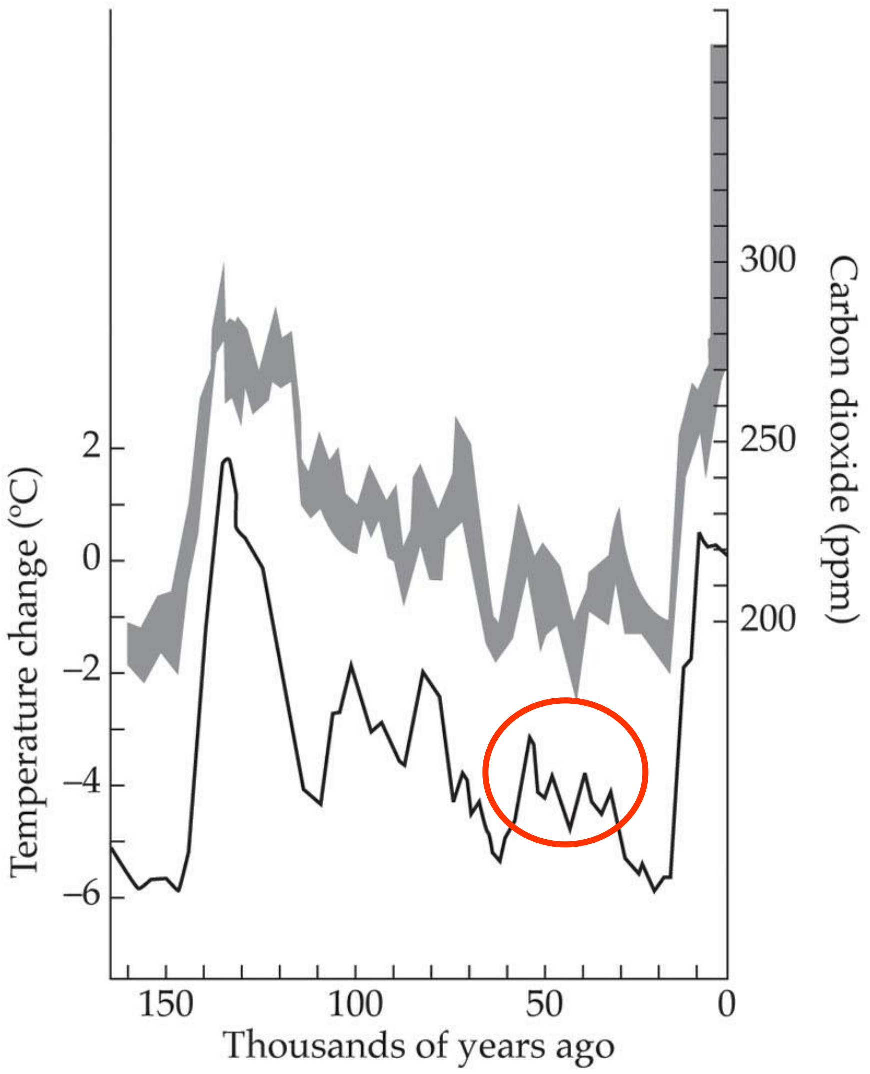
https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

Temperature and CO_2 concentration in the atmosphere over the past 400 000 years (from the Vostok ice core)



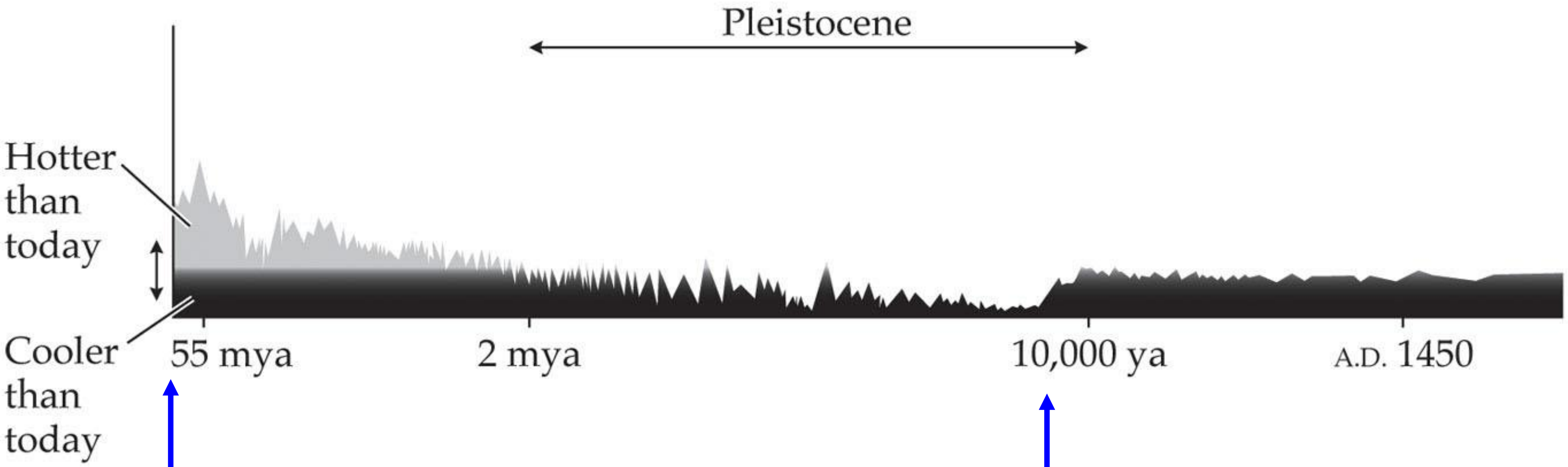
Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3June), pp 429-436, 1999.

The relationship between temperature and carbon dioxide over the past 160,000 years



PRINCIPLES OF CONSERVATION BIOLOGY, Third Edition, Figure 10.3

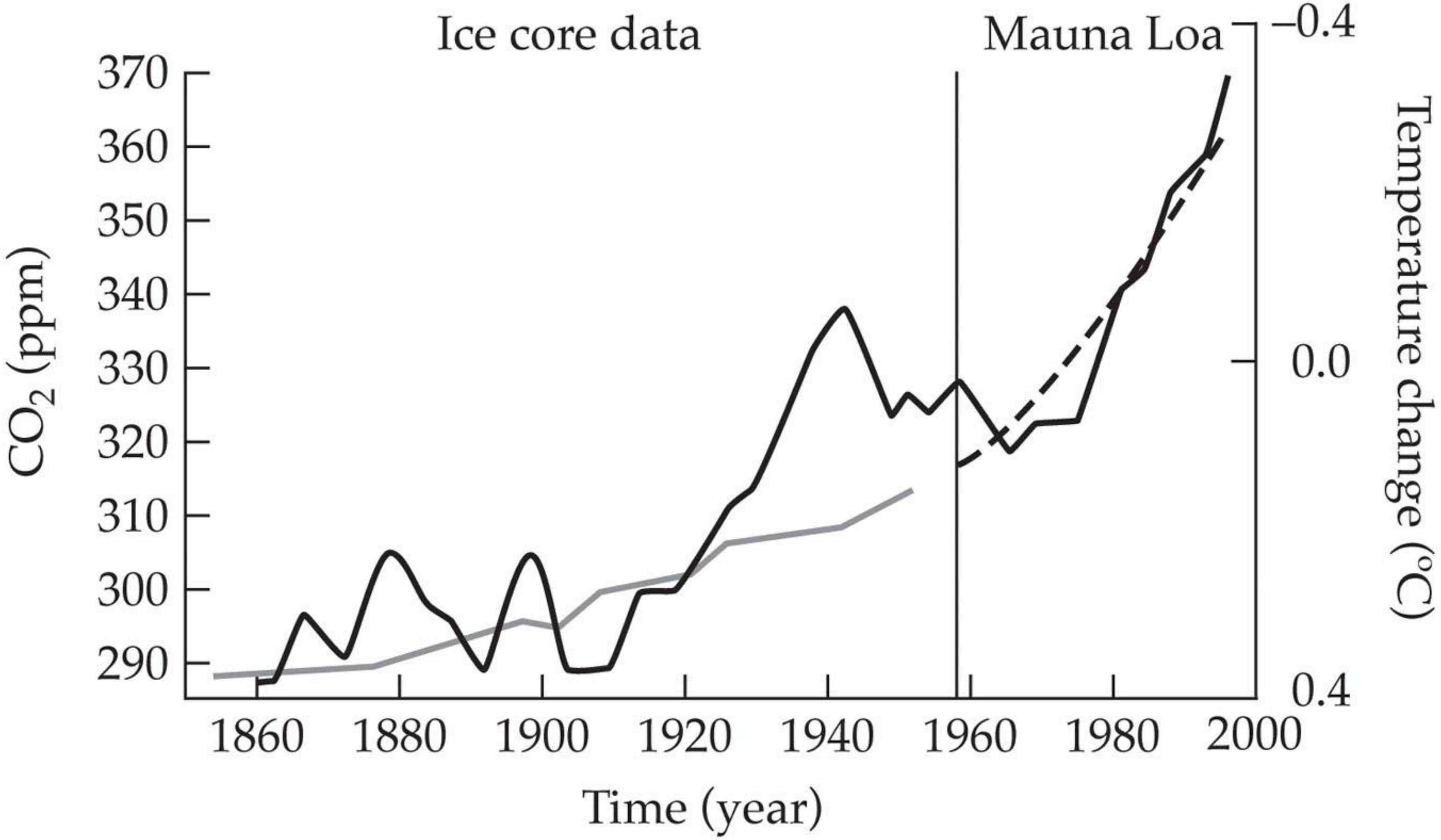
Average global temperature over the last 65 million years



Dinosaur Extinction

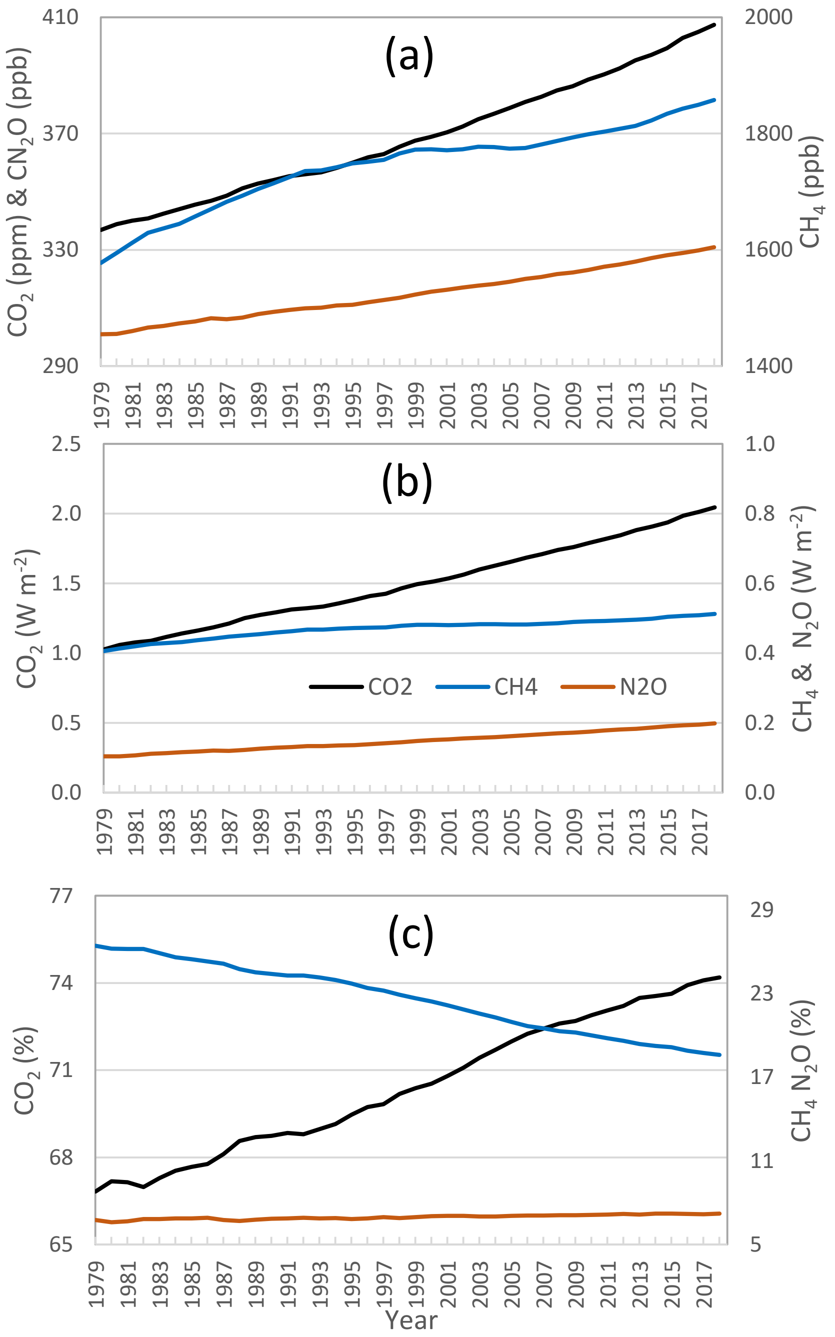
Most recent glacier

Relationship between twentieth century levels of atmospheric carbon dioxide and global temperature



5.1 Introduction

Figure 5-1. Long-term changes in three major greenhouse gas (GHG) species (CO_2, CH_4 and N_2O) concentrations (a), their radiative forcing (RF) (b), and their RF portion of the total during 1979-2018. Data source: https://www.esrl.noaa.gov/gmd/aggi/NOAA_MoleFractions_2019.csv (downloaded on 29 March 2020).

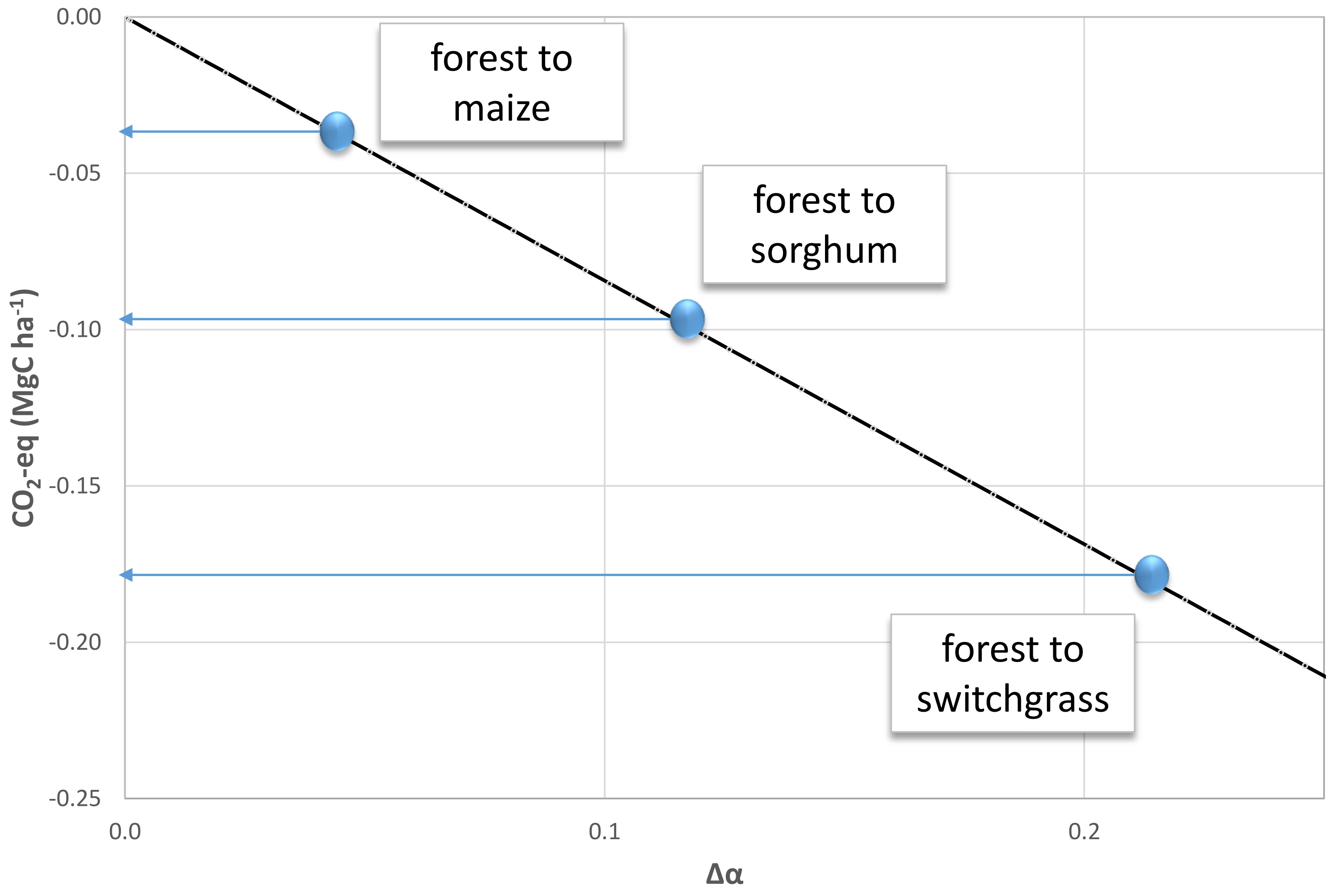


1) Another frontier in quantifying GWP of terrestrial ecosystems is resulted from the changes in albedo ($\Delta\alpha_s$) that reflect more solar radiation back to outer space (*e.g.*, lighter canopies) or keep more radiation energy within Earth systems (*e.g.*, taller and denser canopies) (Chapter 1). This is known as the radiative forcing (RF_s) of land surface.

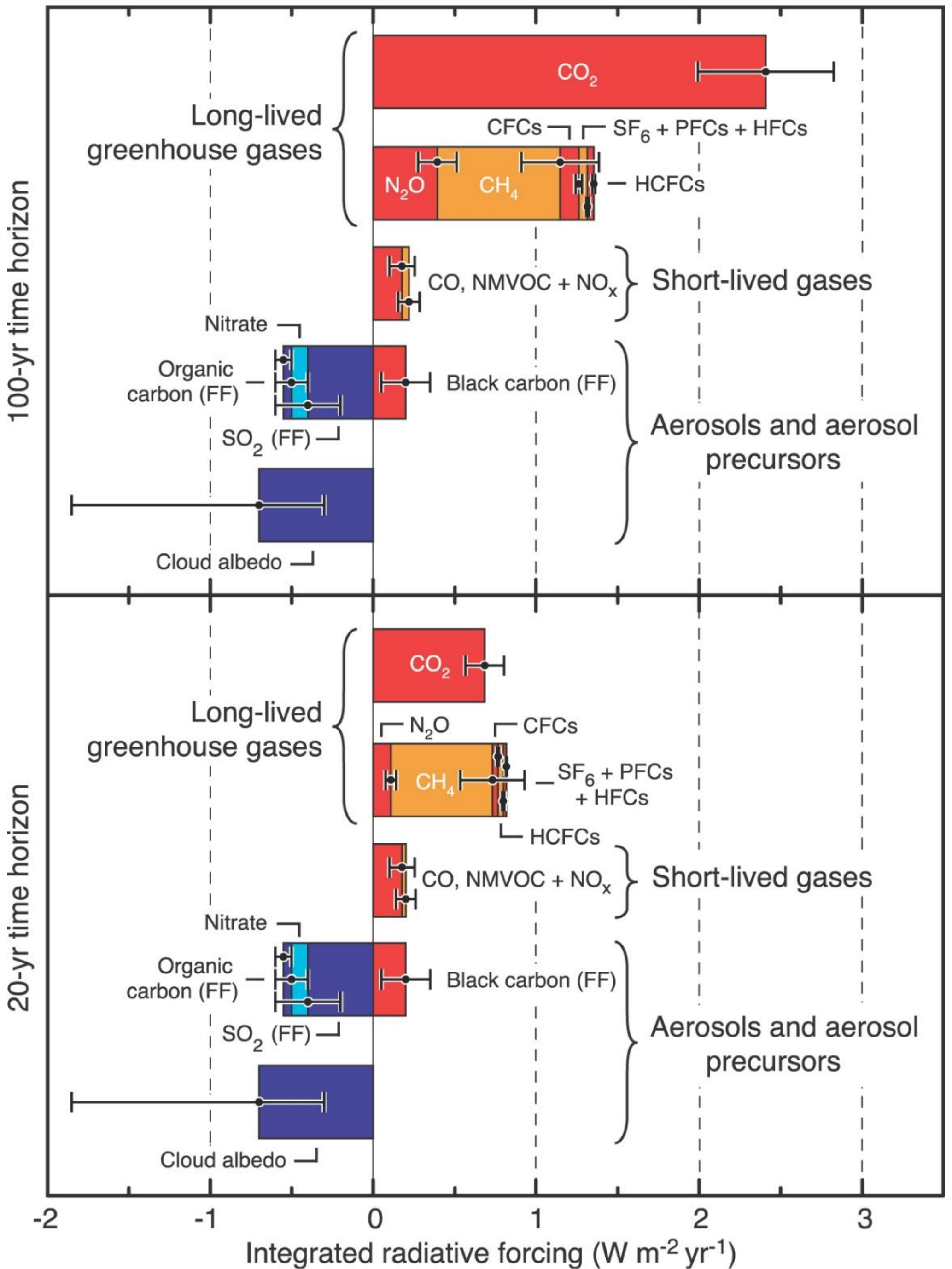
2) Imagine an area that can reflect 1% more solar radiation (*i.e.*, an increase of albedo by 1%). With an atmospheric transmission of 0.854, the total amount of solar energy that reaches the ground will be ~1170 W m^{-2} (*i.e.*, solar constant times 0.854).

3) Assuming the same transmittance for the outgoing shortwave radiation, 1% more reflection is equivalent to ~10 W m^{-2} (*i.e.*, 1170*0.854*0.01). This value is equivalent to a cooling effect of ~11 kgCO_2, or ~3 kgC m^{-2} (see Section 5.2 for conversion).

Figure 5-3. Calculated CO_2-eq due to changes in albedo (α) that can result in either warming (positive values) or cooling (negative values) when a unit of land area (ha) is converted. Three examples of land conversions are based on our field measurements of albedo at the KBS (see Section 5.3 for detailed calculations).



Integrated Radiative Forcing for Year 2000 Global Emissions
(Weighted by 100-yr and 20-yr time horizons)

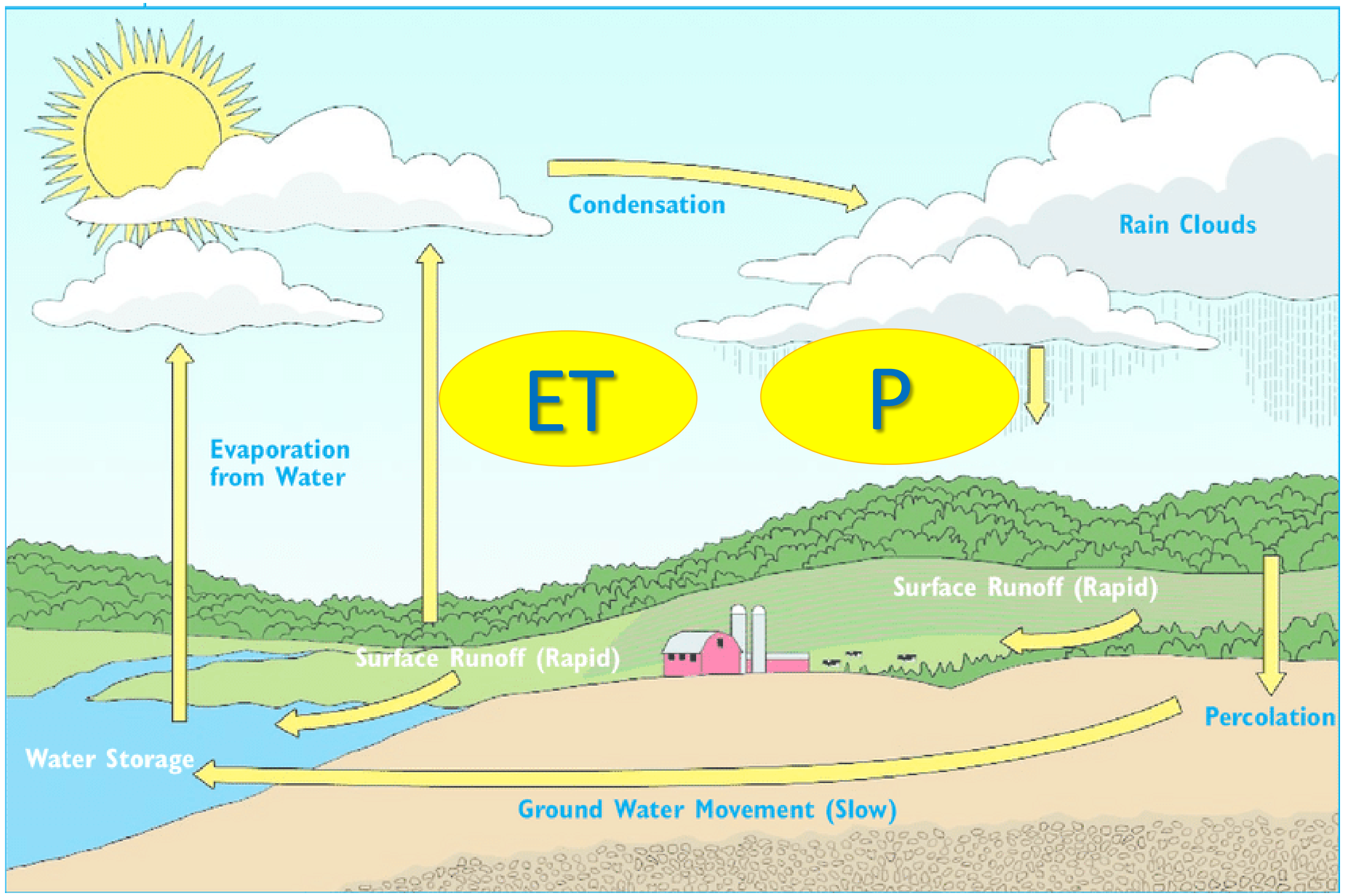


In Class exercise: download the long term changes in atmospheric GHG, Sea level, temperature, and precipitation and explore the changes. Another purpose of this exercise is to get familiar with the databases for your future research.

- CO_2, CH_4, N_2O and SF_6: https://gml.noaa.gov/ccgg/trends/data.html
- Sea Level: https://climate.nasa.gov/vital-signs/sea-level/
- Temperature and Precipitation: https://climate.nasa.gov/vital-signs/global-temperature/

A thirsty globe!

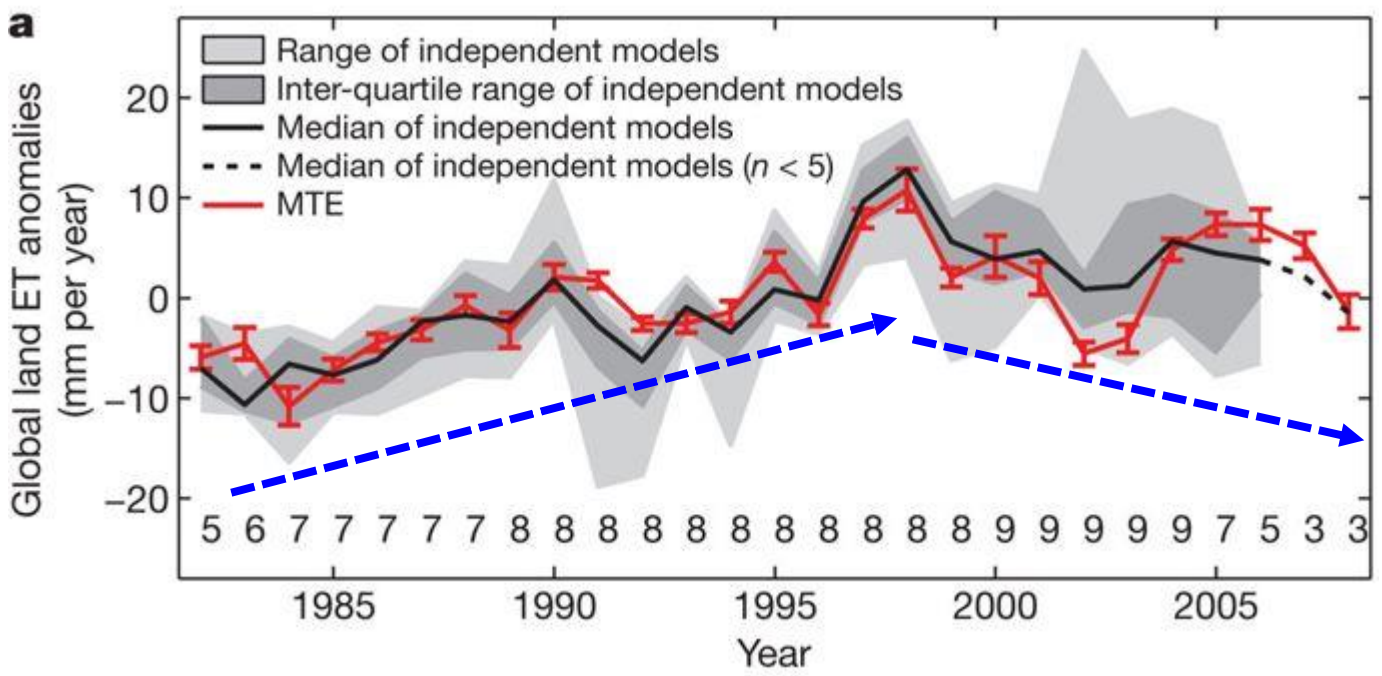
- Evapotranspiration (ET): amount of water evaporated from land surface to the atmosphere
- The total precipitation (P) across the globe remains the same over time
- Change in ET will determines the amount of water for soils, rivers and ground water



A thirsty globe!

Jung et al. 2010. Recent decline in the global land evapotranspiration trend due to limited moisture supply. Nature 467.7318: 951-954.

- Evapotranspiration (ET) has been increasing with warming climate until ~1998, but decreased since then;
- We may have more freshwater;



Unfortunately

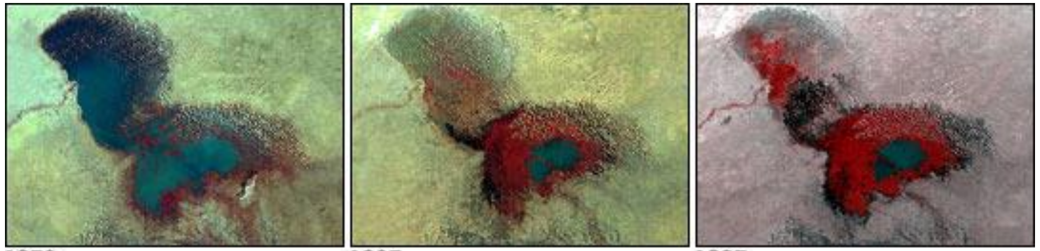
This change was driven primarily by moisture limitation in the Southern Hemisphere, particularly Africa and Australia. In these regions, soil moisture decreased from 1998 to 2008. Hence, increasing soil-moisture limitations on ET largely explain the recent decline of the global ET.

UN environment programme

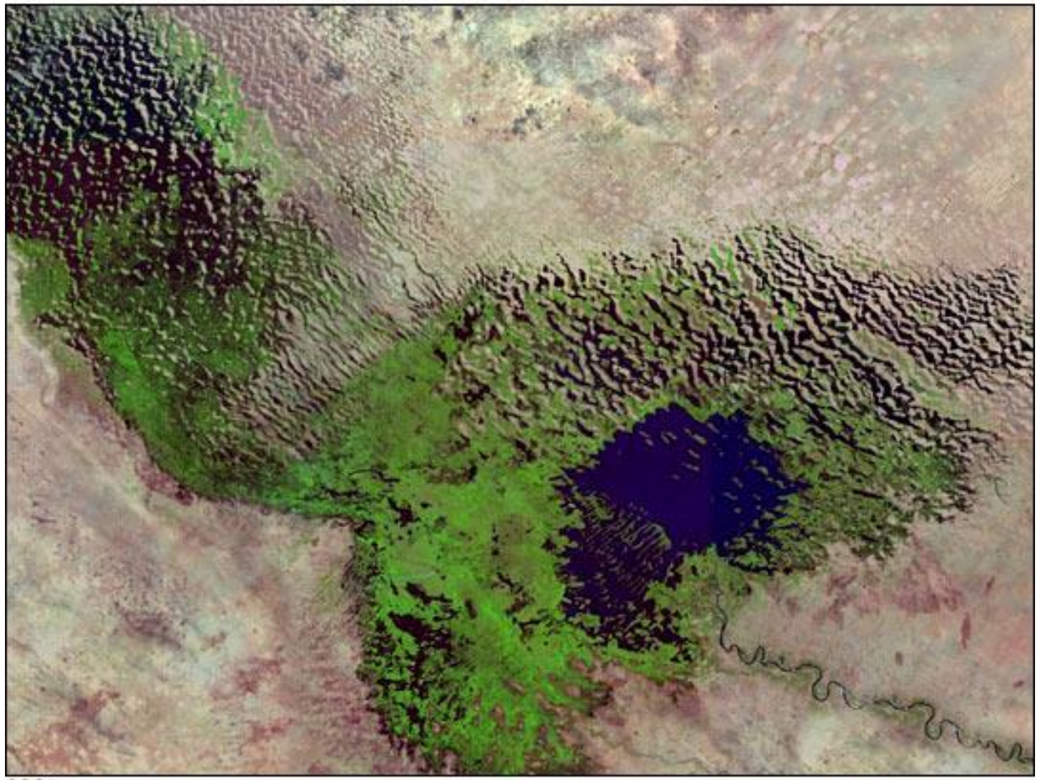
Lake Disappearance!

Lake Chad, once one of the African continent's largest bodies of fresh water, has dramatically decreased in size due to climate change and human demand for water.

- Hundreds lakes across the globes disappear each year, especially in dryland regions.
- Over the last 60 years, the lake's size has decreased by 90% as a result of over use of the water, extended drought and the impacts of climate change.
- The surface area of the lake has plummeted from 26,000 km^2 in 1963 to <1,500 km^2 today (2018) -- shrank by 20 times.



1973 1987 1997



2001

https://earthobservatory.nasa.gov/images/1240/africas-disappearing-lake-chad

List of drying lakes

From Wikipedia, the free encyclopedia

A number of lakes throughout the world are drying or completely dry due to irrigation or urban use diverting inflow.[1][2]

This list is incomplete; you can help by expanding it.

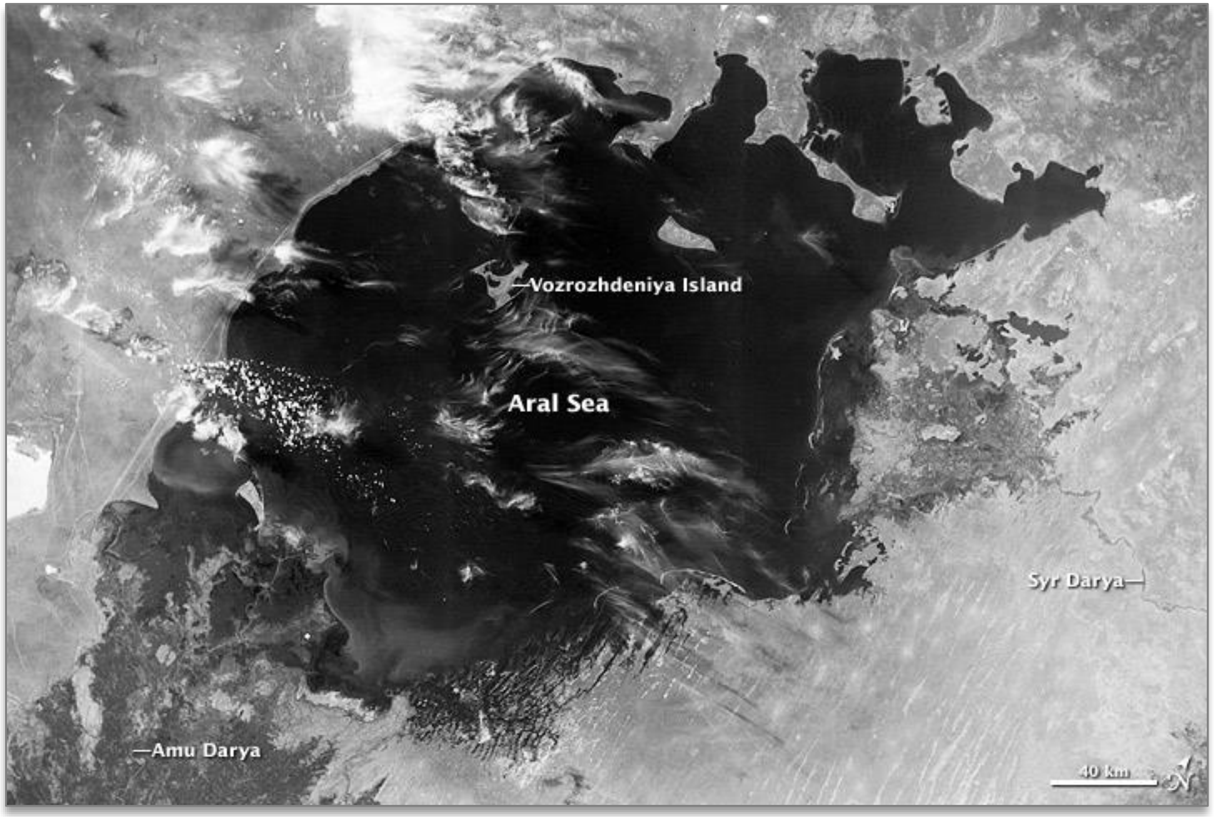
- Dead Sea in Israel, Jordan, and Palestine[3]
- Hamun Lake on the Irano-Afghan border[4]
- Salton Sea in California, U.S.[5]
- Lake Chad in Cameroon, Chad, Niger and Nigeria[6]
- Aral Sea in Kazakhstan and Uzbekistan[7]
- Tulare Lake in California, U.S.[8]
- Lake Urmia in Iran[9]
- Owens Lake in California, U.S.[10]
- Walker Lake in Nevada, U.S.[11]
- Mono Lake in California, U.S.[12]
- Fucine Lake in Italy (fully drained during the 19th century)
- Poyang Lake in Jiangxi, China[13]
- Qinghai Lake in China
- White Bear Lake in Minnesota, U.S.[14]
- Lake Meredith in Texas, U.S.[15]
- Lake Albert in South Australia[16]
- Lake Hindmarsh in Australia[17]
- Lake Poopó in Bolivia[18]
- Lake Copais, in Boeotia, Greece
- Lake George, in New South Wales, Australia[19]
- Nainital, in Uttarakhand, India[20]
- Bakhtegan Lake in Iran
- Lake Amik in Turkey
- Lake Faguibine in Mali[21]
- Lake Chapala in Mexico[22]
- Lake Mead in Nevada and Arizona, U.S.[23]

About Aral Sea

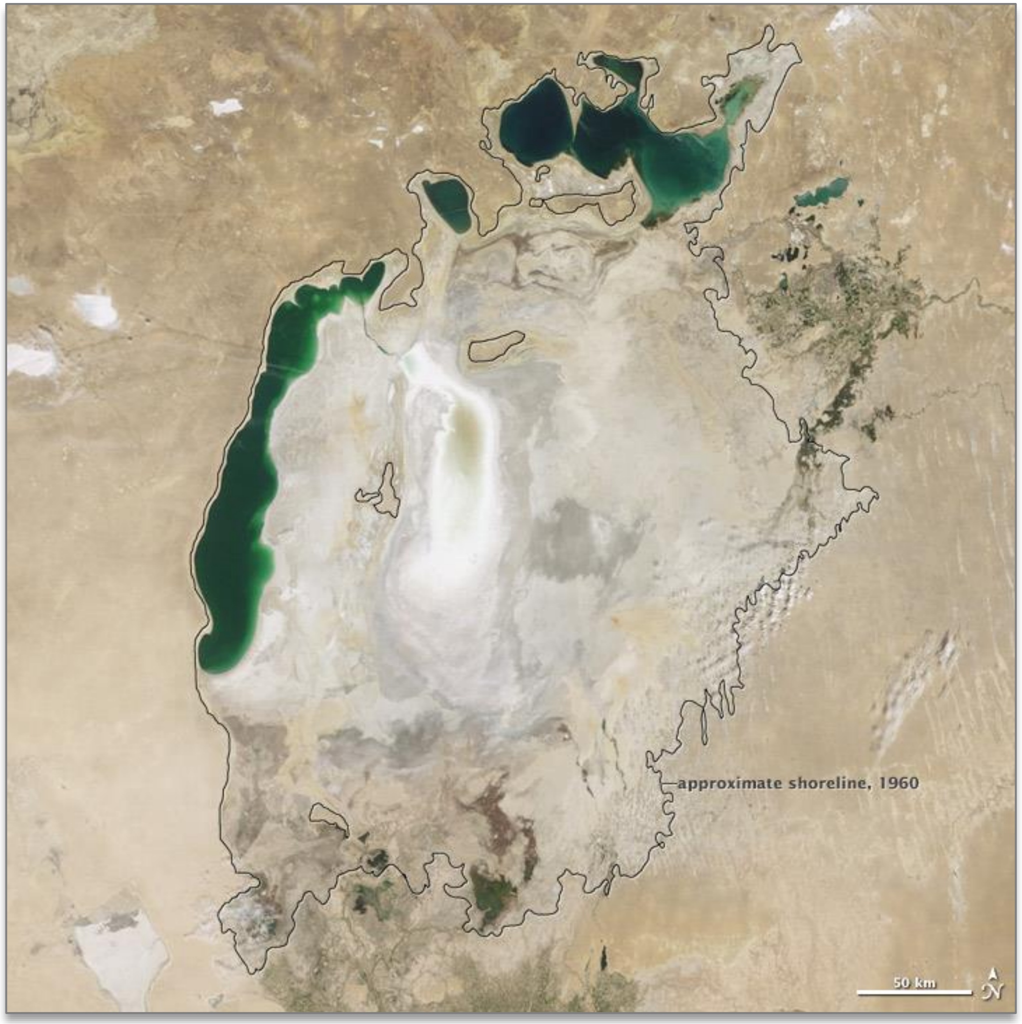
Once the fourth largest lake in the world

About the Aral Sea

1963



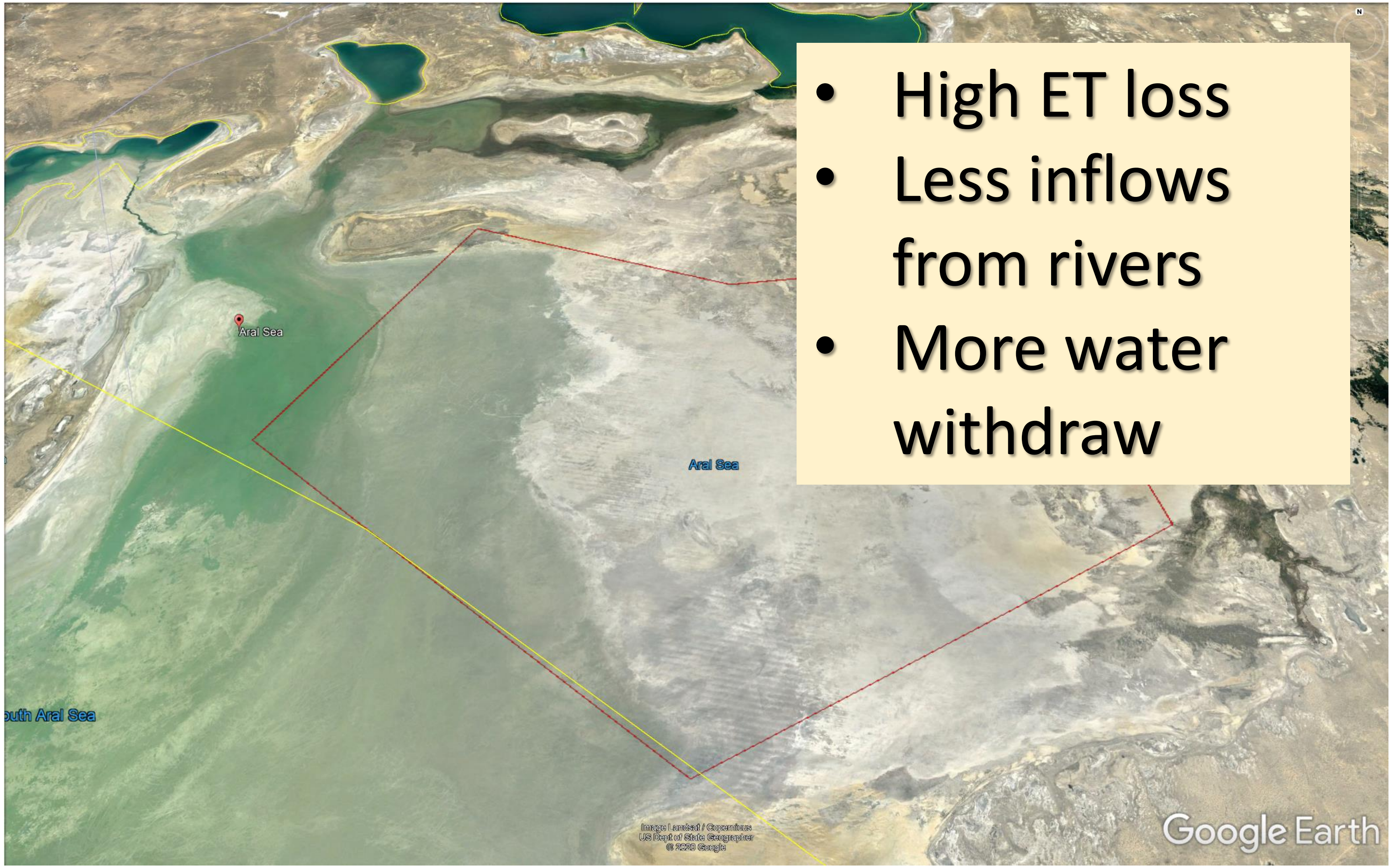
2019



What had happened?

https://youtu.be/UZwLTJroLpE

- Virgin Lands Campaign in mid-1950s for Central Asia during the Soviet time
- Here, most of regional renewable water resources are generated in the mountains where the largest regional rivers originate
- Large-scale irrigation systems have been built to increase the soil fertility to support the agriculture for the Aral Sea
- Reduced inflow and elevated evapotranspiration (ET) caused monumental shrinking of Aral Sea



- High ET loss
- Less inflows from rivers
- More water withdraw

Global Connections: Dairy production in Kazakhstan

PM Mamin holds extended meeting on livestock development

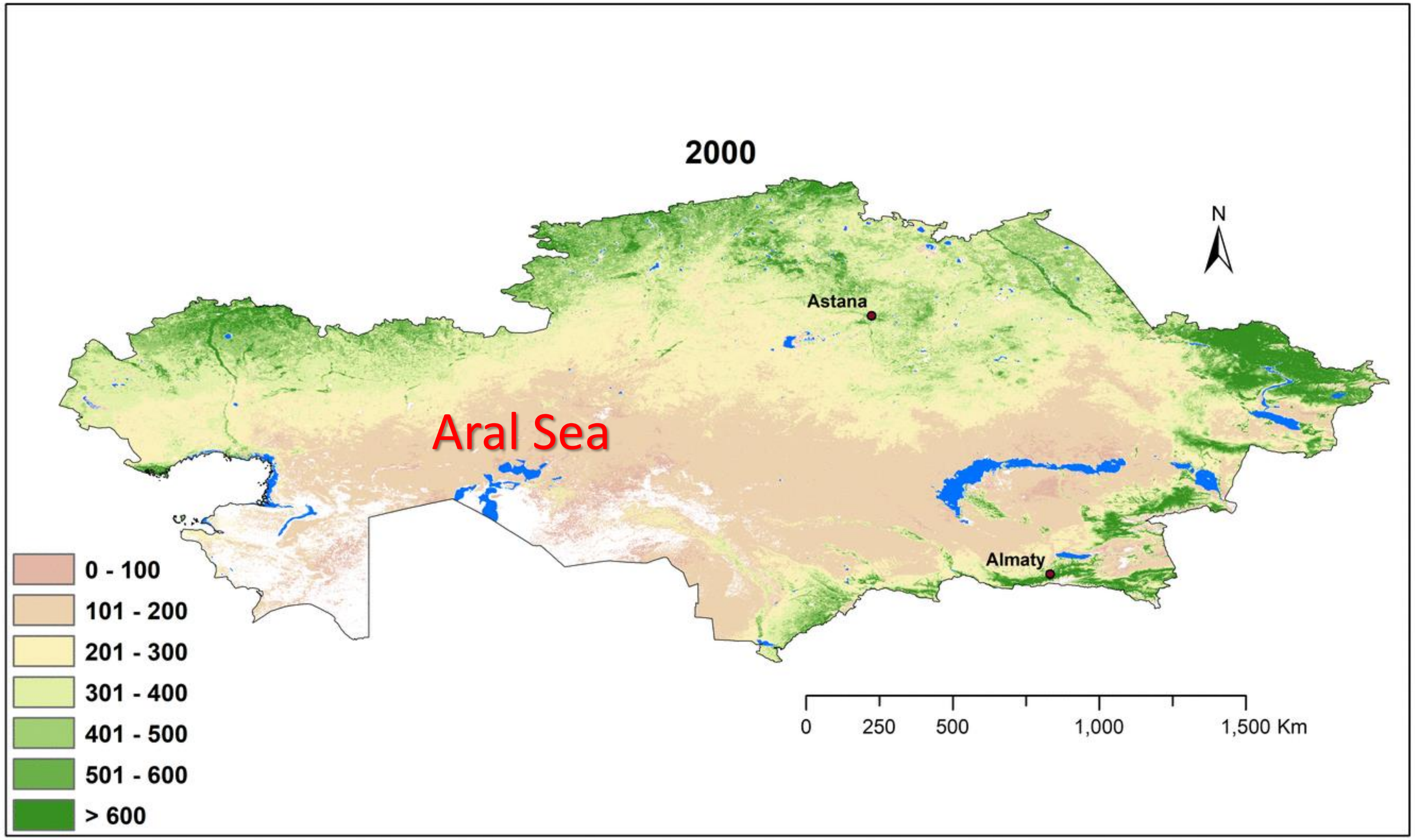
25 December 2019 19:05 Share in:

NUR-SULTAN. KAZINFORM - Prime Minister Askar Mamin chaired a meeting on the development of beef cattle breeding.

- A sectorial program for the development of livestock farming is being implemented in the framework of the State Agro-Industrial Complex Development Program for 2017-2021.
- Kazakhstan is planning to increase the volumes of its meat exports by 2.5 times.
- The main importers of the meat products are Russia, Azerbaijan and Iran.
- Residents of Turkey, the United Arab Emirates, China, Russia and Iran are interested in the meat products from Aral Sea.

Do we have enough grasses to support this large livestock?

Dynamics of net primary ecosystem production (NPP)
in Kazakhstan from 2000 through 2014



Field Trip to Kostanay – a boarding region with Russian

Modern facility and equipment from Italy, Germany, Japan, others

The Tale: Russian Food Table

1) So the reason for more crop/livestock is to satisfy Russians’ food table

2) Italy, Japan, China and others all helped

3) Russia needs import diary products regardless of its large lands

4) Economic depression in Russia

Are USA & NATO countries responsible for the shrinking pace of Aral Sea, at least partially?

Or Shall we blame Russians – an easy target

In 2014, Russia interfered Ukraine – A NATO member

5) USA & NATO Countries imposed sanctions on Russia

Putin was never a fully-fledged climate chang
Addressing a climate conference in 2003, Put
warmer weather so people spend less on fur

Bloomberg Opinion

Technology & Ideas

Even Putin Is Now Worried About Climate Change

Russia has dropped its doubts about joining the Paris accords.

https://www.bloomberg.com/opinion/articles/2019-09-24/putin-is-finally-worried-about-climate-change

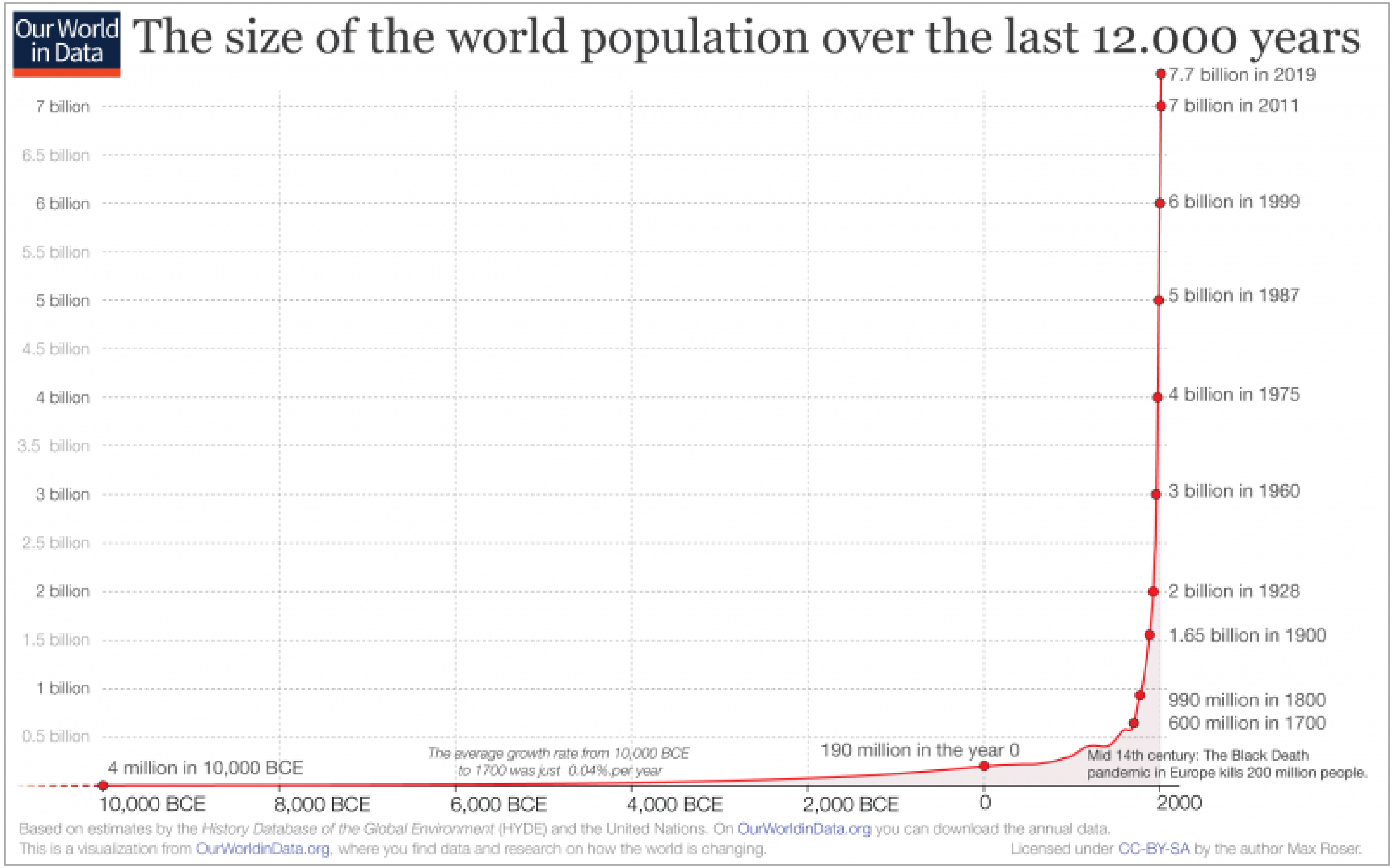
By Leonid Bershidsky
September 24, 2019, 12:00 AM EDT *Corrected September 24, 2019, 3:01 AM EDT*

Russian bears. *Photographer: Alexey Nikolsky/AFP/Getty Images*

Leonid Bershidsky is Bloomberg Opinion's Europe columnist. He was the founding editor of the

After years of procrastination, Russia, the world's fourth-biggest greenhouse gas emitter, has officially joined the Paris climate agreement, which it signed in 2016. It shows that President Vladimir Putin's views of climate change are

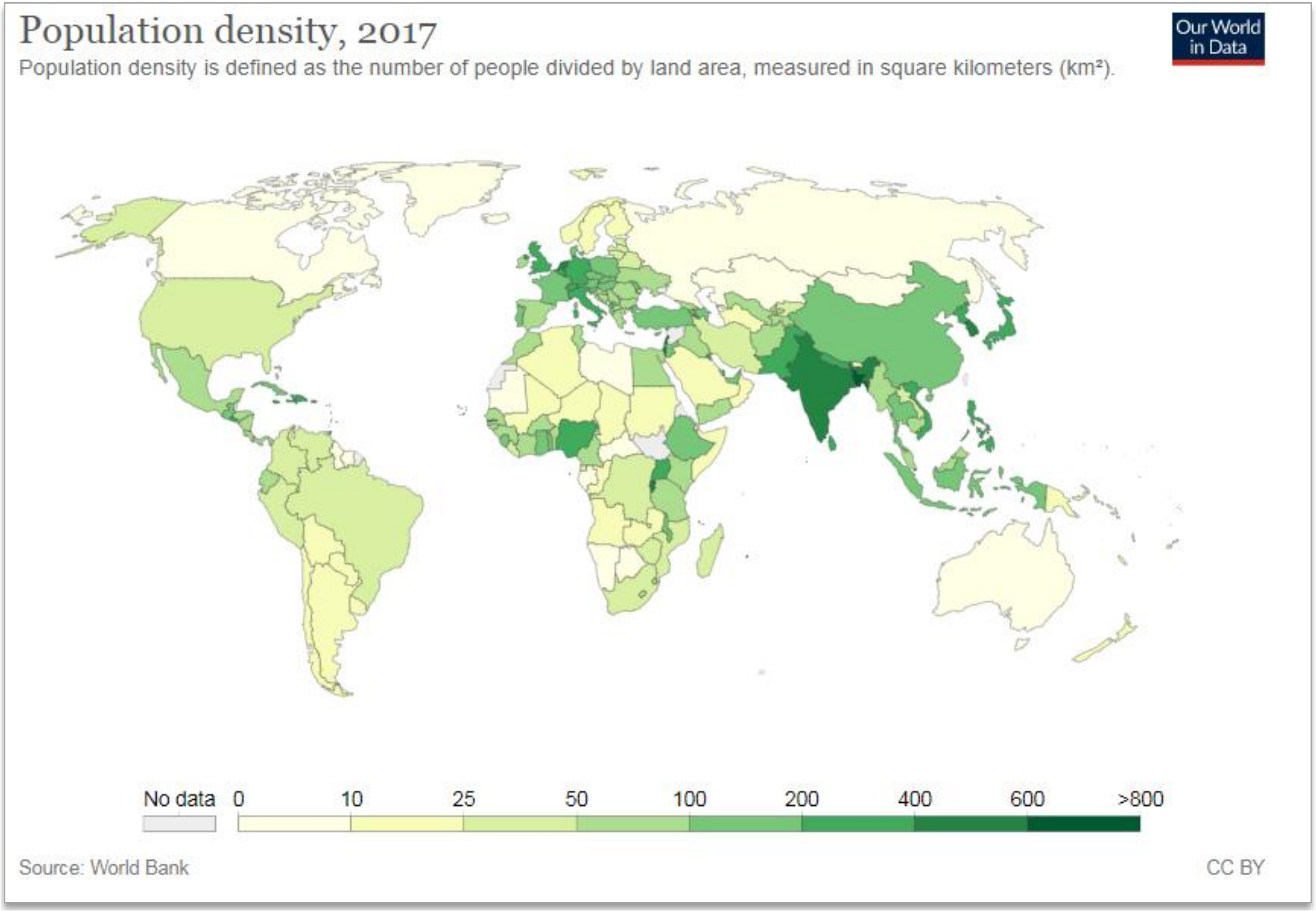
Complex Interconnections: Global Population and growth



https://ourworldindata.org/world-population-growth

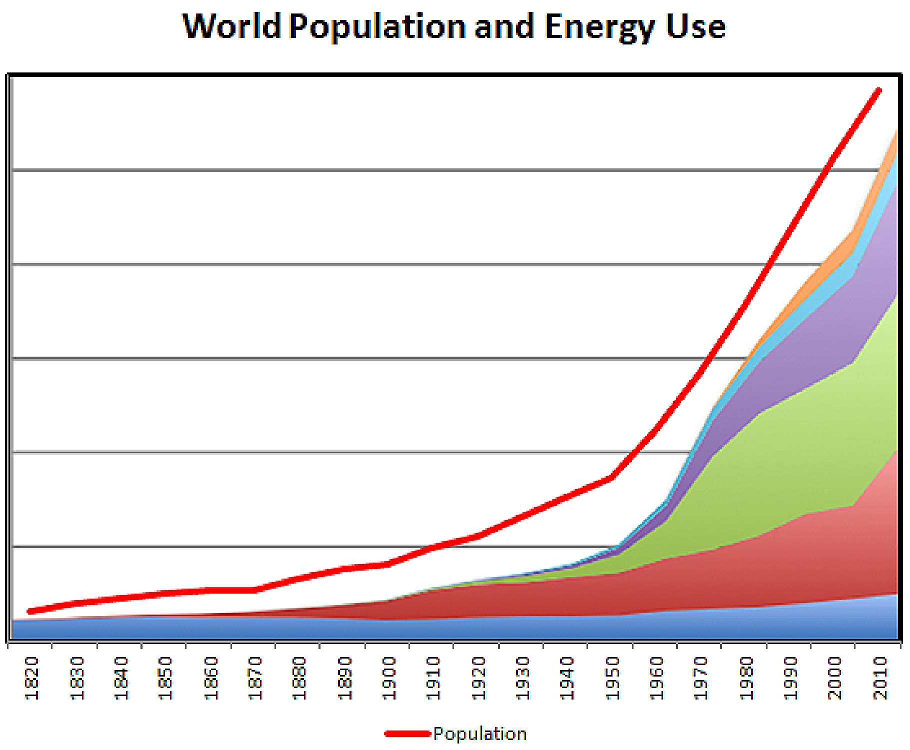
Complex Interconnections: Global Population – uneven distribution

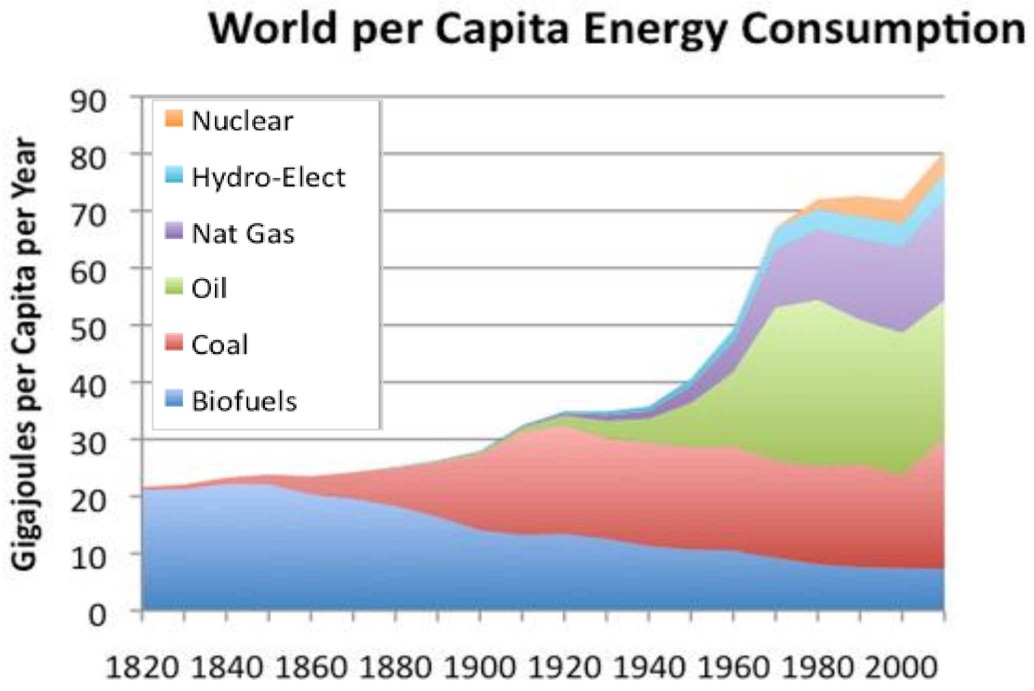
People in developing countries wants the same living standards of Americans!



https://ourworldindata.org/world-population-growth

The world's energy demand is rising!

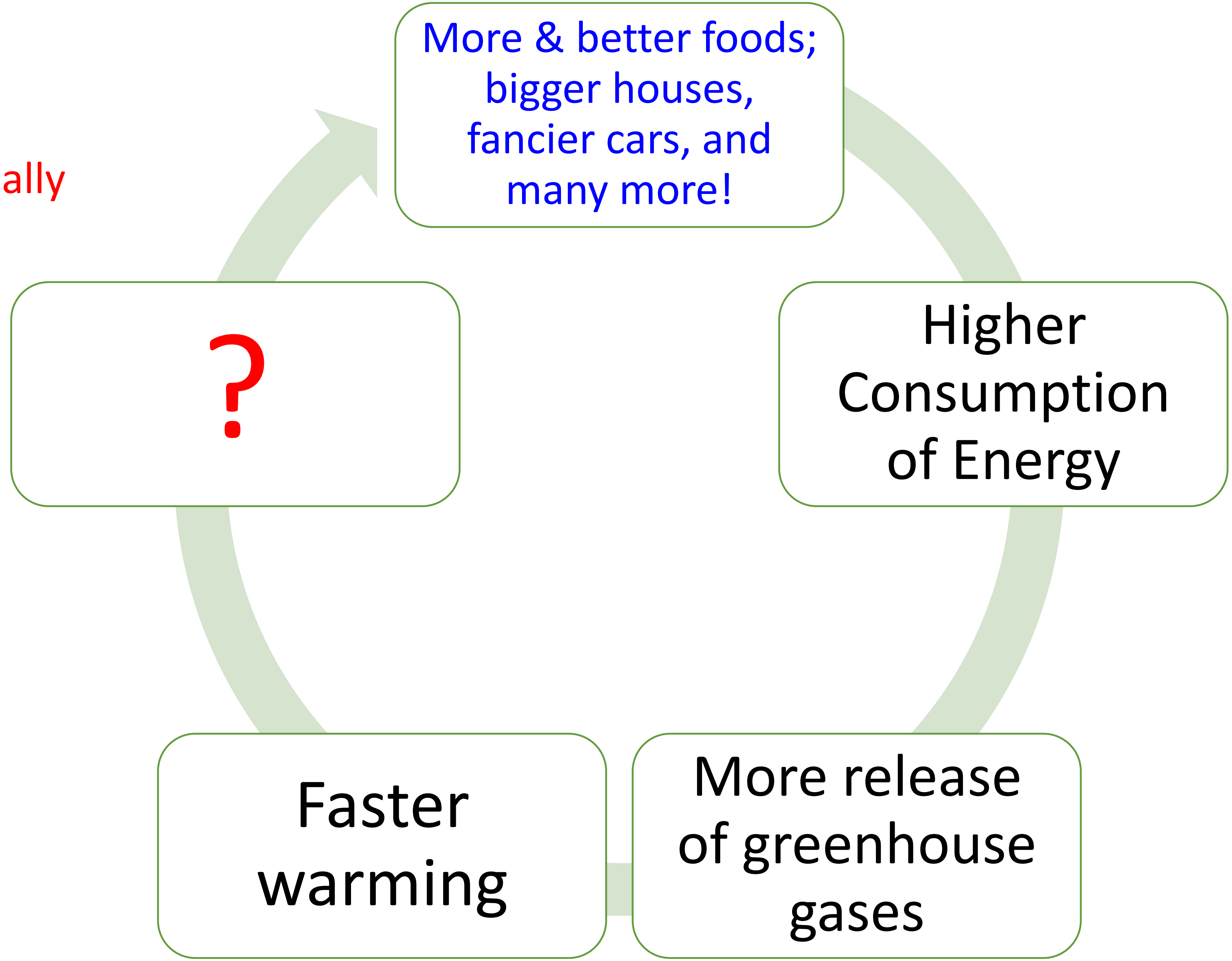




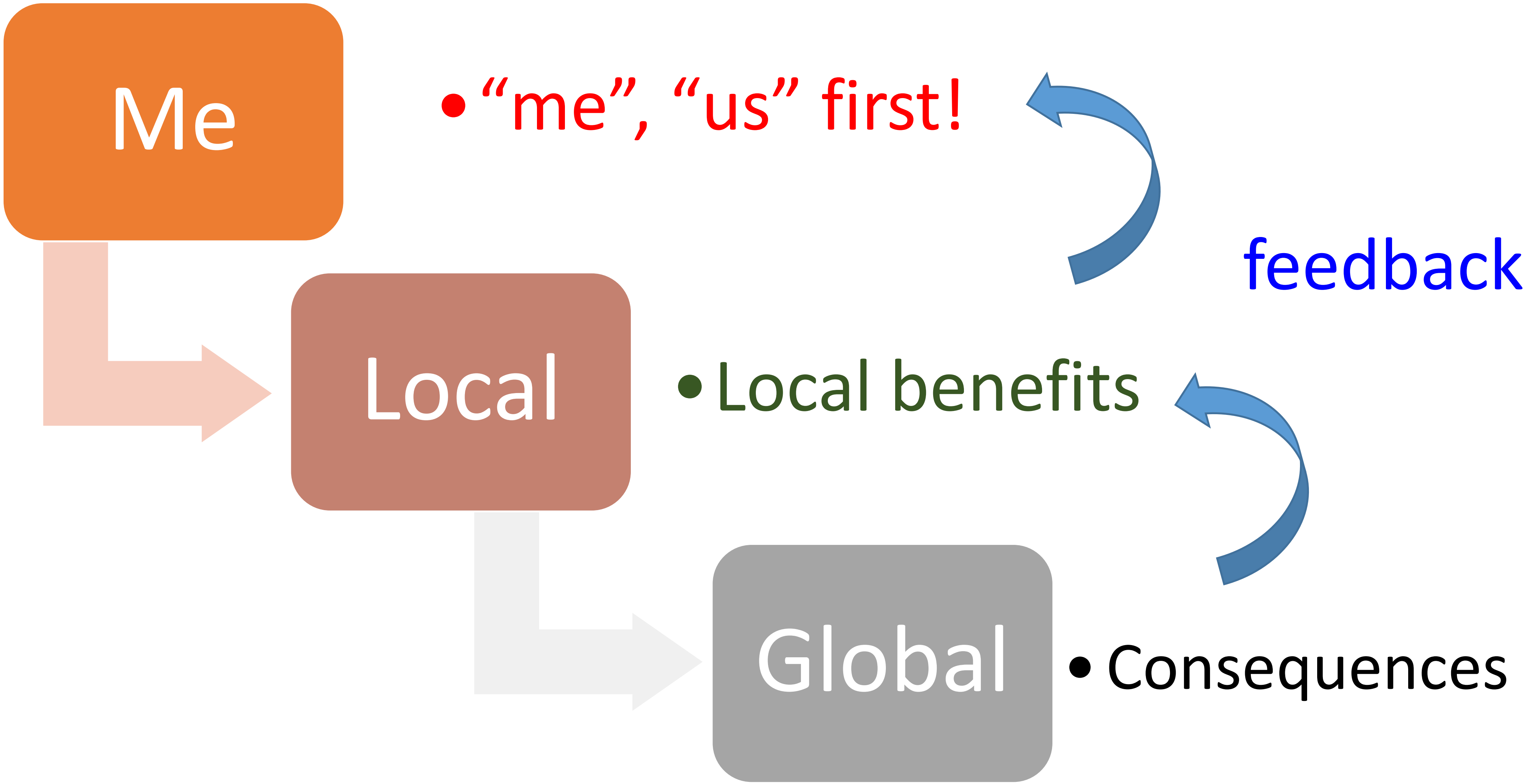
- Nearly 40% of total U.S. energy consumption in 2012 was for residential and commercial buildings;
- Energy consumption has grown exponentially in developing economies (e.g. China, India);
- Governments have pushed a shift from fossil fuels to renewable energy sources, such as solar energy, wind power and biofuels;
- Oil and gas still remain the major primary energy sources to power the world's industries.

Human Nature:

- A positive feedback
- System collapses, eventually



Human Nature

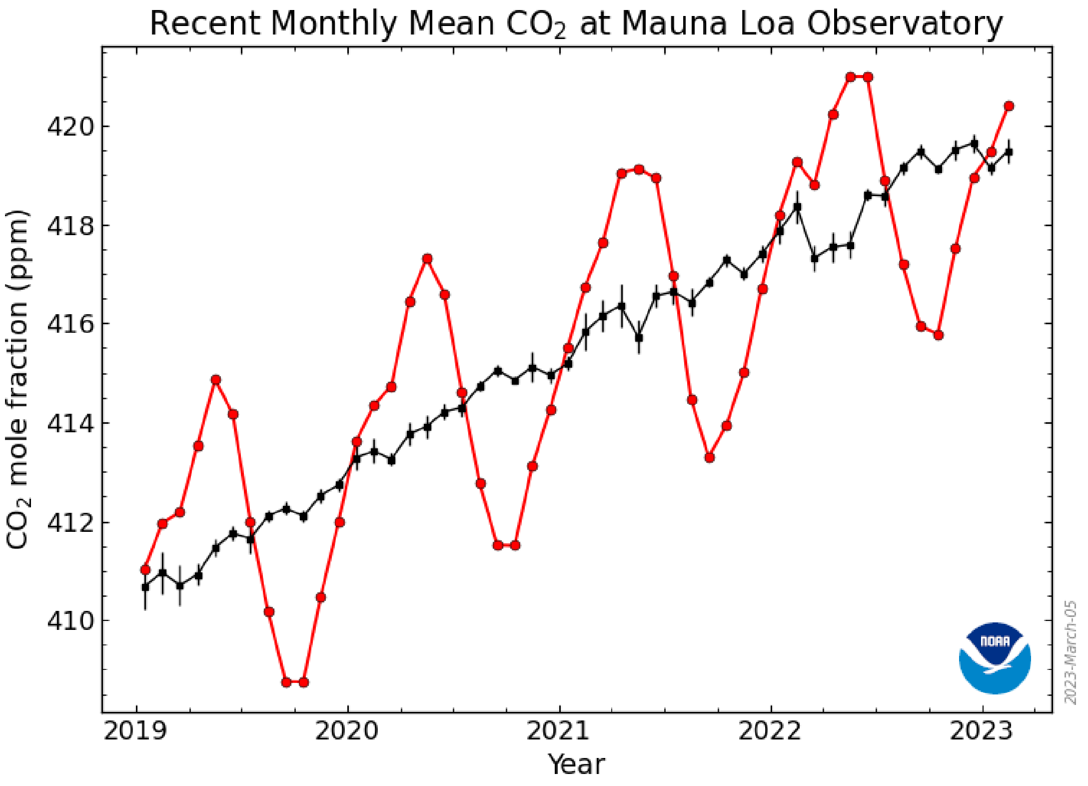


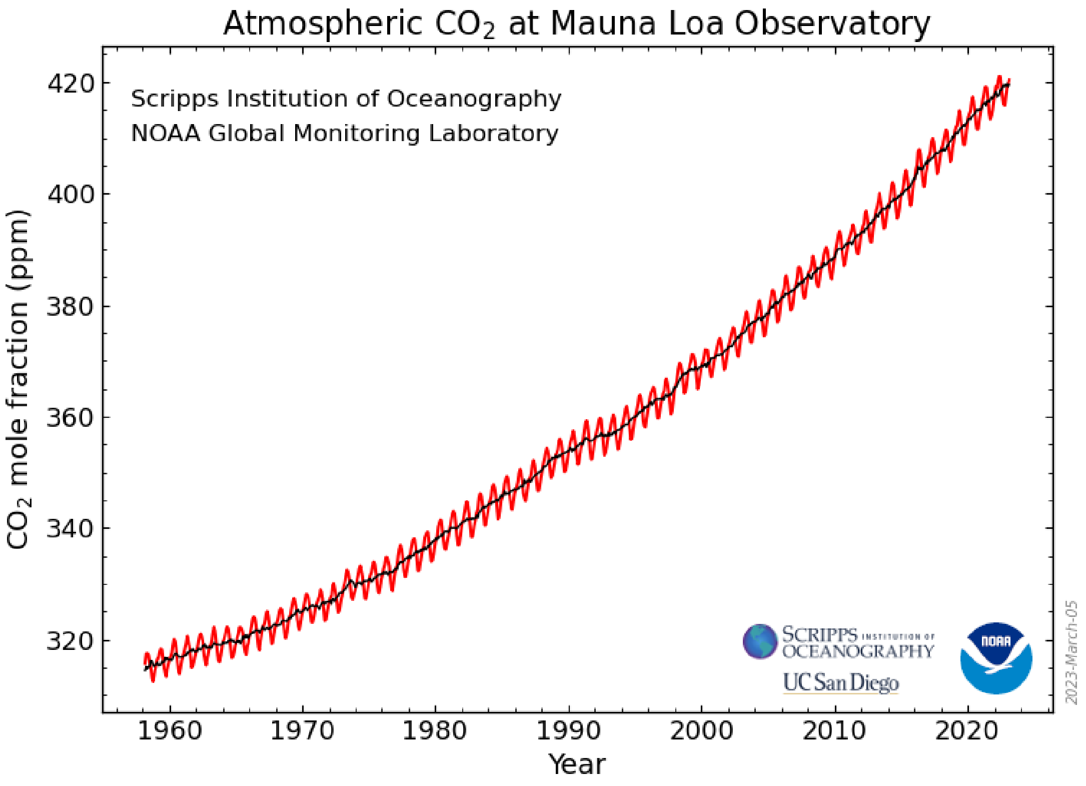
In sum,

1. Globalization is an unavoidable process for now and for the future
2. The changes, including climate, will have consequences (mostly negative so far) on ecosystems, societies, and people
3. Both the causes and consequences are complex and can be remotely connected
4. Solutions are more than just adaptation and mitigation, with education and awareness as the foundational needs for now!

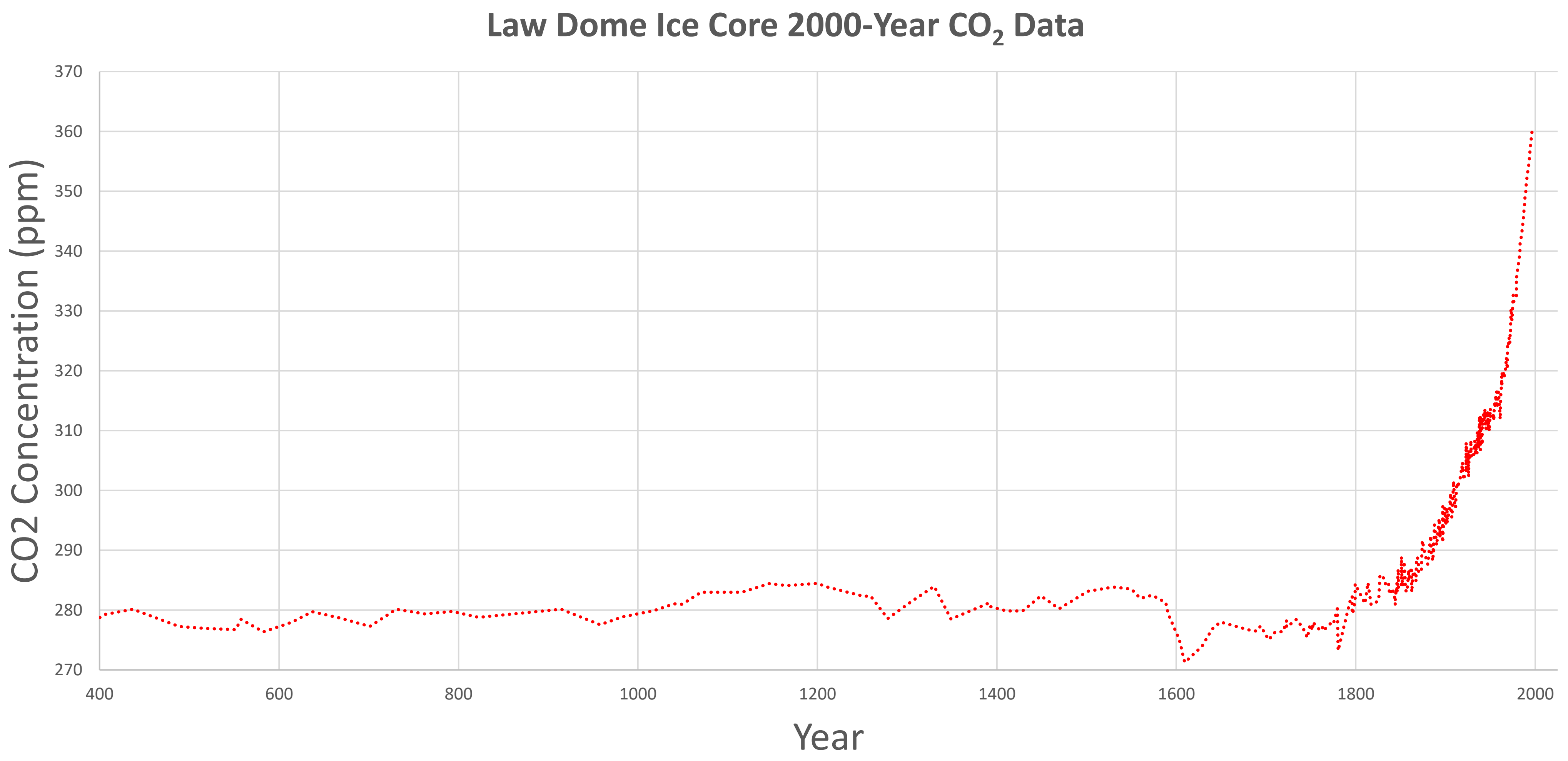
Carbon Stories & Climate Change

Monthly Average Mauna Loa CO_2

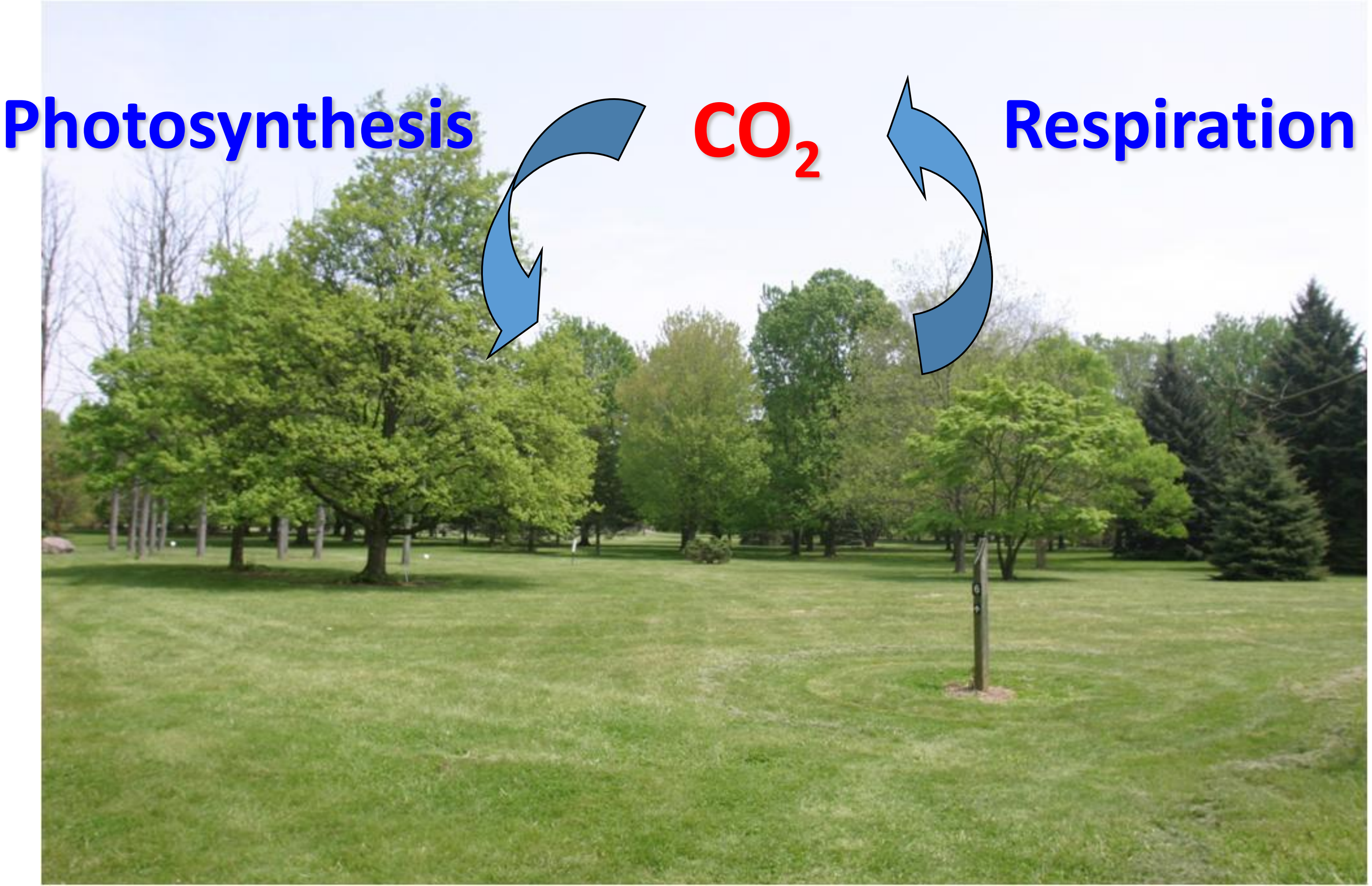




Carbon Stories & Climate Change: a few basics



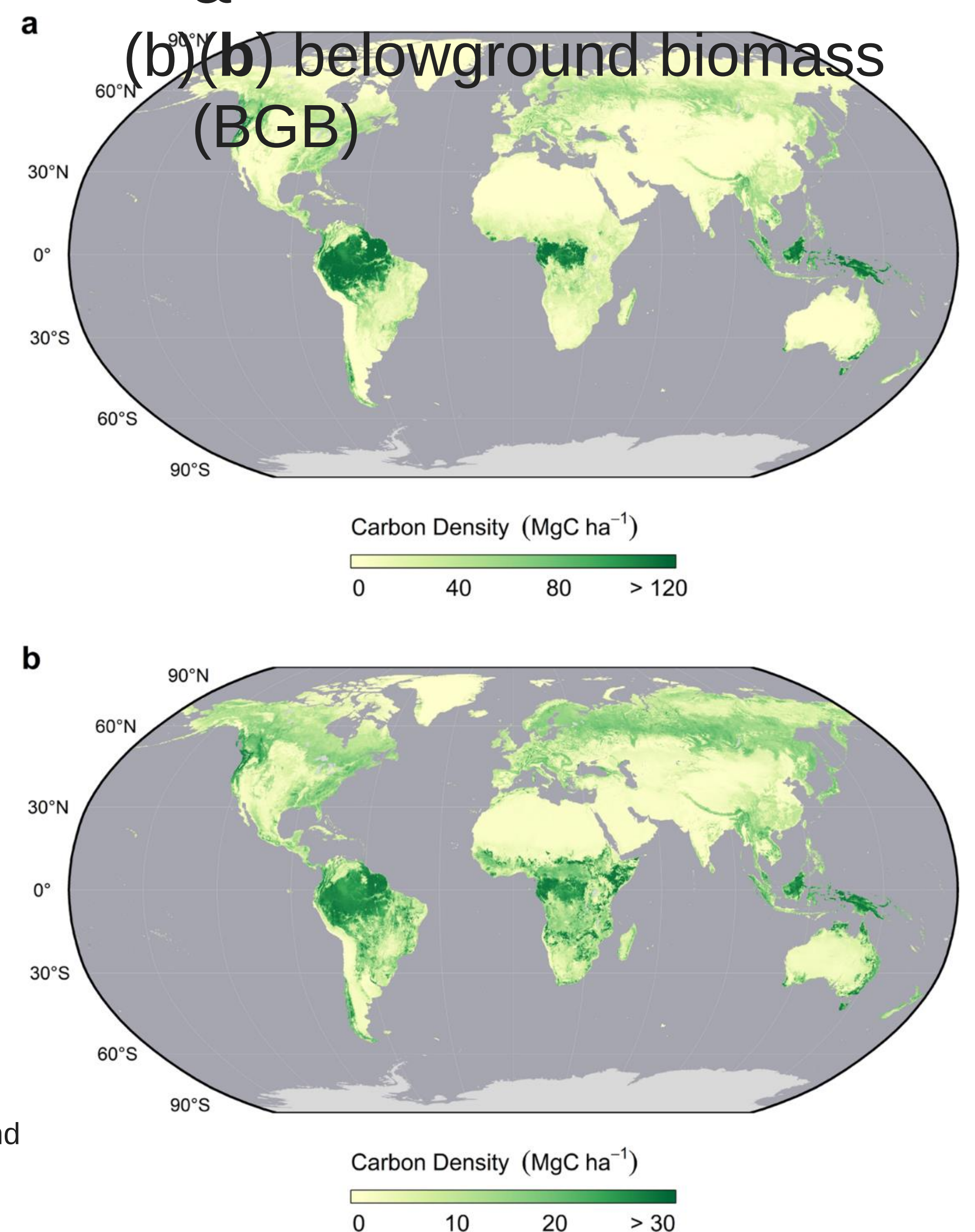
Keeping Carbon in Terrestrial Ecosystems to Battle Global Warming



Carbon Stories & Climate Change: a few basics

(a)Aboveground biomass (AGB)
&
(b)(**b**) belowground biomass (BGB)

- Molecular Weight: 12.011 g/mol
- Stable Isotopic C: ^{13}C and ^{14}C
- Molecular Weight of CO_2: 44.01 g/mol
- Carbon Density of biomass: 0.44 – 0.55
- Gasoline is about 87% carbon and 13% hydrogen by weight. So the carbon in a gallon of gasoline (weighing 6.3 pounds) weighs 5.5 pounds (0. 87 x 6.3 pounds = 5.5 pounds).



Spawn, S. A., Sullivan, C. C., Lark, T. J., & Gibbs, H. K. (2020). Harmonized global maps of above and belowground biomass carbon density in the year 2010. *Scientific Data*, *7*(1), 112.

Carbon Stories & Climate Change: a few basics

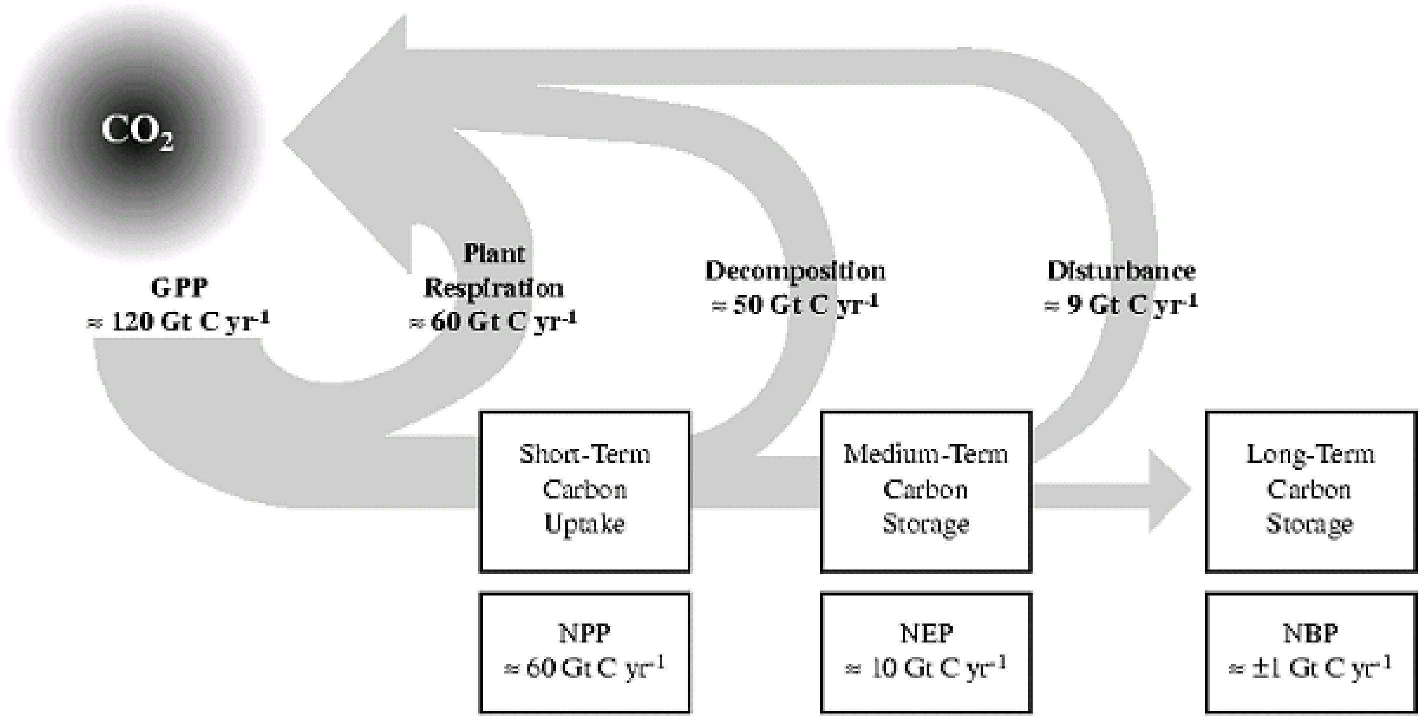
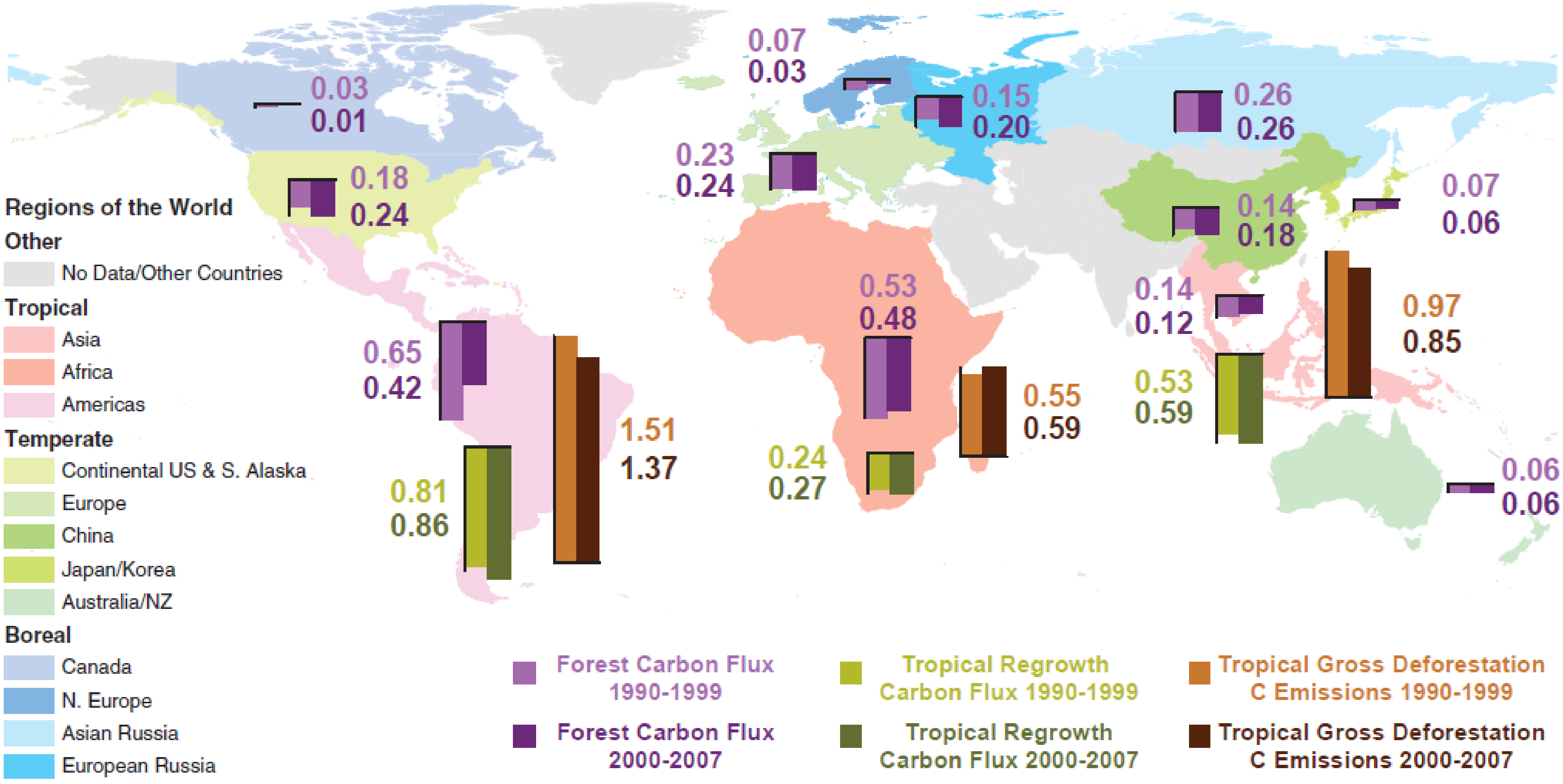


Figure 1-2: *Global terrestrial carbon uptake. Plant (autotrophic) respiration releases CO2 to the atmosphere, reducing GPP to NPP and resulting in short-term carbon uptake. Decomposition (heterotrophic respiration) of litter and soils in excess of that resulting from disturbance further releases CO2 to the atmosphere, reducing NPP to NEP and resulting in medium-term carbon uptake. Disturbance from both natural and anthropogenic sources (e.g., harvest) leads to further release of CO2 to the atmosphere by additional heterotrophic respiration and combustion-which, in turn, leads to long-term carbon storage (adapted from Steffen et al., 1998).*

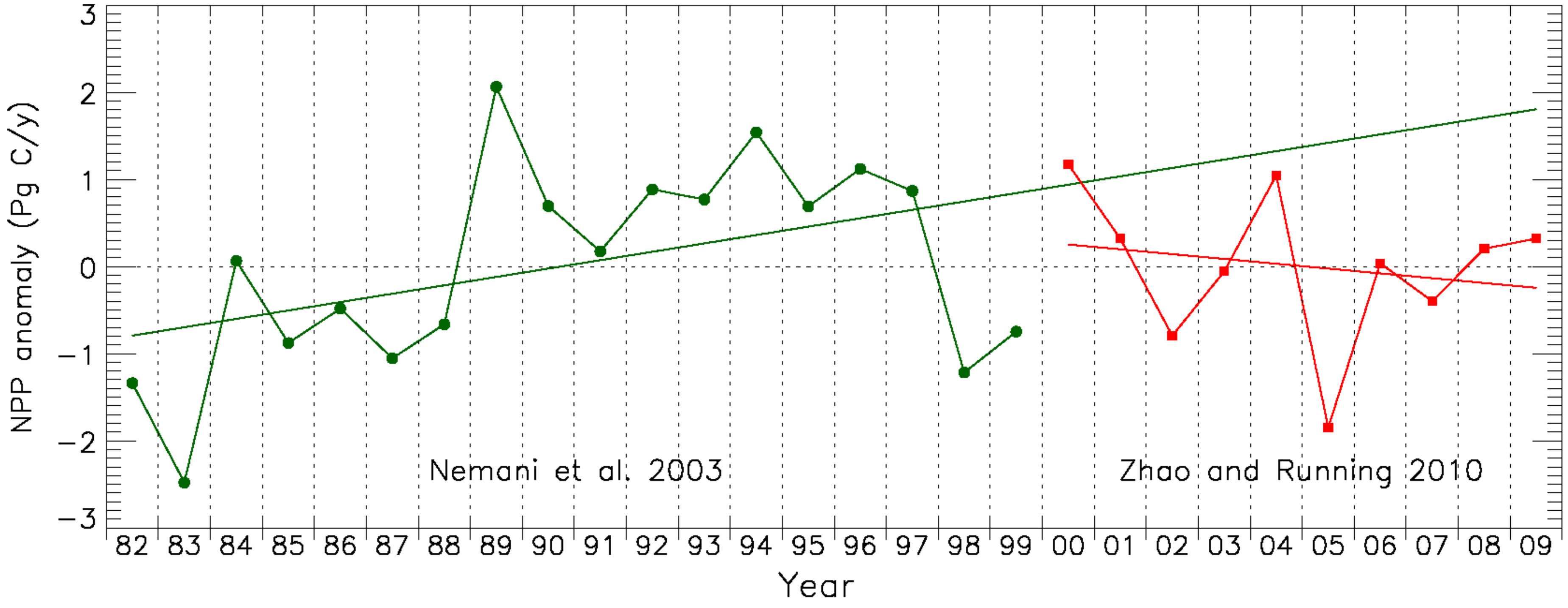
https://archive.ipcc.ch/ipccreports/sres/land_use/index.php?idp=24

Carbon Sinks and Sources (Pg C yr^{-1}) in the World's Forests



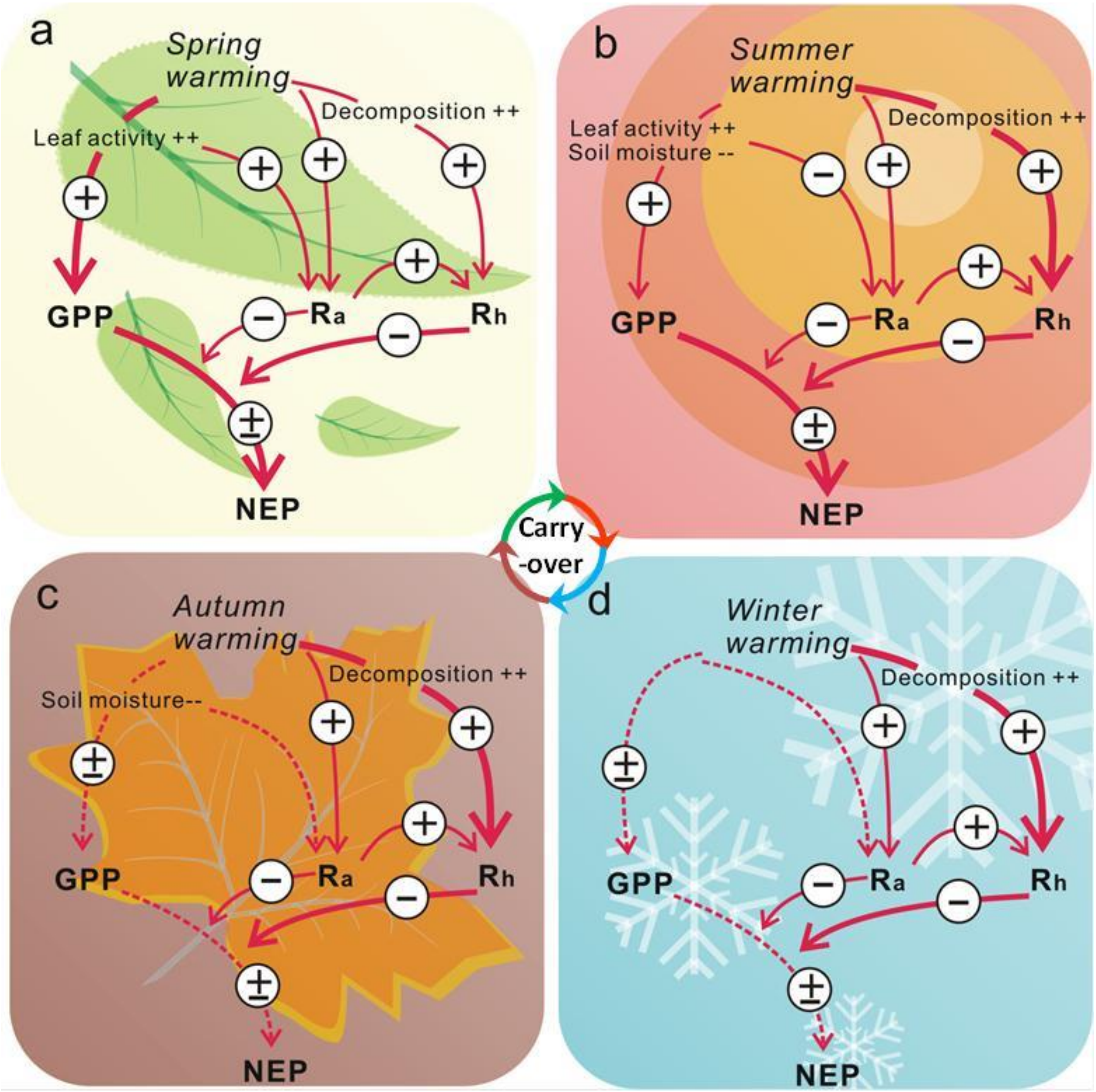
Pan *et al*. (2011) *Science*

Global NPP decreased from 2000 to 2009, with NPP over North Hemisphere continued increasing (winner) and over South Hemisphere decreased; Recent drying trend caused the reduction in NPP in SH.



Zhao & Running (2010). Science

Ecosystem NPP, R_a & R_h respiration, and NEP in response directly to global warming in (a) spring, (b) summer, (c) autumn, and (d) winter.



Xia et al. (Nature-Geoscience), 2014

Carbon Stories & Climate Change: a few basics

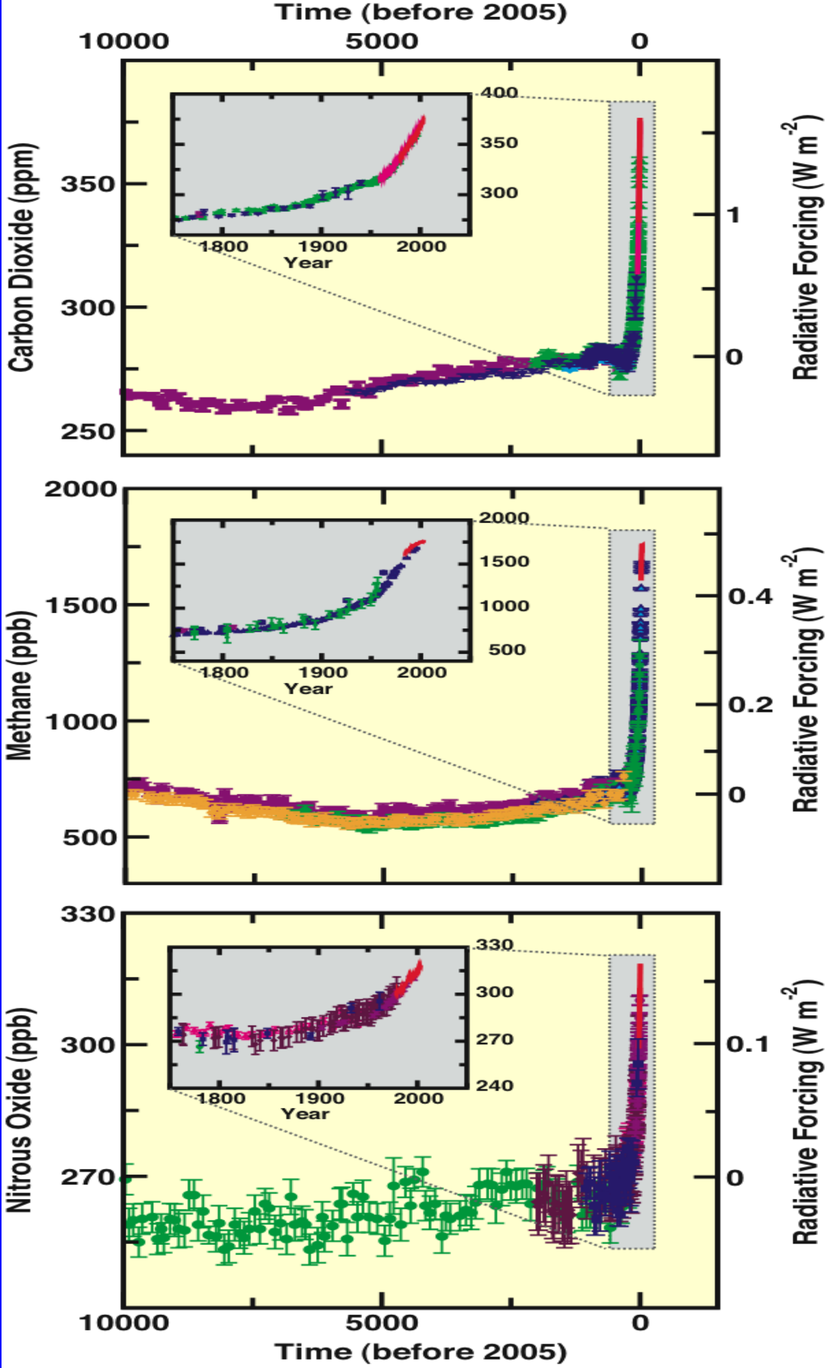
Carbon Stories & Climate Change: a few basics

Human and Natural Drivers of Climate Change

CO_2, CH_4 and N_2O Concentrations

- far exceed pre-industrial values
- increased markedly since 1750
  due to human activities

Relatively little variation before the industrial era



IPCC 2007

2. Current and Future Climate Change

Direct Observations of Recent Climate Change

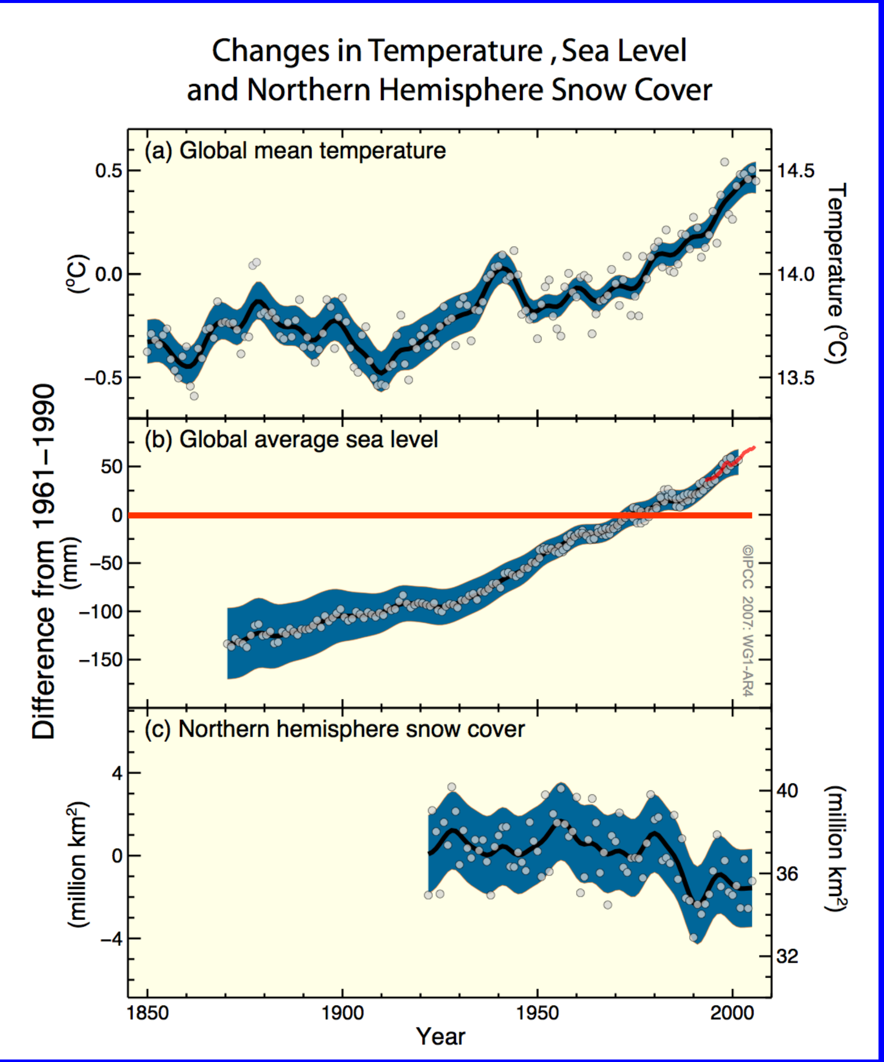
Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.

Direct Observations of Recent Climate Change

Global mean temperature

Global average sea level

Northern hemisphere Snow cover



Direct Observations of Recent Climate Change

- Global average air temperature Updated 100-year linear trend of 0.74 [0.56 to 0.92] °C for 1906-2005

- Larger than corresponding trend of 0.6 [0.4 to 0.8] °C for 1901-2000 given in TAR

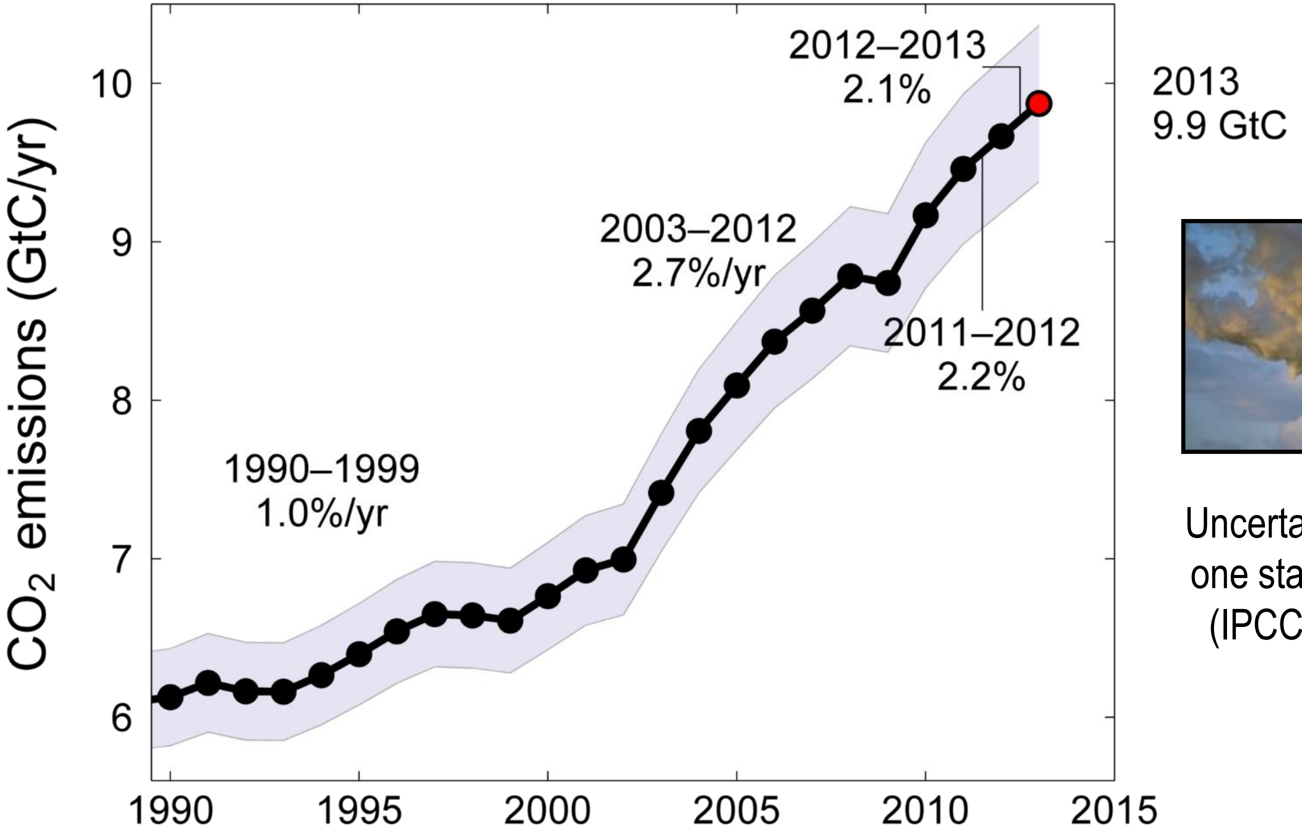
- Average ocean temperature increased to depths of at least 3000 m – ocean has absorbed 80% of heat added


Copyright: Global Carbon Project I Glynn Gorick

Fossil Fuel and Cement Emissions

Global fossil fuel and cement emissions: 9.7 ± 0.5 GtC in 2012, 58% over 1990

● Projection for 2013 : 9.9 ± 0.5 GtC, 61% over 1990



Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

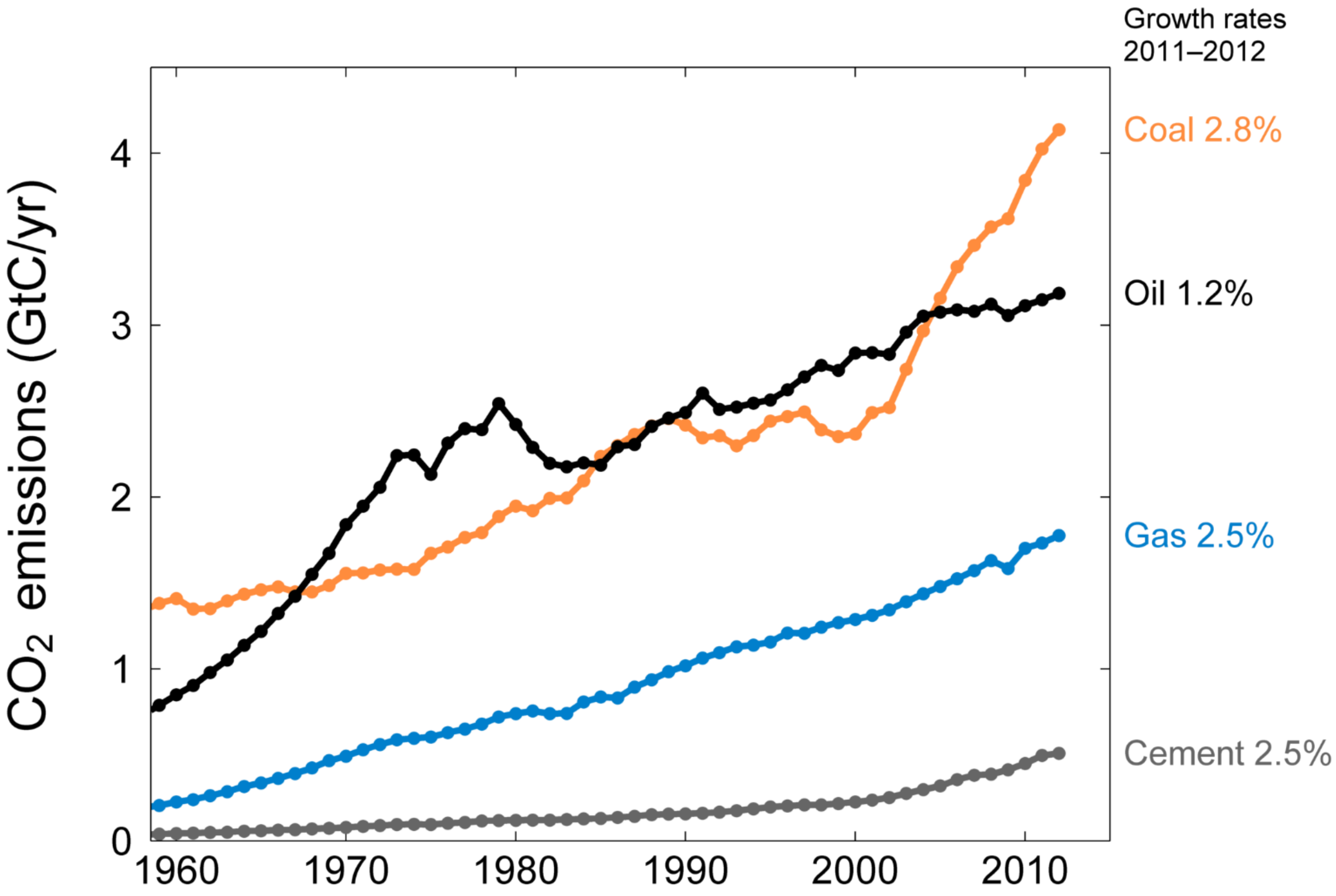
With leap year adjustment: 2012 growth rate is 1.9% and 2013 is 2.4%

Source: Le Quéré et al 2013; CDIAC Data; Global Carbon Project 2013

Emissions from Coal, Oil, Gas, Cement

Share of global emissions in 2012:

coal (43%), oil (33%), gas (18%), cement (5%), flaring (1%, not shown)

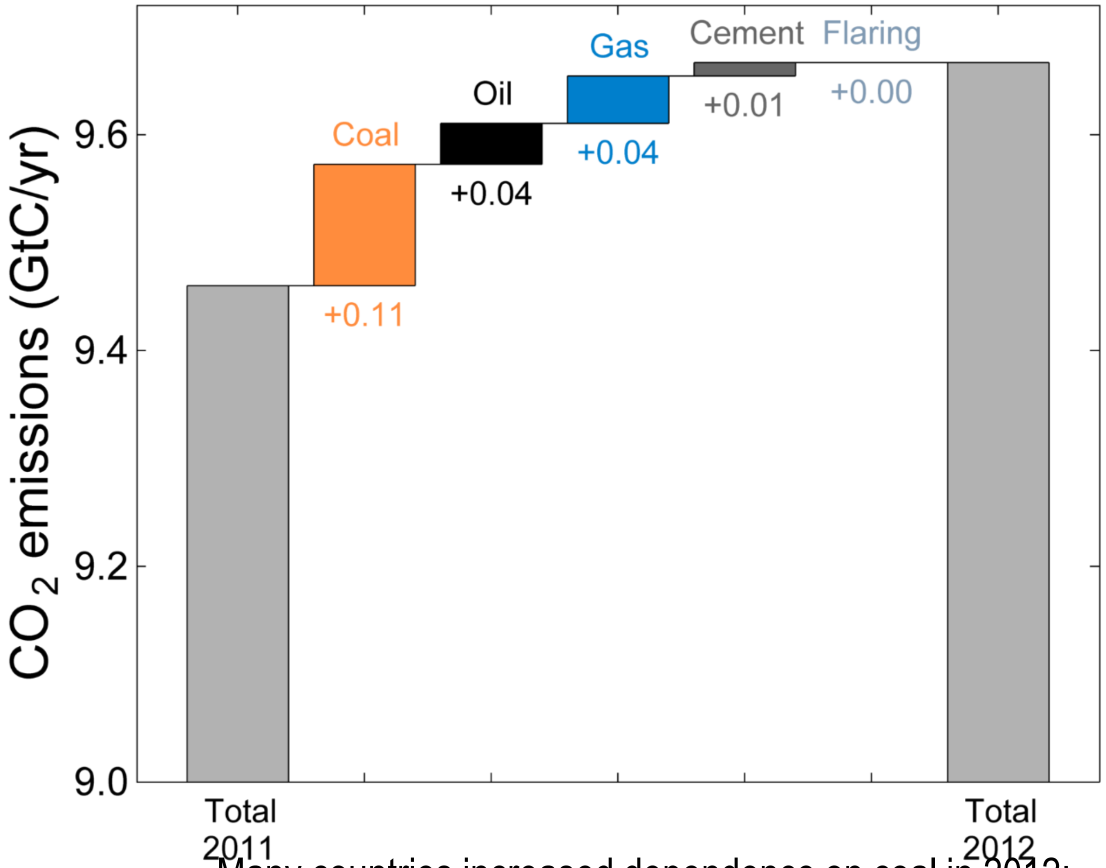


With leap year adjustment in 2012 growth rates are: coal 2.5%, oil 0.9%, gas 2.2%, cement 2.2%.

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Fossil Fuel and Cement Emissions Growth 2012

Coal accounted for 54% of the growth in global emissions in 2012, oil (18%), gas (21%), and cement (6%).



Many countries increased dependence on coal in 2012:

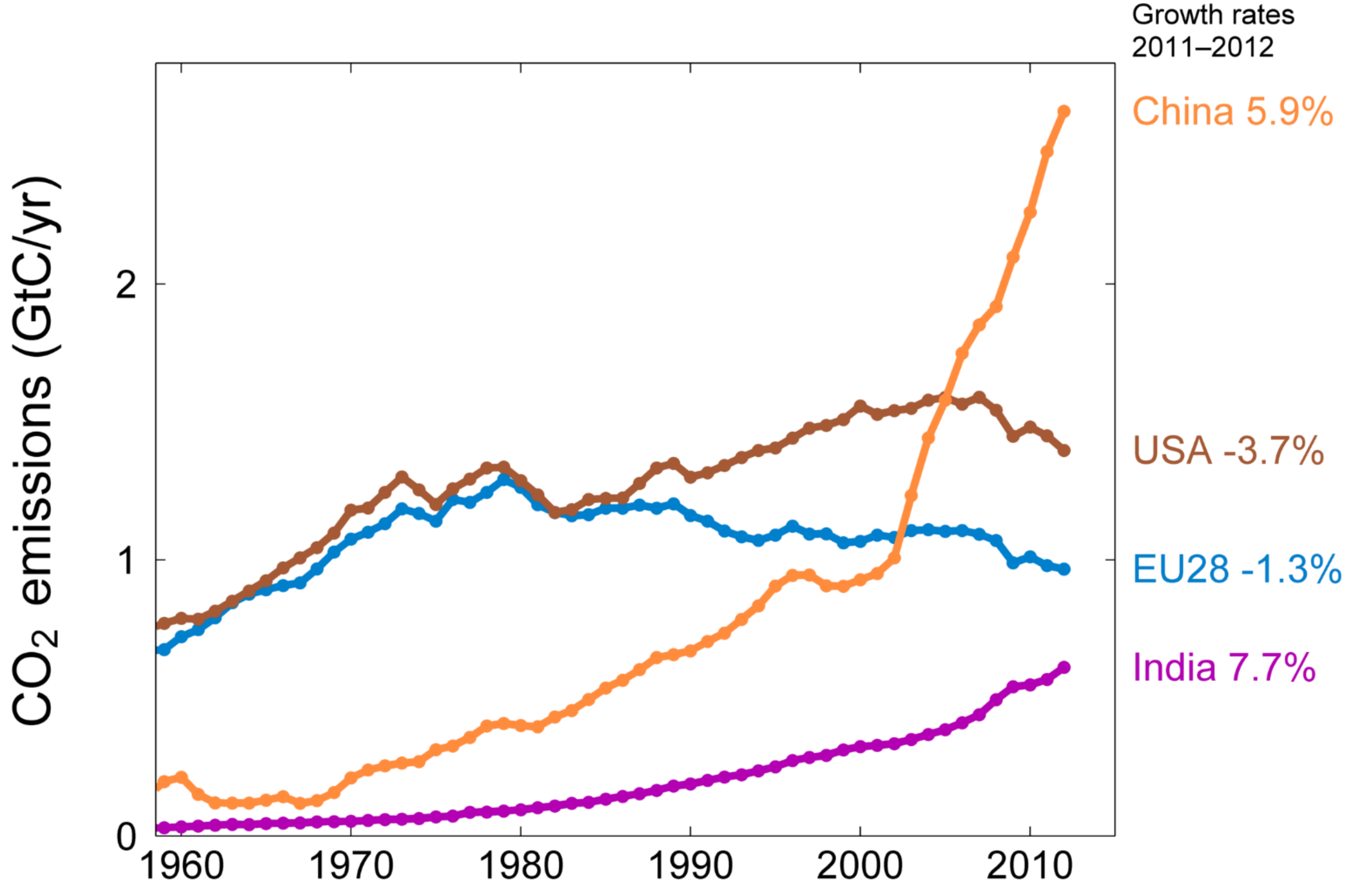
Emissions from coal grew 4.2% in Germany, 5.6% in Japan, 3.0% in the EU28, 10.2% in India.

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Top Fossil Fuel Emitters (Absolute)

Top four emitters in 2012 covered 58% of global emissions

China (27%), United States (14%), EU28 (10%), India (6%)



With leap year adjustment in 2012 growth rates are: China 5.6%, USA -4.0%, EU -1.6%, India 7.4%.

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Fossil Fuel and Cement Emissions Growth 2012

China accounted for 71% of the global emissions growth in 2012, India 21%, Japan 11%.

The USA contributed to a decrease in emissions.

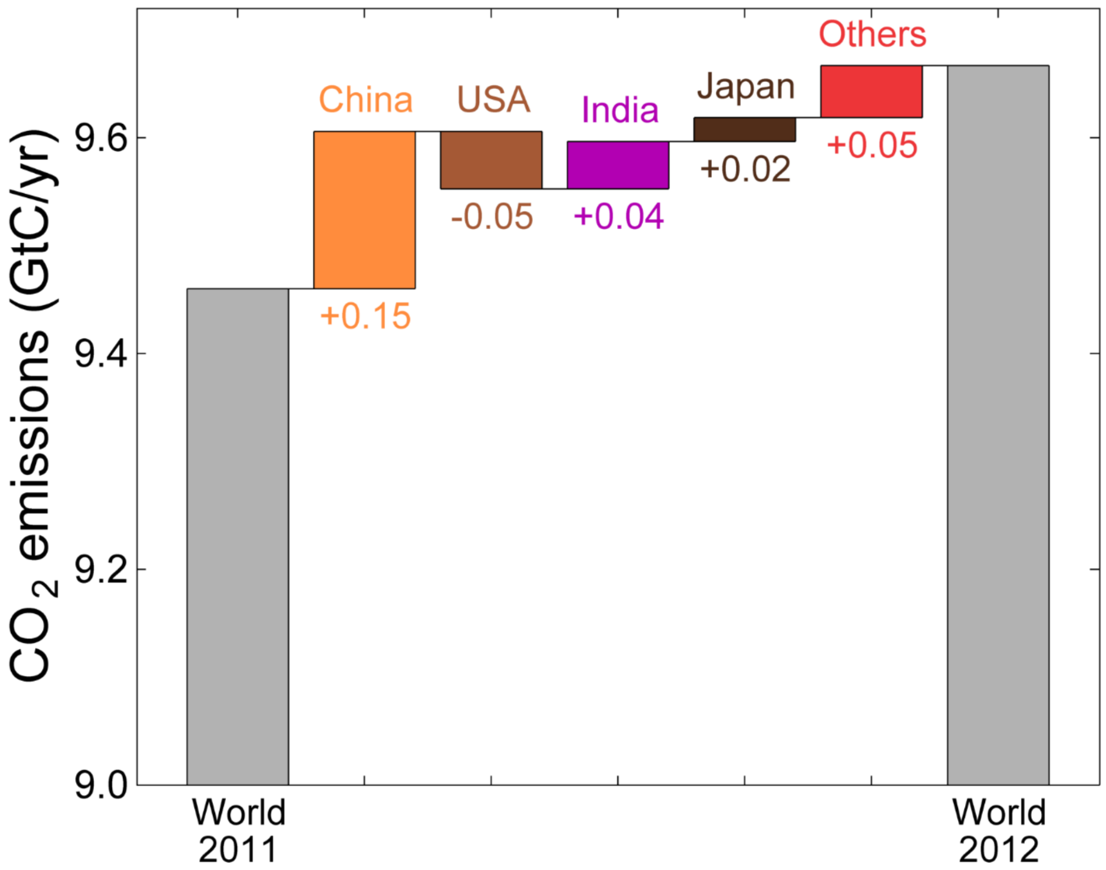


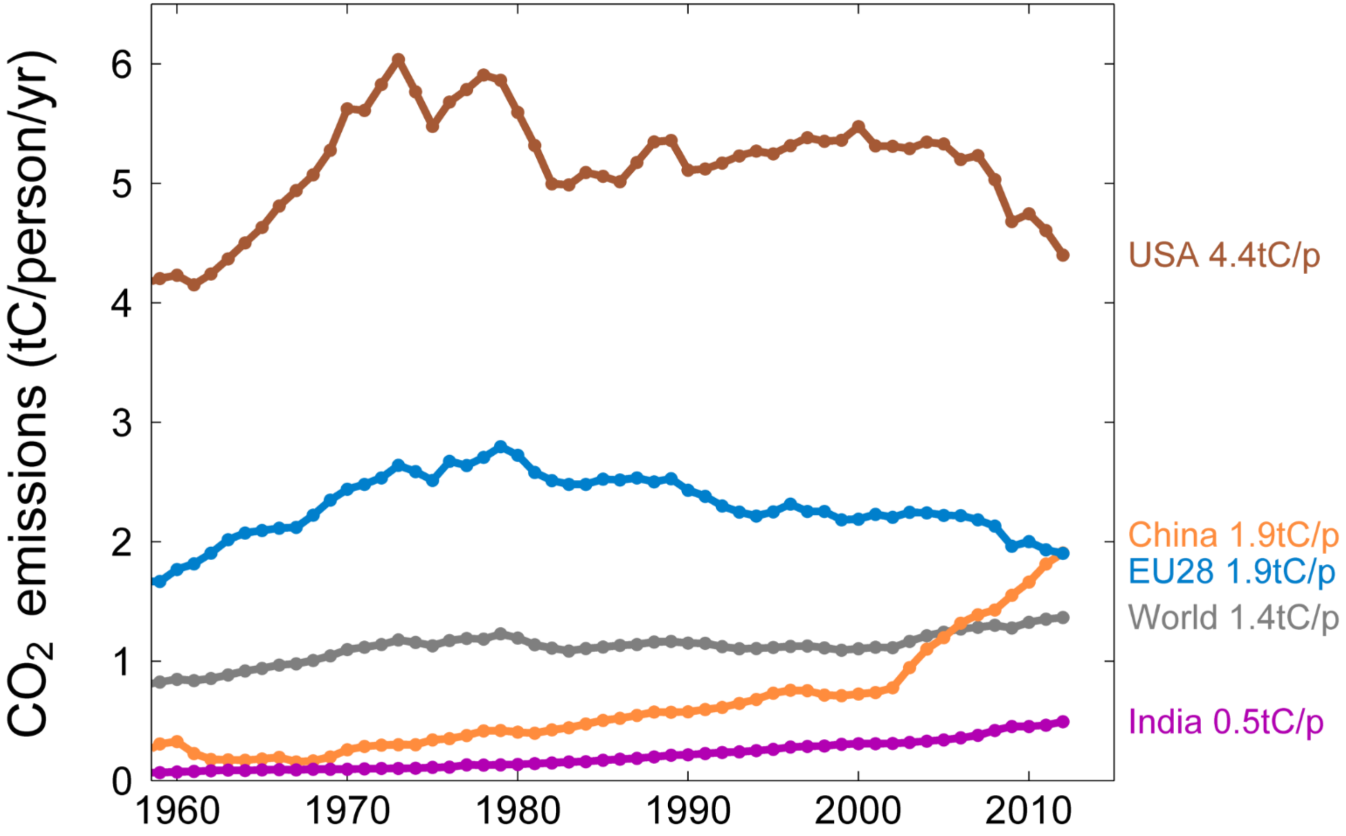
Figure shows the top four countries contributing to emissions changes in 2012

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Top Fossil Fuel Emitters (Per Capita)

Average per capita emissions in 2012

China is growing rapidly and the US is declining fast

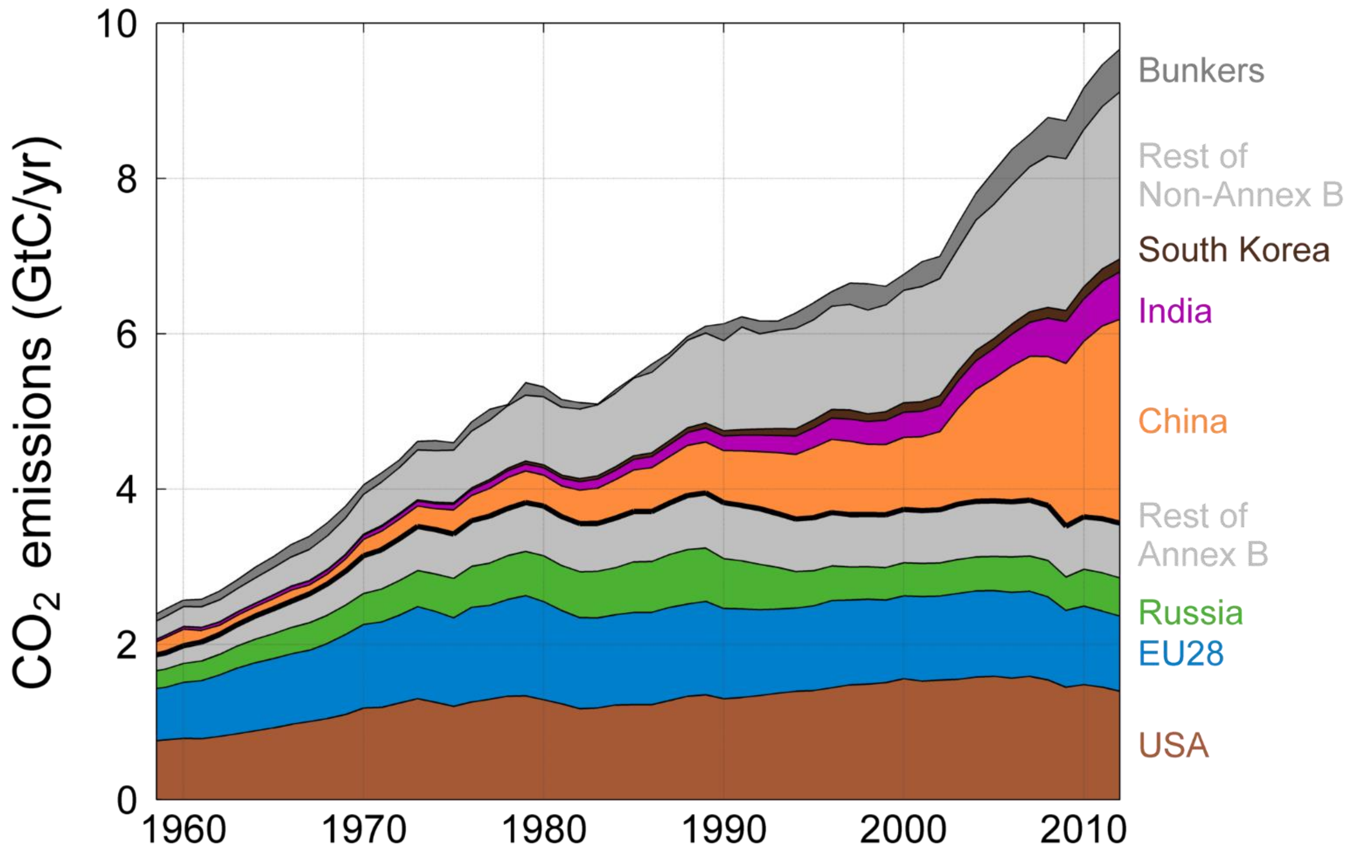


Source: [CDIAC Data](); [Le Quéré et al 2013](); [Global Carbon Project 2013]()

Breakdown of Global Emissions by Country

Emissions from Annex B countries have slightly declined

Emissions from non-Annex B countries have increased rapidly in recent years

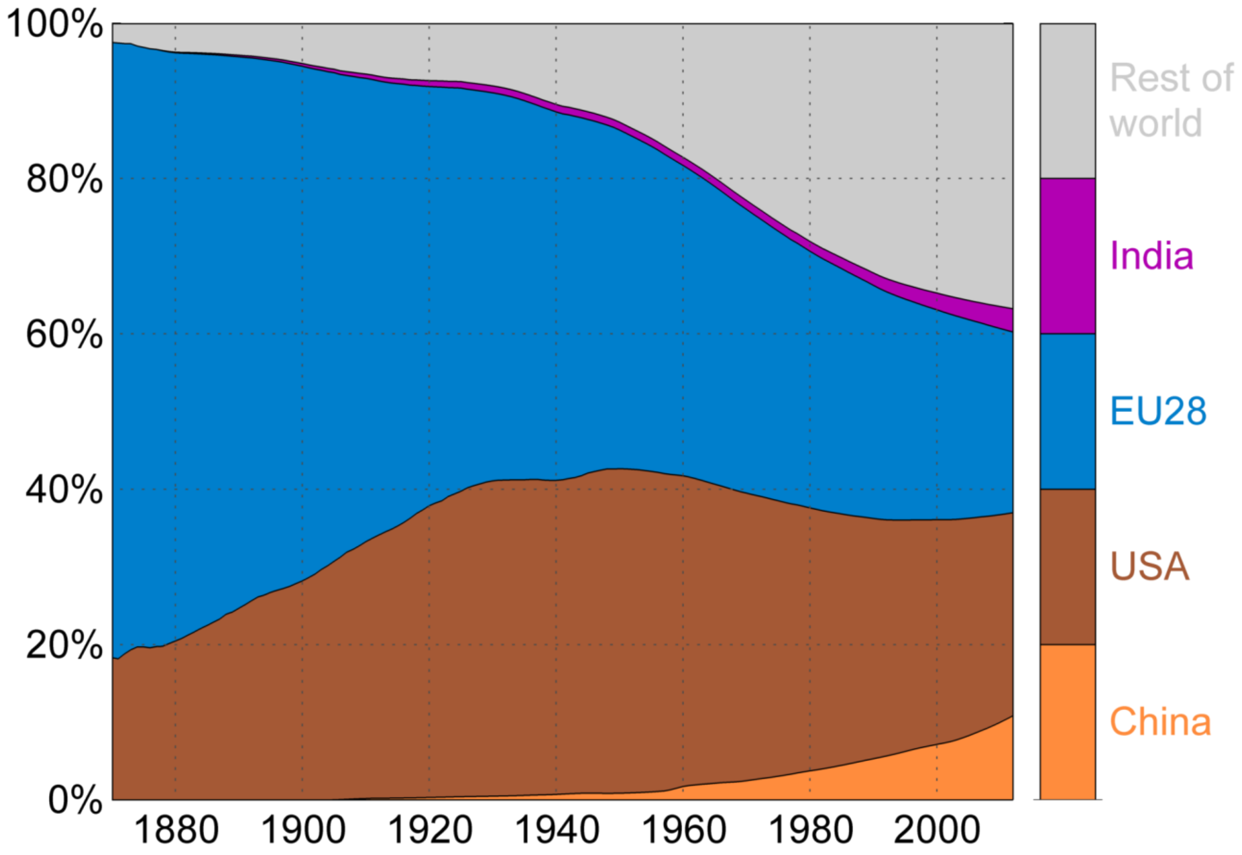


Annex B countries have emission commitments in the Kyoto Protocol

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Historical Cumulative Emissions by Country

Cumulative emissions from fossil-fuel and cement were distributed (1870–2012):
USA (26%), EU28 (23%), China (11%), and India (4%) covering 64% of the total share



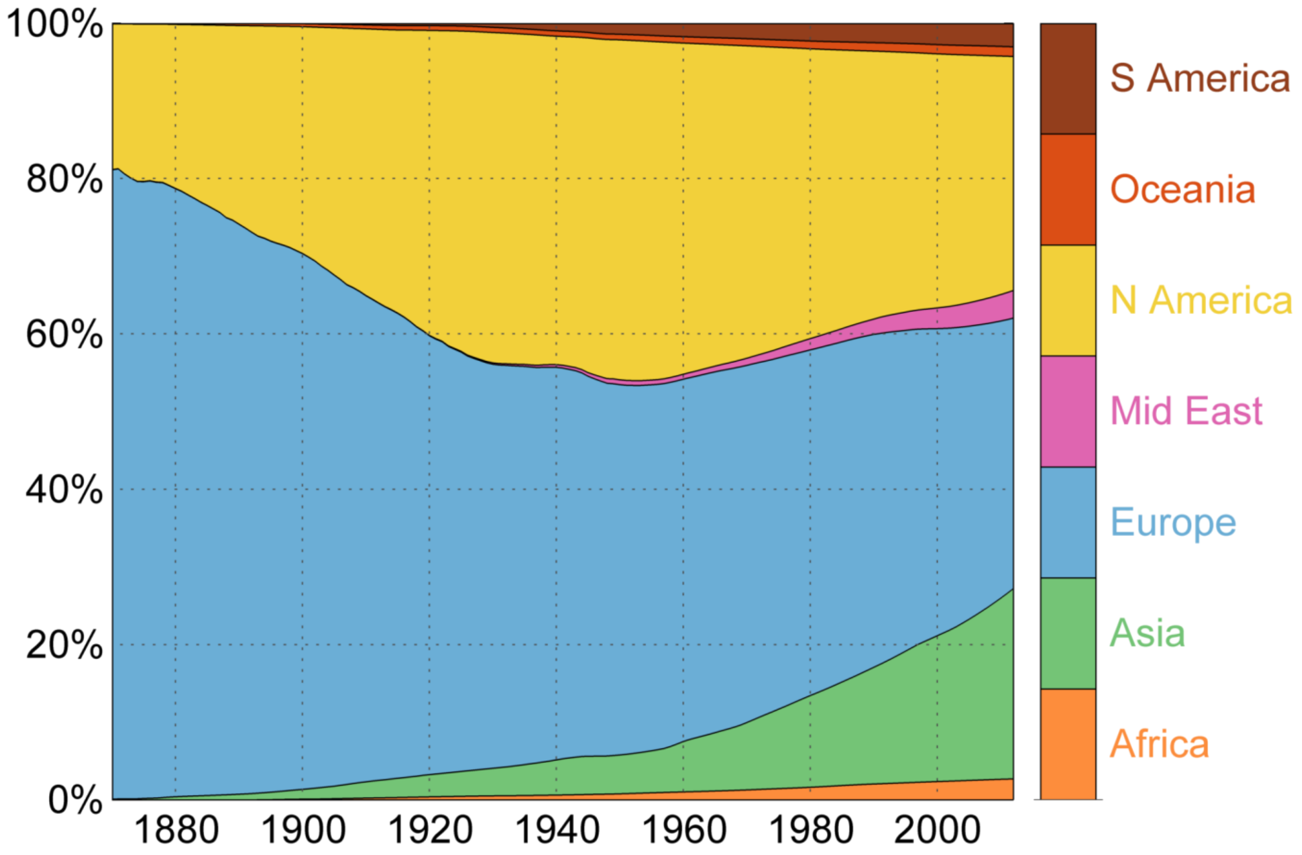
Cumulative emissions (1990–2012) were distributed USA (20%), EU28 (15%), China (18%), India (5%)

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Historical Cumulative Emissions by Region

Cumulative emissions from fossil-fuel and cement (1870–2012)

North America and Europe responsible for most cumulative emissions, but Asia growing fast

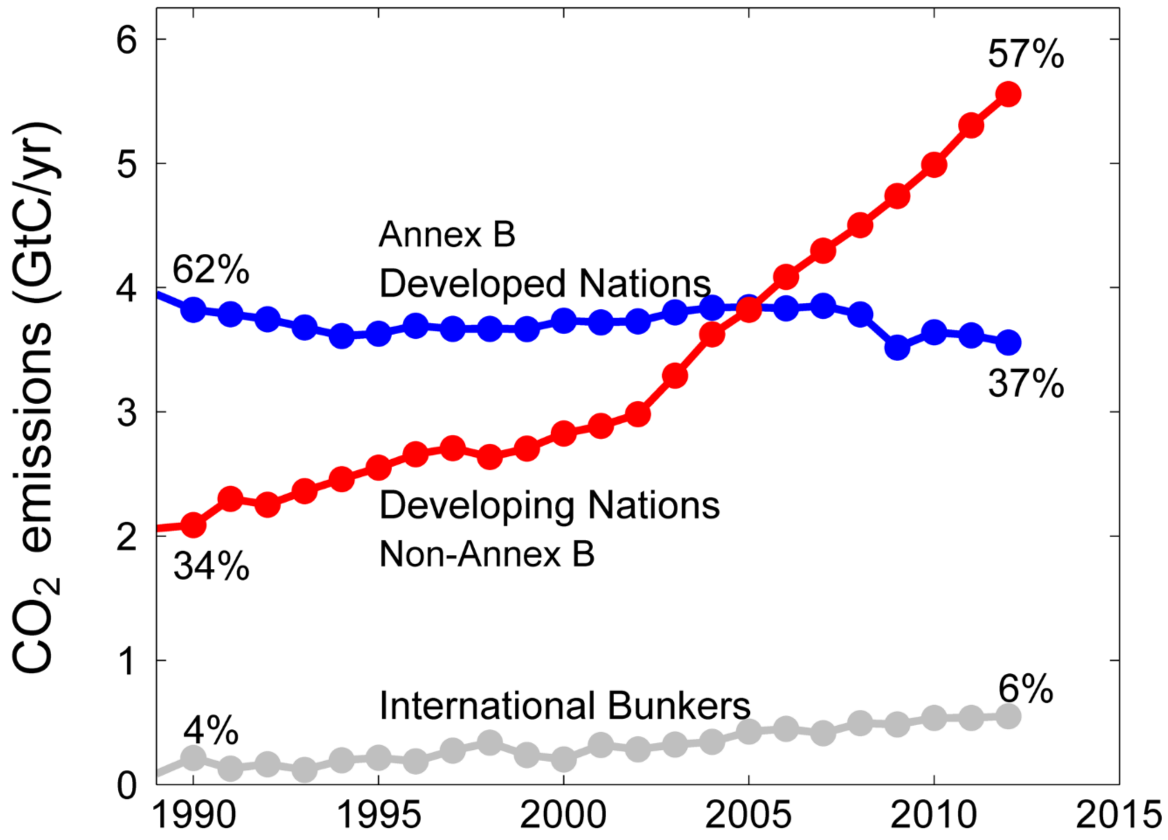


Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Territorial Emissions as per the Kyoto Protocol

The Kyoto Protocol was negotiated in the context of emissions in 1990

The global distribution of emissions is now starkly different

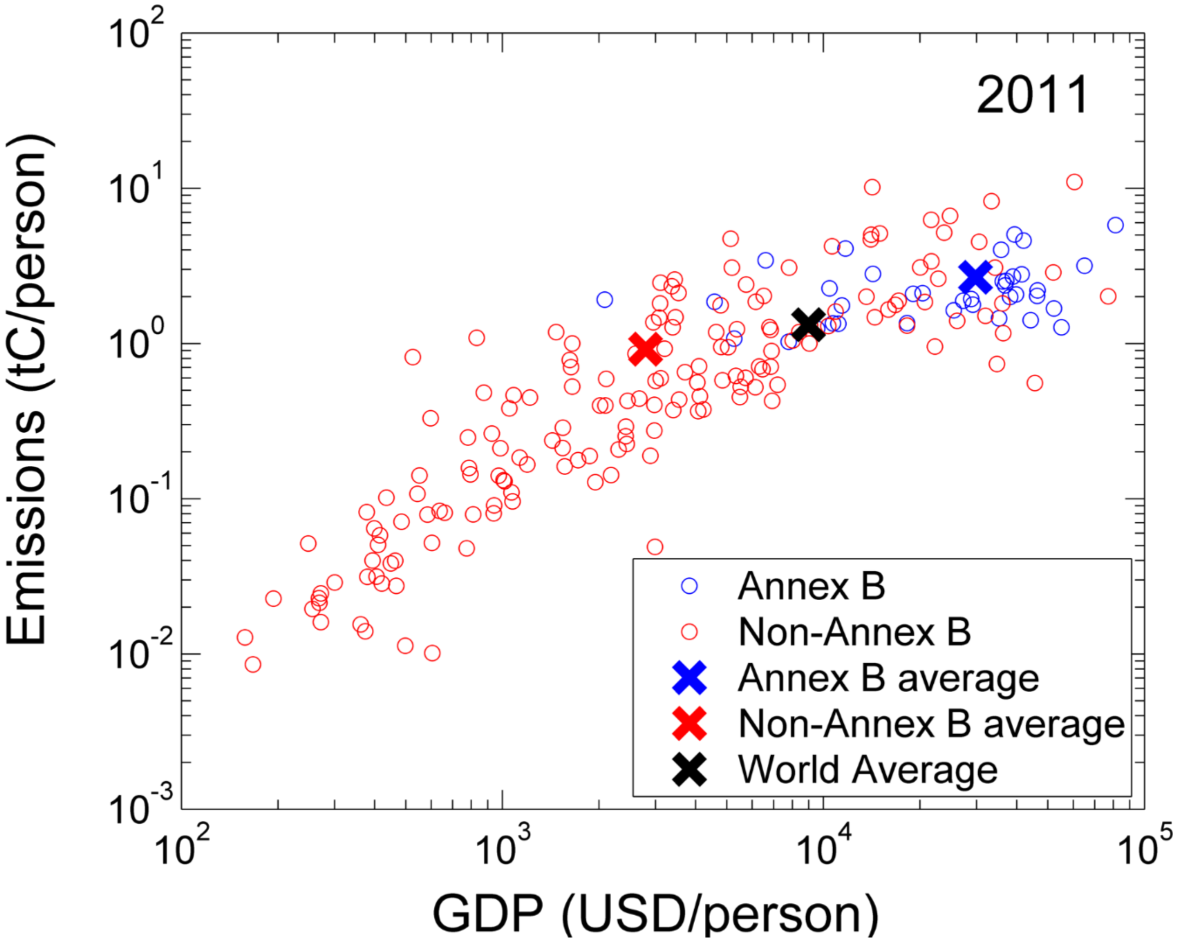


Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Annex B versus non-Annex B Countries

Annex B countries have emission reduction commitments in the Kyoto Protocol

Annex B countries do not necessarily have highest economic activity per capita



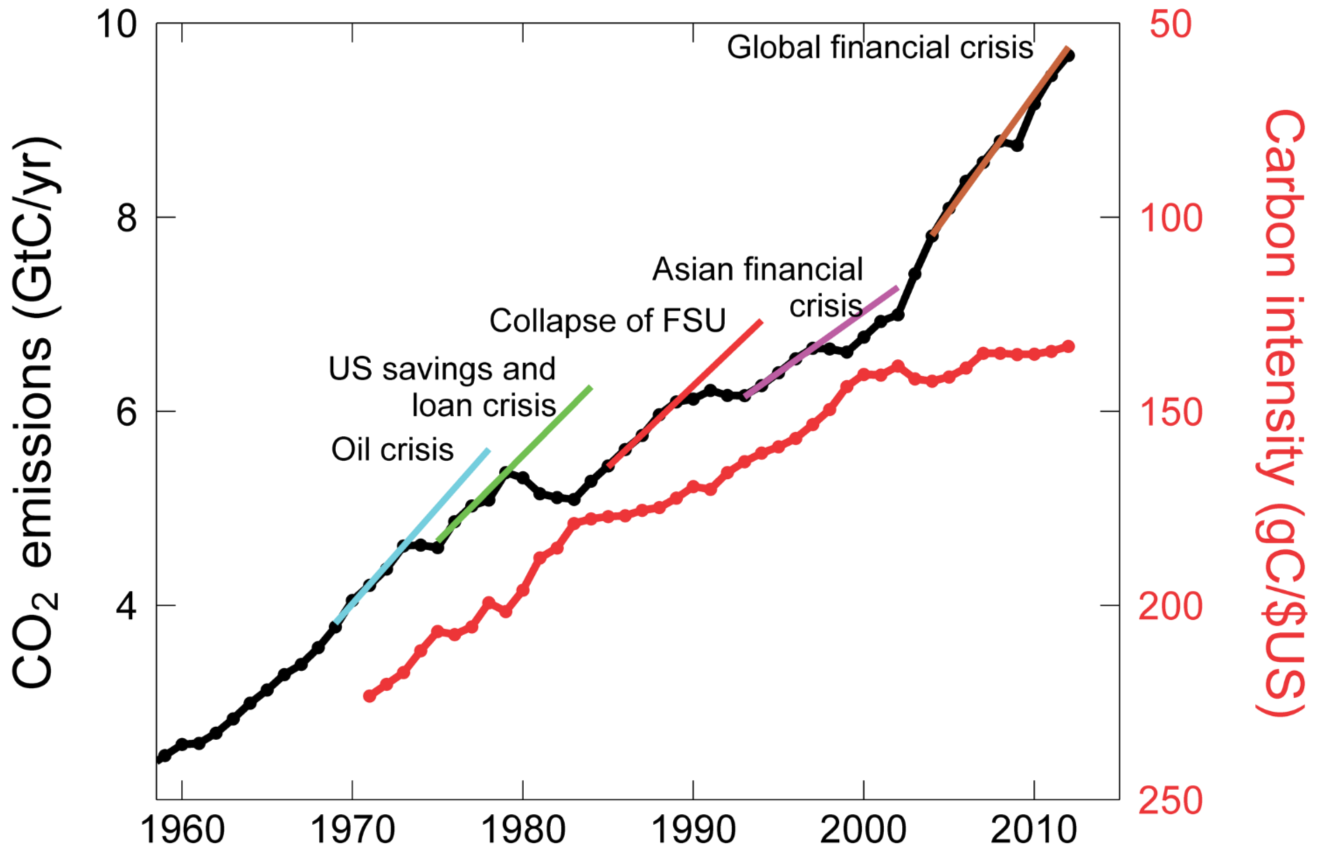
GDP is measured in Market Exchange Rates

Source: CDIAC Data; Unstats; Global Carbon Project 2013

Carbon Intensity of Economic Activity

The global financial crisis of 2008–2009 had no lasting effect on emissions

Carbon intensity has had minimal improvement with increased economic activity since 2005



Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Key Statistics

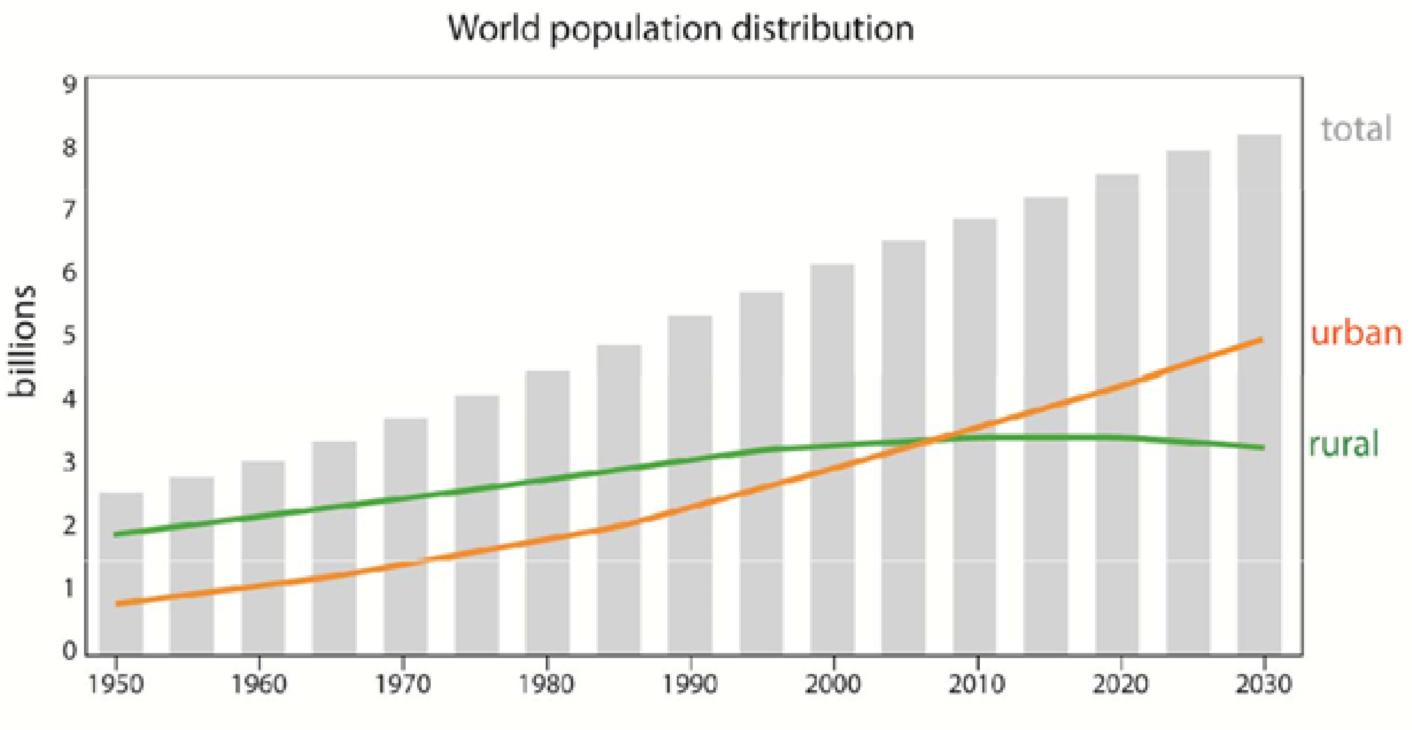
Emissions 2012

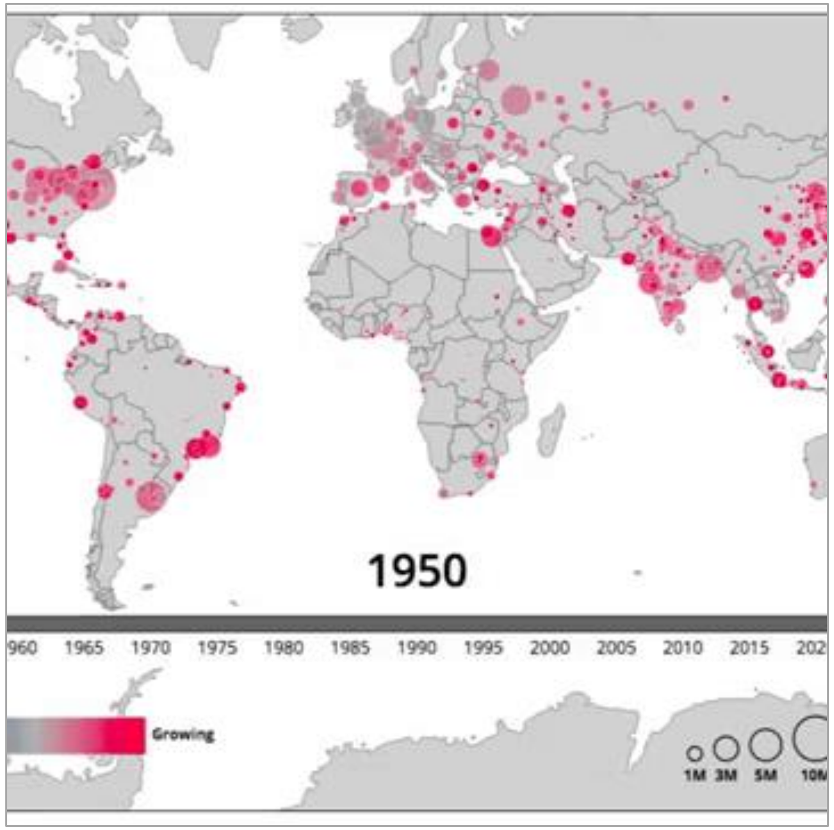
Region/Country	Per capita	Total		Growth 2012	
	tC per person	Gt C	%	Gt C	% per year
Global (with bunkers)	1.4	9.7	-	0.21	2.2
Developed Countries (Annex B)					
Annex B	3.0	3.60	37	-0.058	-1.6
USA	4.6	1.40	14	-0.053	-3.7
Russian Federation	3.4	0.50	5.0	-0.001	-0.2
Japan	2.5	3.40	3.5	0.022	6.9
Germany	2.4	0.20	2.1	0.004	1.8
Canada	4.0	0.14	1.4	-0.001	-0.6
Developing Countries (non-Annex B)					
Non-Annex B	0.9	5.6	57	0.251	4.7
China	1.8	2.6	27	0.146	5.9
India	0.5	0.61	6.3	0.044	7.7
South Korea	3.4	0.17	1.7	0.002	1.1
Iran	2.1	0.16	1.7	0.005	3.1
Saudi Arabia	4.6	0.14	1.4	0.008	5.9
International Bunkers					
Aviation and Shipping	-	0.55	6	0.014	2.5

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Complex Interconnections: Urbanization

By 2050, ~70% people will live in urban!

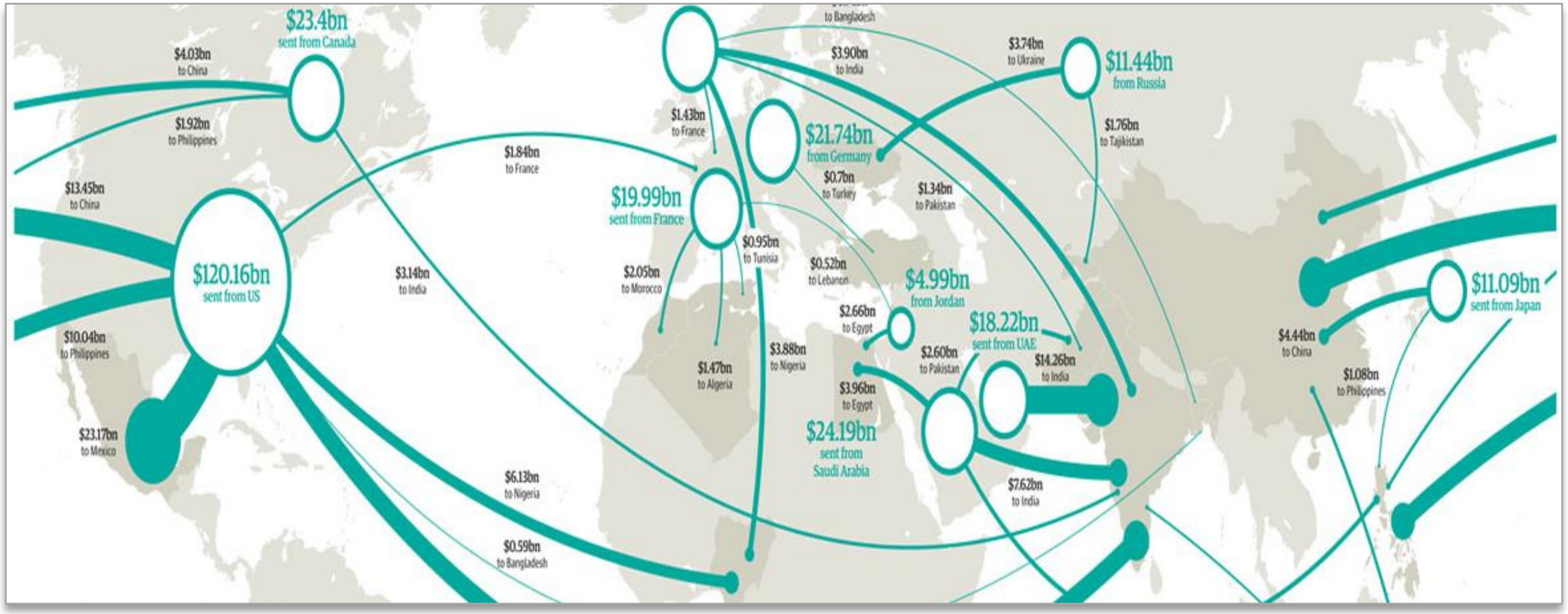




https://www.mathematica.org/commentary/global-urbanization

Global Remittances: another complexity

“The planet has undoubtedly ‘gotten smaller’, thanks to the amazing influence of the internet and a host of other technological advances. These changes leave us not only with more ways to communicate long distances, to send money remittance and to travel; they also give us more interest in foreign cultures and more opportunity to work remotely.”



https://blog.sharemoney.com/wheres-my-money-incredible-infographic-of-global-remittances/

Global Remittance: another complexity

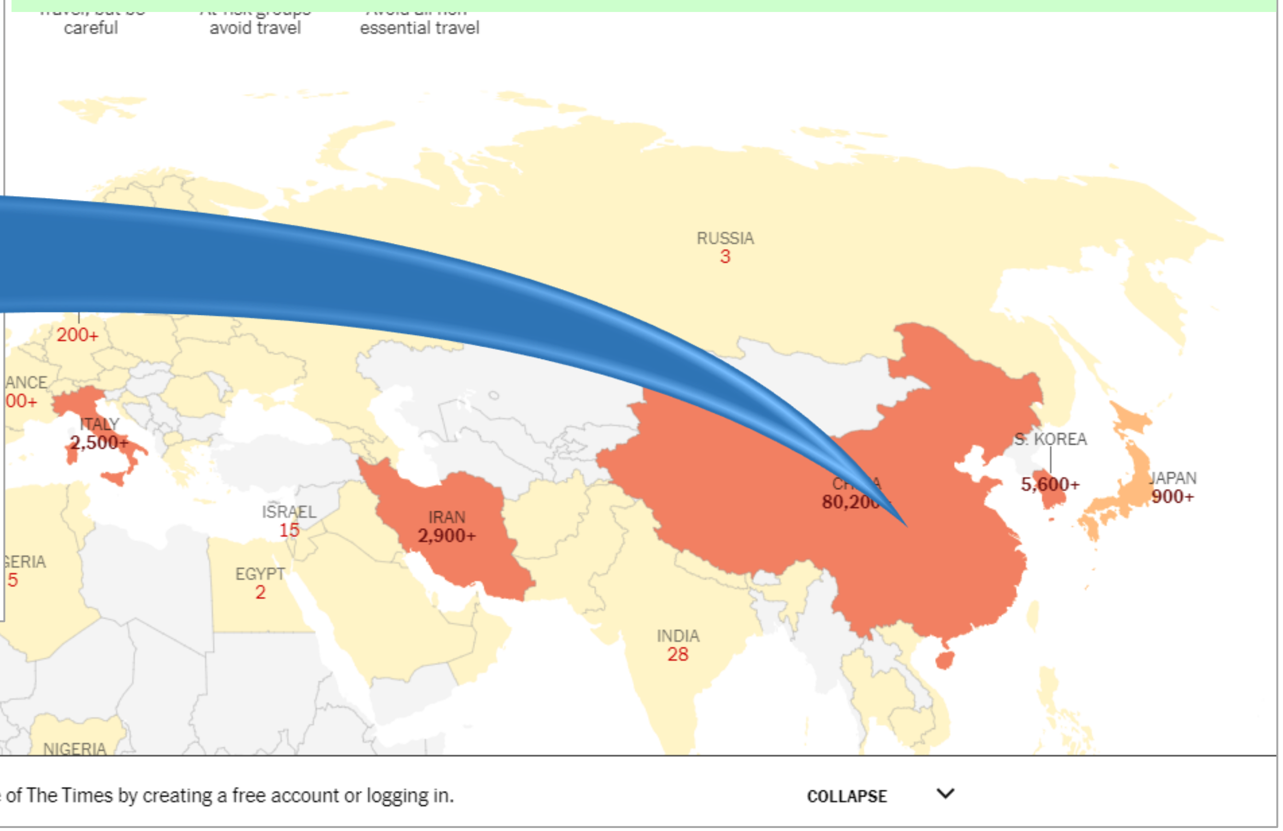
- In many developing economies, workers migrate from rural to urbans in search of gainful employment.
- Labor migrants often remit a portion of their earnings to their families back home – global impacts.
- The top five recipients of remittances relative to GDP were Nepal, Liberia, Tajikistan, Kyrgyzstan, & Bermuda, comprising 32.2%, 31.2%, 28.8%, 25.7%, and 25.0% of their GDP.
- Global remittances in 2015 were >$210 billion; it reached $529 billion in 2018 and $550 billion in 2019. This is >3 times of Kaz GDP in 2019 ($170 billion)
- Global remittances are projected to decline sharply by 20% in 2020, due to the economic crisis induced by the **COVID-19** pandemic and shutdown.

https://migrationdataportal.org/themes/remittances

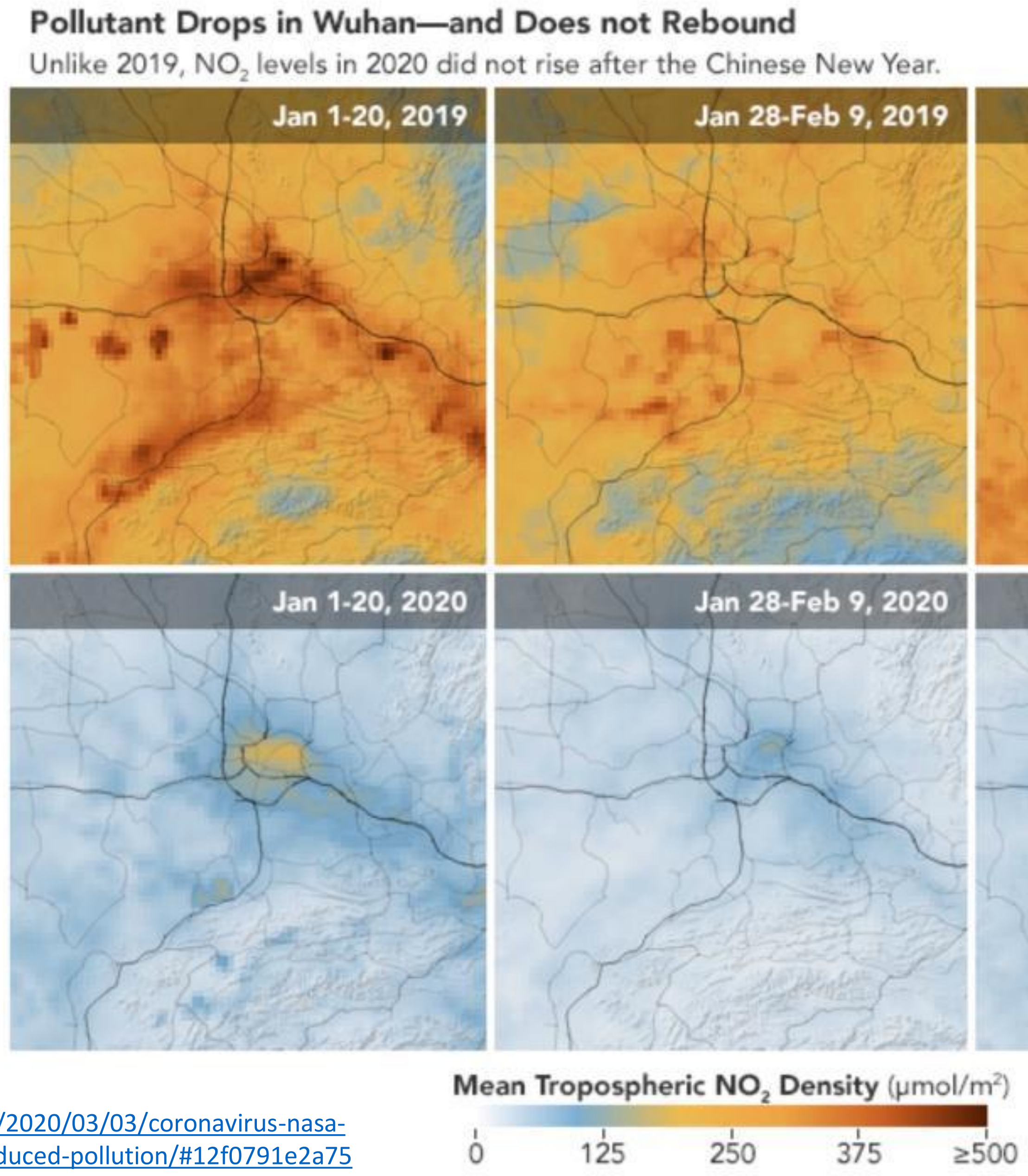
What happens in one place can affect elsewhere, globally.

Coronavirus concerns: Shelves emptied of face masks, sanitizer

- Not mentioning the tumbling stock market!
- Global health is our health!



Complex Interconnections: Corona Virus



https://www.forbes.com/sites/trevornace/2020/03/03/coronavirus-nasa-reveals-how-cinas-lockdown-drastically-reduced-pollution/#12f0791e2a75

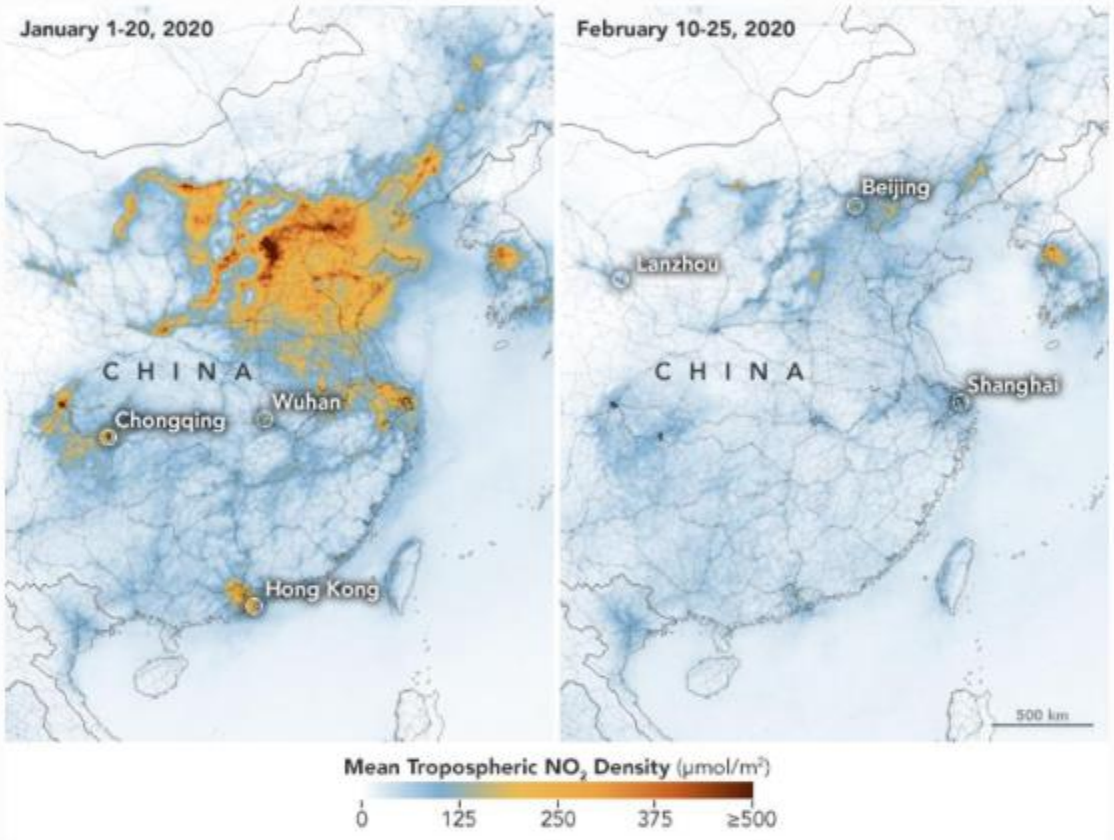
Complex Interconnections: Corona Virus

- The map below shows how NO_2 concentration changed from the period right before the Chinese government shut down transportation and factories compared to after the shutdown. The darker red areas show higher concentrations of NO_2, centered primarily around Beijing.
- The first reduction in NO_2 surrounded Wuhan and since then spread across the country. NASA scientists note that this is the most dramatic drop in pollution over a short time period across a county they have seen.

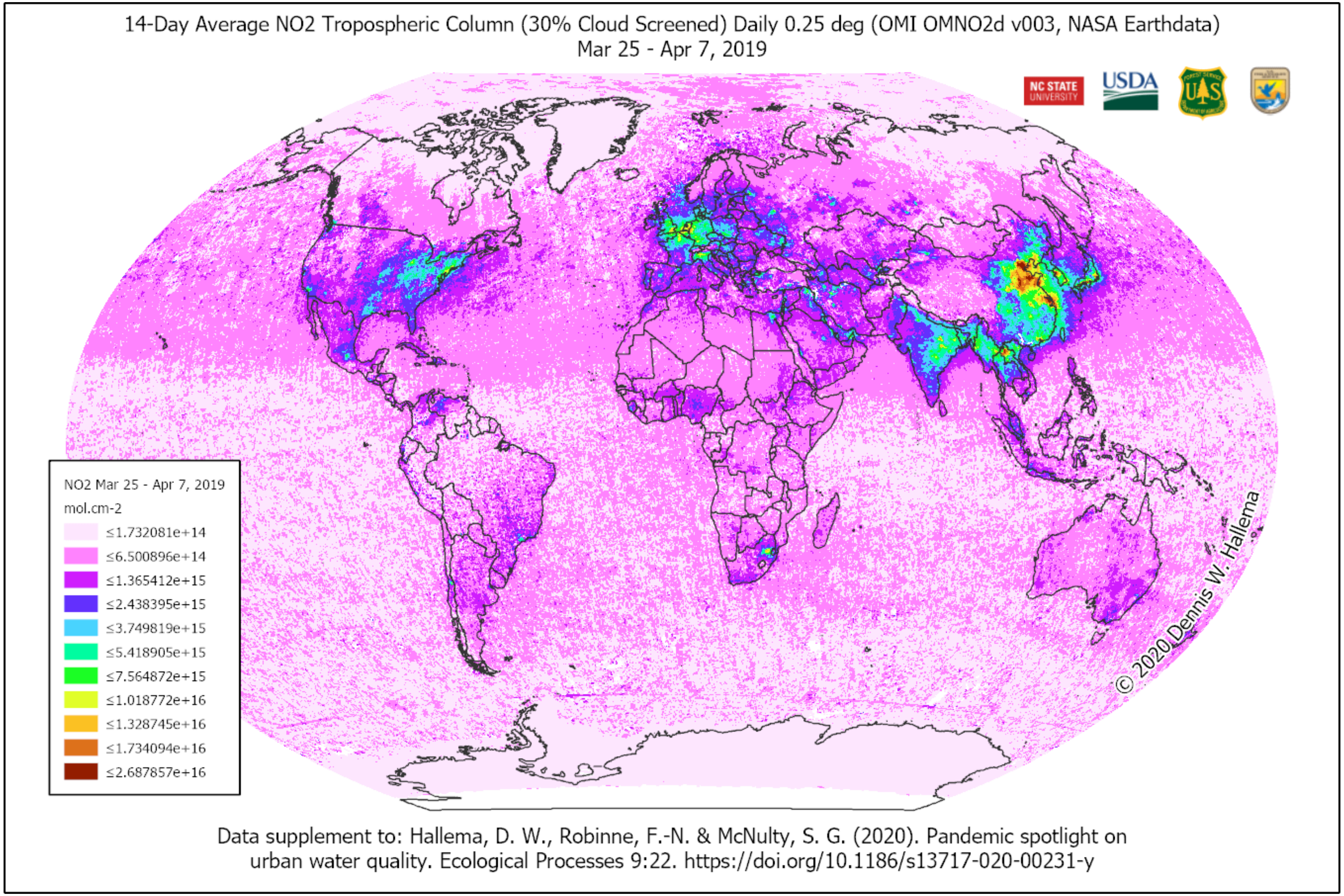
https://www.forbes.com/sites/trevornace/2020/03/03/coronavirus-nasa-reveals-how-cinas-lockdown-drastically-reduced-pollution/#12f0791e2a75

Coronavirus: NASA Reveals How China's Lockdown Drastically Reduced Pollution

Trevor Nace Senior Contributor
Science
Explore More



Nitrogen dioxide before vs after Coronavirus. NASA



Hallema, D. W., Robinne, F. N., & McNulty, S. G. (2020). Pandemic spotlight on urban water quality. *Ecological Processes*, *9*, 1-3.

Complex Interconnections: Corona Virus