

Climate Change

A Natural Process Influenced by Man

The Greenhouse Effect

Simplified Explanation

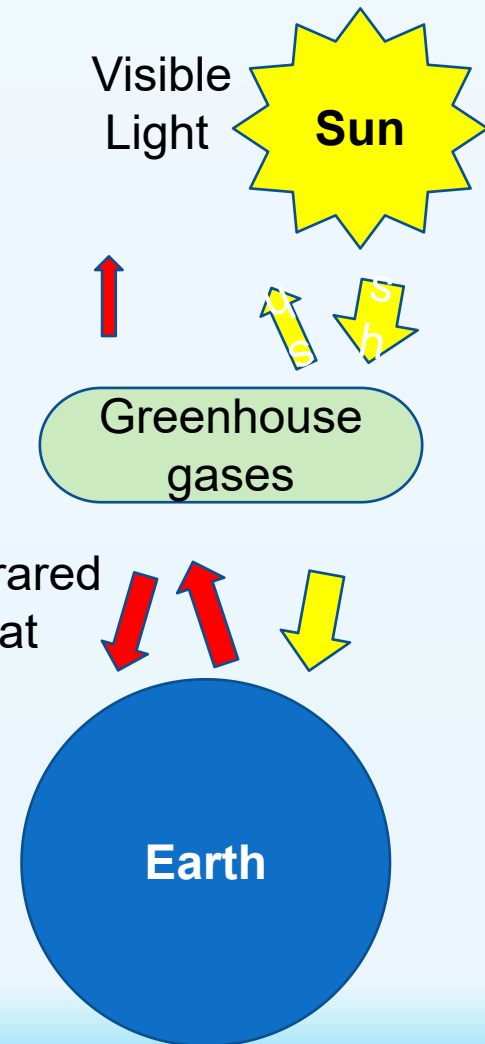
Solar Energy (visible light) emitted from SUN reaches Earth's atmosphere

- Some reflected back to SPACE
- Some absorbed by ATMOSPHERE & CLOUDS
- Some strikes and warms the EARTH surfaces

Solar energy re-emitted from EARTH's surface as radiant energy

- **Greenhouse gases** in atmosphere act like 1-way valves
 - More transparent to energy emitted from the Sun than energy radiating from Earth
 - Absorbs energy radiating from Earth
 - Reradiates some energy back towards Earth

Greenhouse gases trap more of the Sun's Energy



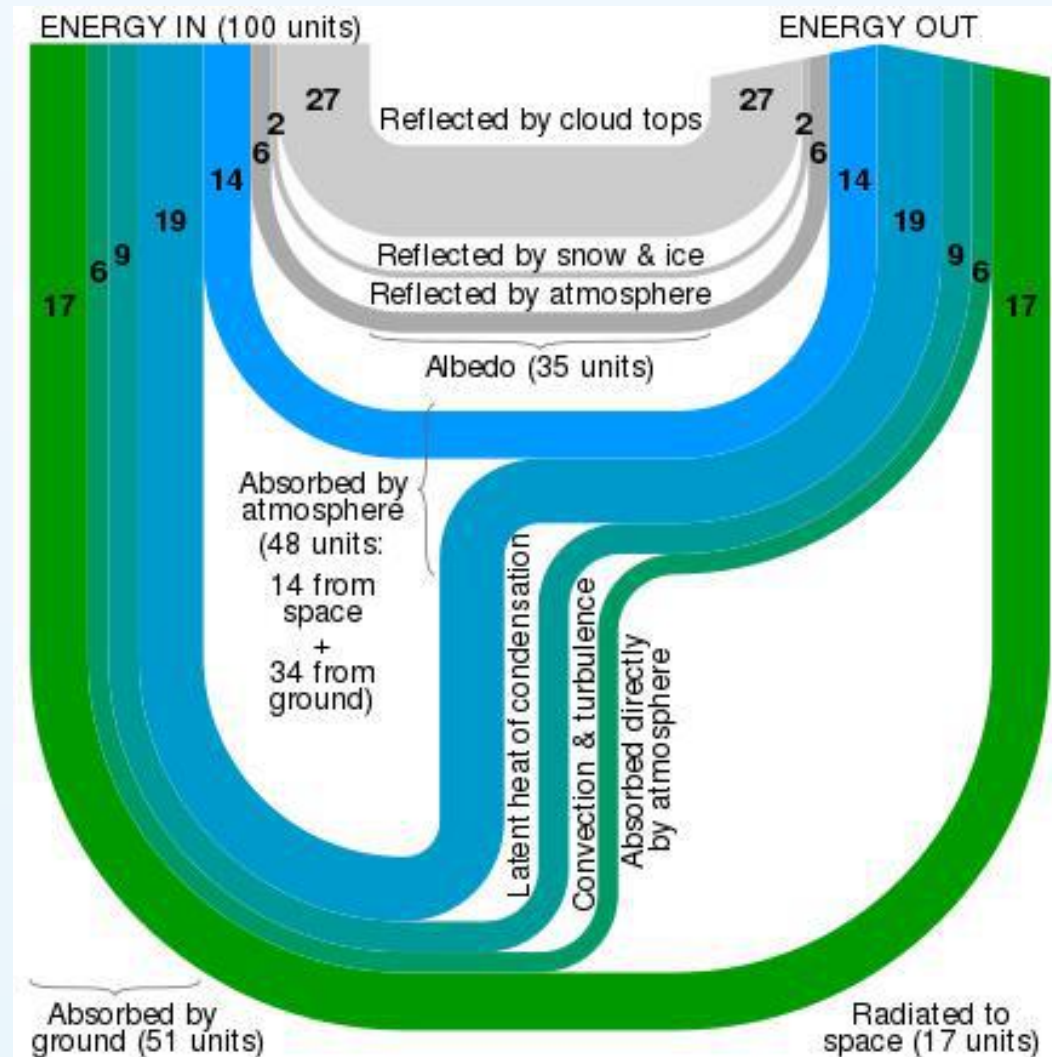
Earth Energy Balance

Energy from Sun

- 35% reflected to space
 - by cloud tops 27%
 - by snow & ice 2%
 - by atmosphere 6%
- 65% absorbed
 - by atmosphere 14%
 - by ground **51%**

Energy from Ground

- **17%** radiated to space
- **34%** to atmosphere
 - 19% latent heat
 - 9% convection
 - 6% absorbed directly by atmosphere



Climate Models

Large Uncertainty Yet Useful

Climate models

- Used to predict impact of man on the environment
- Cover atmosphere, oceans, land & ice-covered regions of the planet
- Equations represent processes & interactions driving Earth's climate
- Modeling uncertainties due to an incomplete understanding
 - Cloud formation
 - Water vapor and aerosols
 - Natural variability in the climate system
 - Ocean circulation
 - Thawing permafrost
 - Ice sheet collapse and sea level rise
 - measurement errors from imprecise observational instruments

Better at estimating temperature trends than absolute values

- Huge nodes due to computer hardware limitations and sparse measurements to validate models severely limit accuracy

Climate Models “too hot” *Exaggerates Impacts of Global Warming*

Authors of United Nations report on climate change report say

SCIENCEINSIDER | CLIMATE

Use of ‘too hot’ climate models exaggerates impacts of global warming

U.N. report authors say researchers should avoid suspect models

4 MAY 2022 • 11:00 AM • BY PAUL VOOSSEN

Equity over meritocracy generates bad predictions and decisions

- Large variation in accuracy of models (some good others bad)
- Equity says: Results of each model treated equally (no matter how faulty)
- **Merit**ocracy: Most accurate models used for temperature predictions
- UN belief in equity over **merit** (competance) extends from people to modeling

Equity over meritocray always produces worse results

- Less competent people (or models) produces less competent results

Global Warming vs Climate Change

Global warming

- **Long-term heating** of Earth's climate system observed since pre-industrial period due to **human activity**

Climate Change

- **Long-term changes** in average weather patterns which define **local** and **global** climates due to **natural processes & human activities**

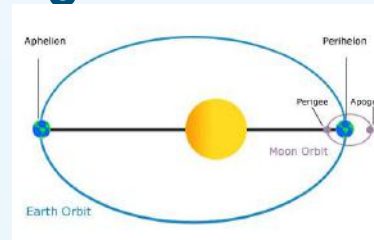
Multiple forces effect global warming and climate change

- **Nature**

- Solar activity



Earth's orbit



Volcanic Activity

- **Man**

- Fossil fuel use



Land use



- **Man + Nature**

- Wildfires



Global Warming Potential (GWP) *Defined*

Different GHGs have different effects on the Earth's warming

- **Radiative efficiency:** some gases absorb more energy
- **Lifetime:** some gases remain in the atmosphere longer

Global warming potential (GWP)

- Defines **warming** effect of gases, by mass, **relative to Carbon Dioxide (CO₂)**
- **CO₂** has a GWP of 1 and **remains in atmosphere for 300 years or more**

Potential heating estimated for 20 and 100 years

- Gases which breakdown or drop out of the atmosphere within 100 years have higher 20-year than 100-year GWPs
- Multiple factors effect the GWP
 - Location of emissions:
 - Longer distance to drop out from higher altitude
 - Solar radiation

- "Understanding Global Warming Potentials." EPA, Environmental Protection Agency, 14 Feb. 2017, [www.epa.gov/ghgemissions/understanding-global-warming-potentials#:~:text=The%20larger%20the%20GWP%2C%20the,for%20GWPs%20is%20100%20years.&text=Nitrous%20Oxide%20\(N2O,than%20100%20years%2C%20on%20average.](http://www.epa.gov/ghgemissions/understanding-global-warming-potentials#:~:text=The%20larger%20the%20GWP%2C%20the,for%20GWPs%20is%20100%20years.&text=Nitrous%20Oxide%20(N2O,than%20100%20years%2C%20on%20average.)

Global Warming Potential (GWP) Values

Primary man-made greenhouse gases

Gas	20-year GWP	100-year GWP	Atms Concentration [ppb]		
			pre-industrial	2021	increase
Carbon Dioxide (CO ₂)	1	1	278	414.7	49%
Methane (CH ₄)	84-87	28-36	0.722	1.896	163%
Nitrous Oxide (N ₂ O)	264	265	0.271	0.335	24%

Water vapor is the most abundant greenhouse gas

- Complexity of water vapor cycle with evaporation, condensation, & cloud formation causes differences in heating predictions
 - Some analysis predicts minimal net heating effect as reflectance of solar energy from above offsets reflectance of radiant energy from Earth
 - Others claim responsibility for 50% of total greenhouse gas effect
 - Others claim a net cooling effect
- Understanding Global Warming Potentials." EPA, Environmental Protection Agency, 14 Feb. 2017, [www.epa.gov/ghgemissions/understanding-global-warming-potentials#:~:text=The%20larger%20the%20GWP%2C%20the,for%20GWPs%20is%20100%20years.&text=Nitrous%20Oxide%20\(N2O,than%20100%20years%2C%20on%20average.](http://www.epa.gov/ghgemissions/understanding-global-warming-potentials#:~:text=The%20larger%20the%20GWP%2C%20the,for%20GWPs%20is%20100%20years.&text=Nitrous%20Oxide%20(N2O,than%20100%20years%2C%20on%20average.)

Water Vapor & the Hydrological Cycle

Water vapor

- Occurs as humidity & clouds
- Warmer air holds more moisture

Man-made warming

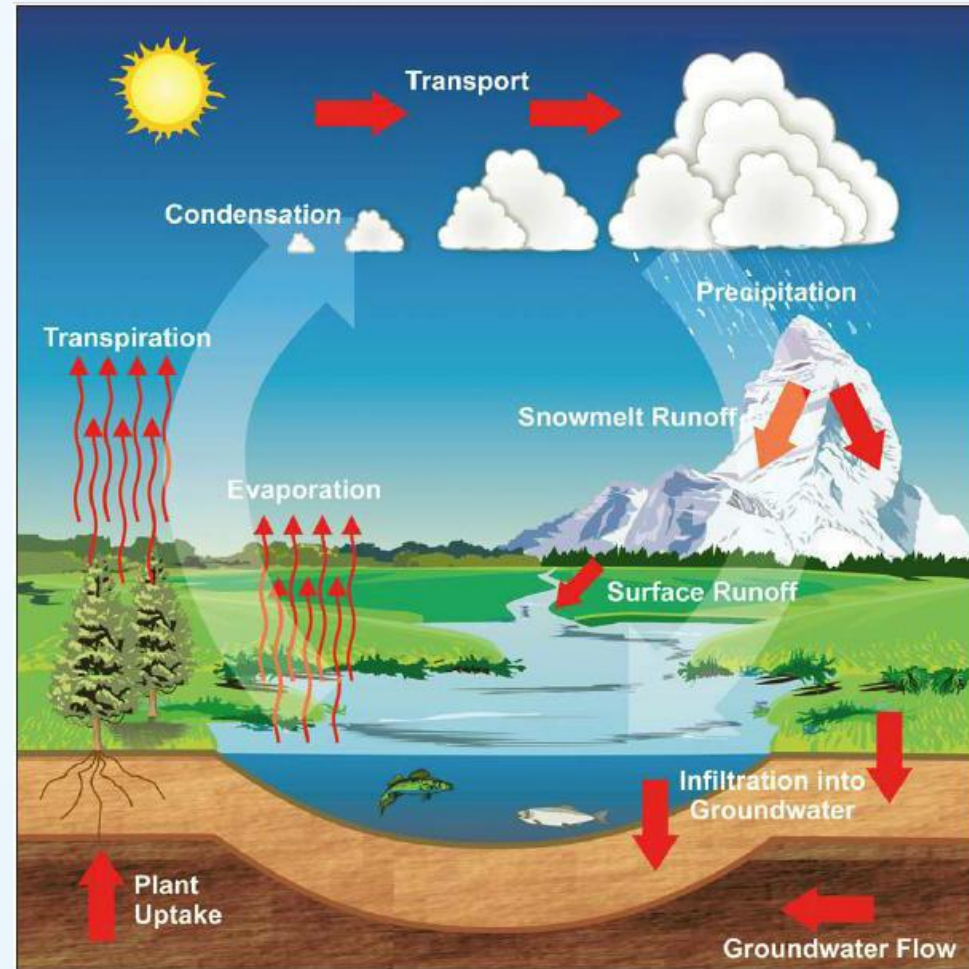
- ↑ Air & ground temperatures
- ↑ Evaporation
- ↑ Transpiration
- ↑ Water content of air

Clouds cool

- Reflects Sun's energy to space

Humidity warms

- Reflects Earth's radiant energy



- Buis, Alan. "Steamy Relationships: How Atmospheric Water Vapor Supercharges Earth's Greenhouse Effect." *Climate Change: Vital Signs of the Planet*, NASA, 8 Feb. 2022, climate.nasa.gov/ask-nasa-climate/3143/steamy-relationships-how-atmospheric-water-vapor-supercharges-earths-greenhouse-effect/. Accessed 26 Apr. 2022.

How Clean is Natural Gas (methane)

Less CO₂ than Coal but More Methane

While utilities tout natural gas (methane) as a clean fuel and important element in the fight against global warming

- It generates about **half the CO₂** as coal when burned in efficient turbines
- It produces virtually none of the toxic by-products of coal
- Extraction does not scar the earth like strip mining

Gas has 85 times the warming potential of CO₂ (over 20 years)

- **Leakage:** during the drilling, storage, transport & consumption poorly tracked
- **Warming effect:** often unaccounted for when gas replaces other fuels

Gas use increasing to replace coal & backup solar & wind

○ **Wind & Solar power plants = natural gas turbines inefficiently run**

- Turbines **burn more gas** to respond to variability of unreliable renewables
- Turbines wear out quicker



"Combined Cycle Power Plant GE Gas Power,." GEpower-V2, www.ge.com/gas-power/resources/education/combined-cycle-power-plants.

Greenhouse Gas Monitoring



National Ocean & Atmospheric Administration (NOAA) responsible for monitoring atmospheric greenhouse gas concentrations

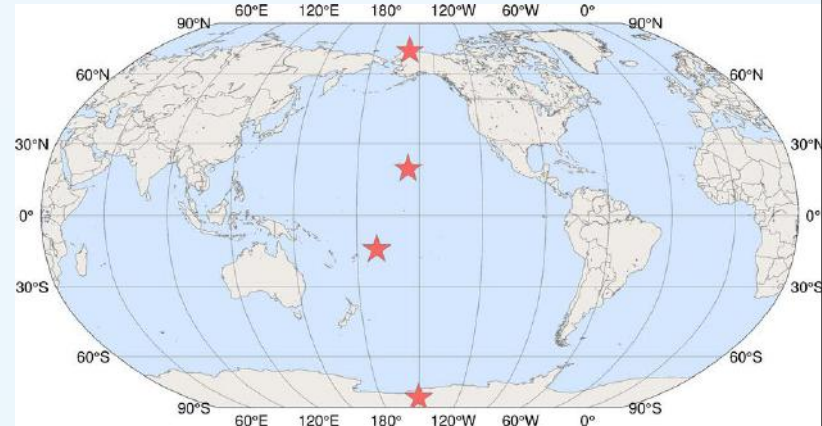
- **Global Monitoring Laboratory**

- **Collects & analyzes** more than 15,000 air samples annually from **4 primary** & 50 cooperative sampling sites

- **Barrow Alaska**
- **Mauna Aloha, Hawaii**
- **America Samoa**
- **South Pole, Antarctica**

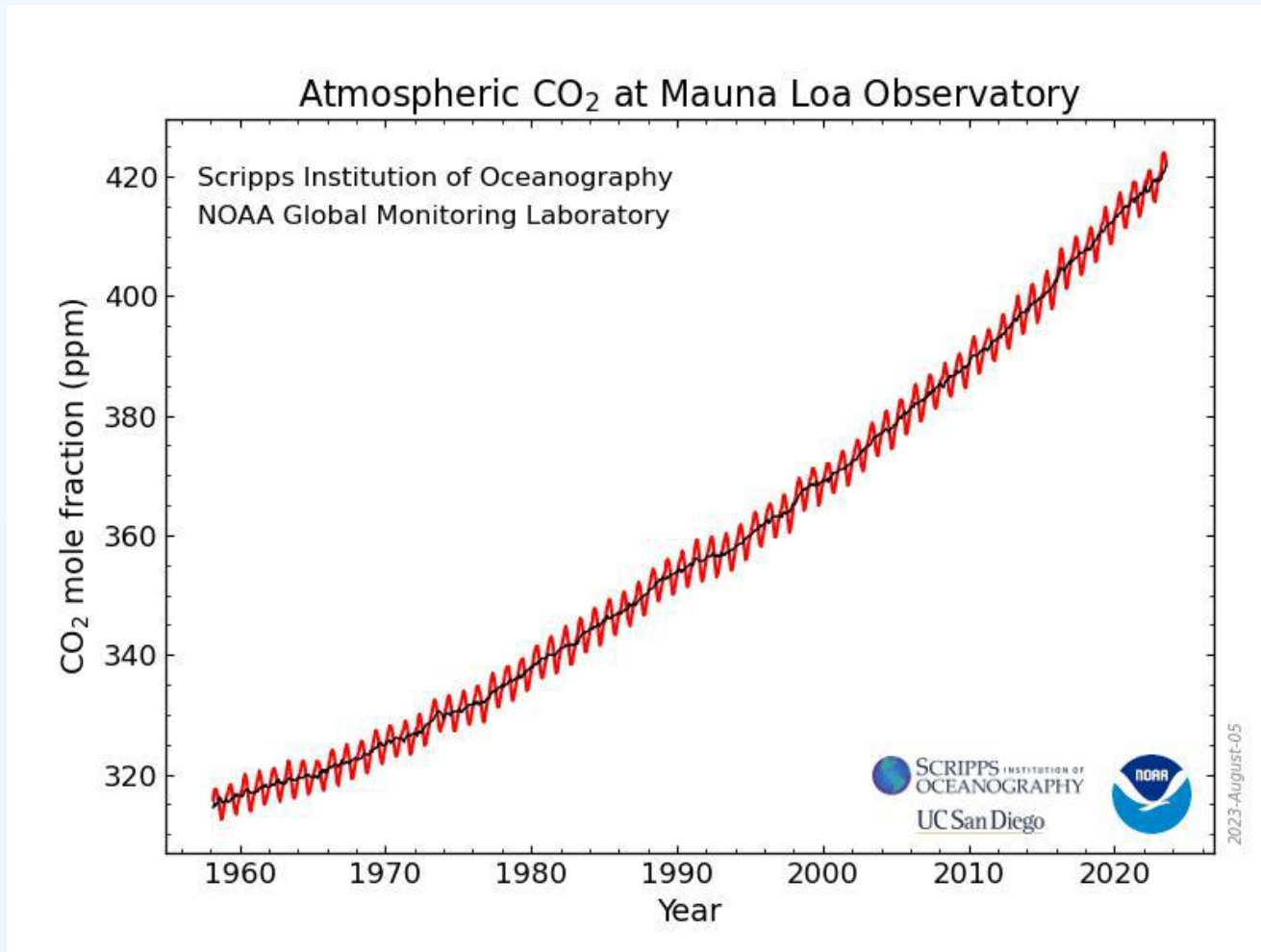
- **Calculates** the global average levels of **four** primary greenhouse gases

- **Carbon dioxide (CO₂)**
- **Methane (NH₃)**
- **Nitrous oxide (N₂O)**
- **Sulfur hexafluoride (SF₆)**



Atmospheric CO₂ Levels Since 1958

Steady increase

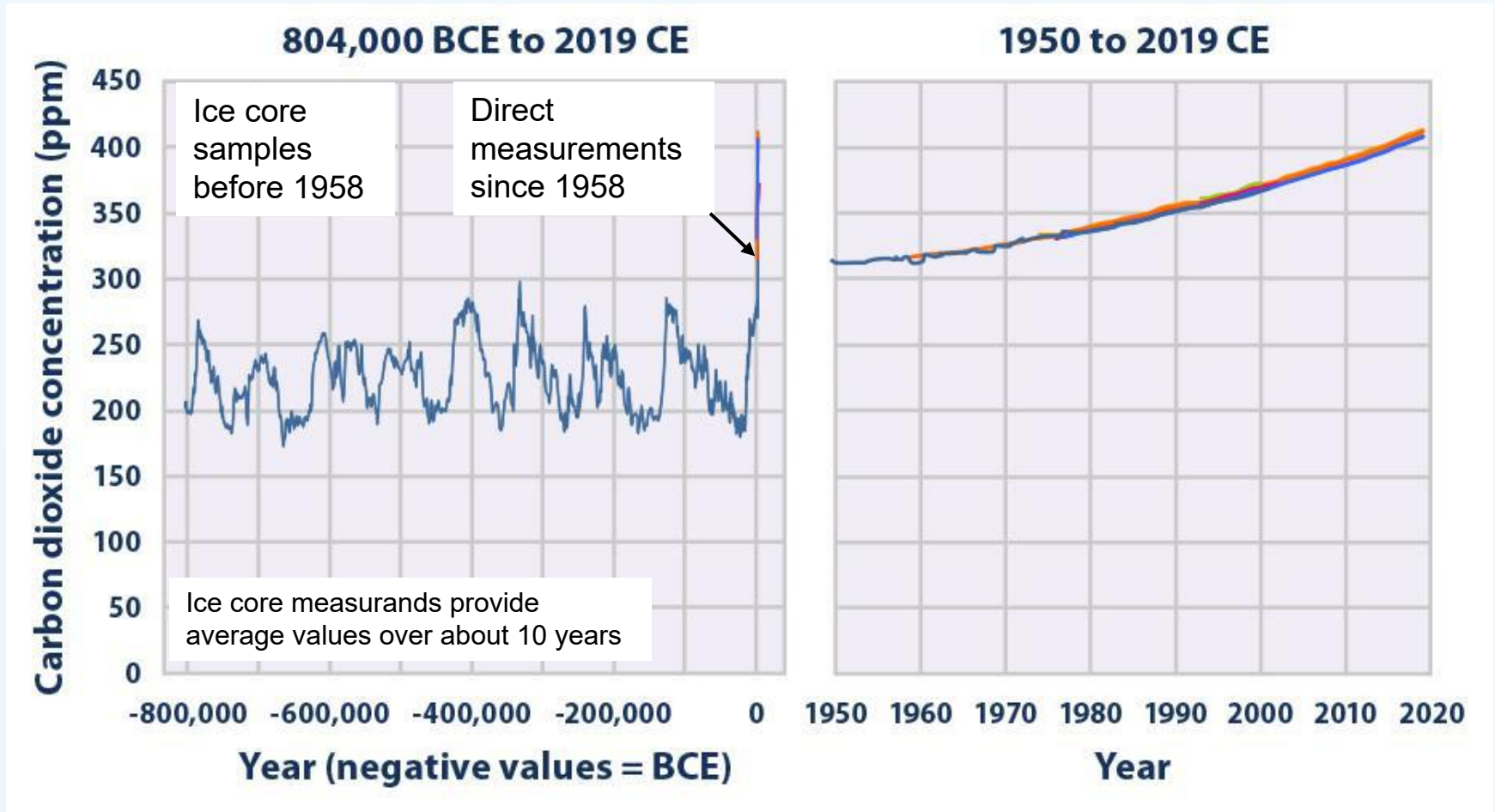


Data source: ESRL Web Team. "ESRL Global Monitoring Division - Global Greenhouse Gas Reference Network." NOAA.gov, 2005, www.esrl.noaa.gov/gmd/ccgg/trends/.

Atmospheric CO₂ Levels

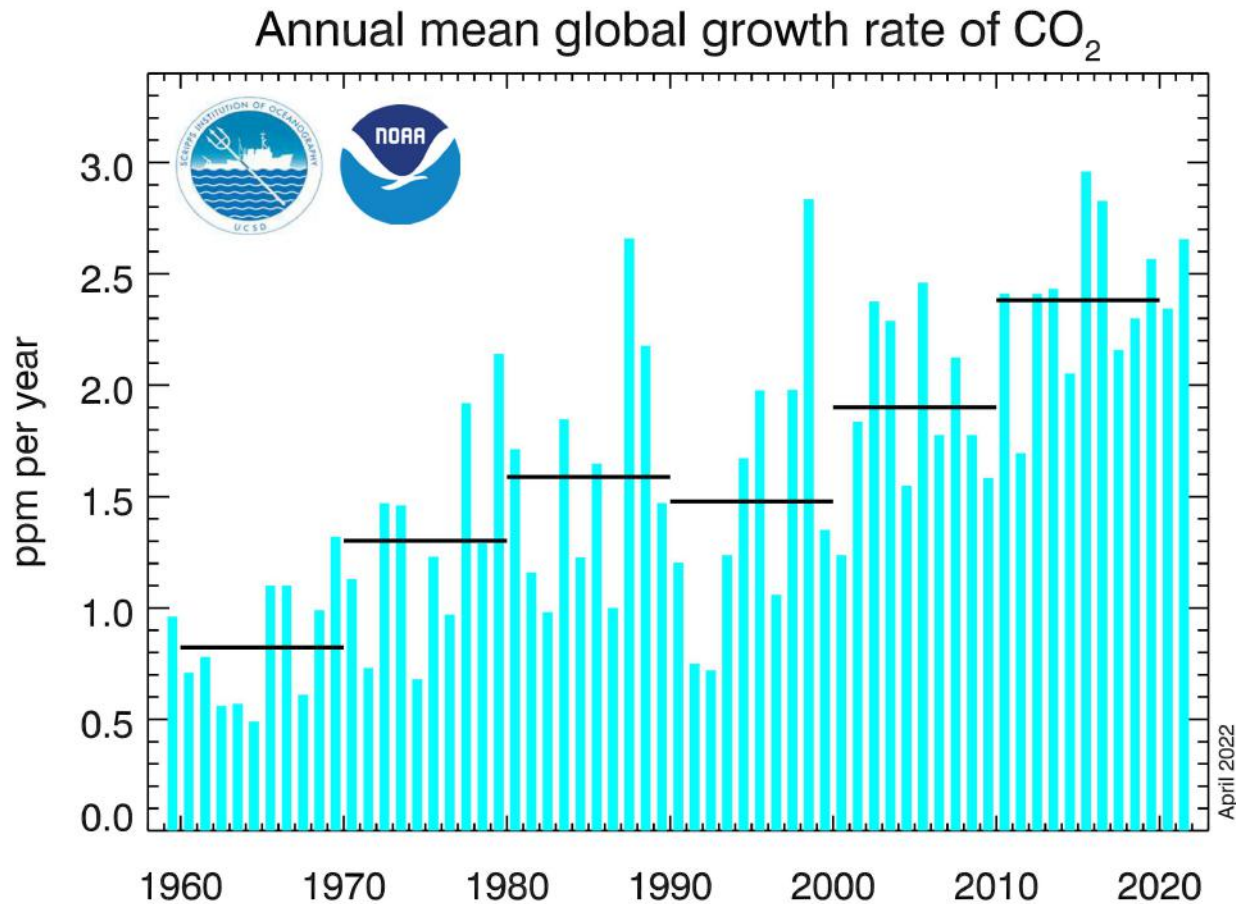
Ice Core Samples (-800,000 BC – 1958)

CO₂ rises 1/3rd in 60 years relative to peak 800,000 year sampling



Annual Growth Rate of CO₂ 1958 to 2021

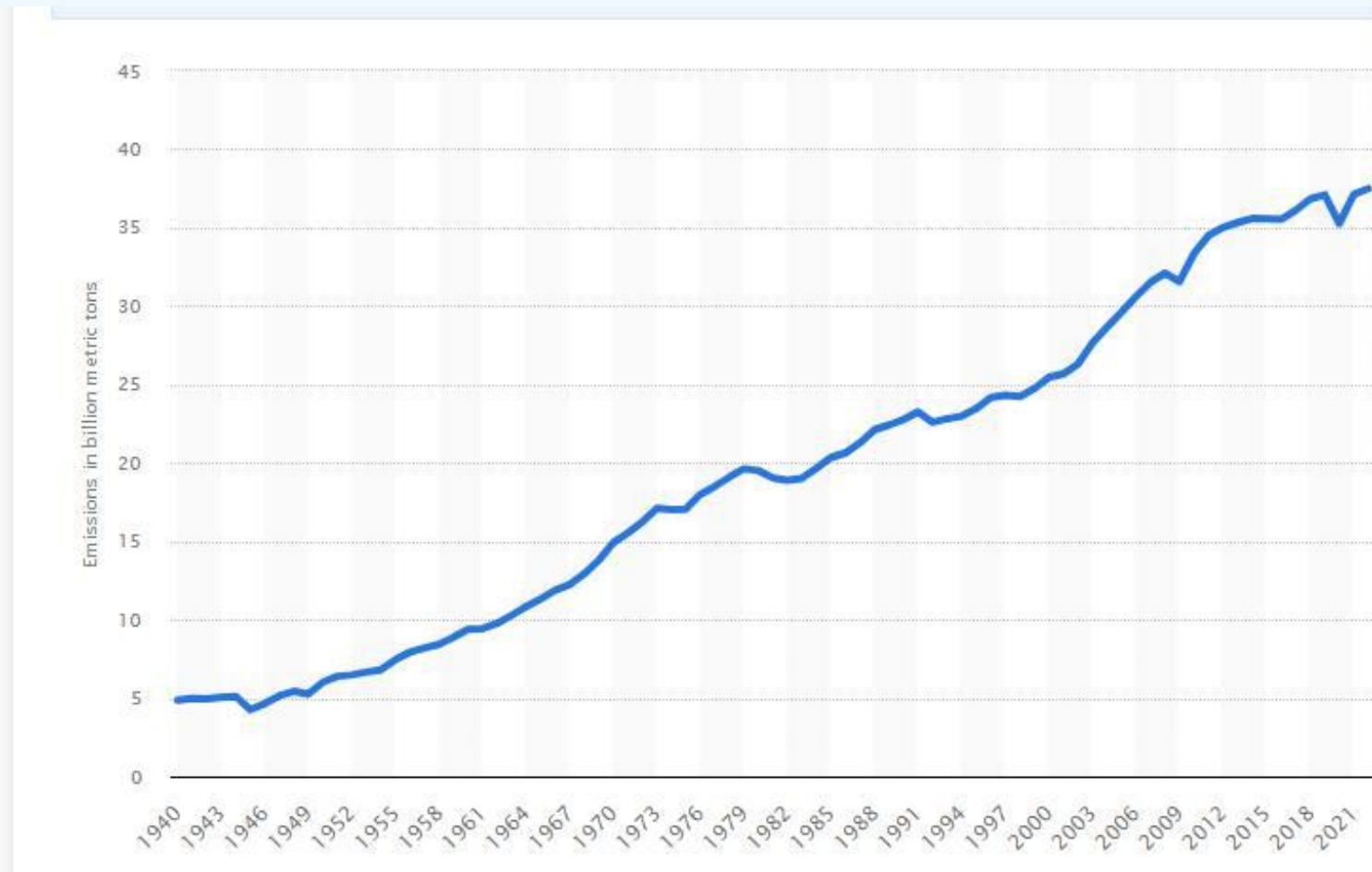
Atmospheric CO₂ levels accelerating upward



*“Increase in Atmospheric Methane Set Another Record during 2021 | National Oceanic and Atmospheric Administration.”
Www.noaa.gov, 7 Apr. 2022, www.noaa.gov/news-release/increase-in-atmospheric-methane-set-another-record-during-2021.
Accessed 25 Apr. 2022.*

Annual Worldwide CO₂ Emissions *Since 1940*

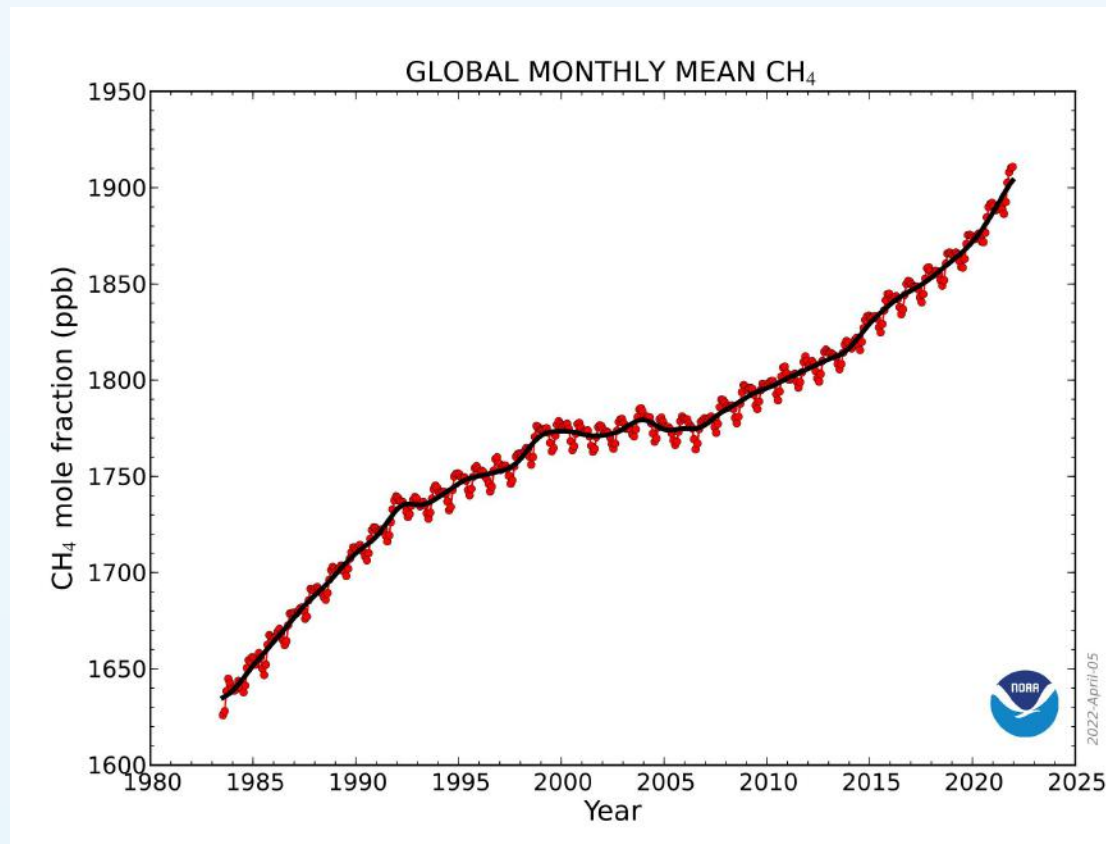
Recent reductions in growth rate due to gas replacing coal



Atmospheric Methane (CH₄) Levels 1982 to 2021

Asymptotic rise due to multiple factors

- Leakage from increased gas use
 - Coal replacement
 - Primary backup for unreliable renewables
 - Wind = gas plant
 - Solar = gas plant
- Permafrost thaw (Russia)
 - Temperatures rose 11 F above normal in 2020
 - Massive methane release from thawing soil
- Dams
 - Area specific

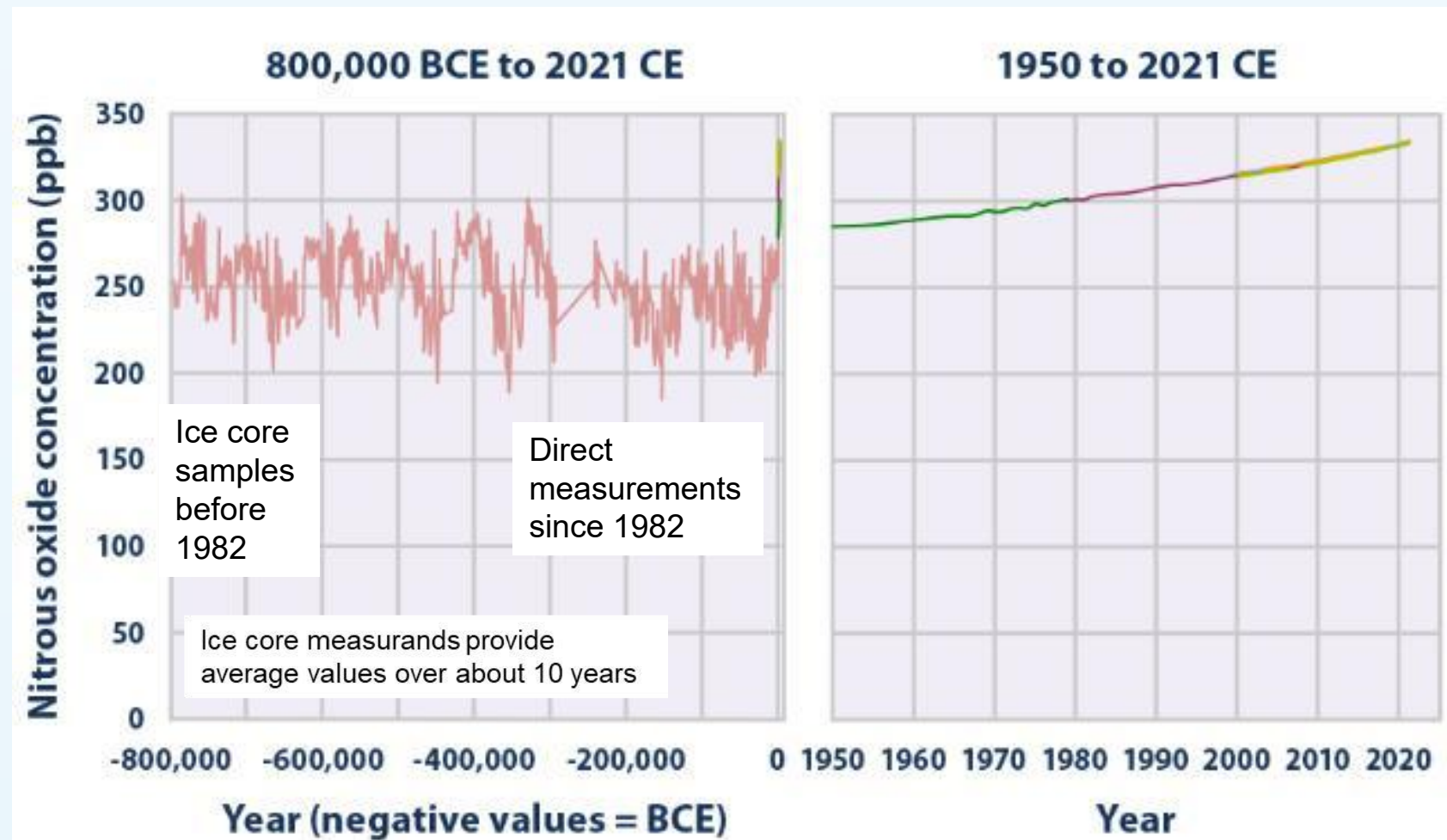


("Increase in Atmospheric Methane Set Another Record during 2021 | National Oceanic and Atmospheric Administration")

("Permafrost Thaw in Siberia Creates a Ticking 'Methane Bomb' of Greenhouse Gases, Scientists Warn." Smithsonian Magazine)

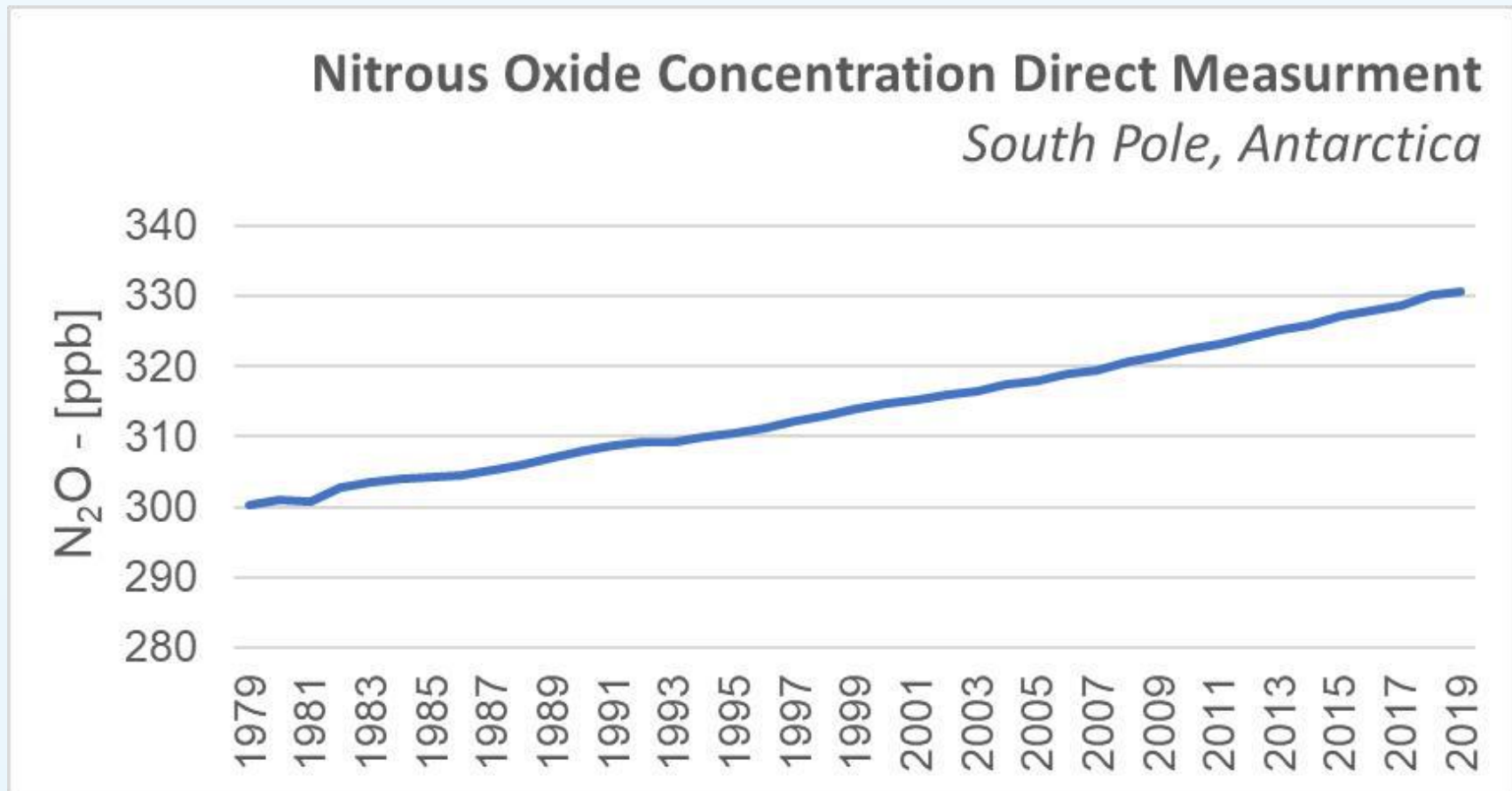
Atmospheric Methane (NH₃) Levels Ice Core Samples (-800,000 BC – 1982)

NH₂ rises 150% in 40 years relative to peak 800,000 year sampling



Atmospheric Nitrous Oxide (N₂O) Levels 1979 to 2019

Manmade Impact much less compared to CO₂ & NH₃

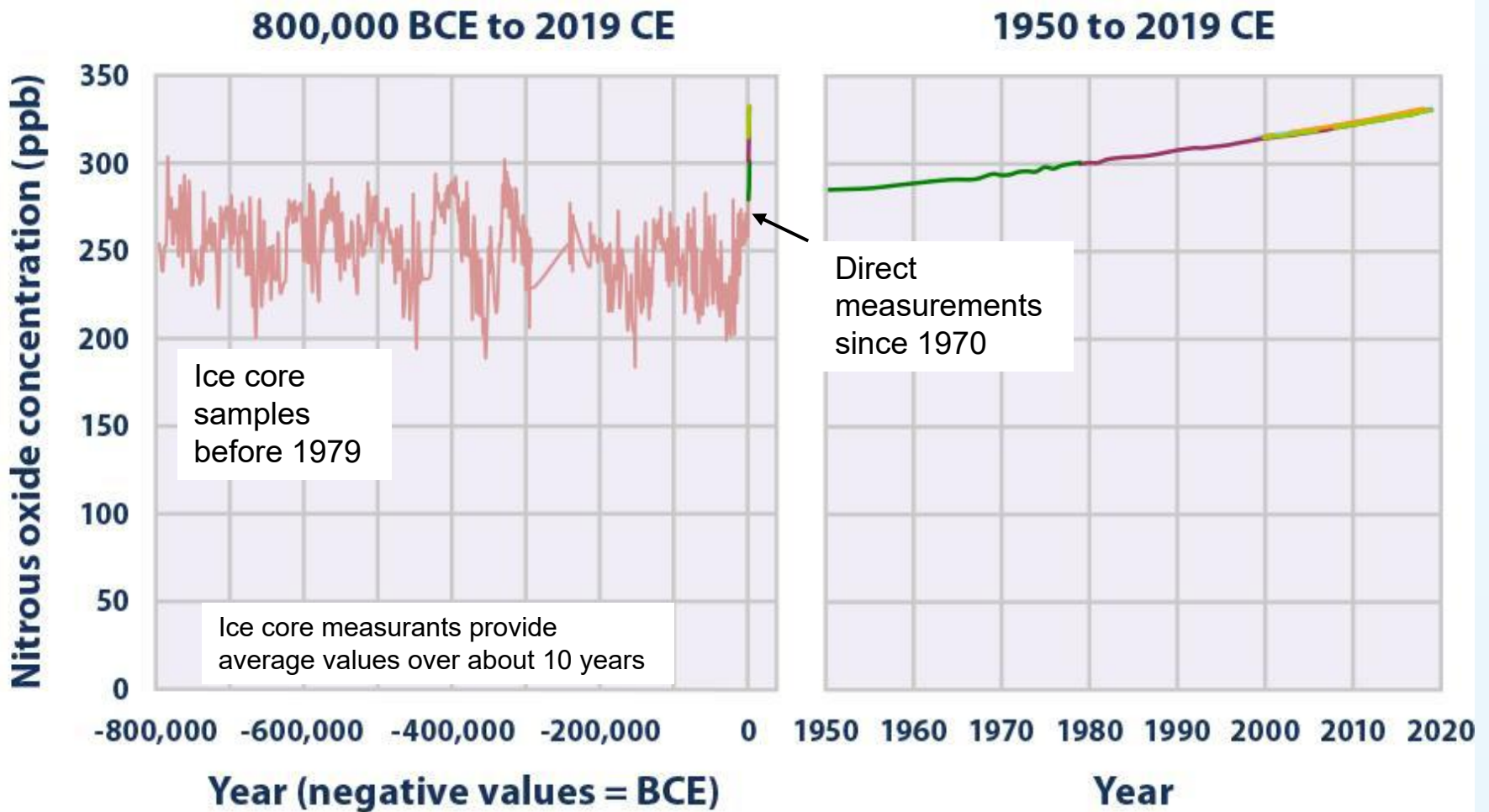


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Atmospheric Nitrous Oxide (N₂O) Levels Ice Core Samples (-800,000 BC – 1979)

N₂O rises 15% in 40 years relative to peak 800,000 year sampling



Primary Manmade Sources of Carbon Dioxide CO₂

Transportation:

- Fuel for transport (autos, planes, & train)
- Facility construction (roads and rail construction)



Electricity Generation:

- Coal and natural gas consumption



Heating

- Natural gas consumption



Industry:

- Fossil fuel consumption to run equipment or generate electricity:
- Chemical reactions
 - Cement
 - Certain metal production processes



Primary Sources of Methane Emissions



Natural wetlands & Paddy rice fields



Emission from livestock production systems

- Digestive processes & manure decomposition



Biomass burning

- Includes forest fires, charcoal combustion, & firewood burning

Anaerobic decomposition of organic waste

- Landfills & waste water treatment



Energy and Industry

- :Leakage from natural gas drilling, storage, & distribution, and oil drilling

Thawing of Permafrost:



64% of emissions estimated to come from human actions

Heilig, Gerhard K. "The Greenhouse Gas Methane (CH₄): Sources and Sinks, the Impact of Population Growth, Possible Interventions." *Population and Environment*, vol. 16, no. 2, Nov. 1994, pp. 109–137, link.springer.com/article/10.1007/BF02208779, 10.1007/bf02208779. Accessed 26 Apr. 2022.

Primary Sources of Nitrous Oxides (NO₃)

Natural Sources

- Soils under natural vegetation
- Tundra
- The Oceans



Manmade Sources

• Agricultural:

- Soil management (fertilizer, cultivation, and manure management);
- Fuel combustion
- Biomass combustion



• Industry:

- By-product of chemical processes
- By-product of waste-water treatment

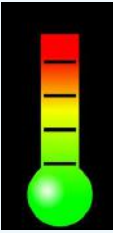


1/3rd of emissions estimated to come from human actions

Global Warming

Positive Feedback Mechanisms

Positive Feedback are natural processes that respond to global warming by further increasing temperatures

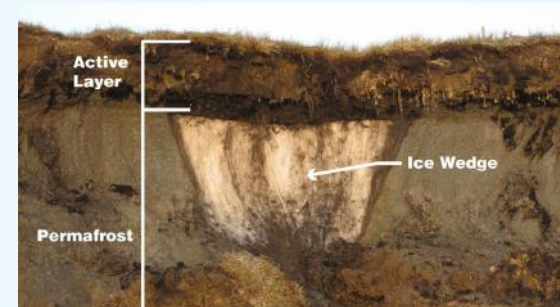


- Increased (↑) Temperature =



- ↑ **Microbe activity in Wetlands** =
- ↑ **CH₄ release** =
- ↑ **Temperature**

- ↑ **Permafrost melt** =
- ↑ **CH₄ release** =
- ↑ **Temperature**



- Drier forests =
- ↑ **Wildfires** =
- ↑ **CO₂ generation** =
- ↑ **Temperature**

- ↑ **Glacier melt** =
- ↑ **Solar absorption** from uncovered ground or ocean =
- ↑ **Temperatures** (ice reflects more solar energy back to space)



Total US Greenhouse Gas Emissions *by Economic Sector 2019*

Transportation

- Cars, trucks, ships, trains & planes

Electricity Generation

- **62% generated from fossil fuels**

Industry

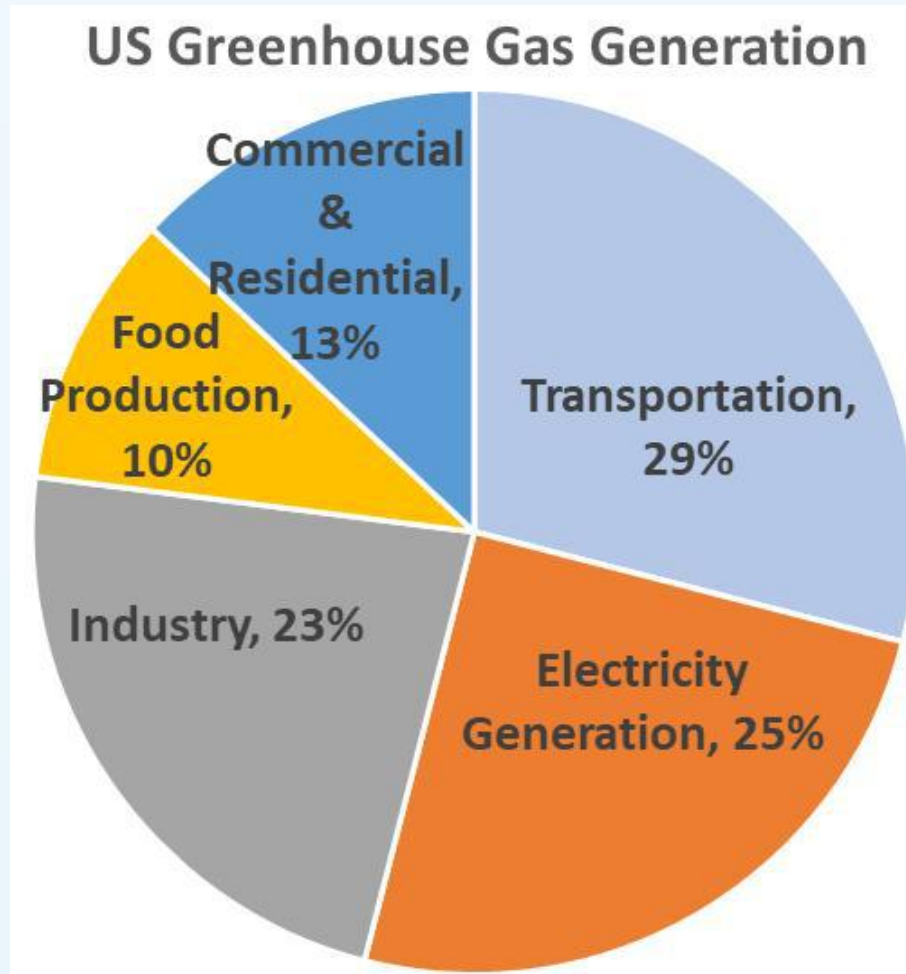
- Mostly fossil fuel burning & chemical reactions to produce raw materials

Commercial & Residential

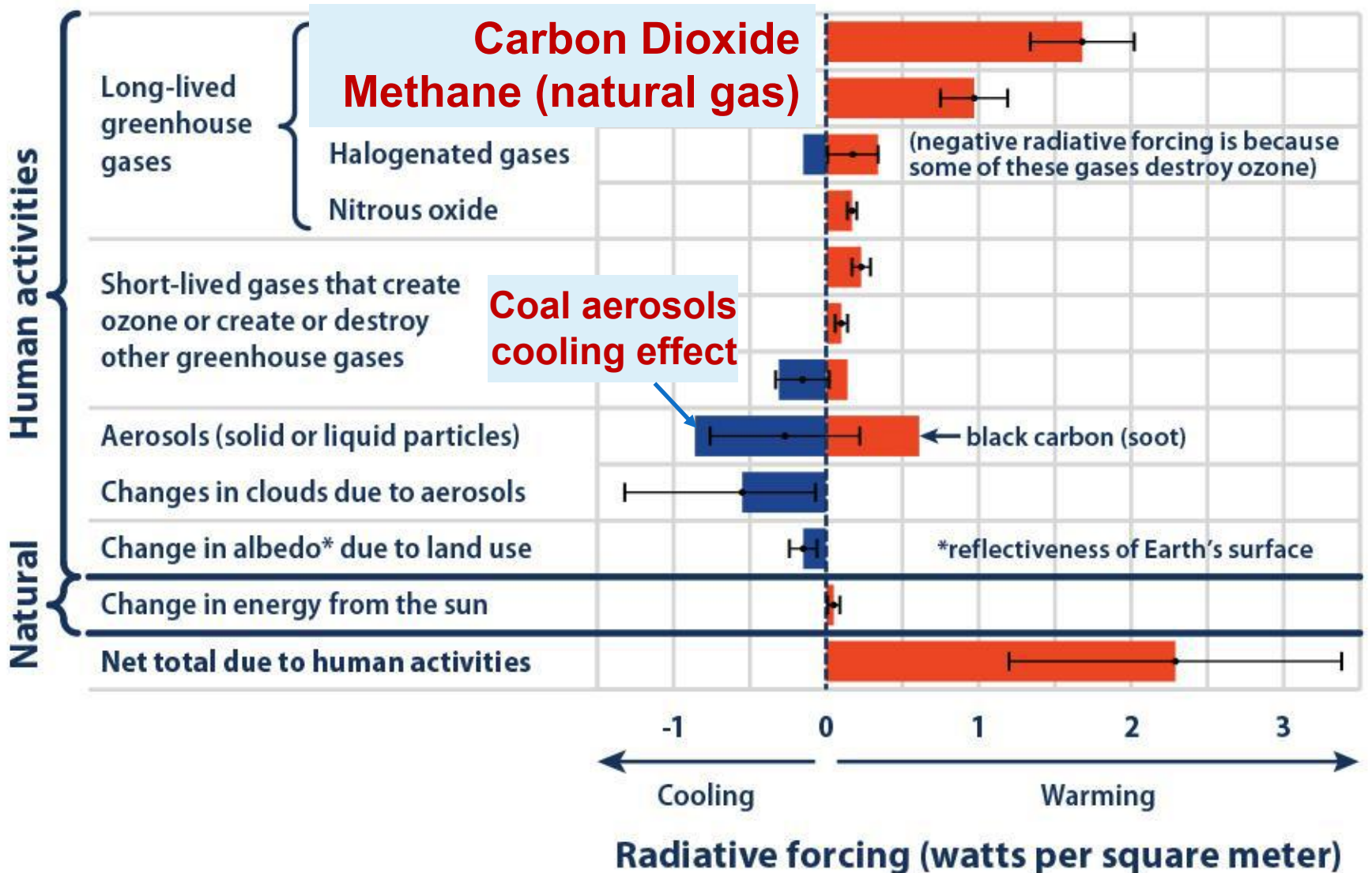
- Fossil fuels burned for heating
- Waste handling

Food Production

- Livestock
- Waste handling



Heating Caused by Human Activities (2016)



Sources of Primary Greenhouse Gases

Carbon Dioxide (CO₂)

- **Transportation:** fuel for transport (autos, planes, & train), facility construction (roads and rail construction)
- **Electricity Generation:** coal and natural gas consumption
- **Heating:** natural gas consumption
- **Industry:** fossil fuel consumption to run equipment or generate electricity: chemical reactions (cement and certain metal production processes)

Methane (CH₄) Mother Nature is the Largest Source

- **Nature:** swamps, permafrost melt,
- **Agriculture:** domestic livestock (digestive processes & manure)
- **Energy and Industry:** Leakage from natural gas use (drilling, storage, distribution)
- **Waste from Homes & Businesses:** Landfills, waste water treatment

Nitrous Oxides (N₂O)

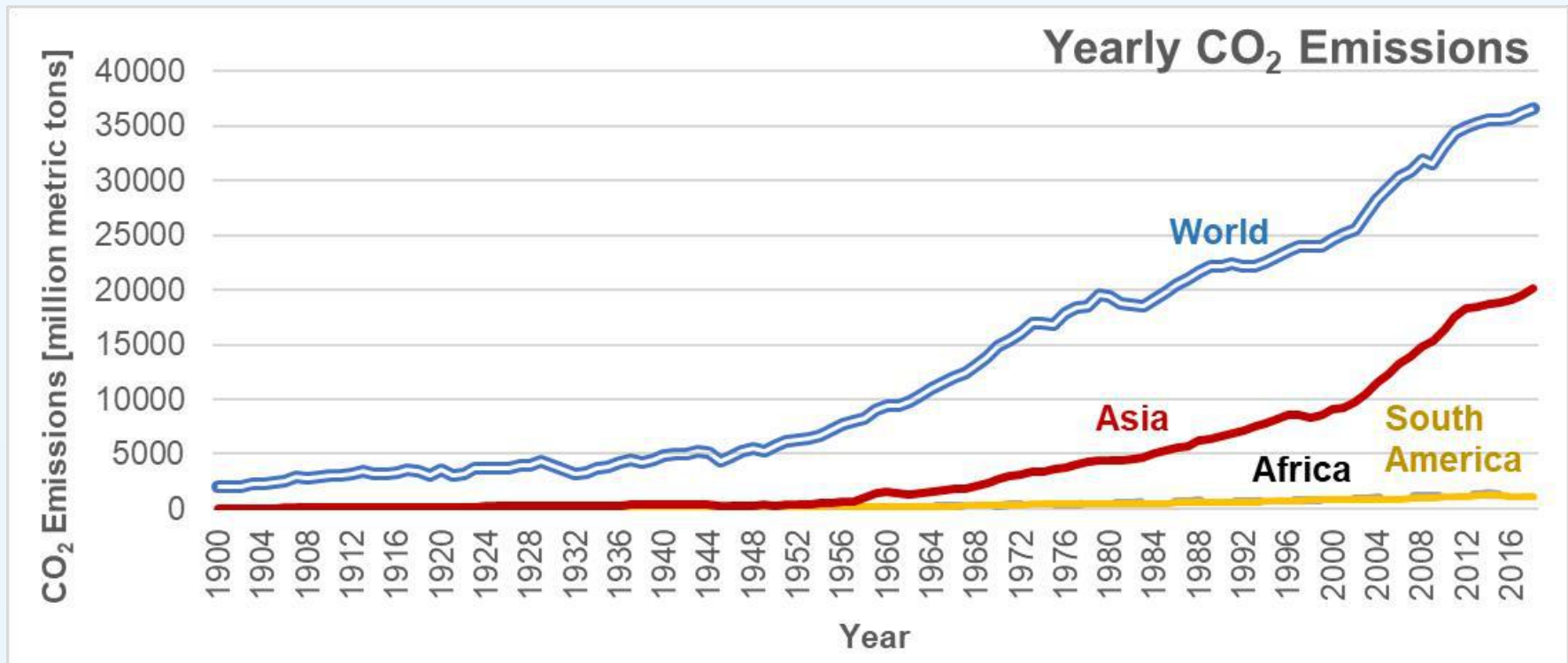
- **Agricultural:** soil management (fertilizer and manure management); fuel combustion;
- **Industry:** by-product of chemical processes and waste-water treatment

CO₂ Emissions

You Ain't Seen Nothing Yet

The only measurement that matters for climate change is greenhouse-gas emissions—and they continue to rise

- As South America & Africa develop CO₂ emission trends will follow Asia unless **RELIABLE 24/7** low carbon generation is implemented



Data source: Ritchie, Hannah, and Max Roser. "CO₂ and Other Greenhouse Gas Emissions." *Our World in Data*, 2017, ourworldindata.org/co2-and-other-greenhouse-gas-emissions.

Methane Transport from Trees

Methane (CH₄) causes 35-45-times more radiative heating than CO₂ on a mass basis during the first 100 years

CH₄ Generated by microbes in the soil

- Wetlands largest source of CH₄
- Prominent issue in Amazon

Trees act as conduit, transferring CH₄ from soils to atmosphere

- Deep roots pickup CH₄ over a large volume of ground

Important parameter in climate models previously unaccounted for

- Latest research indicates amount dramatically underestimated
- Could be 5 to 10% of worldwide generation

Too much credit taken for trees in battle against climate change

Covey, Kristofer R., and J. Patrick Megonigal. "Methane Production and Emissions in Trees and Forests." *New Phytologist*, vol. 222, no. 1, 11 Jan. 2019, pp. 35–51, 10.1111/nph.15624. Accessed 29 Sept. 2020.

Gauci, Vincent, et al. "Non-Flooded Riparian Amazon Trees Are a Regionally Significant Methane Source." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 380, no. 2215, 6 Dec. 2021, 10.1098/rsta.2020.0446. Accessed 23 Oct. 2022.

Global Warming

Positive Feedback Mechanisms

Positive Feedback are natural processes that respond to global warming by further increasing temperatures

- **Positive Feedbacks** difficult to stop since they build on themselves
 - **Increased (↑) Temperature =**
 - ↑ **microbe activity in wetlands** = ↑ **CH₄ release** = ↑ **Temperature**
 - ↑ **permafrost melt** = ↑ **CH₄ release** = ↑ **Temperature**
 - **Dryer forests** = ↑ **wildfires** = ↑ **CO₂ generation** = ↑ **Temperature**
 - ↑ **Glacier melt** = ↑ **solar absorption** from uncovered ground or ocean = ↑ **Temperatures** (ice reflects more solar energy back to space)

Methane



Wetlands

Methane



Permafrost

Carbon Dioxide

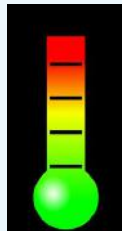


Wildfires

Solar Gain



Solar Gains



US Greenhouse Emissions (2019)

Transportation Sector

Transportation is the largest GHG generator

Electricity Generation

- 62% generated from fossil fuels

Industry

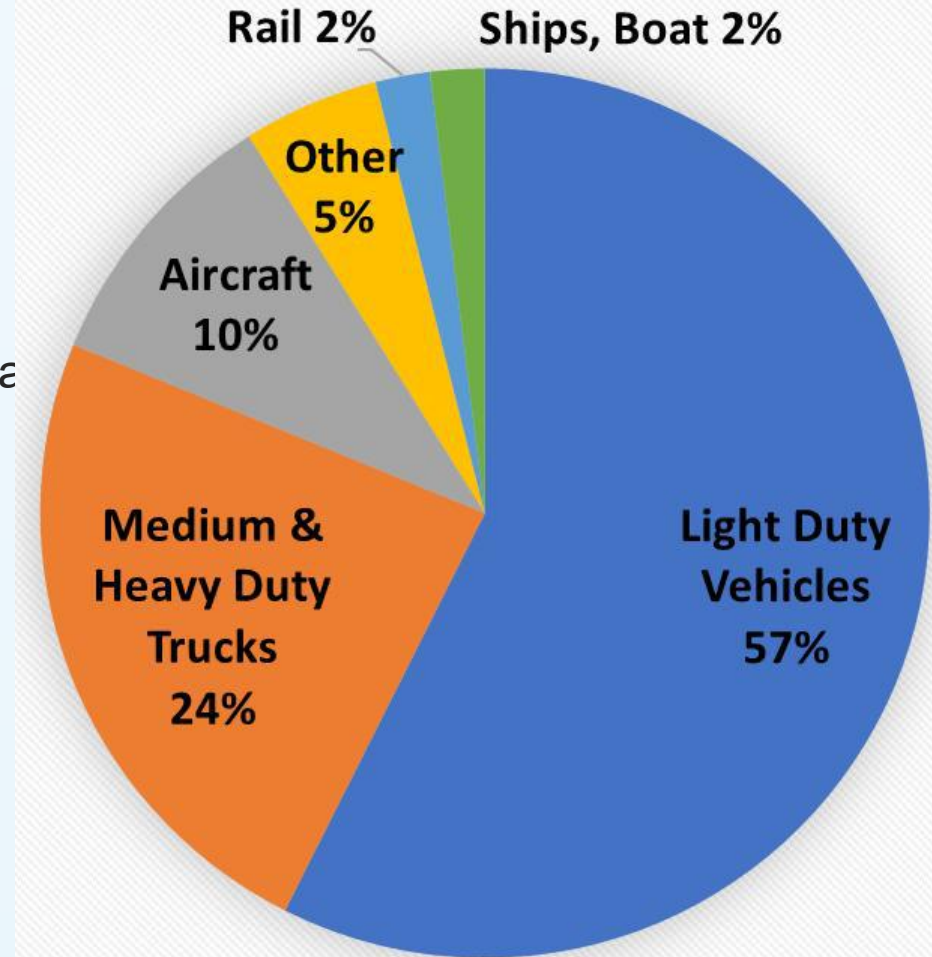
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Commercial & Residential

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- Waste handling

Food Production

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Atmospheric Temperature Trends

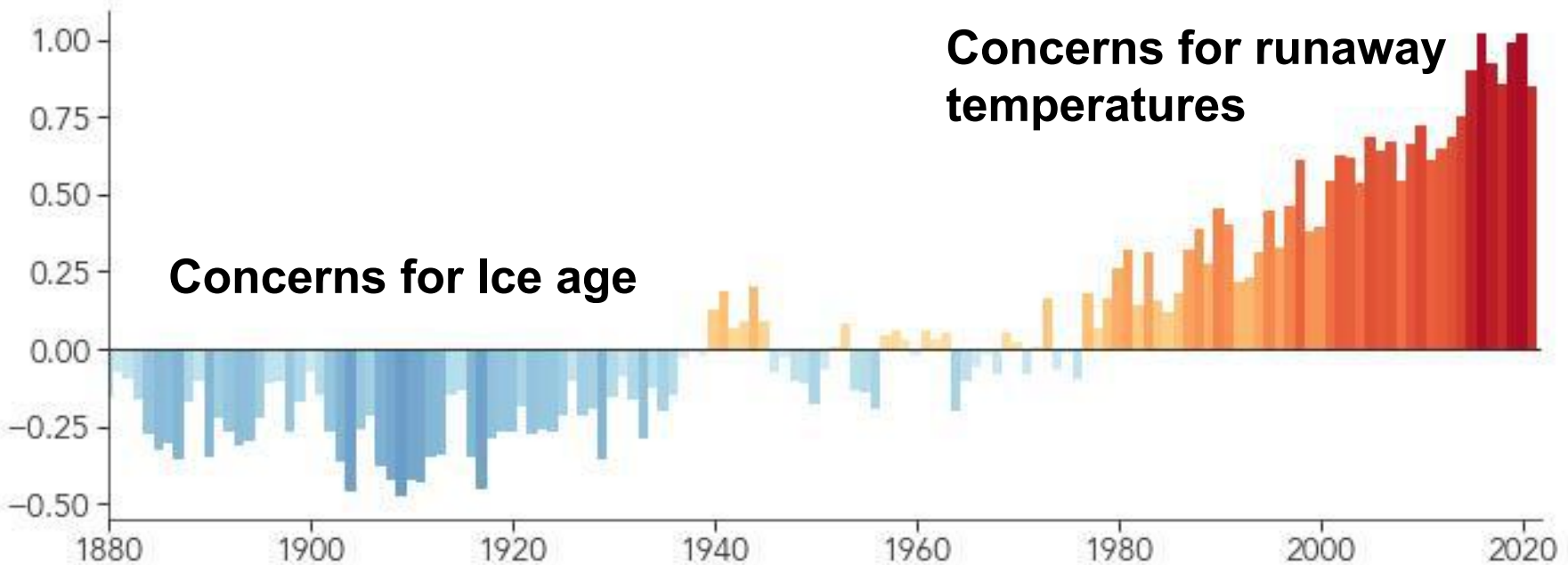
Worldwide 1880 - 2021

Accelerating atmospheric temperature rise since 1980

- **Incident Solar Load** on downward trend as temperatures rise
- **Climate change** eliminates past concerns over mini ice age

2021 ties 2018 for Sixth Warmest Year on Record

Global Temperature Anomaly (°C compared to the 1951-1980 average)

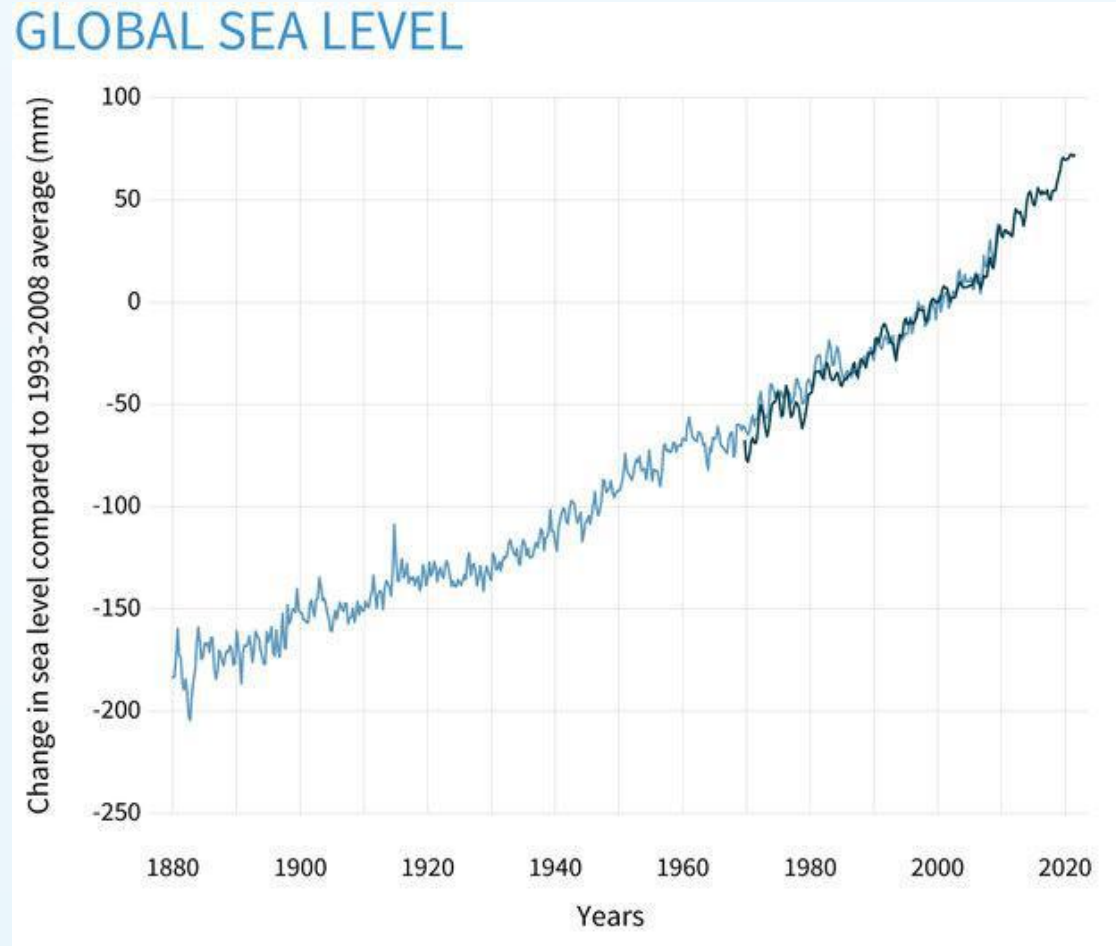


Global Sea Level Measurements

1880 - 2020

Costal flooding up across the globe as sea levels rise

- Global mean sea level 8-9" higher since 1880
- Frequency of flooding along US coast
 - 1950-1959 **5** days/year
 - 2011-2020 **15** days/year
- Flooding driven by multiple factors beyond sea level
 - Wave size
 - Atmospheric pressure
 - Wind stresses



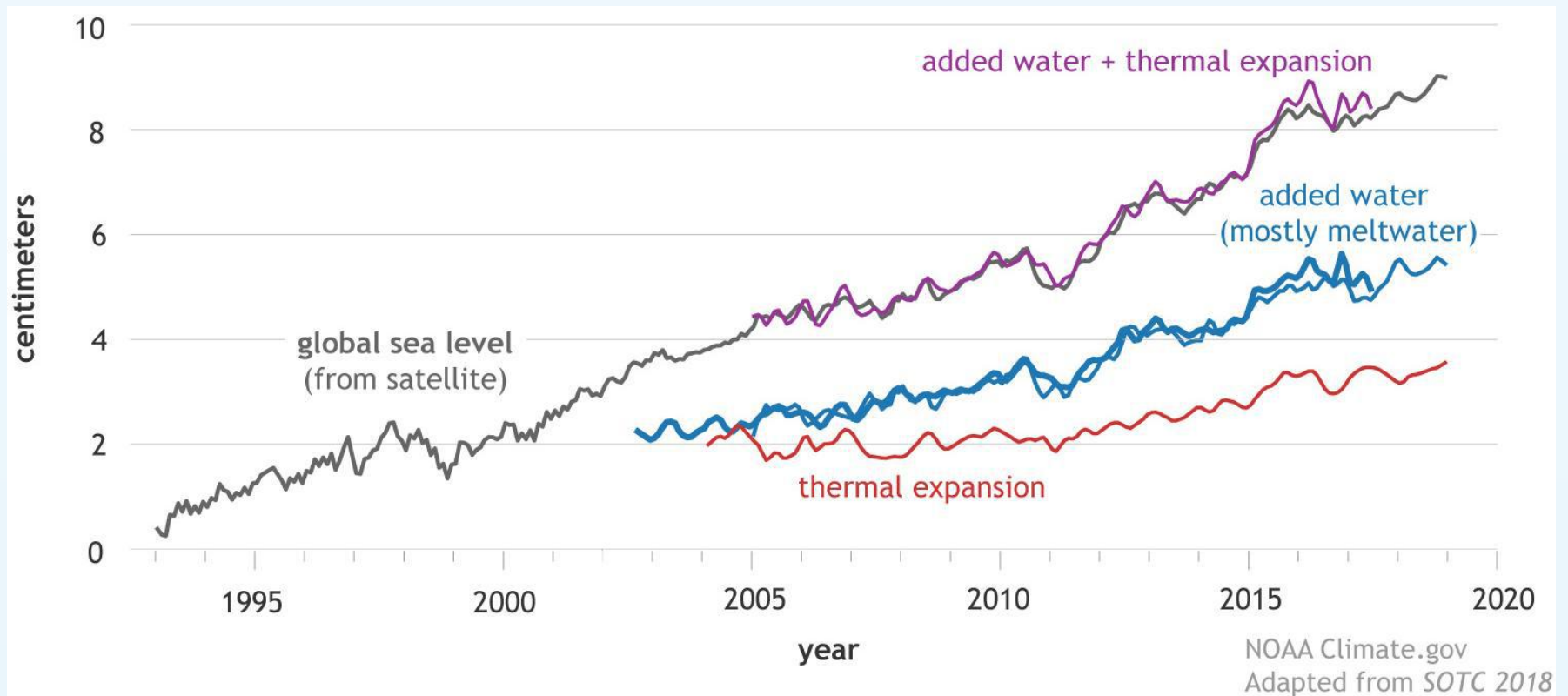
Lindsey, Rebecca. "Climate Change: Global Sea Level." Climate.gov, NOAA, 14 Aug. 2020, www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level.

US EPA, OA. "Climate Change Indicators: Coastal Flooding | US EPA." US EPA, Apr. 2021, www.epa.gov/climate-indicators/climate-change-indicators-coastal-flooding. Accessed 30 Apr. 2022.

Contributors to Global Sea Level Rise

Two primary contributors to seal level rise

- **Thermal Expansion:** water expands when heated
- Land based glaciers and ice sheets **melt and drain** into the oceans



Lindsey, Rebecca. "Climate Change: Global Sea Level." Climate.gov, NOAA, 14 Aug. 2020, www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level.

Climate Change Winners

Global warming boosts the economies of some 70 countries

Deloitte accounting firm publishes objective report

- Identified 70 (cold) countries benefiting from global warming
- Listed 130 countries suffering negative economic effects from global warming
- **Pulled report 4 days later** since showing positive benefits from global warming for anyone is unacceptable in a **culture of controlled naratives**

Reduced weather related deaths (today 90% due to cold weather)

- 4.6 million of 5.1 million weather related deaths due to cold weather (2021)

Increased agricultural production in northern regions

- Longer growing season

Reduced heating requirment in northern regions

More trade through Northwest passage due to reduced arctic ice

More plant growth everywhere due to higher CO2 levels

“Deloitte Scraps Report on Climate Change Benefit for GDP.” France 24, 2 Oct. 2020, www.france24.com/en/20201002-deloitte-scraps-report-on-climate-change-benefit-for-gdp. Accessed 18 Aug. 2023..“Human Deaths from Hot and Cold Temperatures and Implications For....” The Breakthrough Institute, thebreakthrough.org/issues/energy/human-deaths-from-hot-and-cold-temperatures-and-implications-for-climate-change.

Climate Change Losers

Occuring or Likely to Occur

Global warming losers overwhelm winners

- Society designed around existing sea levels & weather patterns
- Higher populations in warmer regions: India 1.4 billion vs Russia 143 million

Reduced agricultural production from drought/high temperatures?

- Green effect of higher CO2 levels could result in increased production

Increased wildfires

Tropical diseases spread as temperature rises

More frequent shoreline flooding leading to climate migration

More heat deaths where electricity is unavailable for cooling

Higher air conditioning loads

Reduced water storage from snowpack and glaciers