

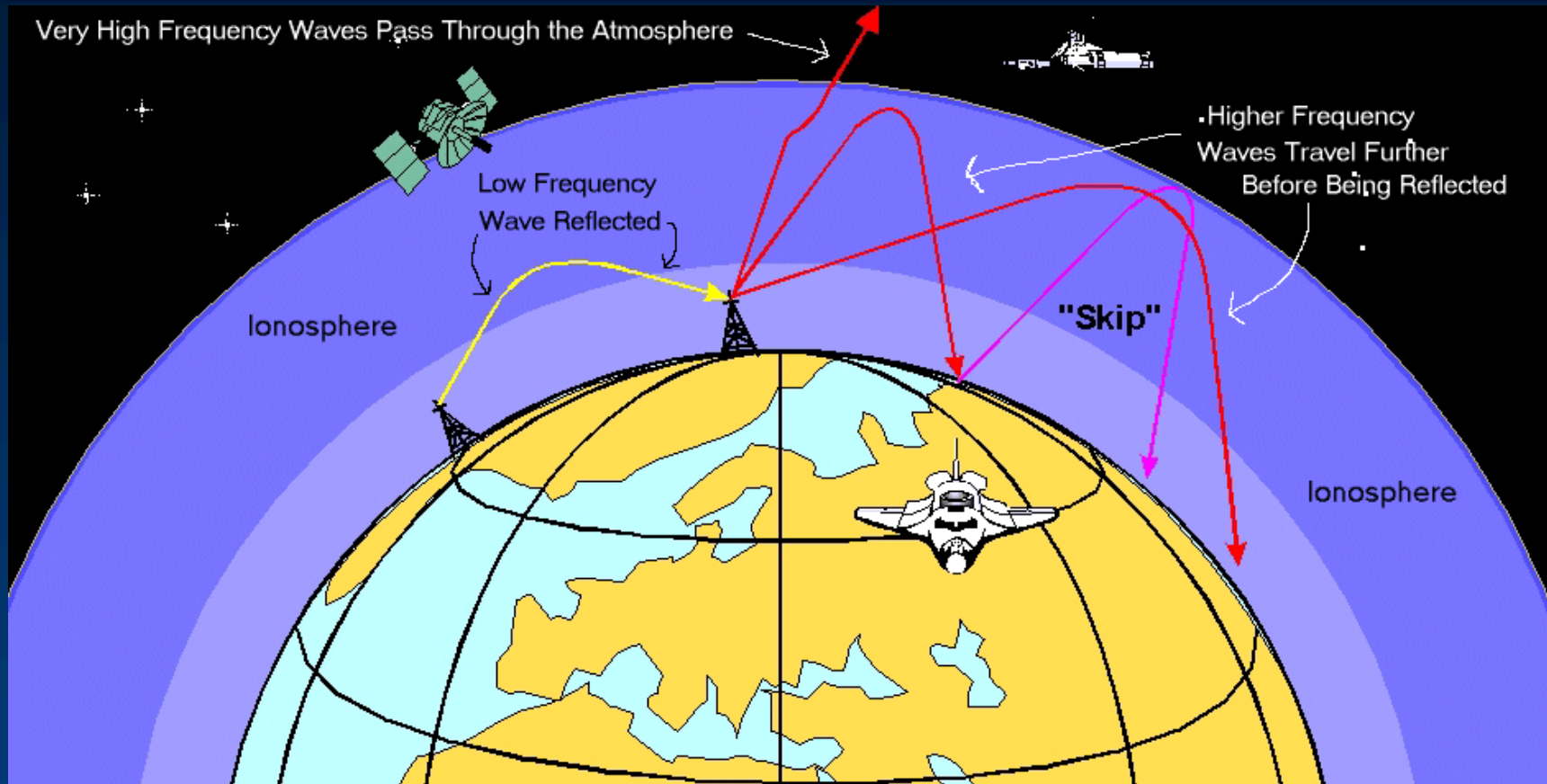
The Earth's atmosphere - unique in Solar System

Table 9-4 Chemical Compositions of Three Planetary Atmospheres

	Venus	Earth	Mars
Nitrogen (N ₂)	3.5%	78.08%	2.7%
Oxygen (O ₂)	almost zero	20.95%	almost zero
Carbon dioxide (CO ₂)	96.5%	0.035%	95.3%
Water vapor (H ₂ O)	0.003%	about 1%	0.03%
Other gases	almost zero	almost zero	2%

0.042%

Earth's atmosphere has changed over time



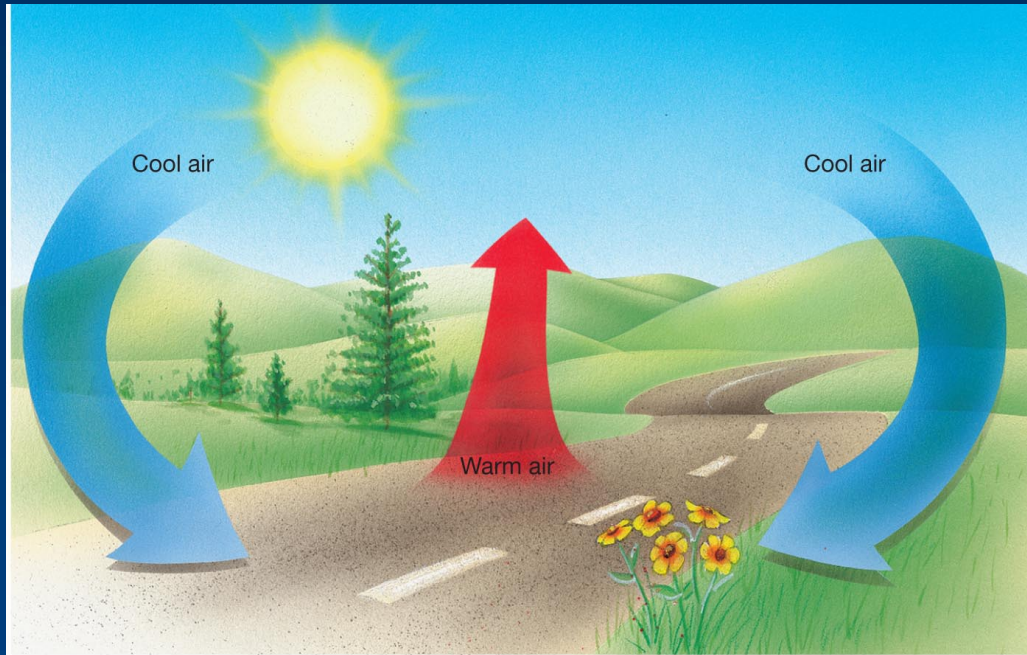
- The ionosphere:
 - Particles in the upper atmosphere ionized by the Sun
 - Radio signals below ~ 10 MHz can bounce off the ionosphere allowing communications over the horizon.

Question: at high altitudes, T of atmosphere is very high, e.g. 1000 °C at 300 km, near orbit of space shuttle. Why don't astronauts get cooked?

Answer: While T is high (what does T really measure?), ionosphere is very low density – about 10^{-11} as dense as air at sea level. Heat content is low.

Convection

Earth's surface heated by Sun. Must get rid of the energy as fast as it gets it. Could do this by radiating, but atmosphere at surface thick enough so that radiation gets out slowly. Result: heat is trapped near surface, leading to convection.



Convection also occurs when you boil water, or soup. Heat is released by radiation higher up.

Convection causes both small-scale turbulence and large scale circulation patterns. It also occurs within Earth, on other planets, and in stars.

How hot should the Earth be at its surface?

Total power in sunlight that reaches the top of our atmosphere is $1360 \text{ W/m}^2 \pi r^2 = 1.75 \times 10^{17} \text{ W}$.

Earth's albedo is 0.31, so 31% gets reflected back into space.

If Earth had no atmosphere, 69% is absorbed by Earth's surface, and would be reradiated. This amounts to

$$(0.69)(1.75 \times 10^{17} \text{ W}) = 1.21 \times 10^{17} \text{ W}$$

Absorbed, reradiated emission from warm object:
blackbody spectrum.

How much power would one square meter of Earth radiate (**emergent flux**)?

Area = $4\pi r^2$ where $r = 6.38 \times 10^6$ m

$$A = 4\pi(6.38 \times 10^6)^2 = 5.1 \times 10^{14} \text{ m}^2$$

Power radiated per square meter is

$$\frac{1.21 \times 10^{17} \text{ W}}{5.1 \times 10^{14} \text{ m}^2} = 237 \text{ W per square meter}$$

So what's the temperature?

Recall Stefan-Boltzmann law: $F = \sigma T^4$, so

$$T = \sqrt[4]{\frac{F}{\sigma}} = \sqrt[4]{\frac{237 \text{ W m}^{-2}}{5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}}}$$

$$T = 254 \text{ K} = -19^\circ \text{ C}$$

Huh? Actual average surface temperature is
288 K = +15 C !

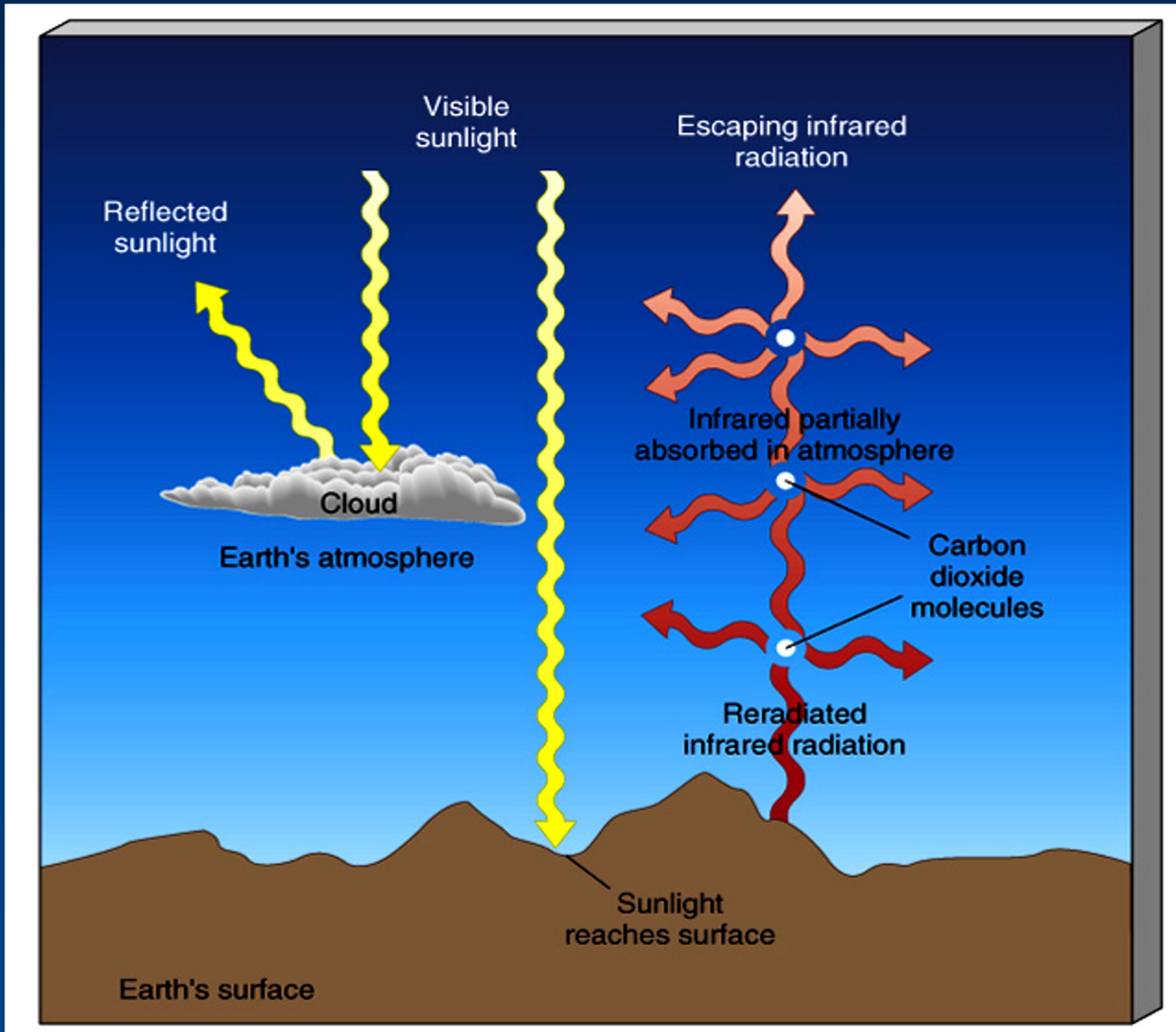
What's going on? First, consider how a blackbody at $T=254\text{ K}$ would radiate:

$$\lambda_{\text{max}} = \frac{0.0029}{T} = \frac{0.0029}{254\text{K}} = 1.14 \times 10^{-5} \text{ m}$$
$$\lambda_{\text{max}} = 11.4 \mu\text{m}$$

What kind of radiation is this?

Infrared

Earth is warmer than expected due to the Greenhouse Effect.

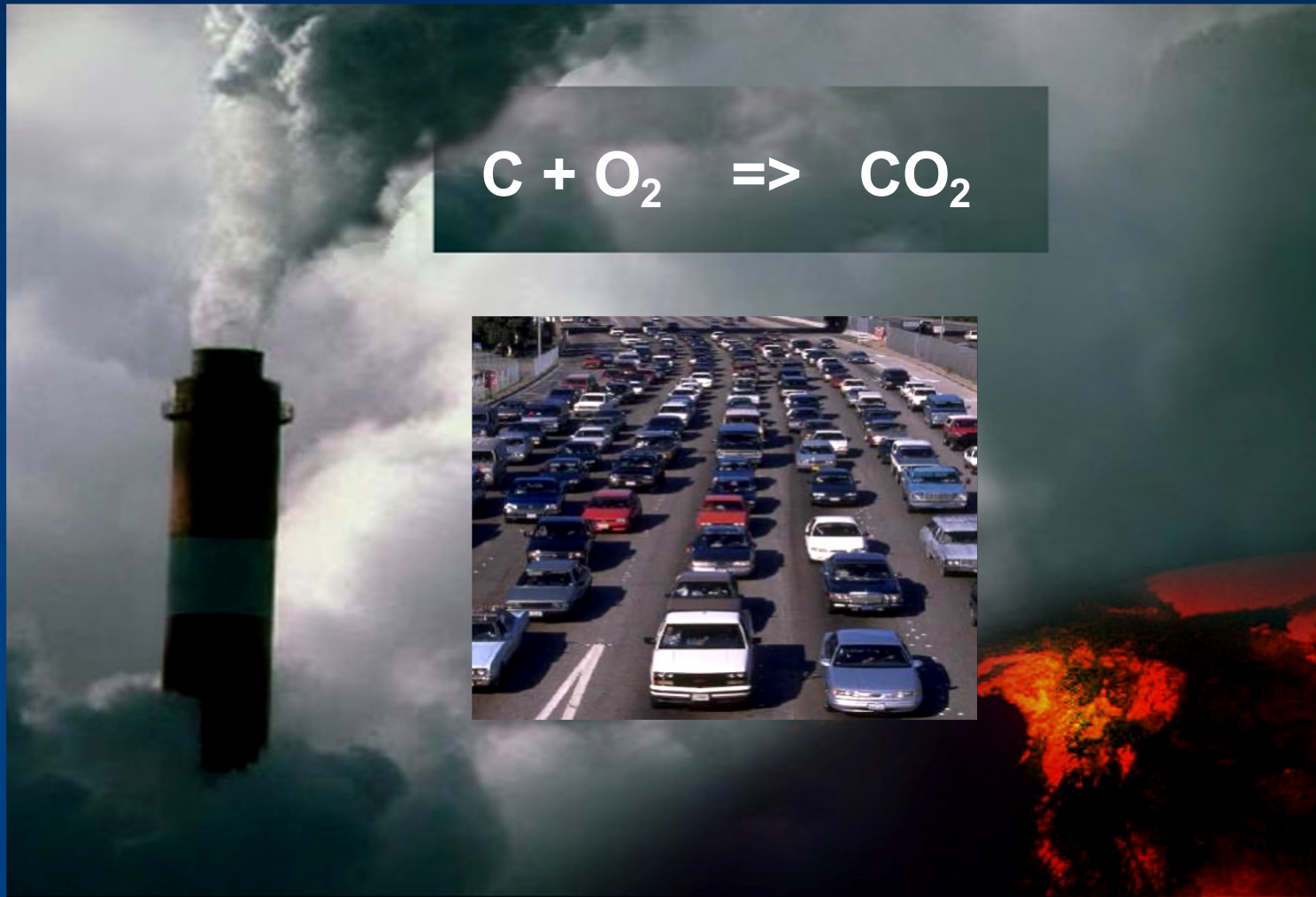


Predominant greenhouse gases are water vapor (H₂O) and carbon dioxide (CO₂).

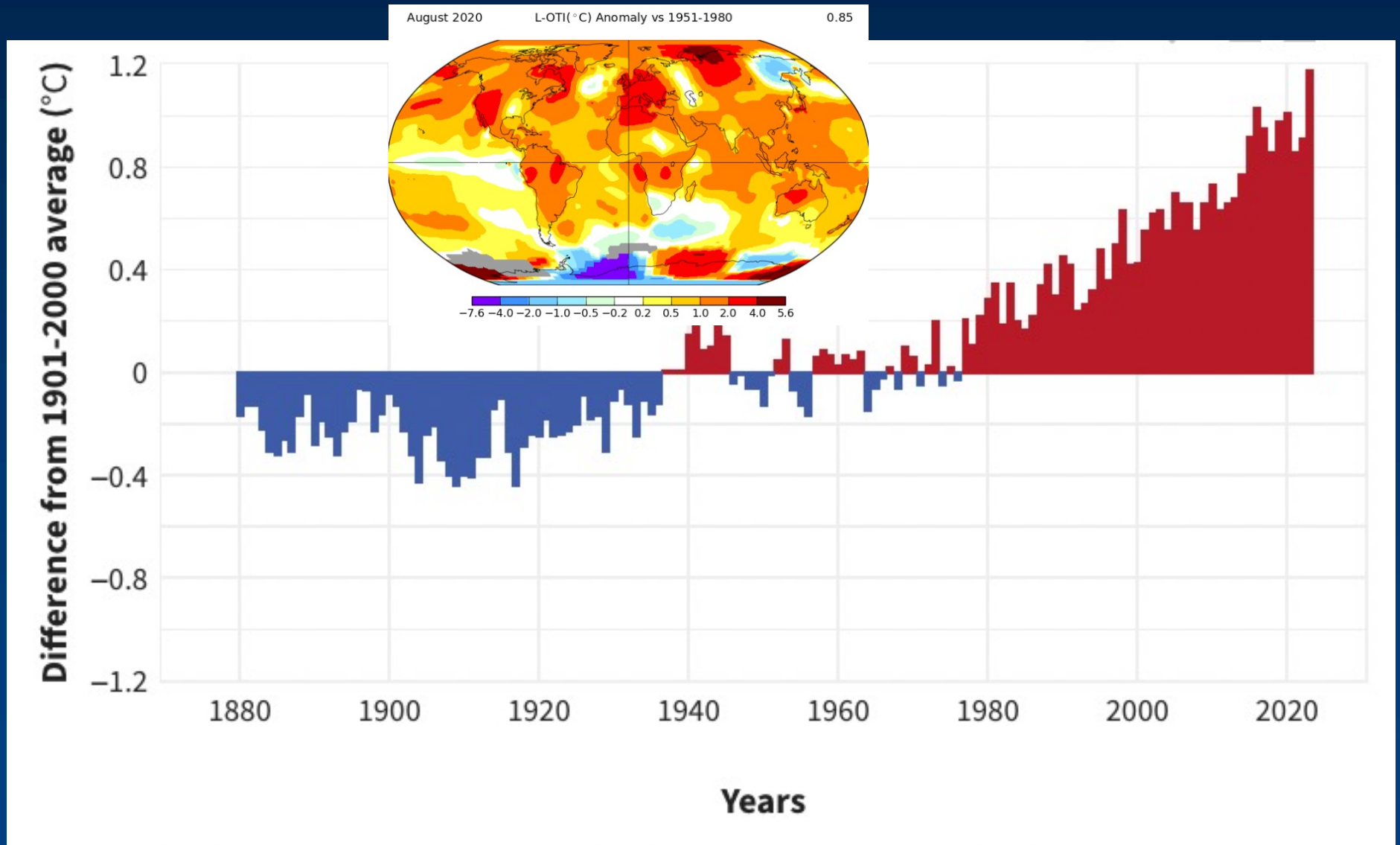
They are transparent to visible light, but not to infrared radiation.

Global warming: primary cause

- Pollution: Burning carbon-containing fossil fuels produces carbon dioxide

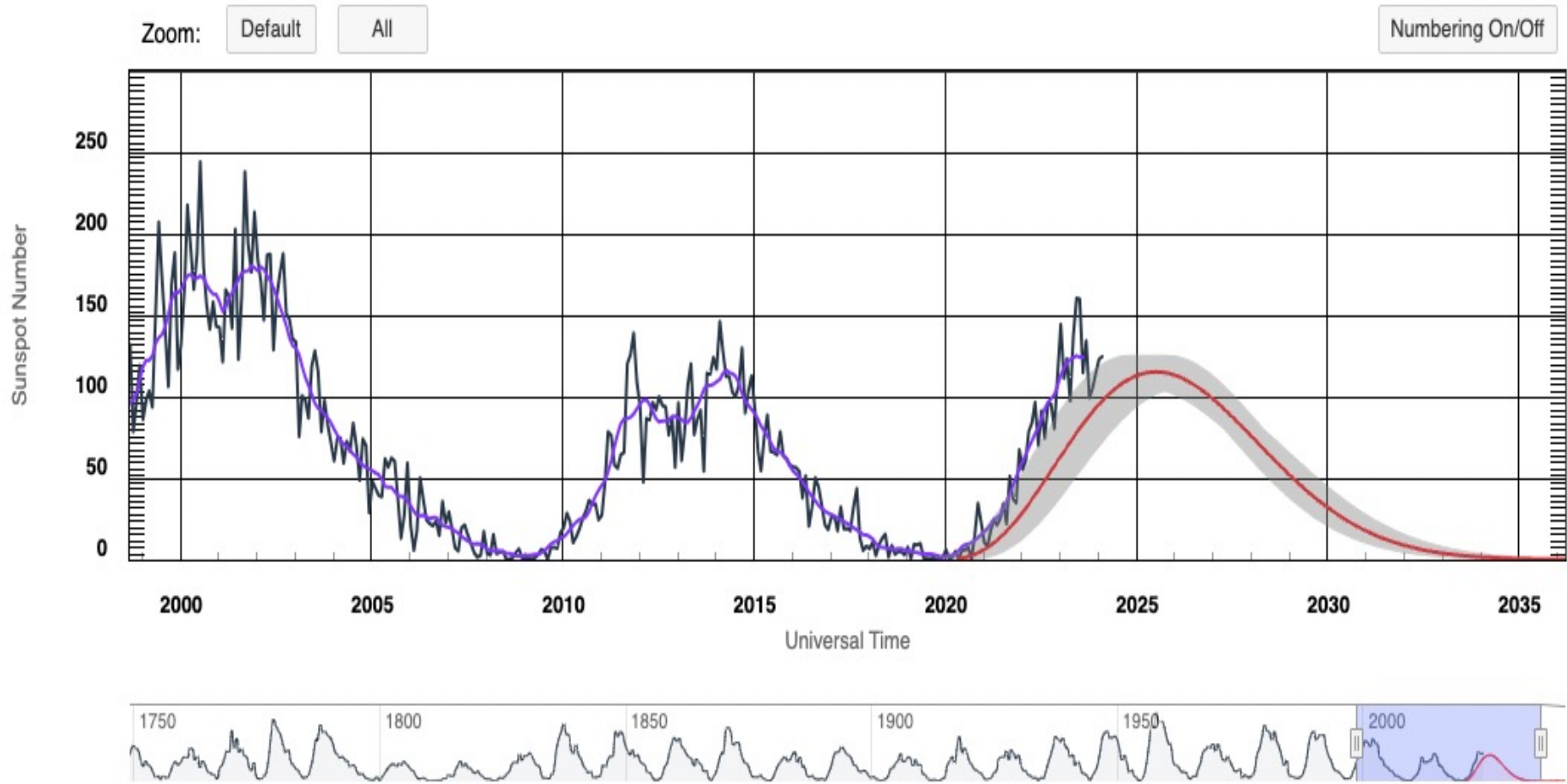


2023 hottest year on record
2020 was third hottest year ever



Solar Variability

ISES Solar Cycle Sunspot Number Progression



<https://www.swpc.noaa.gov/products/solar-cycle-progression>

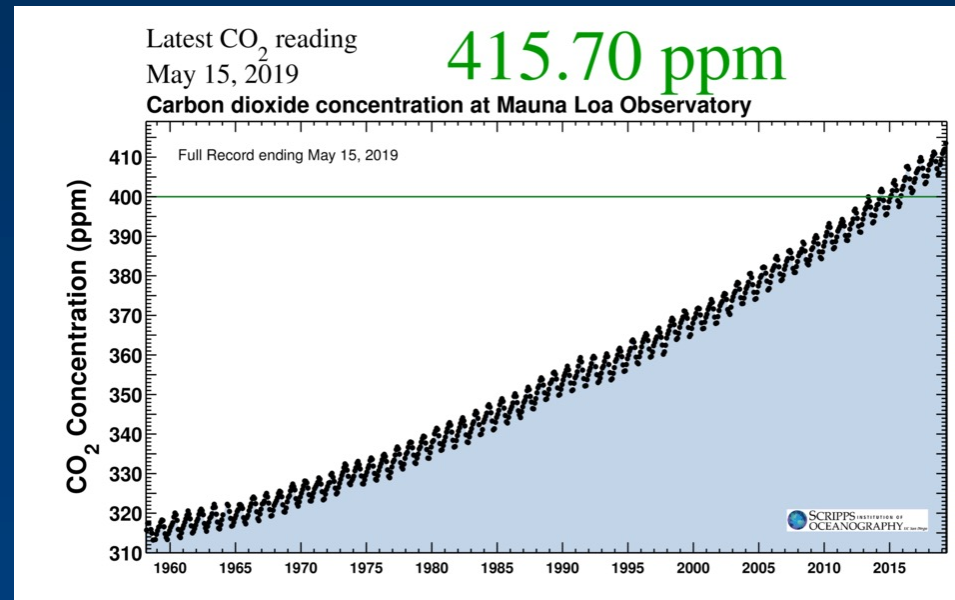
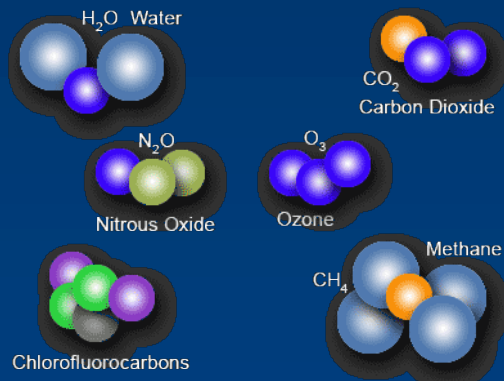
Increase in greenhouse gases

- Humans are putting CO₂ into atmosphere, especially through use of petroleum products.
- Removal of forests decreases Earth's capacity to absorb CO₂, and produce oxygen.
- Global warming?

GLOBAL WARMING!!!

Greenhouse gases

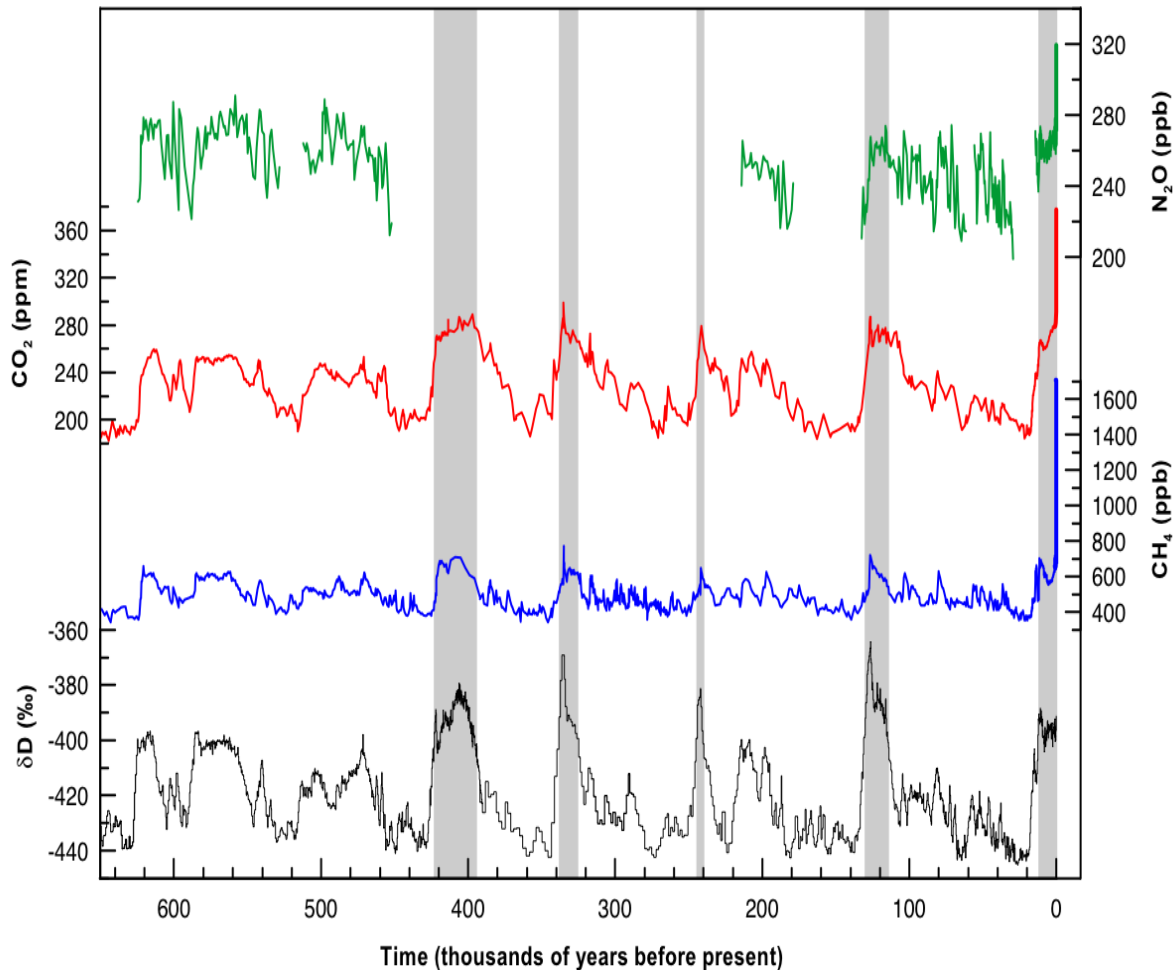
- CO₂ increases through use of petroleum products, fuel and biomass decay and burning.
- Increased 33% since 1958:



- CH₄ increases from grazing ruminant animals, sewage, biomass decay, gas leaks



Glacial-Interglacial Ice Core Data



- Humans have increased CO₂ more than 35% since industrial revolution

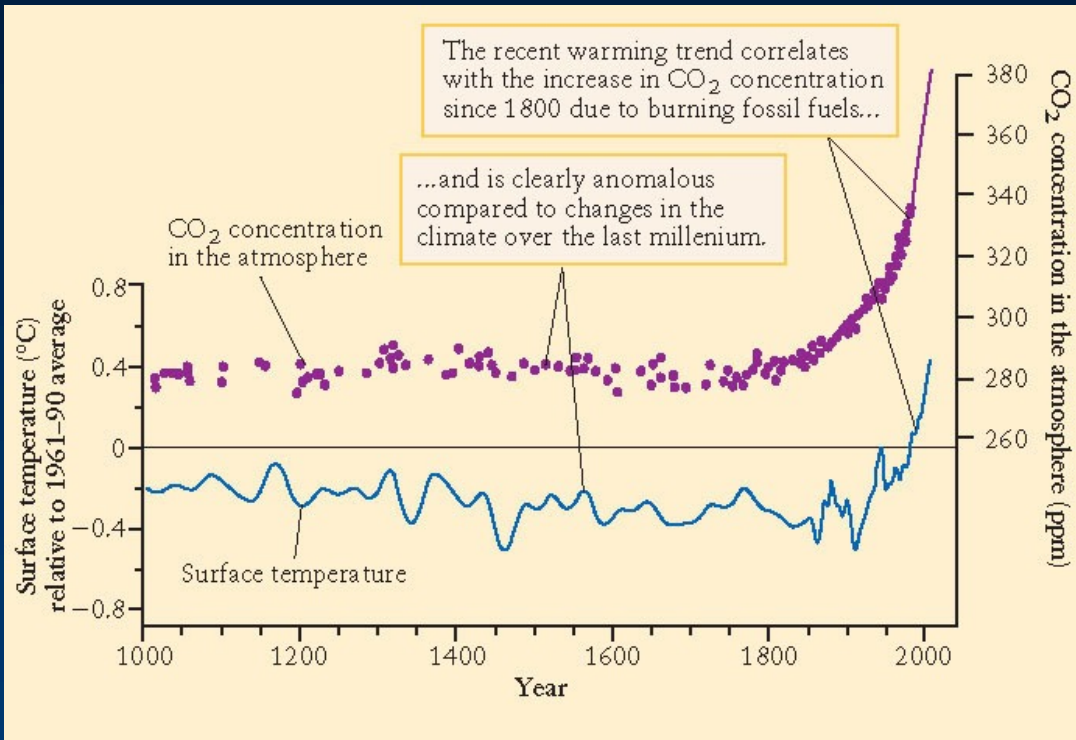
National Oceanic and Atmospheric Administration 2006

- The most CO₂ in 650,000 years

(IPCC) 2007

- The most CO₂ in 800,000 years

(IPCC) 2014



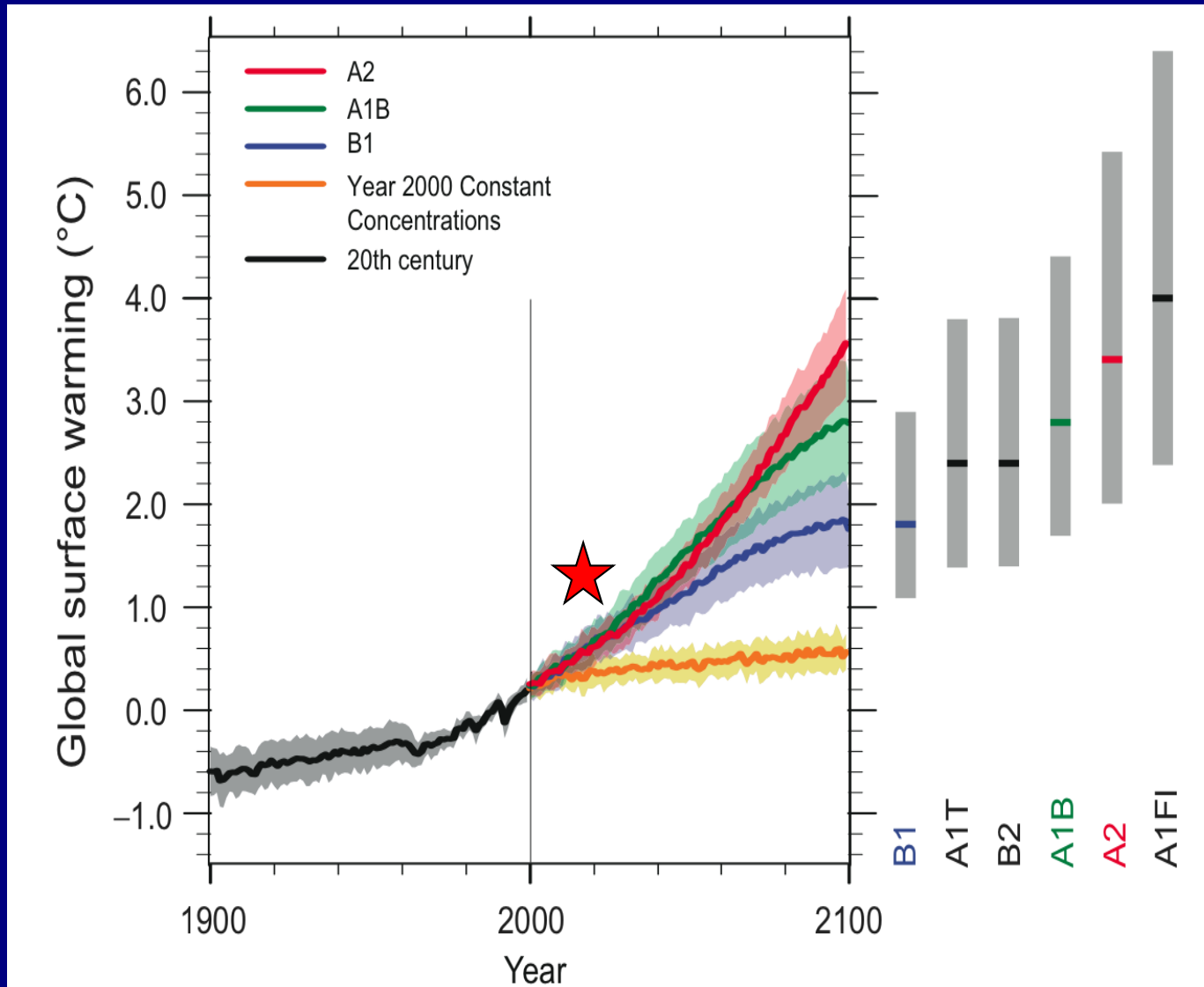
CO₂ data from bubbles trapped in ice, depth indicates age.

Recent T data from thermometers, historical data also from trapped air bubbles in ice. Oxygen isotope ratio sensitive T indicator.

- "Warming of the climate system is unequivocal"

Intergovernmental Panel on Climate Change (IPCC) 2007

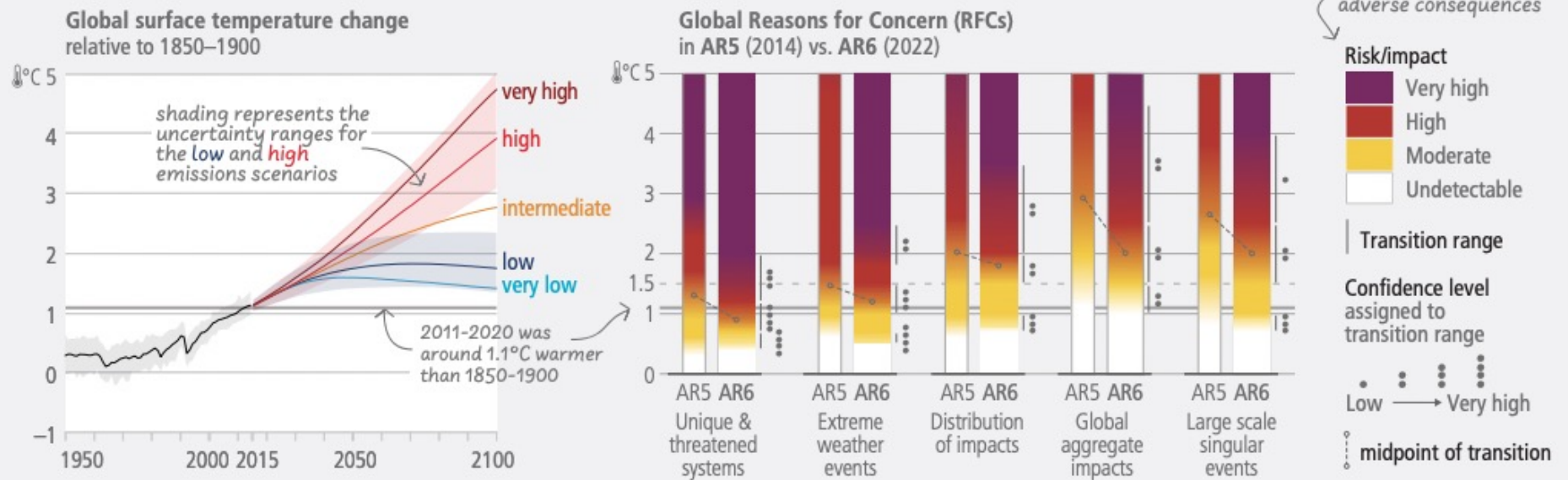
Temperature Predictions



IPCC report from 2023

Risks are increasing with every increment of warming

a) High risks are now assessed to occur at lower global warming levels

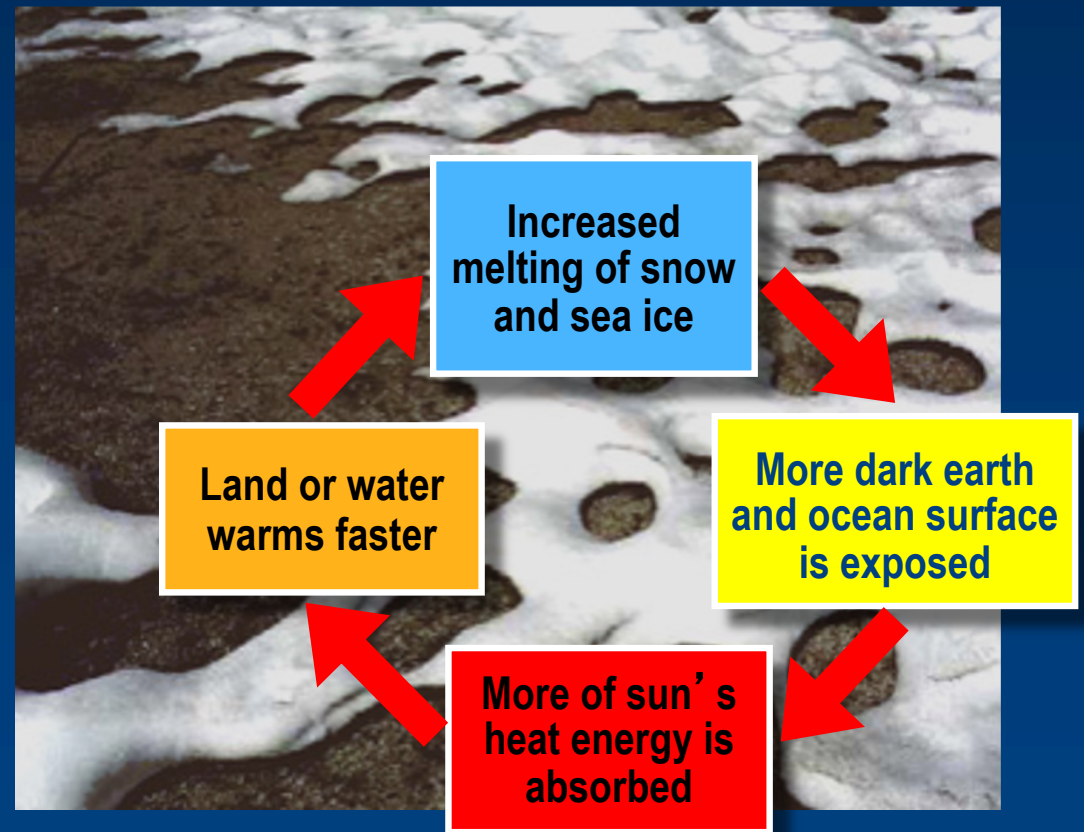


Why has Alaska warmed the most?

The Albedo Effect

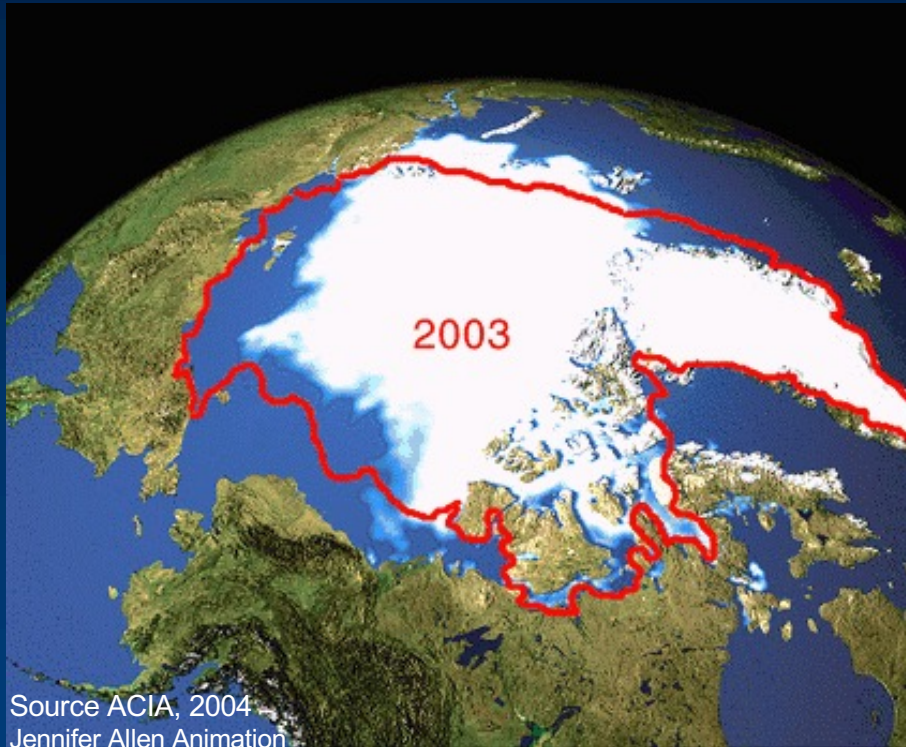
- Snow and sea ice reflect 85-90% of sun's energy.
- Ocean surface and dark soil reflect only 10-20%.

(ACIA 2004)



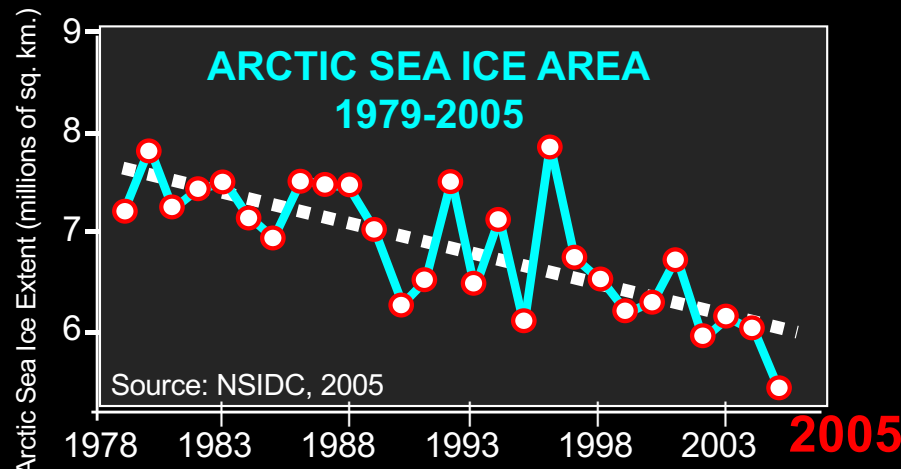
“White shirt versus Black shirt”

Melting Sea Ice



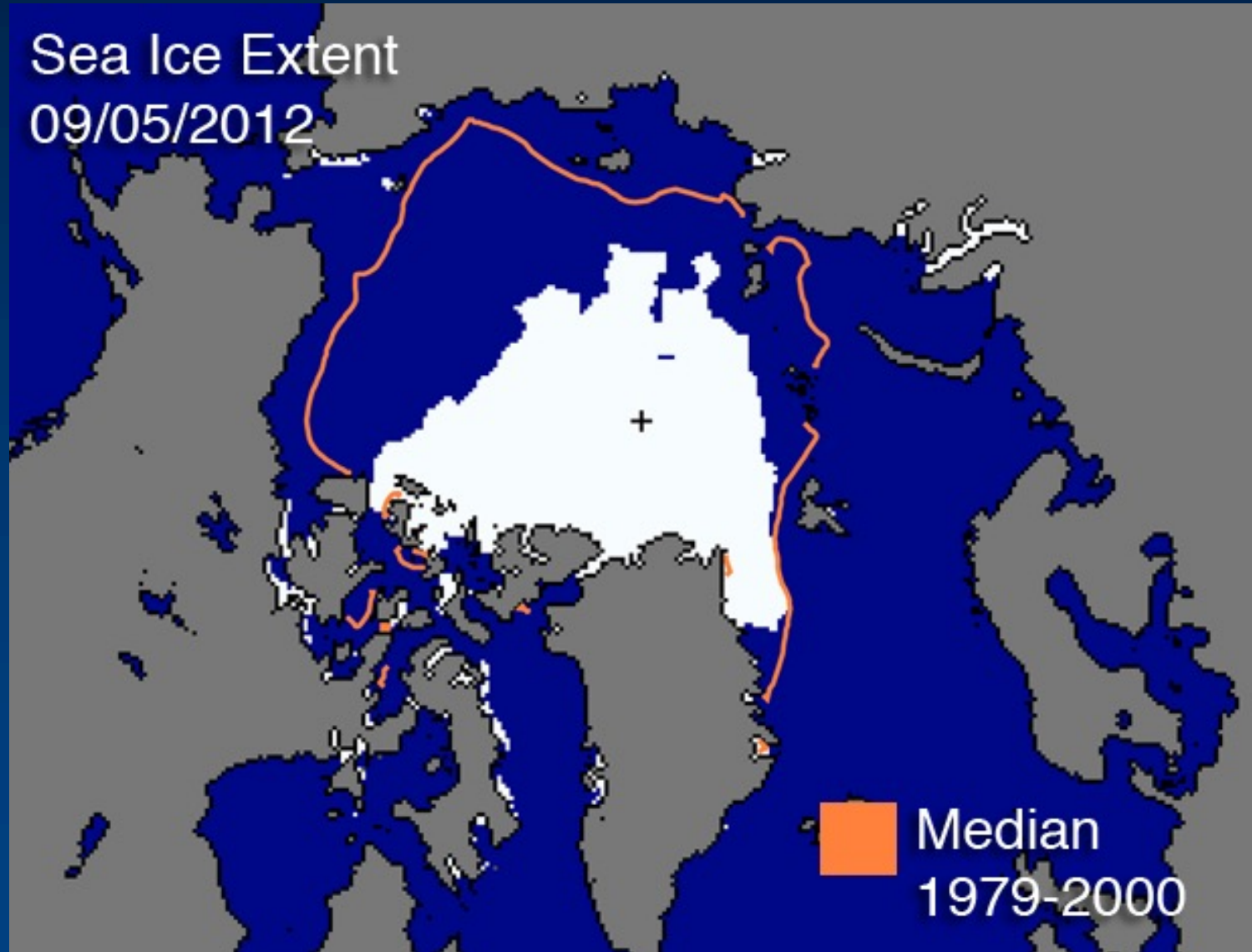
Source ACIA, 2004
Jennifer Allen Animation

- An area twice the size of Texas has melted away since 1979 (over 20% decrease). (National Snow and Ice Data Center 2005)
- Ice 40% thinner. (Rothrock, D.A, et al. 1999)
- Ice only 6 – 9 feet thick at North Pole (NOAA FAQ 2007).
- Bering Sea Ice Sheet also retreating (Science 3/10/06).

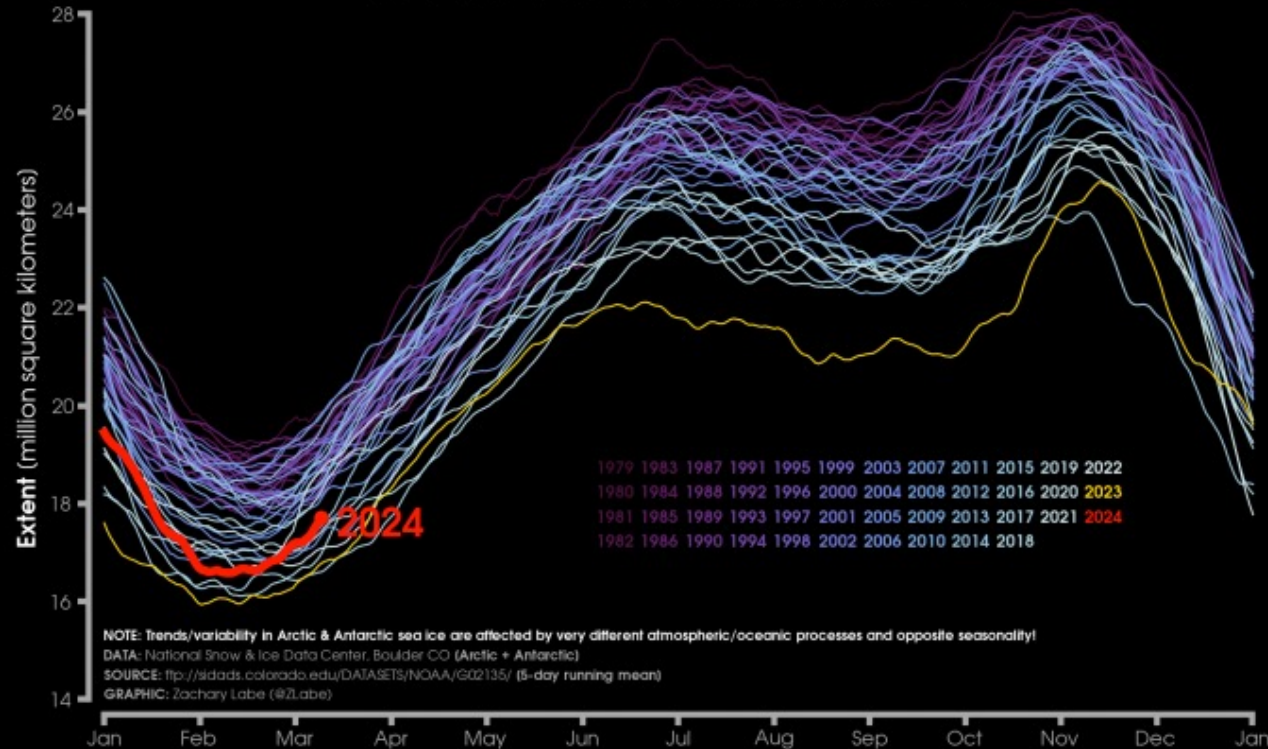


September 2012

Sea Ice Extent
09/05/2012



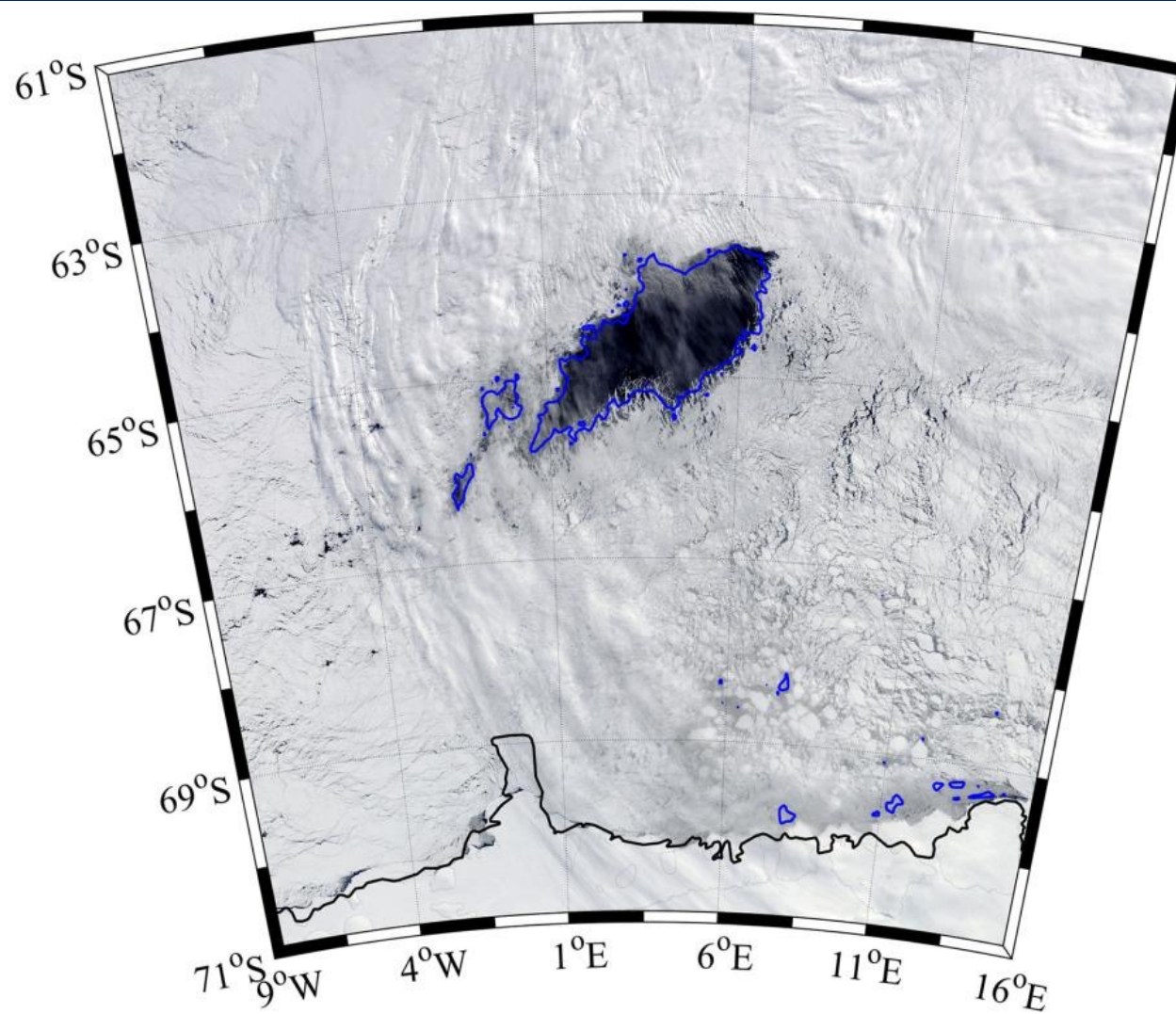
GLOBAL SEA ICE



Global sea ice extent (Arctic + Antarctic) for each year from 1979 to 2024 (satellite-era; NSIDC, DMSP SSM/I-SSMIS). 2023 is highlighted with a yellow line. 2024 is shown using a red line (updated 3/11/2024).

Zachary Labe

Hole in the Antarctic Sea Ice October 2017



Glacial Retreat

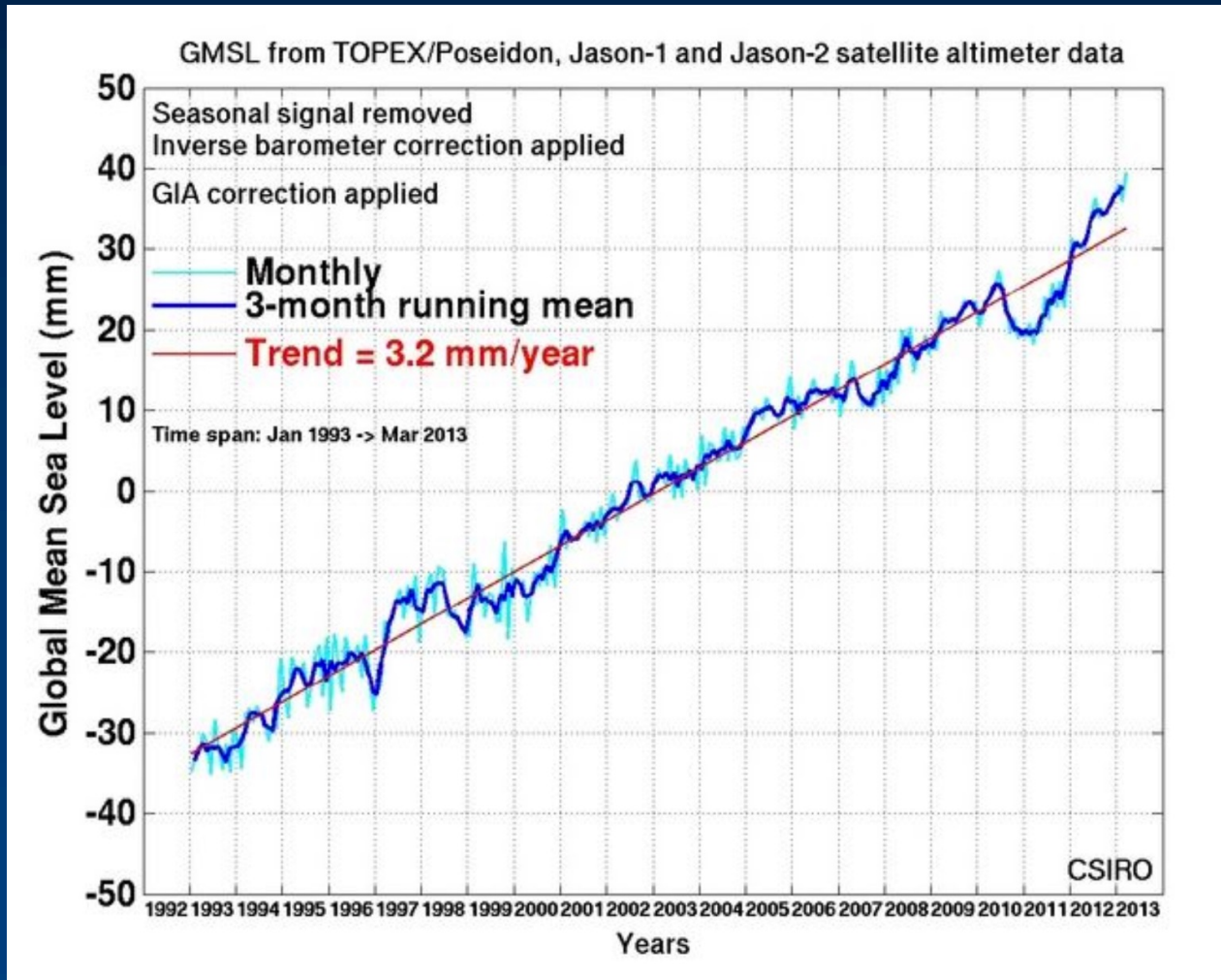
McCall Glacier Glacier Bay (Riggs Glacier)

- The rapid retreat of Alaska's glaciers represents about 50% of the estimated mass loss by glaciers through 2004 worldwide. (ACIA 2004)
- Loss of over 588 billion cubic yards between '61 and '98. (Climate Change 11/05)
- Alaska's glaciers are responsible for at least 9% of the global sea level rise in the past century. (ACIA 2004)



Inundation

- Sea level has increased 3.2 mm/year between 1993 and 2003 (IPCC 2007).
- 1 meter of sea level rise by 2100 (IPCC 2019)
- This is 10-20 times faster than during the last 3,000 years (ACIA 2004).



1993

2013

Die Offs



Warmer temperatures lead to die offs like this one in Rio de Janeiro

Ocean Nations Threatened

Maldives nation held cabinet meeting 20 feet under water.

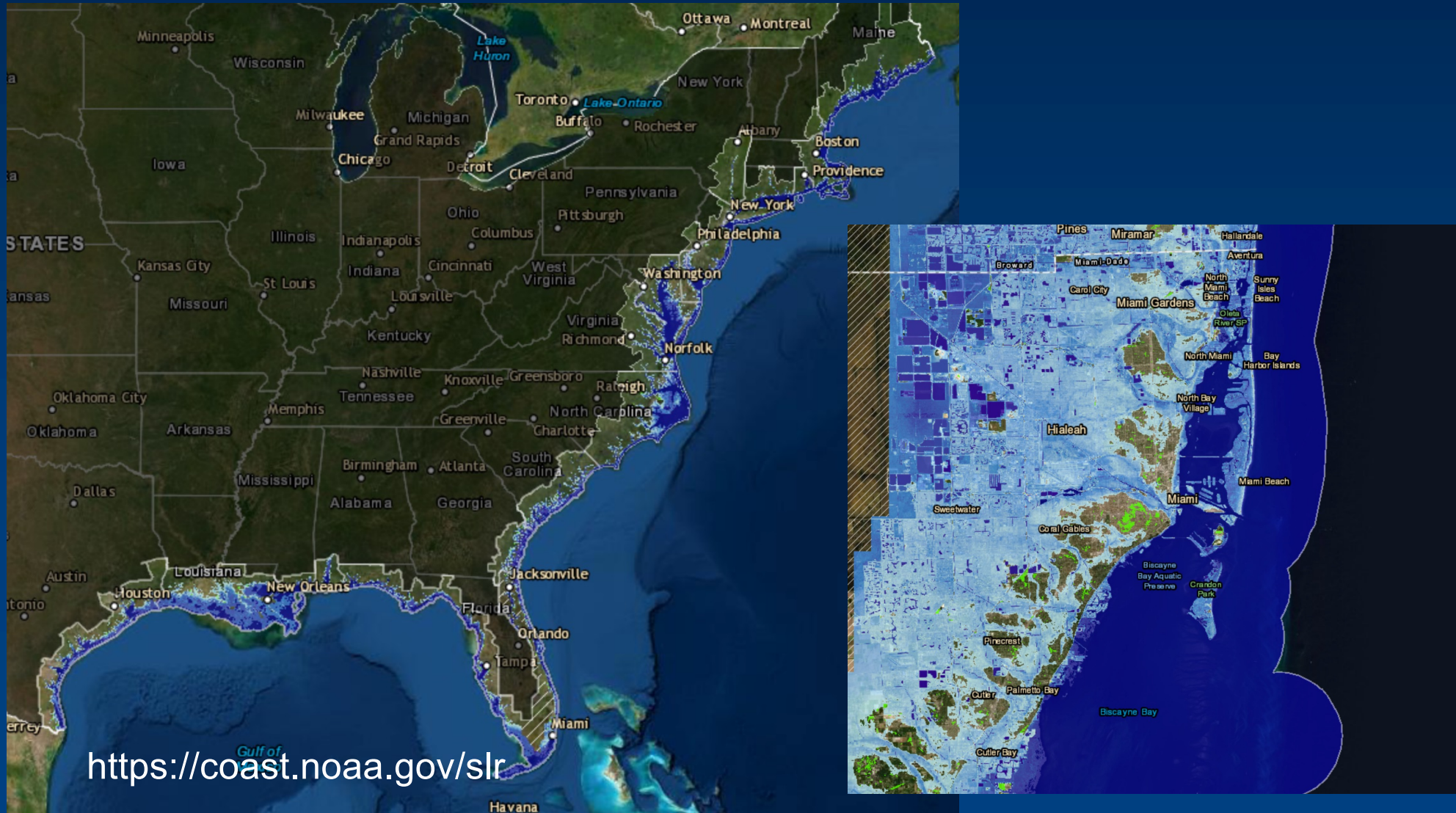
Tuvalu nation considering exodus (highest elevation is 15 feet)

New Moore Island went under in March 2010



Inundation

Inundation from 3 Meter Sea Level Rise (or, 1m rise + 2m storm surge)



Hurricane Sandy

12' surge
tides+storm

72 people
killed

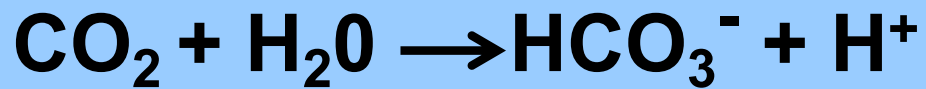
\$50 billion
in damages



Ocean Acidification

Over the last 200 years, about 50% of all CO₂ produced on earth has been absorbed by the ocean. (Royal Society 6/05)

Dissolves in sea water



(ACID)

Water becomes more acidic.

Remains in the atmosphere (greenhouse gas)

CO₂

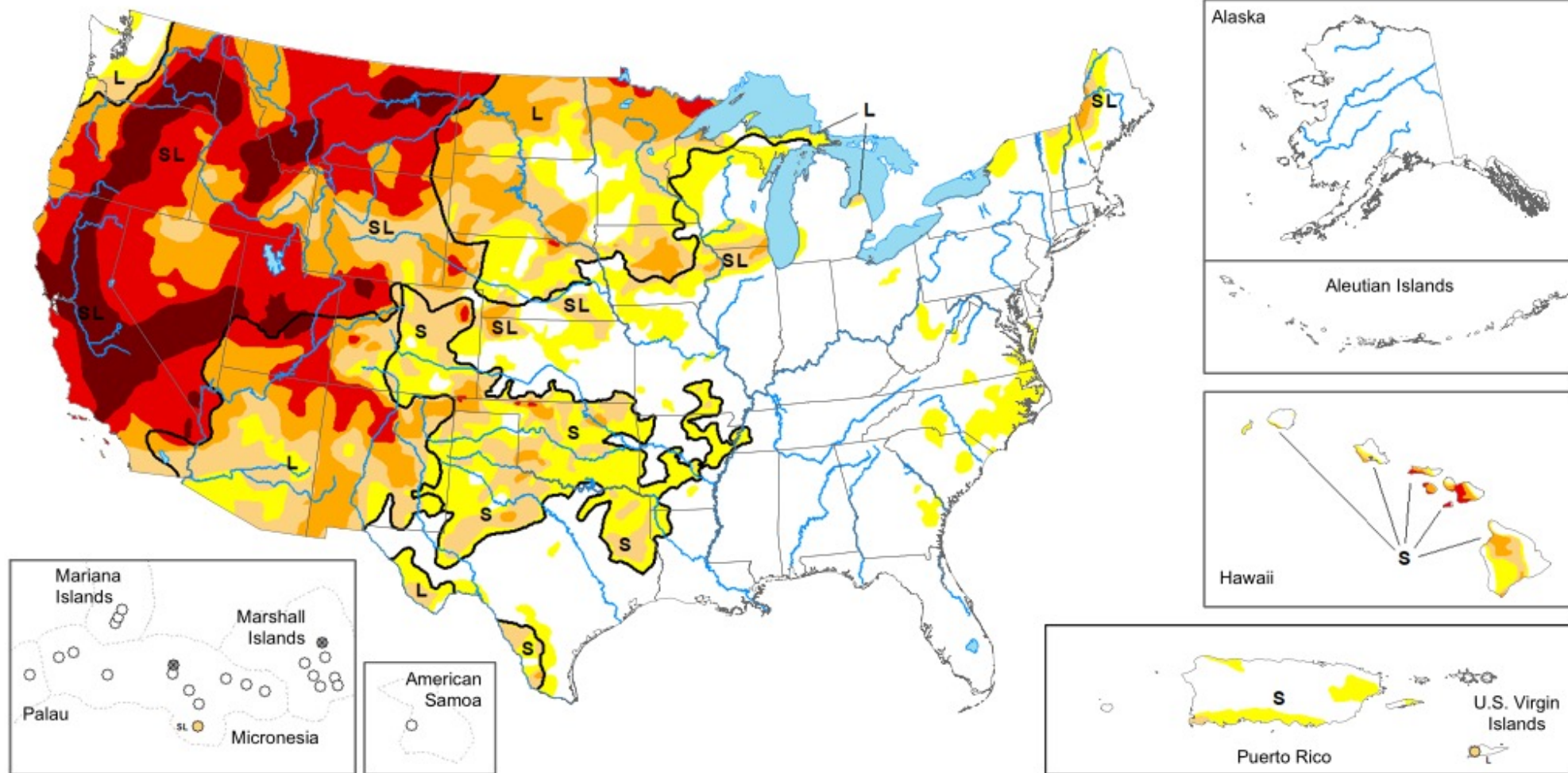
CO₂



Drought

Map released: October 21, 2021

Data valid: October 19, 2021



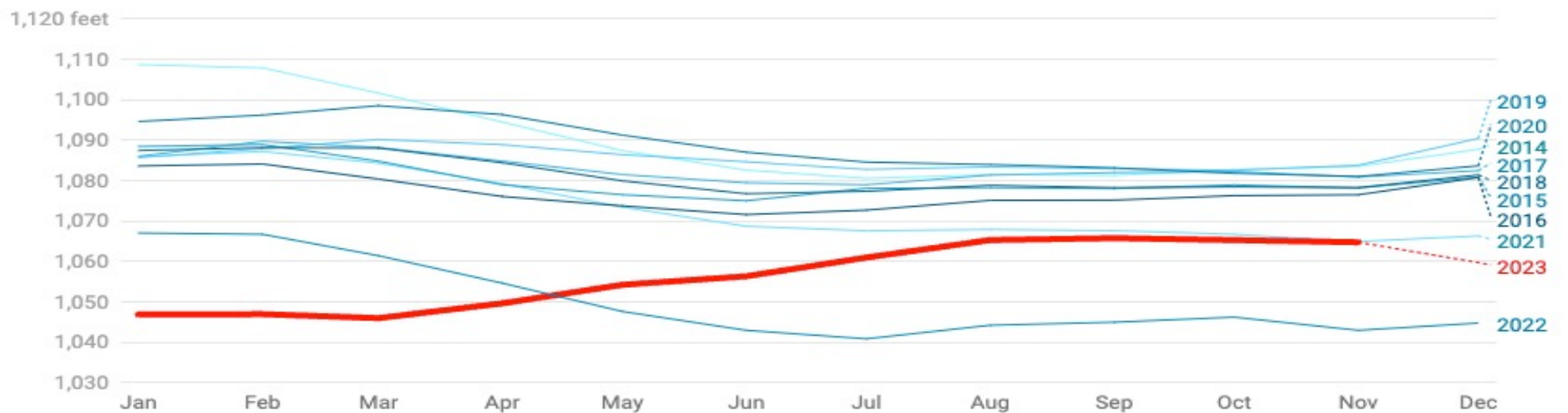
Lake Mead in Nevada supplies water for 25 million people

Full
1230'



(Photo: U.S. Bureau of Reclamation)

1100'



End-of-month elevation levels of Lake Mead, as recorded at Hoover Dam, from Jan 2014–Nov 2023.

Chart: Ian Randall • Source: [US Bureau of Reclamation](#) • Created with [Datawrapper](#)

900'
Dead
pool

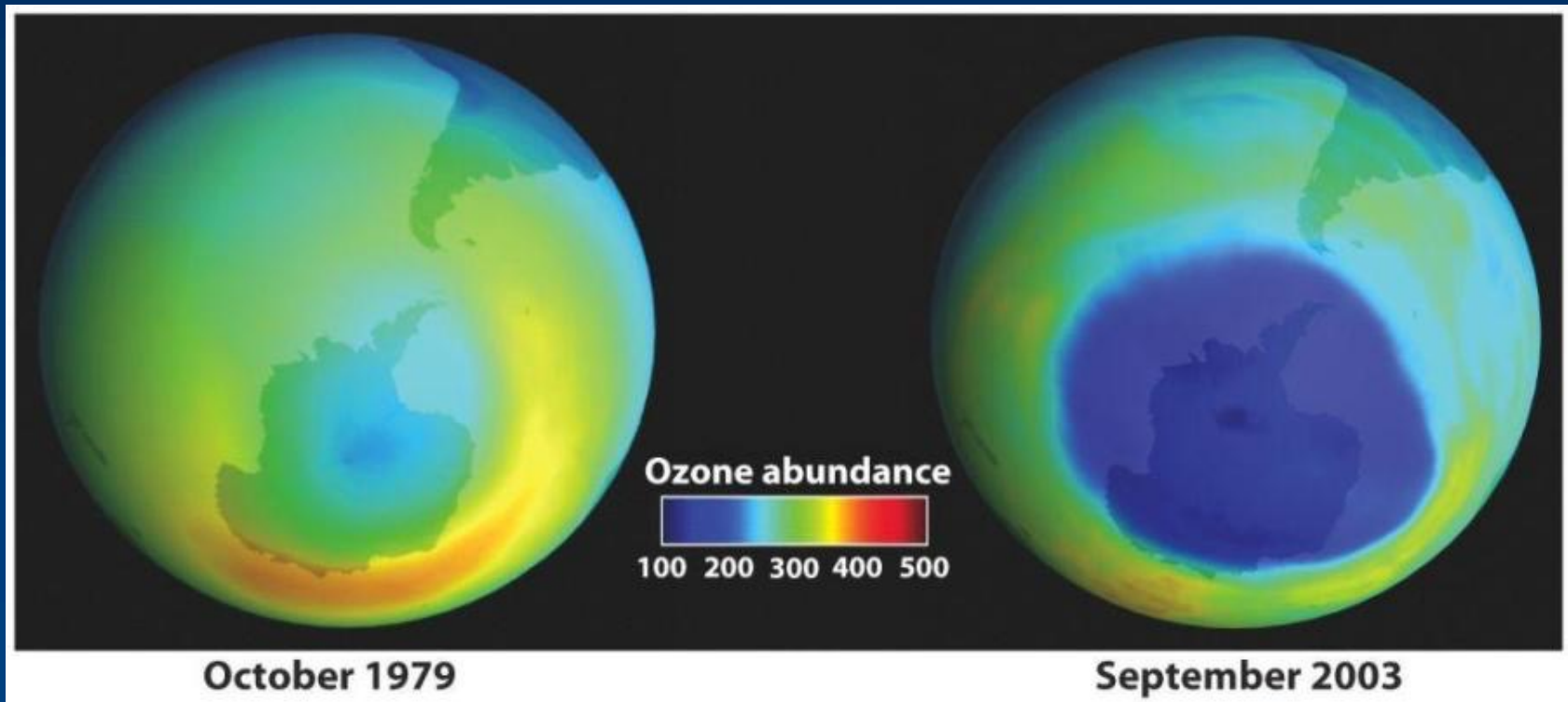
Impact on Ski Industry

- In the US skiing is a \$5B industry
- 2006 saw a 78% decline in skiers visiting the pacific northwest US
- Ski Seasons have shortened by 1 day/year for the last 20 years
- Many European ski resorts below 1800 m (6000 ft) will close
- 50 to 90% of Alpine glaciers will be gone by 2100
- Some resort to snowmaking
 - Expensive
 - Requires lots of water
 - Requires lots of energy
- In New Mexico, many ski areas can't open until after Xmas



Finally, CFCs: refrigerants and aerosol propellants (spray cans), affects the ozone layer!

Chlorofluorocarbons (CFCs) and halons have damaged ozone layer. Now banned, but damage will take years to heal. (Use sunscreen!)



1979 – 2003 decrease of 50% in ozone over Antarctica, 10 – 20% over mid-latitudes.

Paris Agreement on Climate

- To keep global temperatures "well below" 2.0C (3.6F) above pre-industrial times and "endeavour to limit" them even more, to 1.5C
- To limit the amount of greenhouse gases emitted by human activity to the same levels that trees, soil and oceans can absorb naturally, beginning at some point between 2050 and 2100
- To review each country's contribution to cutting emissions every five years so they scale up to the challenge
- For rich countries to help poorer nations by providing "climate finance" to adapt to climate change and switch to renewable energy.

Astro2110 Agreement on Climate

What can we do to stop Global Warming?

What We Can Do

REDUCE CO₂ EMISSIONS

1. Is it Achievable?
2. Action Is Essential at Every Level
 - Individual
 - Corporate
 - Local
 - State
 - Federal
 - International
3. Critical Steps



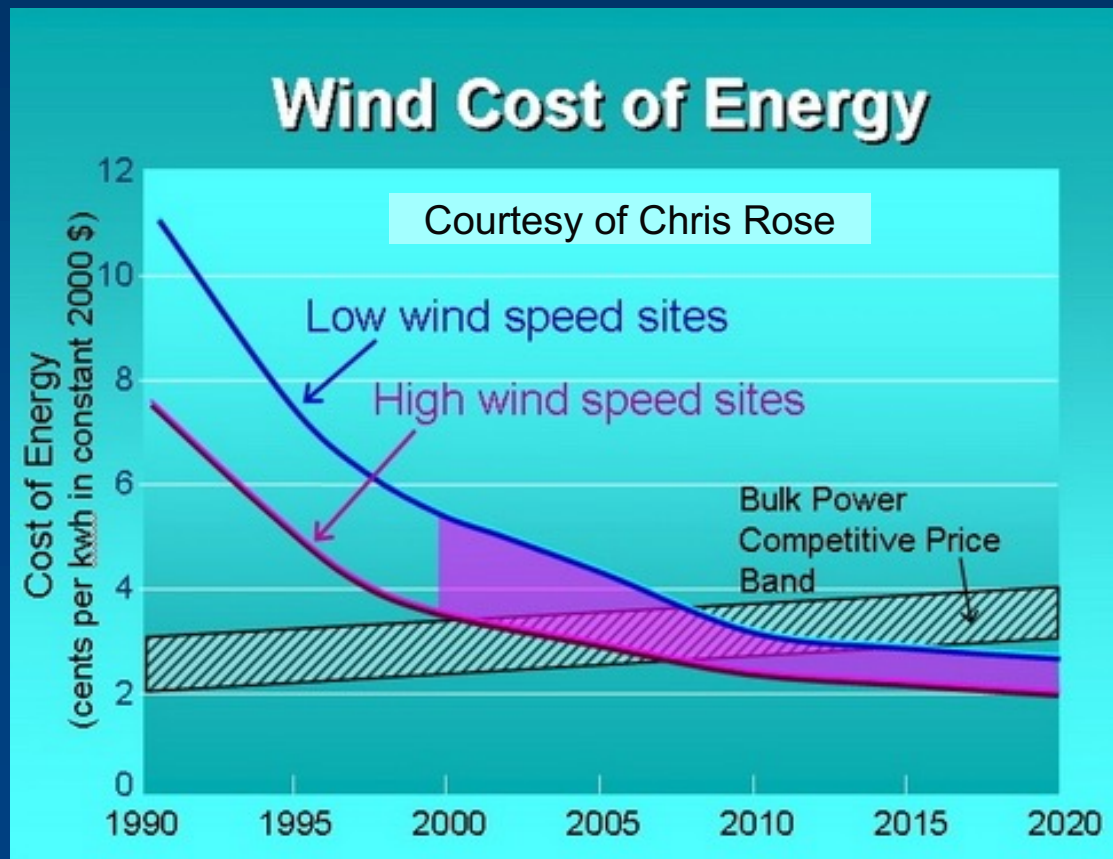
Go Electric!



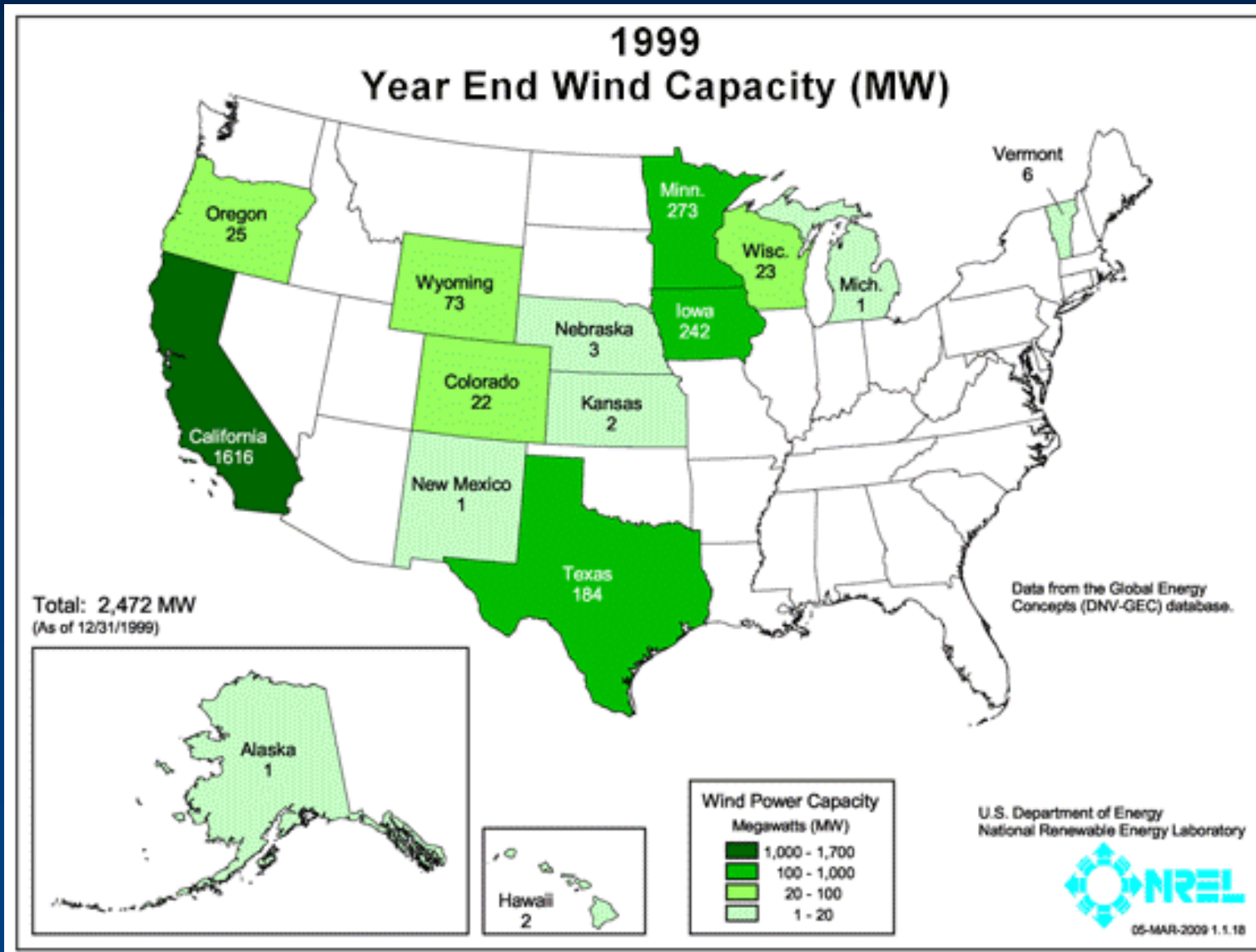
Wind Power



NM wind:
1680 MWatt
as of 2017
(ranked 6th
Nationwide)



Wind Power



NM wind:
4000 MWatt
as of 2022
(ranked 14th
Nationwide)

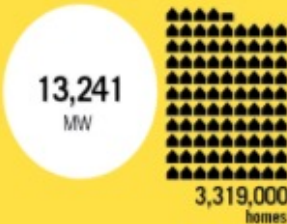
US Total:
122,478 MW

TOP 10 SOLAR STATES

State ranking based on the amount of cumulative solar electric capacity installed (as of December 2015)



1 California



2 Arizona



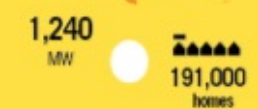
3 North Carolina



4 New Jersey



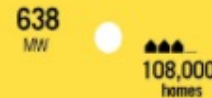
5 Nevada



6 Massachusetts



7 New York



8 Hawaii



9 Colorado



10 Texas



● Cumulative Installed Solar Capacity (MW)¹

▲ Homes powered by solar² (35,000 homes)

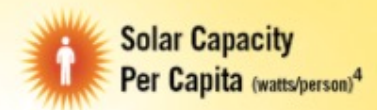
(an estimate of the number of homes powered per megawatt of solar capacity installed, including both photovoltaic and concentrating solar power)



TOP 10 SOLAR STATES REMIXED



1	75,598	California
2	15,095	Massachusetts
3	8,764	Nevada
4	8,250	New York
5	7,071	New Jersey
6	7,030	Texas
7	6,922	Arizona
8	6,560	Florida
9	5,950	North Carolina
10	4,998	Colorado

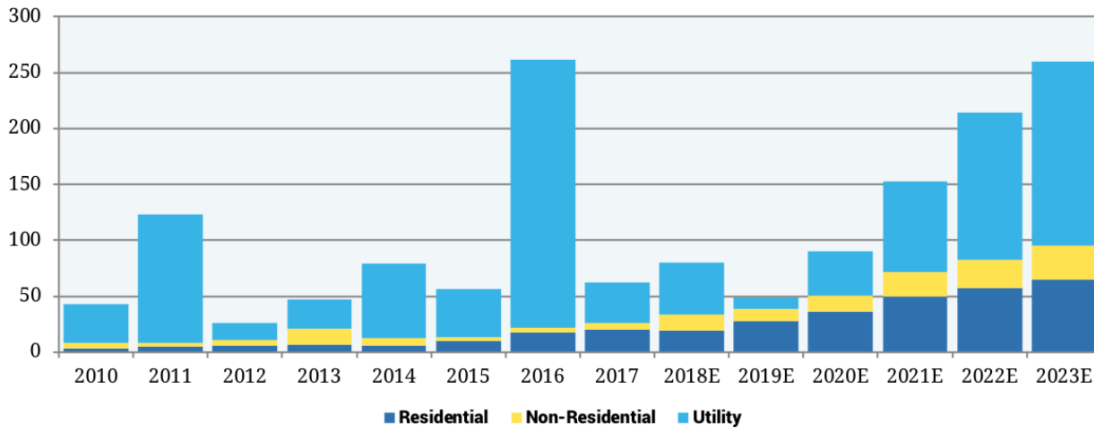


1	429	Nevada
2	394	Hawaii
3	338	California
4	337	Arizona
5	208	North Carolina
6	182	New Jersey
7	175	New Mexico
8	171	Vermont
9	150	Massachusetts
10	99	Colorado

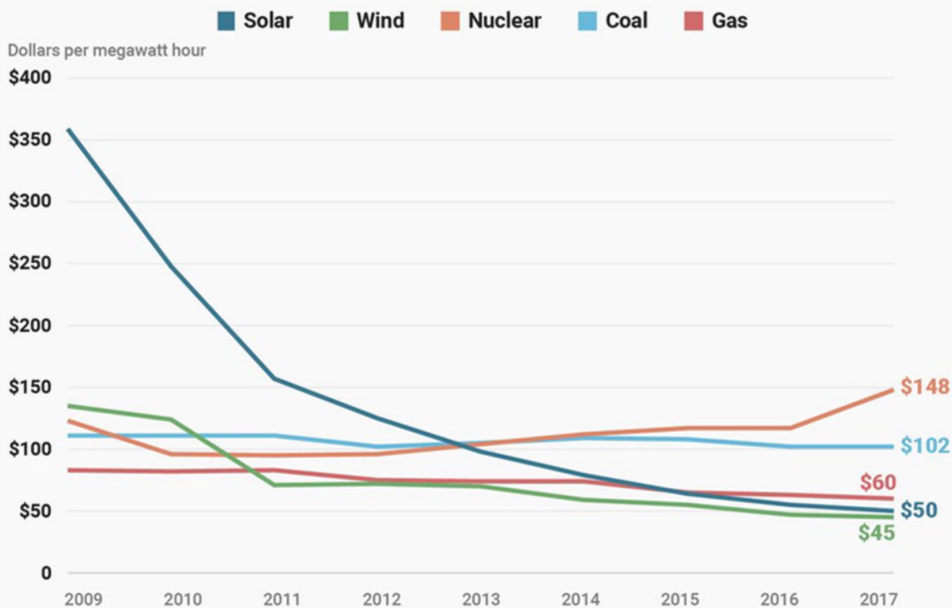
Solar Power

What We Can Do

New Mexico PV Installation Forecast



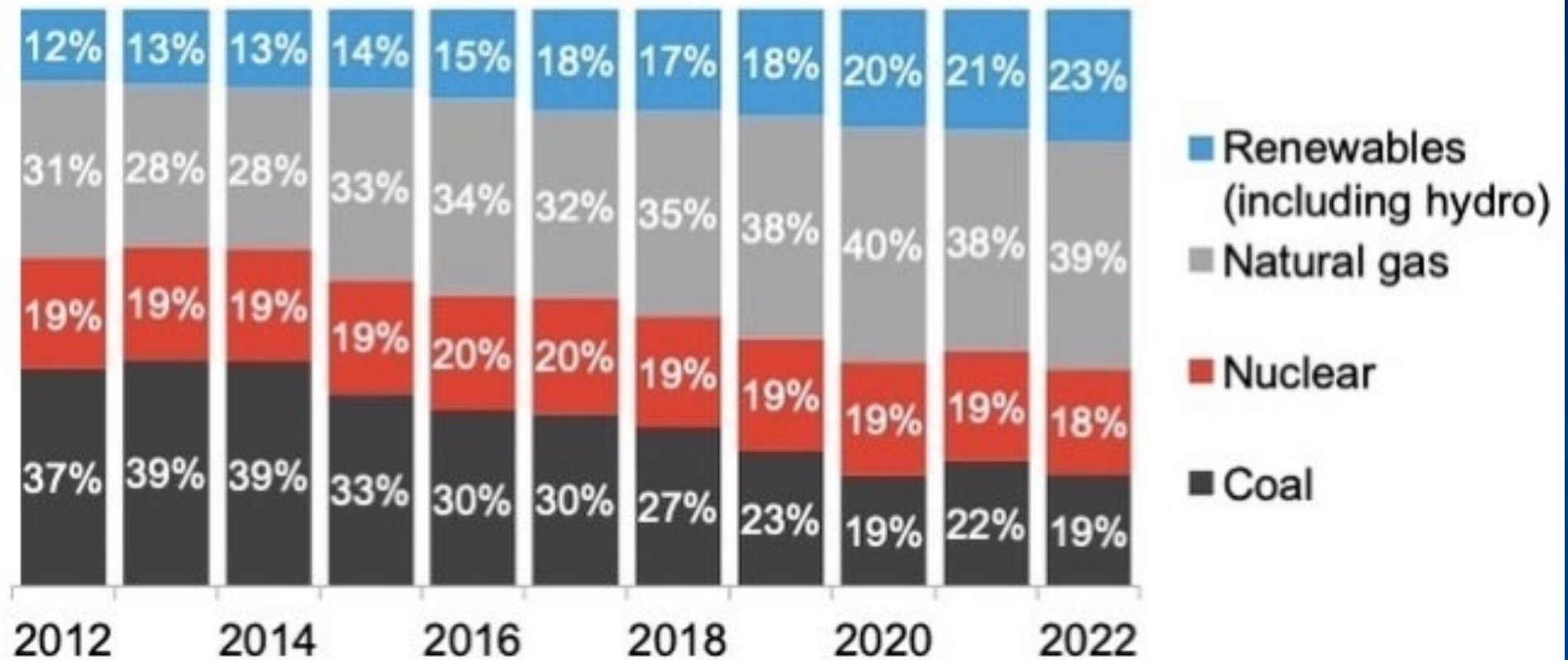
The average cost of energy in North America



Source: Lazard leveled cost of energy analysis

NM solar:
 1900 MWatt
 as of 2024
 (ranked 21st
 Nationwide)

US electricity generation, by fuel type



Per capita electricity generation from fossil fuels, nuclear and renewables, 2022

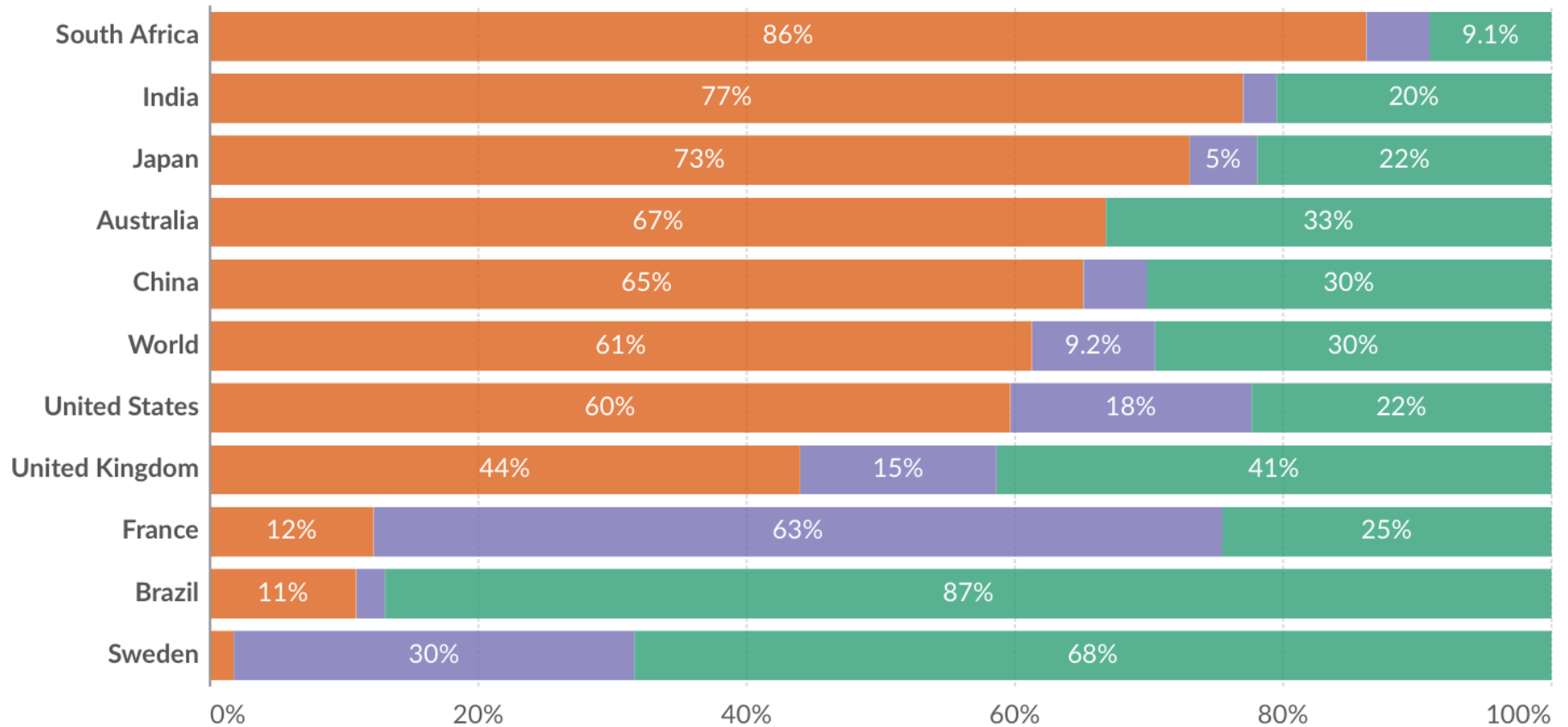
Our World
in Data

Table Chart

Edit countries and regions

Settings

Fossil fuels Nuclear Renewables



1985

2022

Data source: Ember - Yearly Electricity Data (2023) and other sources - [Learn more about this data](#)

OurWorldInData.org/electricity-mix | CC BY



Measuring Your Carbon Footprint

Major Carbon Contributors:

- Electric Consumption
- Gas/Heating Consumption
- Car and Miles Driven
- Miles Flown
- Food consumption (especially meat)

Average Footprint is 30,000 pounds per person in USA



Direct Air Capture

Current Cost (2021) = \$250/ton (bargain)

Global production = 40 billion metric tons/year

Cost = 4×10^{10} x \$250 = 10 trillion dollars/year

Global GDP is currently 75 trillion dollars/year

Conservation: Three Examples

- Bike, Walk, or Bus to work
 - 3/week
 - **Est: 5,000 lbs/year/person**
- Pump Up Tires:
 - 4 million gallon of gas wasted daily in US
 - Extends life of tires by 25%
 - **Est: 1,000 lbs/year/person**
- Eat less meat
 - Give up 1 lb/week
 - **Est: 600 lbs/year/person**



Making a Difference as an Individual

Conservation Measures:

- Walk, bike, ride public transit, or carpool
- Make sure your tires are fully inflated and your car tuned up
- Lower your water heater and home thermostats
- Eat less meat
- Reduce your shower length and temperature
- Buy locally produced food
- Unplug appliances not in use
- Turn off lights when leaving a room
- Use recycled paper
- Reuse or recycle as much as you can
- Cut down on consumerism
- **Encourage elected officials to address global warming on state/national level.**

