



ENERGY AND CLIMATE CHANGE
OLLI – AU
RON EDELSTEIN
ALBERT CHEH
SESSION 1
CLIMATE CHANGE

1. Climate change
2. Current energy landscape
3. Energy efficiency
4. Net-zero buildings and transportation
5. Fossil fuels
6. Nuclear and the electric grid
7. Distributed generation and photovoltaics
8. Other renewables
9. Energy Policy and En-ROADS climate model

LECTURES

- ▶ Where does our energy come from?
- ▶ U.N warning
- ▶ Climate threats to the U.S.
- ▶ Global CO2 emissions over time
- ▶ The greenhouse effect
- ▶ Correlation of global temperatures and CO2
- ▶ Climate change in the news
- ▶ Climate change modeling update
- ▶ Climate change tipping points
- ▶ Ice sheet melting
- ▶ Weather events and climate change
- ▶ Sea level rise
- ▶ Drought, fresh water, and climate change
- ▶ Climate change and hurricanes
- ▶ Carbon uptake by plants during global warming
- ▶ Good news – ocean ecosystems offset GHG emissions
- ▶ Melting permafrost?
- ▶ The new Arctic
- ▶ Conclusions

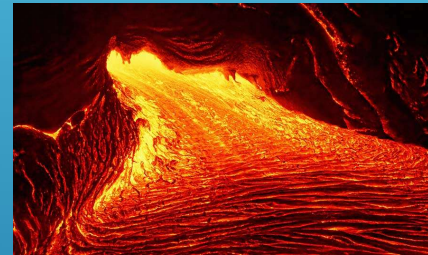
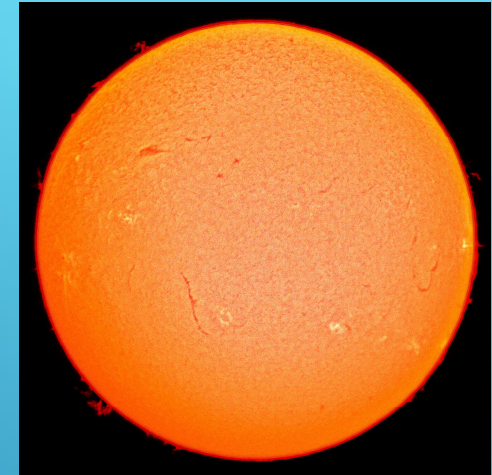
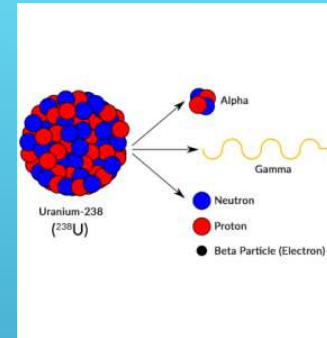


Matanuska Glacier
Alaska - 2017



TABLE OF CONTENTS

- ▶ Most of our energy comes from the sun: solar energy
- ▶ Gravity
- ▶ Radioactive decay
- ▶ Rotation of the earth



WHERE DOES OUR ENERGY COME FROM?



U.N. report says globe could warm by over 2.7C, Washington Post, 9/18/21

- ▶ The U.N. warned that based on the most recent action plans submitted by 101 countries to curb GHG emissions, the planet is on track to warm by more than 2.7C (4.9F) by 2100 – far above what world leader have said to be the safe upper limit of global warming (1.5-2C)
- ▶ Even a lower increase would mean millions of people losing their homes to rising seas, vast sections of permafrost lost, and extinction for scores of animal species
- ▶ President Biden gathered the world's biggest emitters to try to reach an agreement among some of them to cut emissions of methane – a potent GHG – by 30% by 2030
- ▶ But the U.N. warned that if other nations – including China and India – do not submit new, more ambitious plans and instead continue on their current path, GHG emissions would increase by 16% by 2030, putting the planet on a trajectory toward 2.7C of global warming
- ▶ According to the IPCC, increases to 1.5C requires a 45% reduction in CO2 emissions by 2030; limiting warming to 2C would require a 25% reduction
- ▶ Many of the biggest emitters – China, India, and Turkey have yet to formally commit to a 2030 emissions reduction target.
- ▶ Equally worrisome, Brazil and Mexico submitted *weaker* targets than they did 5 years ago, and Russia said it could emit *more* in 2030 than it does today
- ▶ Secretary of State Blinken said that the IPCC report “provided irrefutable evidence of the crisis now upon us.”
- ▶ U.N General Secretary Guterres said, “The world is on a catastrophic pathway to 2.7C of heating.”

U.N. WARNING



U.N. General Secretary
Guterres

U.S. Secretary of State
Blinken



- ▶ Earth experienced its sixth hottest year on record in 2021. The title for all-time hottest year still goes to 2020. The seven hottest years on record have all occurred in the last seven years.
- ▶ Each of the last 4 decades have been warmer than the one before.
- ▶ It's not just global average temperatures are increasing. The consequences of climate change, including extreme weather events and climate-related disasters, are also growing more severe all over the world.
- ▶ Last year, there were 20 billion-dollar disasters in the U.S. That's just shy of the 22 disasters in 2020. Worldwide, insurance losses exceeded \$100 billion for only the third time since 1970.
- ▶ Extreme events around the globe included Hurricane Ida, which killed dozens of people in the U.S. as it swept from the Gulf Coast to the Northeast; Typhoon Rai, which killed hundreds of people in the Philippines; extreme wildfires in western U.S., Europe, and India; record breaking floods in Germany; and an unprecedented heat wave in the Pacific Northwest.

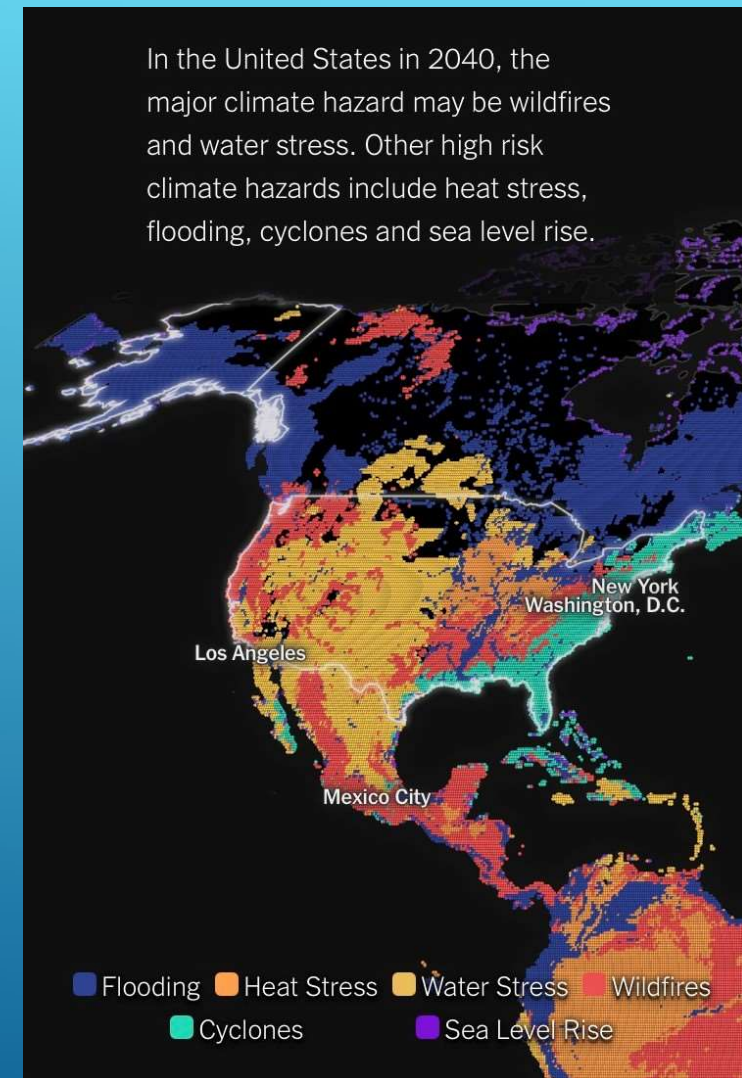


**2021 WAS THE SIXTH HOTTEST YEAR ON RECORD,
E&E NEWS, 1/13/2022**

What are the top climate threats to your country? N.Y. Times, 1/28/21

- ▶ In the U.S. in 2040, the major climate hazard may be wildfires and water stress
- ▶ Other high-risk climate hazards include heat stress, flooding, hurricanes, and sea level rise
- ▶ Overall, in the U.S., roughly 80% of the population, GDP, and agriculture might be exposed to at least one climate hazard in the future

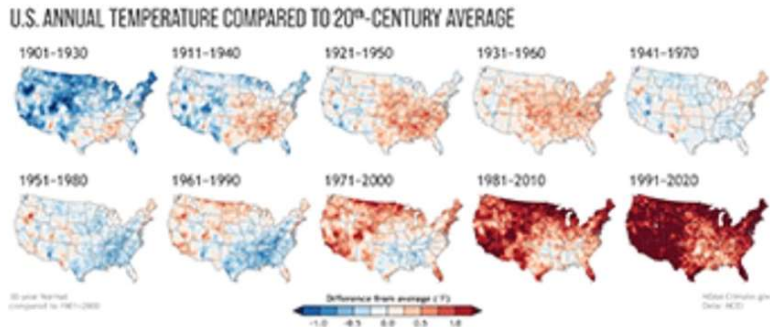
CLIMATE THREATS TO U.S.



NOAA's new 'normal' makes it official: U.S. is heating up, EandE News, 5/5/21

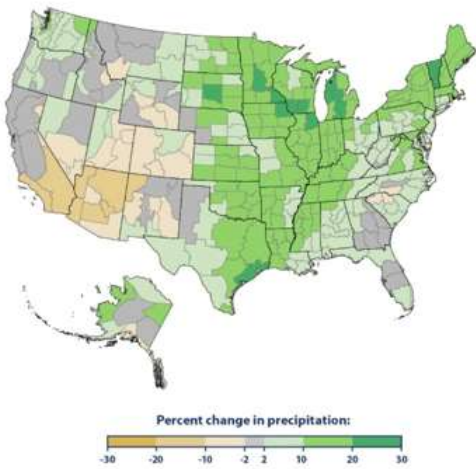
- ▶ NOAA released a new 30-year set of climate data yesterday that offers an updated standard for what will define “normal” weather in the next decade
- ▶ One thing is clear: the nation is getting warmer; at least most of it
- ▶ NOAA said the overall trend from 1991-2020 showed the West, the South, and the eastern parts of the U.S. heating up, with an increase of anywhere from 0.5-1.5F
- ▶ “The influence of long-term global warming is obvious,” a NOAA spokesperson said
- ▶ “It’s warmer pretty much everywhere, except for the north-central U.S., here temperatures stayed the same or were even a little cooler.”
- ▶ “it’s wetter in the eastern two-thirds of the U.S. and also the Pacific NW, but it was drier in the SW

U.S. IS HEATING UP



[+] Annual U.S. temperature compared to the 20th-century average for each U.S. Climate Normals period from 1901-1930 (upper left) to 1991-2020 (lower right). Jared Rennie, North Carolina Institute for Climate Studies/NCEI/NOAA
Climate.gov

Figure 3. Change in Precipitation in the United States, 1901–2020



Earth could surpass its ability to recover from warming, E&E News, 2/11/22

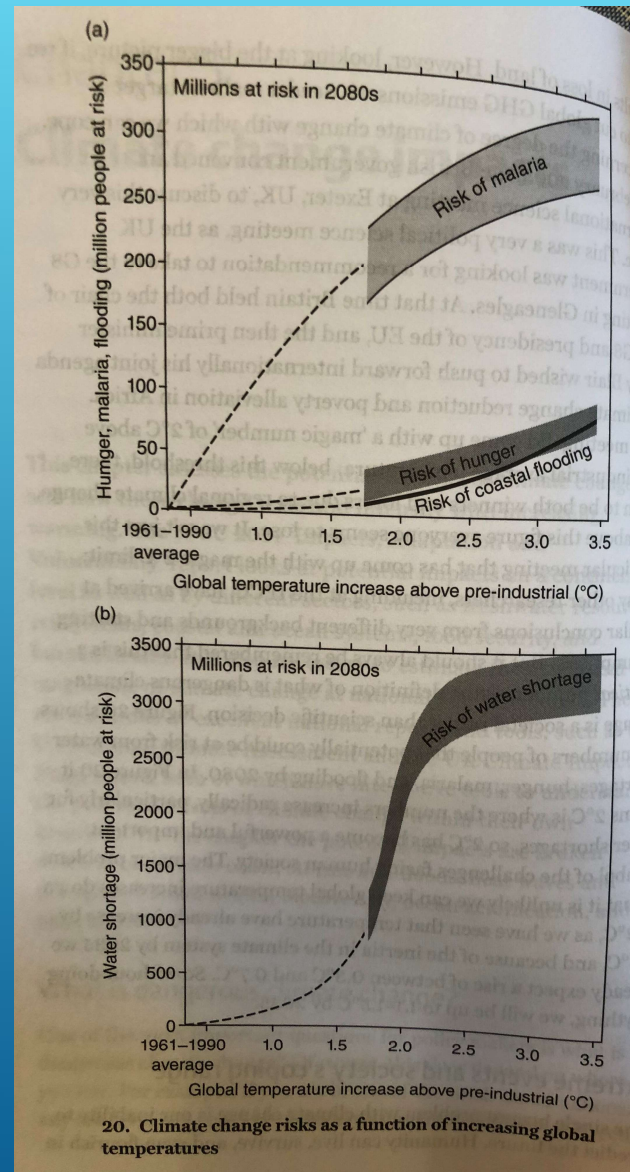
- ▶ Some parts of the planet are approaching the limits of their ability to adapt to climate change, scientists warned
- ▶ Extreme drought and heat could prevent trees from absorbing CO₂, thrusting some ecosystems past the point from which they can recover
- ▶ Some systems, like tropical coral reefs, have already surpassed those limits and are headed toward decline
- ▶ The Intergovernmental Panel on Climate Change (IPCC) is scheduled to release a report that focuses on the limit of Earth's ability to respond to damaging temperature increases



Bleached coral reef

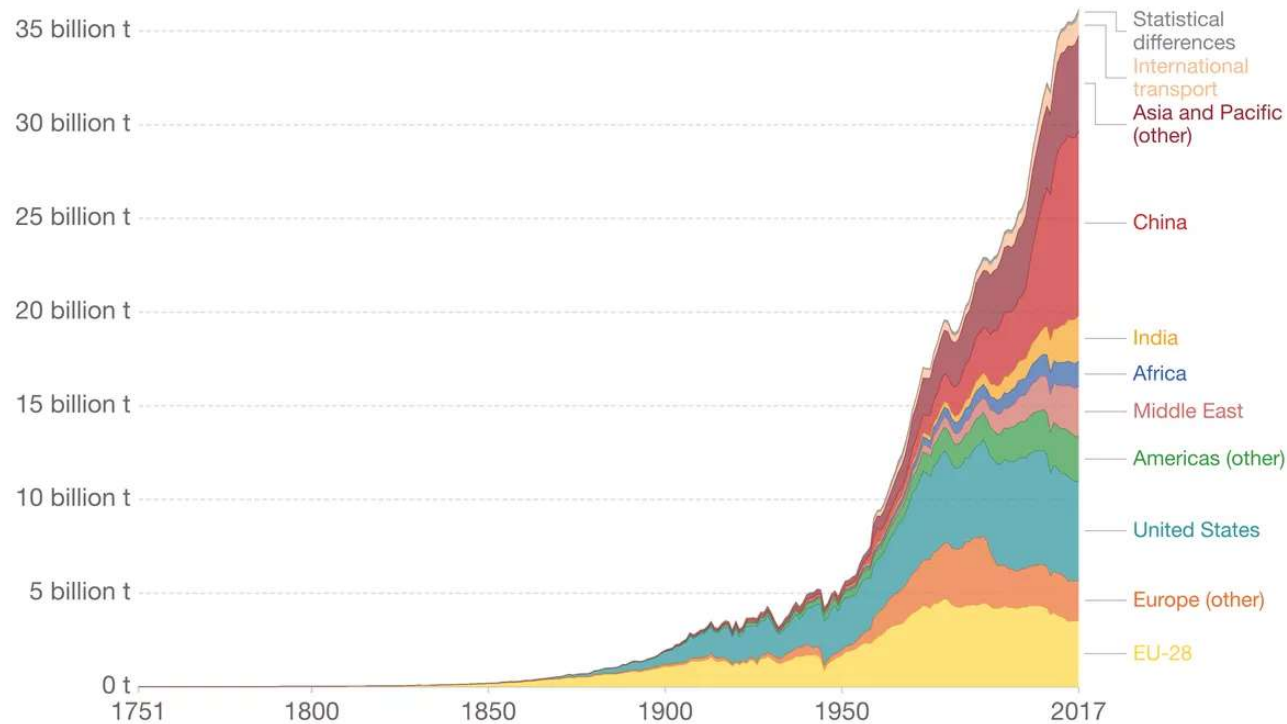
IPCC ASSESSMENT

WHY A 2C GOAL?



Ref: Climate Change:
A short Introduction,
Mark Maslin

Annual total CO₂ emissions, by world region



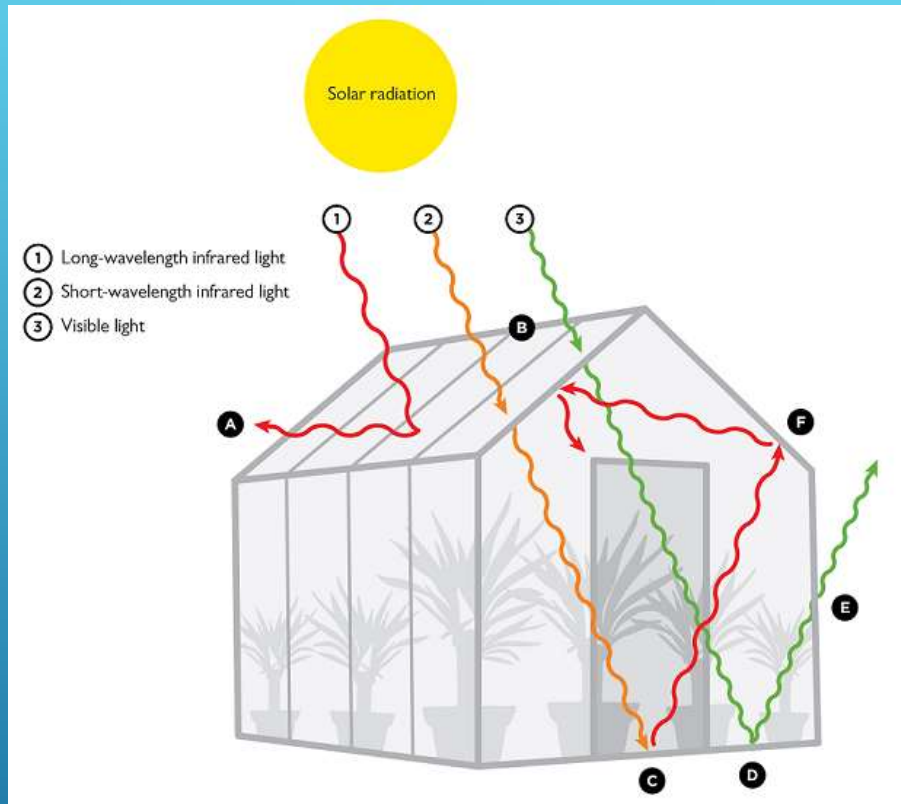
Source: Carbon Dioxide Information Analysis Center (CDIAC); Global Carbon Project (GCP)

Note: The difference between the global estimate and the sum of national totals is labeled "Statistical differences".

OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

GLOBAL CO₂ EMISSIONS CONTINUE TO INCREASE: GUTERRES IS CORRECT

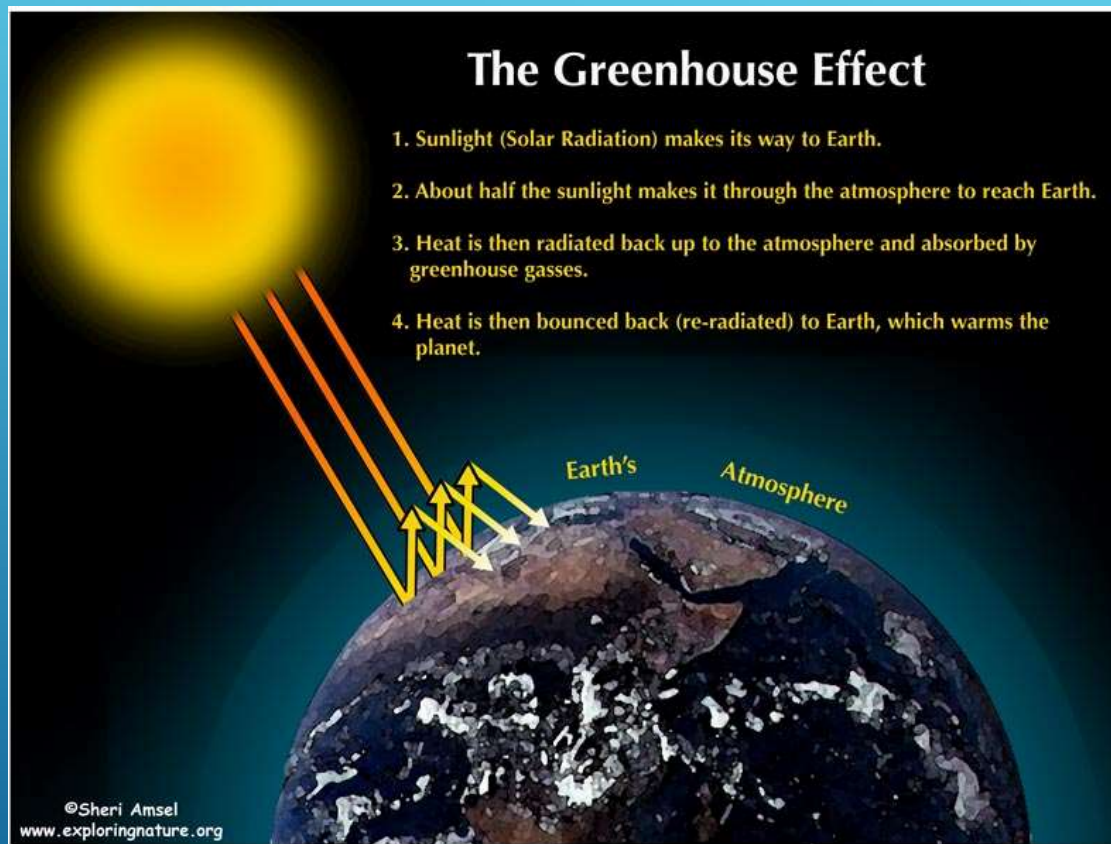
Global Carbon Project,
7/16/20



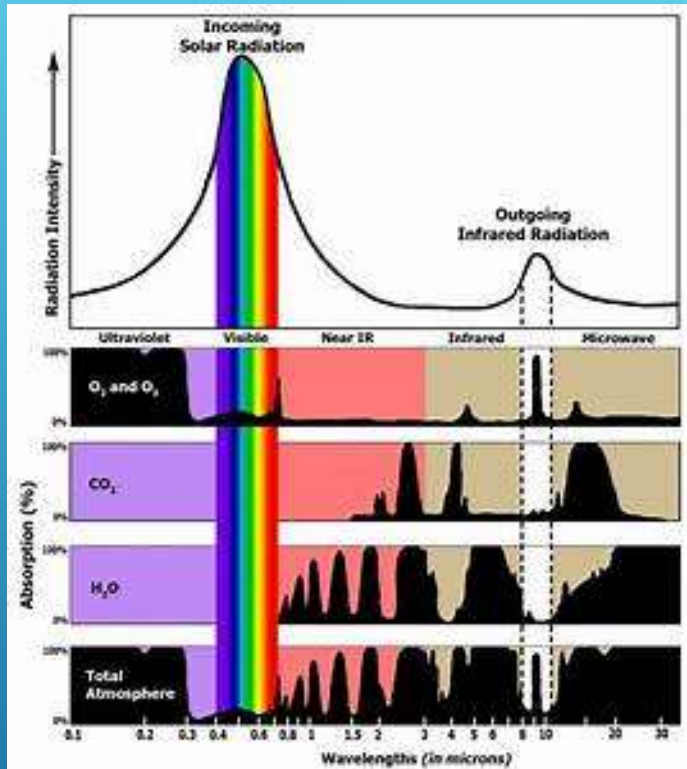
- Glass is transparent to incoming solar (visible) energy
- Glass is opaque to outgoing long-wave infrared energy and reflects that energy back into the greenhouse, warming it

GREENHOUSE EFFECT IN A GREENHOUSE

Greenhouse Effect



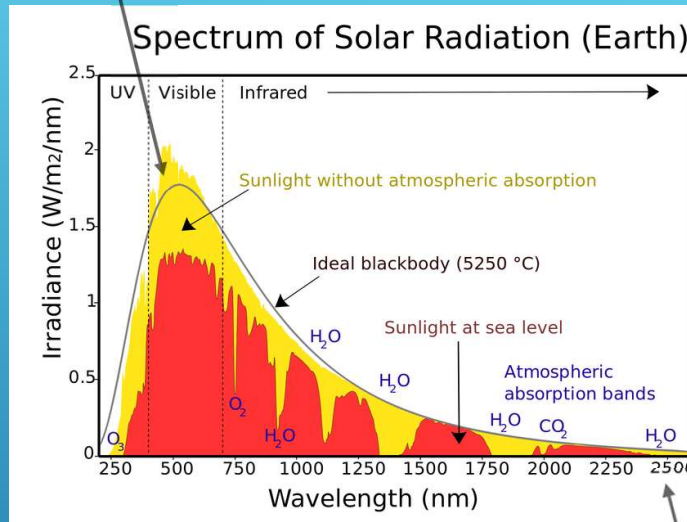
Absorptivity of different gases



Micrometers
(microns)

Absorptivity of Different Gases and impact on incoming solar and outgoing terrestrial radiation: GHG's are virtually transparent to incoming solar visible radiation

9,482F Incoming Solar Radiation



Nanometers*

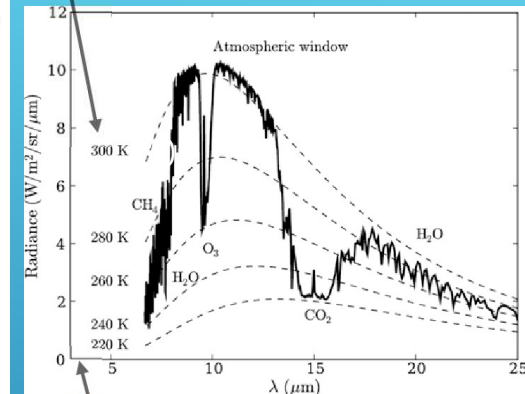
2.5 microns

*1,000 nanometers = 1 micron

UV = 0.01-0.4 microns
Visible = 0.4-0.7 microns
Infrared = 0.7-1,000 microns

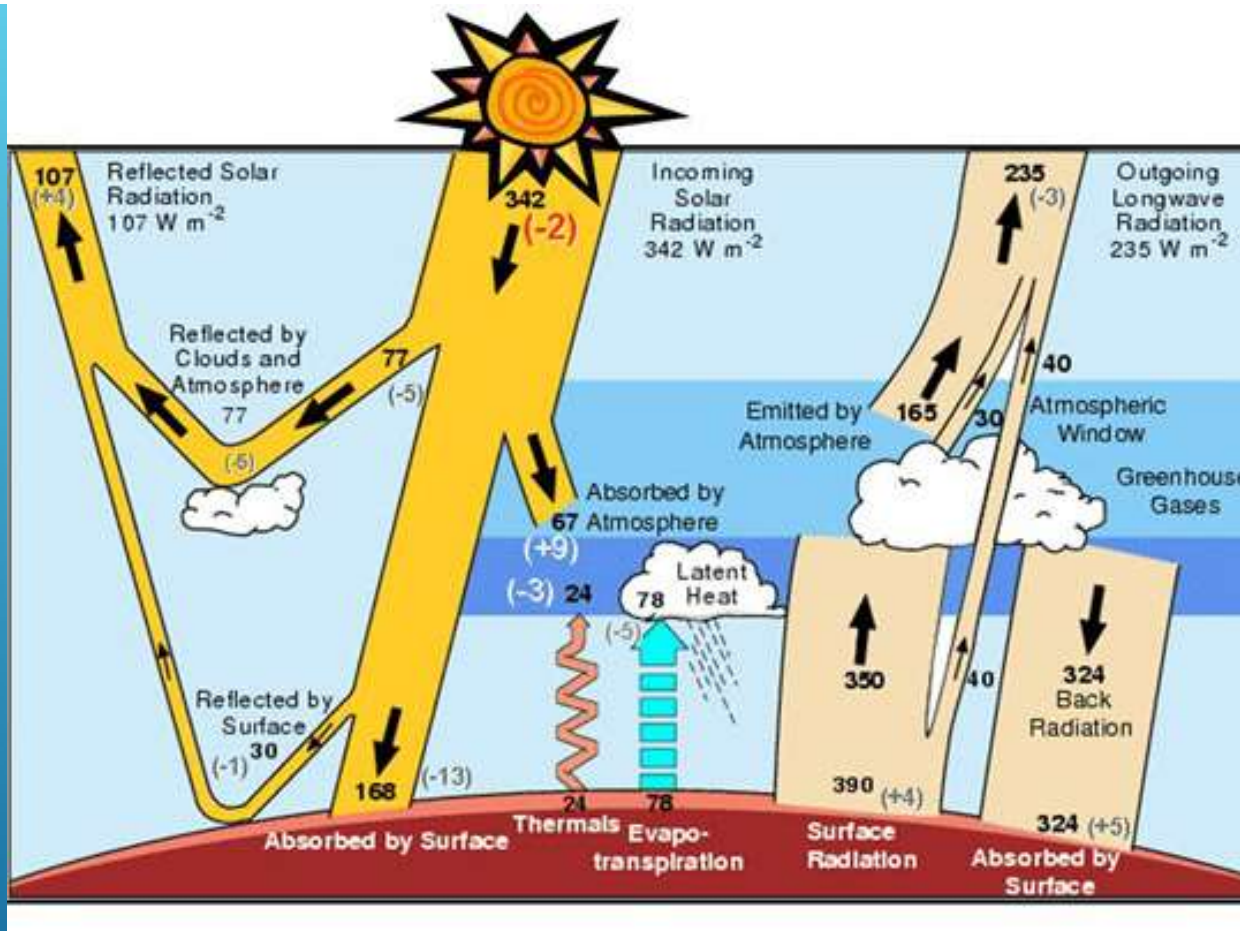
80F

Outgoing terrestrial radiation



Micrometers
(microns)

1,000nm



EARTH'S PRESENT-DAY ENERGY BALANCE

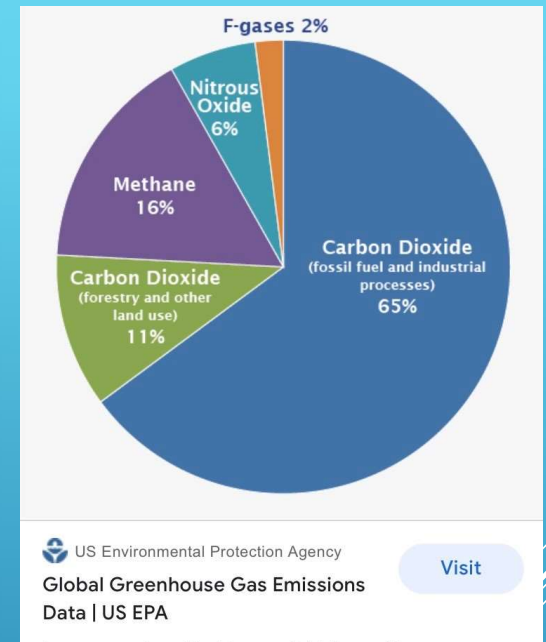


Measuring incoming solar radiation at the edge of space

Global Warming Potential of Primary Greenhouse Gases

Greenhouse Gas	Chemical formula	Global Warming Potential (Time Horizon)	
		20 years	100 years
Carbon Dioxide	CO ₂	1	1
Methane	CH ₄	42-70	16-26
Nitrous Oxide	N ₂ O	280	310
Hydrofluorocarbons	HFCs	460 - 9,100	140-11,700
Perfluorocarbon	PFCs	4,400-6,200	6,500-23,900
Sulphur Hexafluoride	SF ₆	16,300	23,900

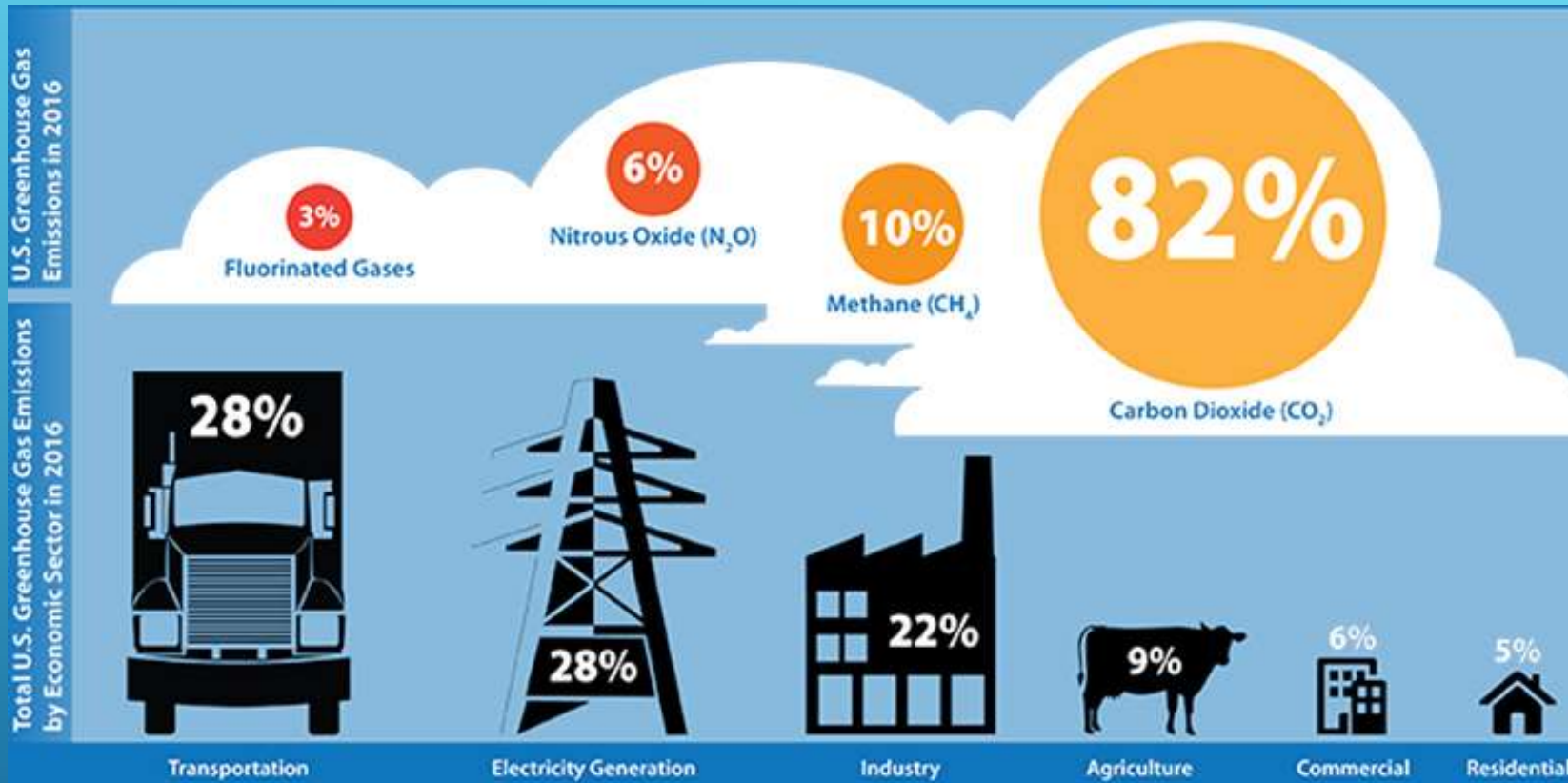
GWP and GHG lifetimes



So CO₂ emitted this year will remain in the atmosphere for hundreds of years

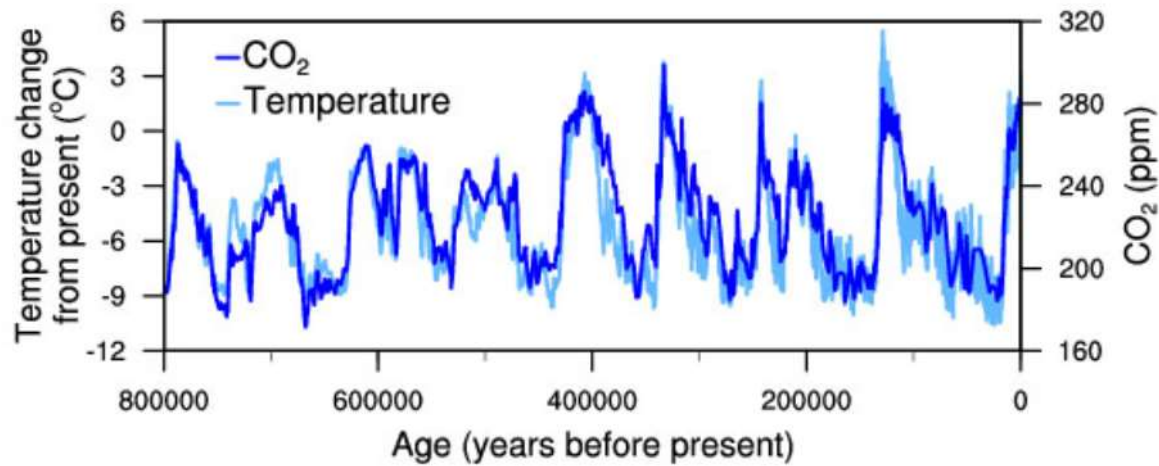
Average lifetimes of GHGs

- CO₂ – 300-1,000 years
- CH₄ – 10-12 years
- NO_x - > 100 years
- HFCs – 15-29 years
- PFCs – 50-200 year
- SF₆ – 3,200 years

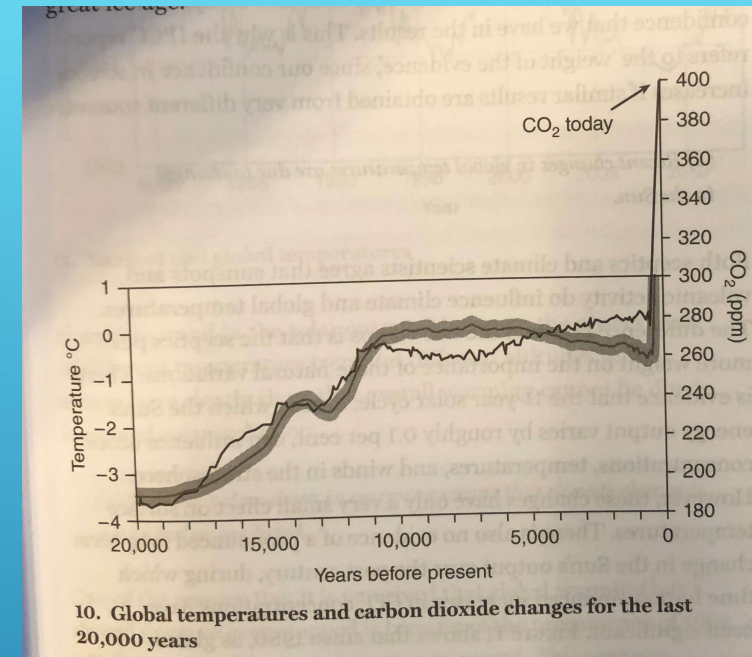


U.S. GREENHOUSE GASES (GHG) CONTRIBUTION TO GLOBAL WARMING

Environmental Health
and Safety Solutions,
2019



Temperature change (light blue) and carbon dioxide change (dark blue) measured from the EPICA Dome C ice core in Antarctica (Jouzel et al. 2007; Lüthi et al. 2008).



The "hockey stick"

From Mark Maslin,
"Climate Change"



CORRELATION OF GLOBAL TEMPERATURES AND CO₂

<https://www.ncdc.noaa.gov/global-warming/temperature-change>

What are the RCPs?

RCP stands for 'Representative Concentration Pathway'. To understand how our climate may change in future, we need to predict how we will behave.

For example, will we continue to burn fossil fuels at an ever-increasing rate, or will we shift towards renewable energy?

Current emissions are tracking close to the RCP8.5 pathway

The RCPs try to capture these future trends. They make predictions of how concentrations of greenhouse gases in the atmosphere will change in future as a result of human activities.

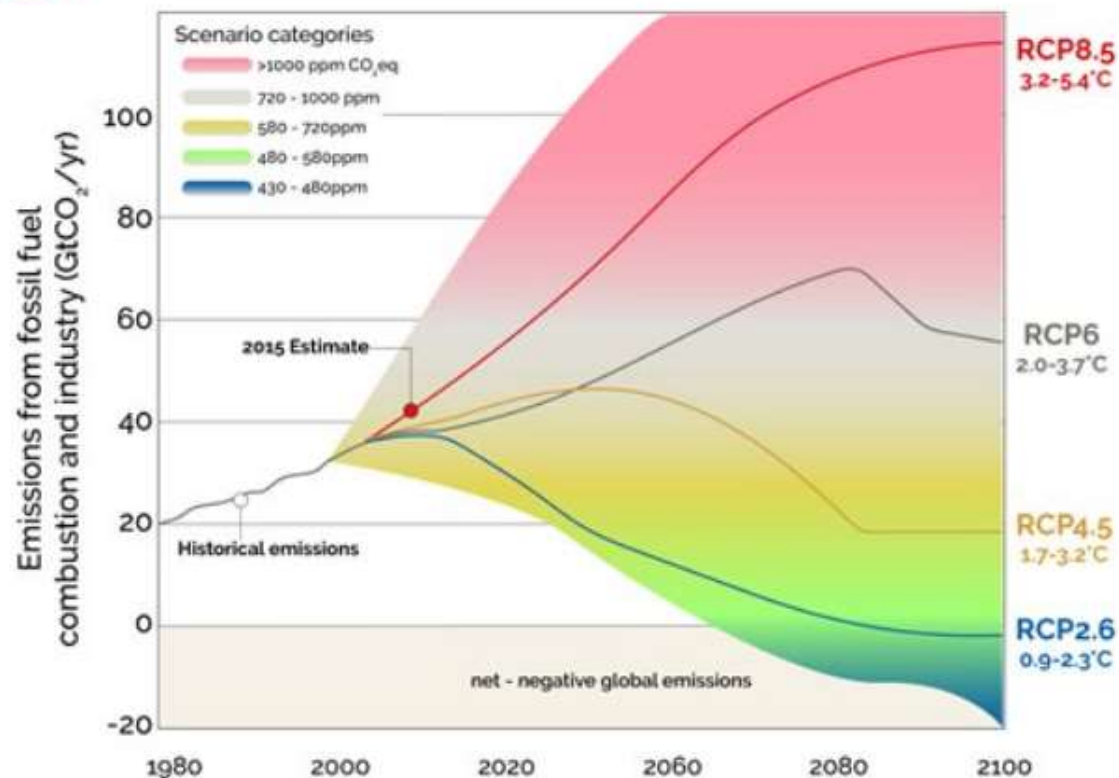
The four RCPs range from very high (RCP8.5) through to very low (RCP2.6) future concentrations. The numerical values of the RCPs (2.6, 4.5, 6.0 and 8.5) refer to the concentrations in 2100.

2°C
increase in temperature
is recognised as the threshold at which climate change becomes dangerous

Effort to curb emissions	Energy generation	New technology	Transport	Temperature 2081-2100 (average increase relative to 1986-2005)	Sea level 2081-2100 (average rise relative to 1986-2005)	Extreme weather 2081-2100	Adaptation required
Low	Coal-fired power		Cars, trucks	RCP 8.5 3.7 °C	0.63 m	Large increase	High level at high cost
Medium	Mix		Mix	RCP 6.0 2.2 °C	0.48 m	Moderate increase	Medium level at medium cost
Medium	Renewable		Mix	RCP 4.5 1.8 °C	0.47 m	Moderate increase	Medium level at medium cost
High	Renewable	Emissions capture	Bicycles, public transport	RCP 2.6 1.0 °C	0.4 m	Small increase	Low level at low cost

RCP8.5 – Business as usual
RCP6.0 – Emissions peak 2080
RCP4.5 -- Emissions peak 2040-2050
RCP2.6 – Emissions peak in 2020

CLIMATE CHANGE SCENARIOS



RCP8.5 – Business as usual
 RCP6.0 – Emissions peak 2080
 RCP4.5 – Emissions peak 2040-2050
 RCP2.6 – Emissions peak in 2020

RCP – Representative Concentration Pathway

1 Gt = 1,000 megatonnes
 1 GT = 1 billion tonnes

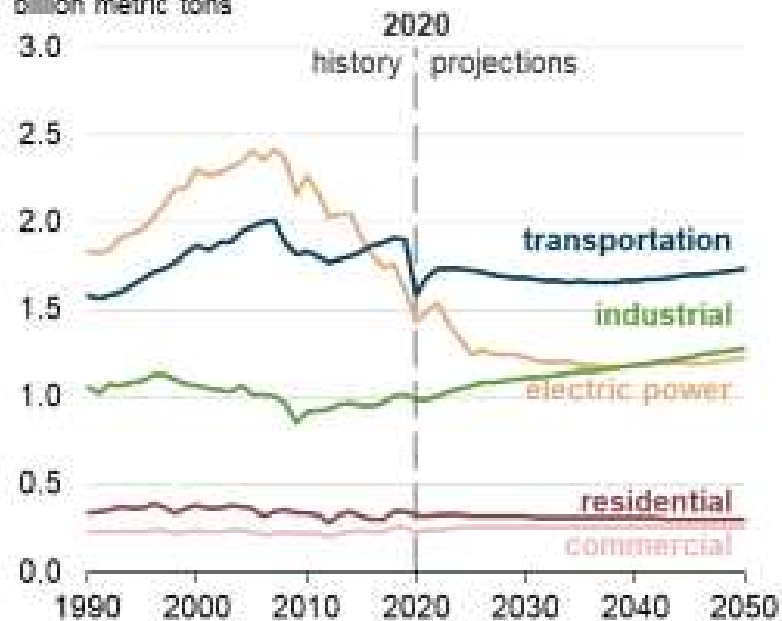
CLIMATE MODELING SCENARIOS: RESULTS



Energy-related carbon dioxide emissions by sector and fuel source

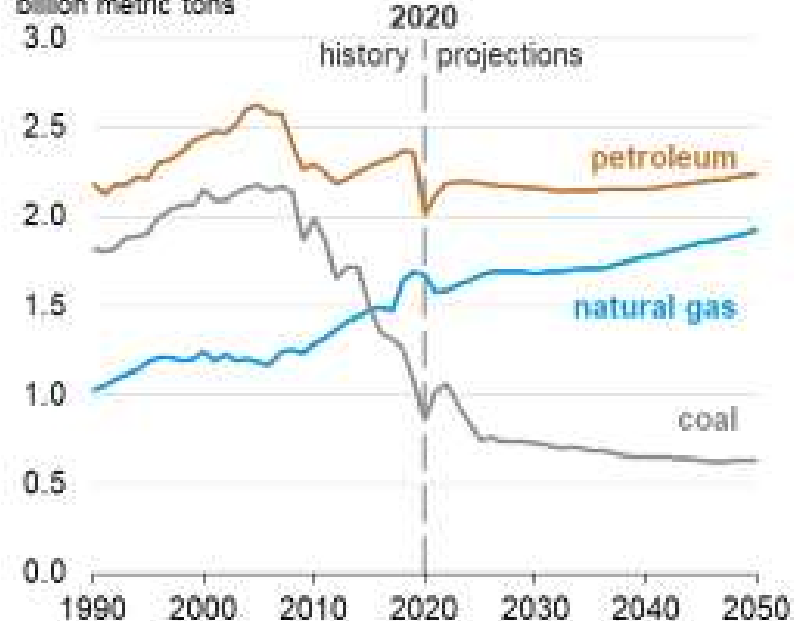
Energy-related carbon dioxide emissions by sector
AEO2021 Reference case

billion metric tons



Energy-related carbon dioxide emissions by fuel
AEO2021 Reference case

billion metric tons



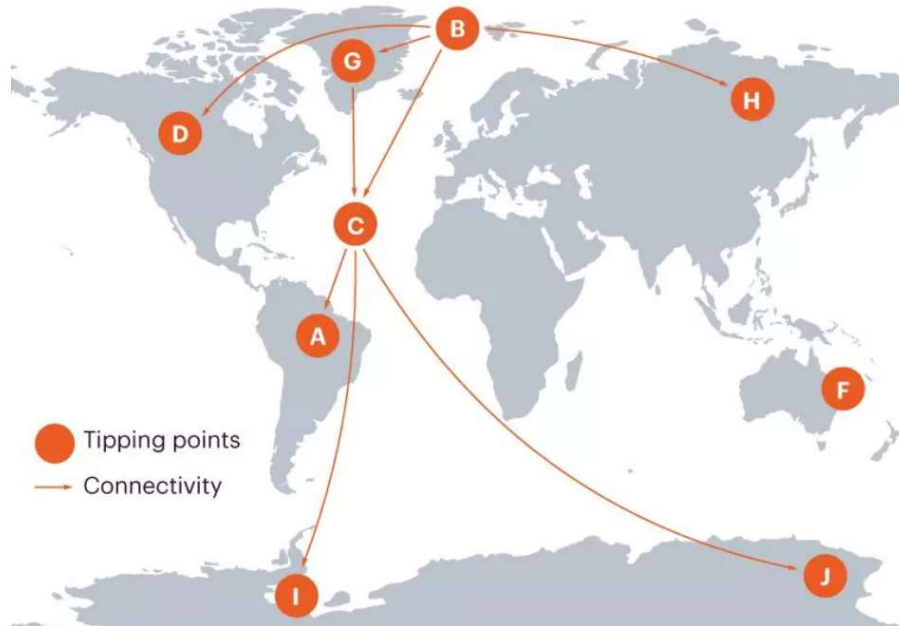
Metric ton = 2,200 pounds

CO₂ Emissions



RAISING THE ALARM

Evidence that tipping points are under way has mounted in the past decade. Domino effects have also been proposed.



A. Amazon rainforest
Frequent droughts

B. Arctic sea ice
Reduction in area

C. Atlantic circulation
In slowdown since 1950s

D. Boreal forest
Fires and pests changing

F. Coral reefs
Large-scale die-offs

G. Greenland ice sheet
Ice loss accelerating

H. Permafrost
Thawing

I. West Antarctic ice sheet
Ice loss accelerating

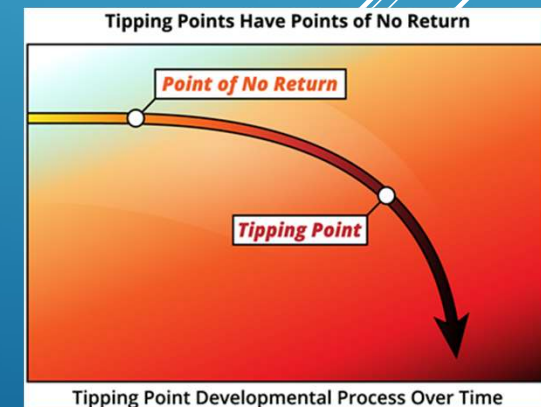
J. Wilkes Basin, East Antarctica
Ice loss accelerating

©nature

Other potential tipping points:
Methane hydrates melting and release

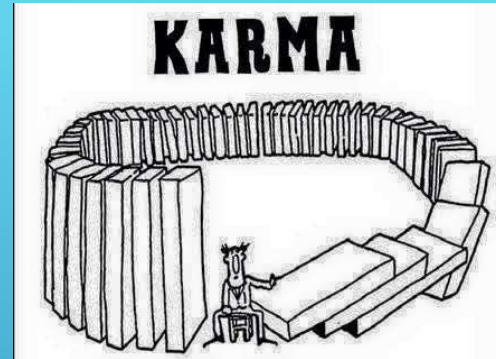
CLIMATE CHANGE TIPPING POINTS

<https://www.nature.com/articles/d41586-019-03595-0>



Tipping elements can destabilize each other, leading to climate domino effects, Science Daily, 6/3/21

- ▶ Under global warming, tipping elements in the Earth system can destabilize each other and eventually lead to climate domino effects
- ▶ The ice sheets on Greenland and West Antarctica are potential starting points for tipping cascades, a new network analysis reveals
- ▶ The risk increases significantly for warming of 1.5-2C, within the temperature range of the Paris Agreement
- ▶ “All in all, this might mean that we have less time to reduce GHG emissions and still prevent tipping processes
- ▶ One example: if there is substantial melt from the Greenland Ice Sheet releasing fresh water into the ocean, this can slow down the Atlantic overturning circulation (including the Gulf Stream) which is driven by temperature and salinity differences and transports large amounts of heat from the tropics to the mid-latitudes and power regions.
- ▶ This can, in turn, lead to net warming in the Southern Ocean, and hence might on the long-run destabilize parts of the Antarctic Ice Sheet
- ▶ This contributes to sea level rise, and rising waters on the fringes of the ice sheets in both hemispheres can contribute to further destabilizing them



Domino effects

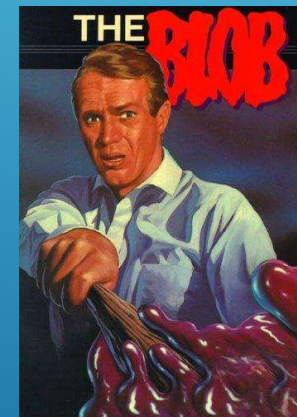
TIPPING POINTS (CONT.)

Current steering weather hits slowest speed in 1,000 years, EandE News, 2/26/21

- ▶ An enormous ocean current that flows between continents in a worldwide circuit that can take centuries to complete is slowing down, and climate change may be partly to blame
- ▶ New research finds that the Atlantic Meridional Overturning Circulation (AMOC) – a major ocean system that ferries water and heat between the equator and the poles – is at its weakest point in more than 1,000 years
 - ▶ The Gulf Stream is part of the AMOC
- ▶ For most of the last 1,600 hundred years the AMOC has been relatively stable. It began weakening in the 19th Century, and hit its slowest point in the last few decades
- ▶ *The system has slowed about 15%*
- ▶ The system acts as a global conveyor belt. Warm water flows north from the equator toward the Arctic, cooling as it goes. Cold water is denser and sinks toward the ocean floor. This cool water travels back to the equator, where it warms up and speeds toward Antarctica
- ▶ The melting of the Greenland ice sheet is pouring fresh water into the northern ocean. Fresh water is less dense than salt water, making it harder for the AMOC to sink toward the seafloor as it flows north. Many scientists think this has contributed to the slowdown
- ▶ “We see the Gulf Stream is slowing down,” said one of the scientists

Danger lurk in Atlantic shifts, N.Y. Times, 3/13/21

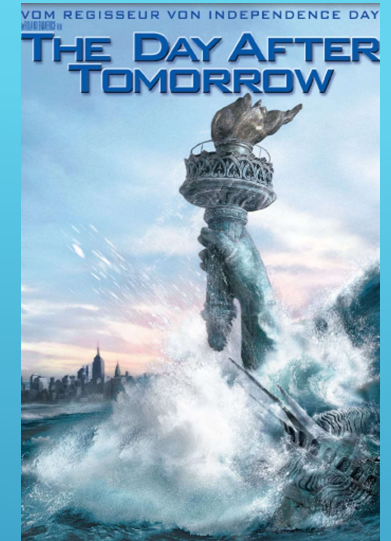
- ▶ Studies show northern portion of the Gulf Stream may be slowing
- ▶ The AMOC has weakened and shut down before in the past 13,000 years. Europe temperatures dropped about 15C below today's averages. Parts of northern Africa and northern South America became much drier
- ▶ There is a 'cold blob' just southeast of Greenland where the North Atlantic has become colder. Everywhere else, ocean temperatures are rising. The cold blob may signal that the northern arm of the Gulf Stream no longer arrives with the same strength to the North Atlantic
- ▶ Some fear that meltwater from Greenland is already inhibiting the northward flow of the Gulf Stream



GULF STREAM SLOWS DOWN

Critical ocean system may be close to collapse, Washington Post, 8/5/21

- ▶ Human-caused warming has led to an “almost complete loss of stability” in the system that drives Atlantic Ocean currents – raising the worrying prospect that this critical aquatic “conveyor belt” could be close to collapse
- ▶ Scientists have warned about a weakening of the Atlantic Meridional Overturning Circulation (AMOC), which transports warm, salty water from the tropics to northern Europe and then sends colder water back south along the ocean floor
- ▶ Scientists have uncovered evidence that the AMOC can turn off abruptly, causing wild temperature swings and other dramatic shifts
- ▶ Those indicators suggest that the AMOC is “running out of steam,” making it more susceptible to disruptions that might knock it out of equilibrium
- ▶ If the AMOC shuts down, it could bring extreme cold to Europe and parts of North America, raise sea levels along the U.S. East Coast, and disrupt seasonal monsoons
- ▶ “This is an increase in understanding ... of how close to a tipping point the AMOC might already be,” said one of the researchers



Poster for Day
After Tomorrow

GULF STREAM (CONT.)

Melting Arctic ice could release methane reserves, EandE News, 3/25/21

- ▶ Vast reserves of methane, a potent GHG, sit below the Arctic sea bed, and researchers say that melting sea ice risks releasing them into the atmosphere, further exacerbating climate change
- ▶ These supplies of methane, a GHG with a global warming potential (GWP) about 30 times that of CO₂, are held below the seafloor by a fragile balance of temperature and pressure
- ▶ But scientists say this equilibrium is in danger of becoming undone. The ice sheets that exert pressure on these methane reserves are melting, which could set the methane free
- ▶ One of the researchers, Dessandier, said that, “We showed that methane release occurred sporadically but over a long time with intense phases of leakage.”
- ▶ Dessandier said “global warming has a long list of consequences, some of them are pretty easy to observe and anticipate. But the ice sheet melting is not a linear phenomenon that simply follows temperature increases. Isostatic rebound* depends on the pressure but the trigger can happen any time and the [methane] gas release seems to keep going for several thousands of years after the start.”

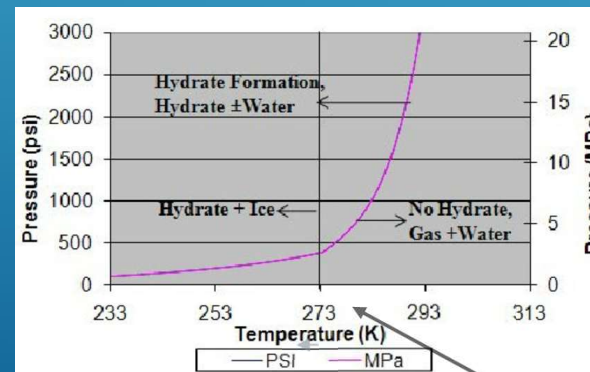


Methane hydrates



An Arctic landscape of snow, ice and meltwater extends beneath partly cloudy skies. NOAA Ocean Exploration & Research/Flickr

Hydrate
formation
zone



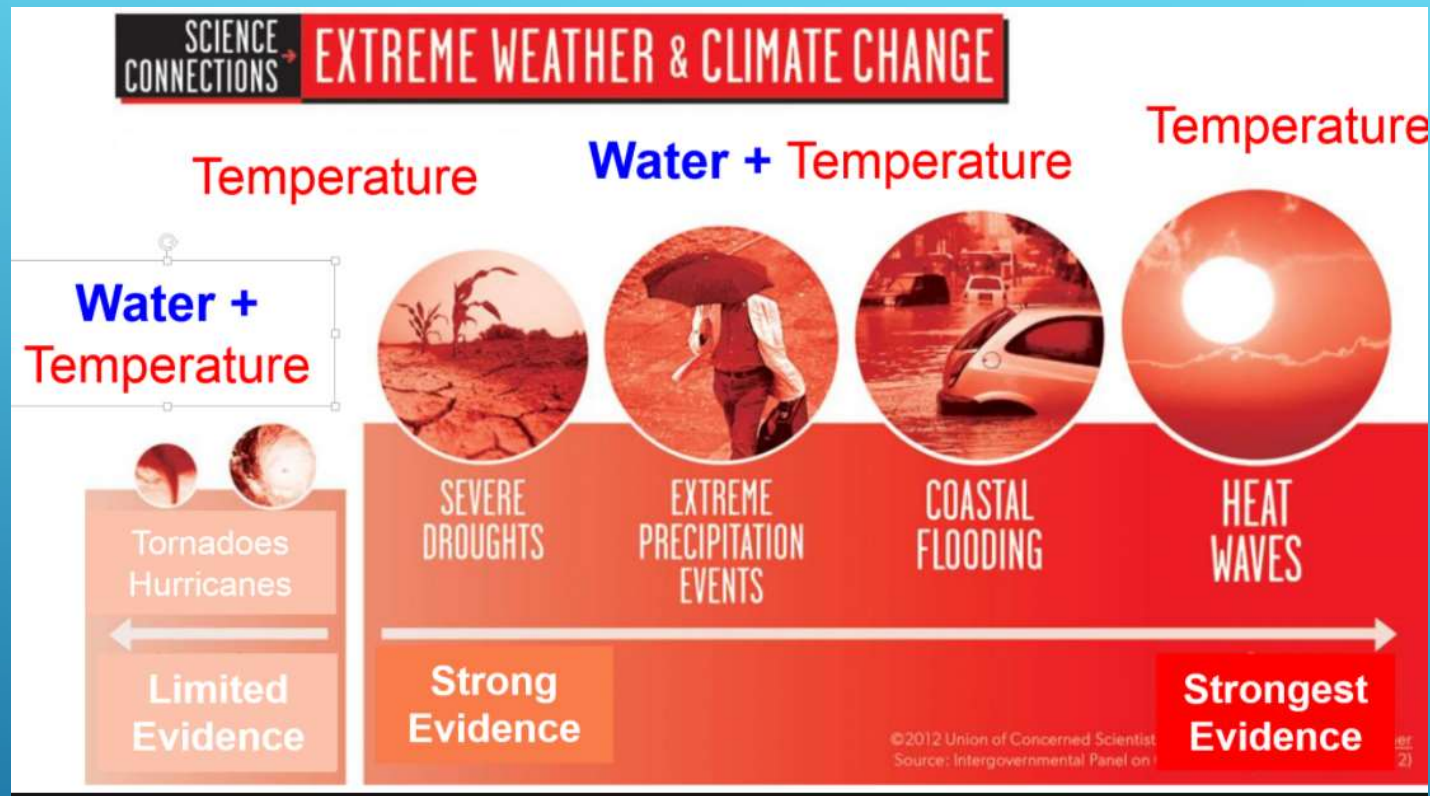
Melting
Arctic Ice

* Iso rebound –
depends on
weight of ice
sheet

METHANE HYDRATES

31F

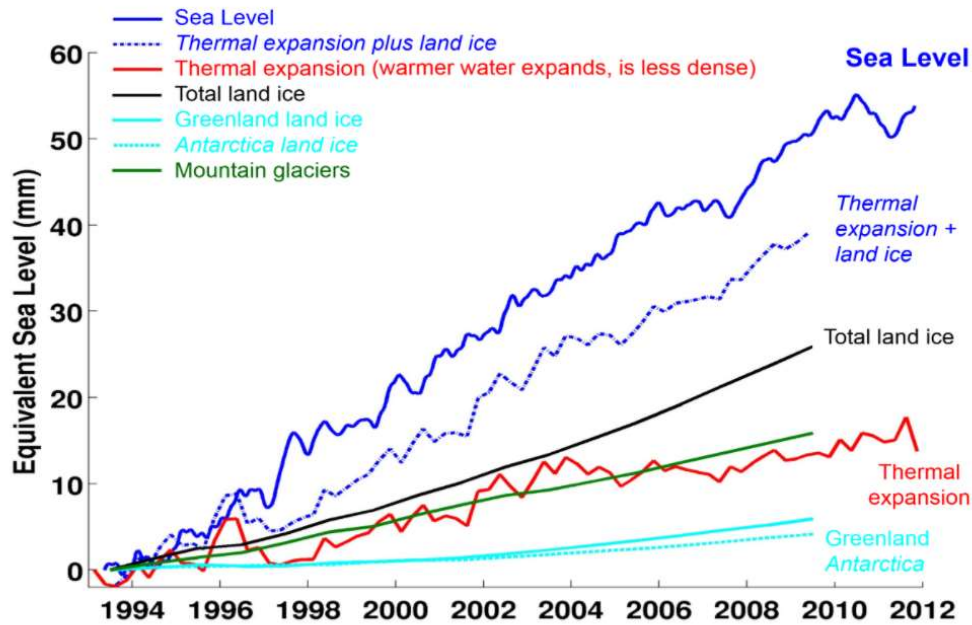
27



WEATHER EVENTS AND CLIMATE CHANGE

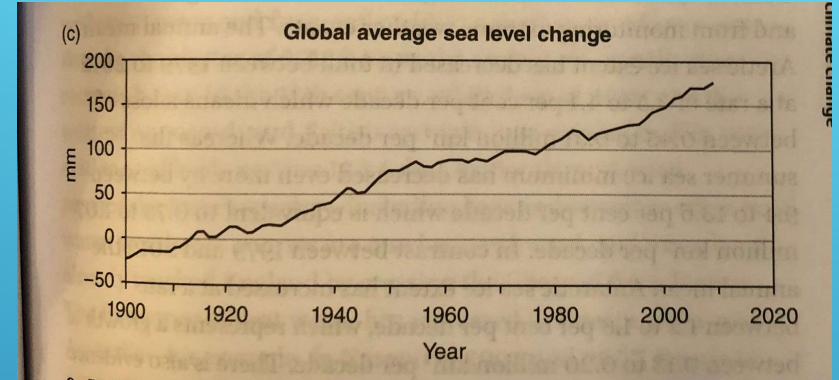
https://globalchange.umich.edu/globalchange1/current/lectures/dangerous_climate/dangerous_climate.html

Causes of Sea Level Rise



Local sea level can "appear" to drop if the land is rising faster (rebound from glacier weight)

Figure 5. The main causes of sea level rise are the thermal expansion of water in the ocean as the ocean warms, and the melting of glaciers and ice sheets on land that contribute water to the oceans.



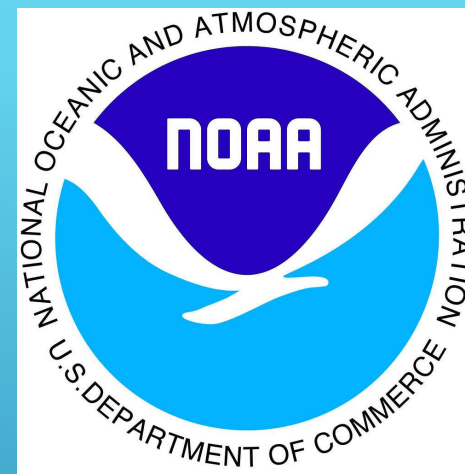
200 mm = 7.9 inches
from Mark Maslin, "Climate Change"

CAUSES OF SEA LEVEL RISE

https://globalchange.umich.edu/globalchange1/current/lectures/dangerous_climate/dangerous_climate.html

Sea levels may rise a foot by 2050, NOAA predicts, EandE News, 2/15/22

- ▶ A NOAA-report warns of a “dramatic increase in the exposure and vulnerability” for tens of millions of Americans who already live in coastal areas at risk of flooding
- ▶ Sea levels along U.S. coastlines will rise by 10-12 inches on average by 2050, equal to the amount over the last century
- ▶ Gina McCarthy, the President’s national climate advisor, said the new report shows the need for the U.S. to “redouble our efforts to cut GHG’s that cause climate change while at the same time help our coastal communities become more resilient in the face of rising seas.”
- ▶ Scientist warned that sea levels will continue to rise to warming that has already occurred, even if mitigation strategy succeeds in lowering surface air temperatures in coming years
- ▶ NOAA officials said the rising sea levels “will create a profound increase of coastal flooding, even in the absence of storms or heavy rainfall.”
- ▶ Impacts include regular flooding affecting homes and businesses, overloading stormwater and wastewater systems, infiltrating coastal groundwater aquifers with saltwater, and stressing coastal wetlands and estuarine ecosystems



SEA LEVELS MAY RISE A FOOT BY 2050

- ▶ Ice loss worldwide accelerated 57% since 1990s, EandE News, 1/25/21
 - ▶ The world's frozen places are shrinking – and they're disappearing at faster rates as time goes by. Altogether, ice losses over the world have sped up by 57% since the 1990s alone
 - ▶ In the 1990's, the world was losing 800 billion tonnes per year. Today, that number has rising to 1.2 trillion tonnes per year
 - ▶ The planet has lost 28 trillion tonnes of ice between 1994 and 2017
 - ▶ The findings: ice is steadily disappearing across much of the world, and a majority of the losses are driven by climate change
 - ▶ Rising air temperatures have caused mountain glaciers to shrink, from the European Alps to the Asian Himalayas to the South American Andes; over 6 trillion tonnes
 - ▶ The Greenland and Antarctic ice sheets have also shed huge volumes of ice; Antarctica has lost 2.6 trillion tonnes and Greenland nearly 4 trillion
 - ▶ In Antarctica, most of the losses stem from marine-terminating glaciers or glaciers that back up to the ocean
 - ▶ In Greenland, more than half of Greenland ice sheet losses come from surface melting
 - ▶ Losses from mountain glaciers and the two ice sheets (Antarctica and Greenland) are major contributors to sea-level rise; they've raised sea level by 34 mm (1.3 inches) since 1994
 - ▶ Losses of sea-based Antarctic ice shelves (8.6 trillion tonnes) doesn't add to sea level rise, but as the ice shelves dissolve, they destabilize the land-based glaciers
 - ▶ Arctic sea ice has been shrinking; Antarctic sea ice has grown
- ▶ Climate threatens a third of Antarctic ice shelf – a study, EandE News, 4/9/21
 - ▶ More than a third of the Antarctic ice sheet is at risk of collapsing if global temperatures rise 4C
 - ▶ At a 2C temperature rise, 17% of the ice sheet is at risk of melting
 - ▶ Although collapsed ice shelves don't directly contribute to sea level rise, they act like a giant cork, holding back the land-based glaciers, whose collapse or melting into the sea will result in sea level rise



Greenland



Arctic



Antarctica

ICE SHEET MELTING

The anatomy of glacial ice loss, 11/5/20

- ▶ Greenland and Antarctica are home to most of the world's glacial ice, including its only two ice sheets. These thick slabs of ice – some 10,000 feet and 15,000 feet thick, respectively – contain most of the freshwater stored on Earth, making them of particular interest to scientists.
- ▶ Combined, the two regions also contain enough ice that, if it were to melt all at once, would raise sea levels by nearly 215 feet – making the study and understanding of them crucial to our near-term adaptability and our long-term survival in a changing world.
- ▶ A glacier is considered "in balance" when the amount of snow that falls and accumulates at its surface (the accumulation zone) is equal to the amount of ice lost through melting, evaporation, calving and other processes.
- ▶ But with annual air temperatures in the Arctic increasing faster than anywhere else in the world, that balance is no longer achievable in Greenland. Warmer ocean waters surrounding the island's tidewater glaciers are also problematic.
- ▶ "In West Antarctica, we have these glaciers resting on bedrock that is under water. Like in Greenland, there is a layer of warmer ocean water below the cold surface layer. So this warm water is able to flow onto the continental shelf, and then all the way underneath the ice shelves – the floating ice that extends from glaciers and the ice sheet," said NASA JPL scientist Helene Seroussi. "The water melts the ice shelves from below, which can cause them to thin and break off."
- ▶ That matters because the ice shelves act like corks. They hold back the ice that is flowing from upstream, slowing its approach to the ocean where it raises sea level. When the ice shelves calve, the cork is essentially removed, allowing more inland ice to flow freely into the ocean.



Antarctic ice sheet calving



Greenland ice sheet melting

GLACIAL ICE LOSS

<https://climate.nasa.gov/news/3038/the-anatomy-of-glacial-ice-loss/>

Glaciers worldwide melted 30% faster since 2000, EandE News, 4/29/21

- ▶ New research suggests that glacier melting worldwide has accelerated by around 30% in the last two decades alone
- ▶ The world's glaciers have lost about 292 billions tonnes of ice annually since 2015. That's more ice than either the Greenland or Antarctic ice sheets lose in a year
- ▶ The study uses satellite data and aerial images to map ore than 200,000 glaciers around the world, from Himalayan Asia to the European Alps, to icy Alaska and northern Canada, ad some glaciers at the edges of Antarctica and Greenland
- ▶ Assuming all the meltwater flows into the oceans, glacial melting would account for about one quarter of sea level rise that's occurred over the last 20 years
- ▶ Some regions are melting faster than others, including Alaska, western Canada, and the Tibetan Plateau
- ▶ The study is a stark reminder that Greenland and Antarctic ice sheets aren't the only parts of the world that are rapidly melting
- ▶ Mountain snow and ice are vital sources of fresh water for about 2 billion people worldwide. When glaciers shrink, it can jeopardize those fresh water supplies

Rain falls on Greenland's summit for the first time in recorded history, Live Science, 8/19/21

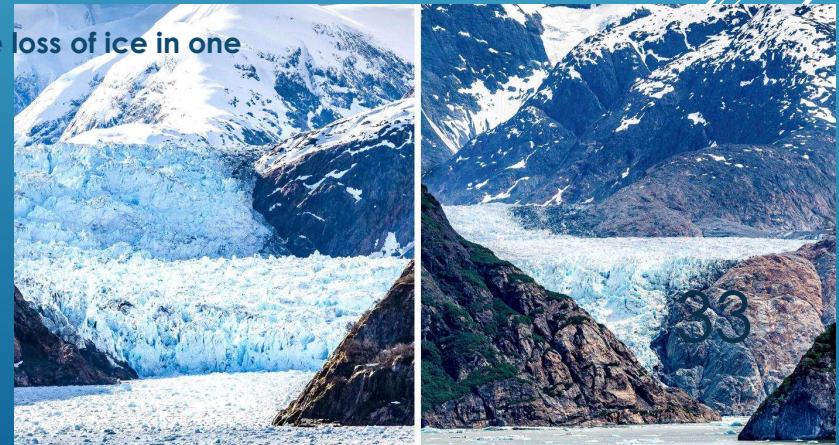
- ▶ 7 billion tons of water fell across the Greenland ice sheet at altitudes above 10,000 feet for the first time ever
- ▶ The rain was accompanied by the melting of up to 337,000 square miles of ice, the loss of ice in one day comparable to a week's worth of melting at this time of year
- ▶ The rainfall is a sure indication that Greenland is warming at a rapid pace

GLACIAL ICE LOSS (CONT.)



Tibetan glaciers melting

Alaskan glaciers melting



Since the start of the 21st century, California and Nevada have suffered extreme wildland fires and droughts that have caused devastating impacts to ecosystems and society. A common feature of these events has been very high evaporative demand—the “thirst” of the atmosphere—which has largely been driven by increased air temperatures caused by anthropogenic climate change.

- ▶ According to new research, climate change and a “thirsty atmosphere” will bring even more extreme wildfire danger and multi-year droughts to Nevada and California by the end of the next century.
- ▶ Climate change projections show consistent future increases in atmospheric evaporative demand over California and Nevada. These changes were largely driven by warmer temperatures, and would likely lead to significant on-the-ground environmental impacts.
- ▶ “Higher evaporative demand during summer and autumn—peak fire season in the region—means faster drying of soil moisture and vegetation, and available fuels becoming more flammable, leading to fires that can burn faster and hotter,” explained lead author Dan McEvoy at DRI.*

An insidious climate threat – a U.S. drought – is the sleeper weather story coming in 2021, NY Times, 1/12/21

- ▶ In the Southwest U.S., population growth and years of drought conditions are putting the region on a collision course with drastic water management decisions.
- ▶ The forecast persistence of La Nina through the winter favors a worsening of drought conditions in the southern U.S.
- ▶ A total of 49% of the Lower-48 states were in moderate-to-exceptional drought conditions as of December 2020
- ▶ There is increasing evidence that the Southwest U.S. is enduring long-term “megadrought” conditions
- ▶ This is partly due to climate change, which worsens drought by increasing temperatures, thereby turbocharging the loss of moisture from plants and soil. Climate change is also shifting weather patterns in ways that favor drier conditions in the Southwest
- ▶ The seasonal precipitation forecast is for a drier-than-average southwestern tier. This would be bad news for CA, NM, and AZ; but also southern TX and FL



DROUGHT AND CLIMATE CHANGE

<https://www.drought.gov/drought/news/climate-change-and-%E2%80%9Catmospheric-thirst%E2%80%9D-increase-fire-danger-and-drought-nevada-and-california>

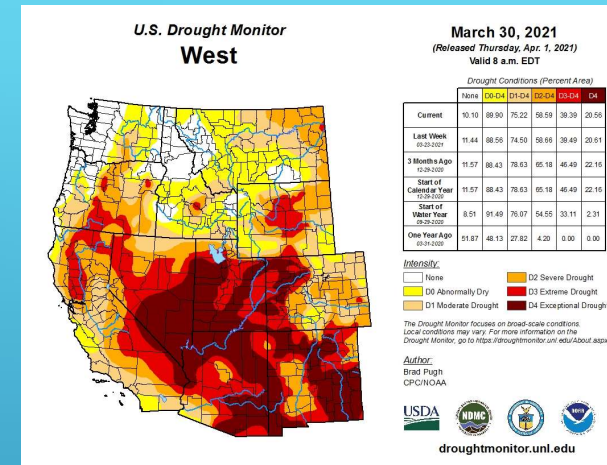
* DRI – Desert Research Institute

Longer drought and unstable rainfall plague the West, EandE News, 4/7/21

- ▶ A new study examines more than 40 years of data across the Western states, from the Pacific Northwest to the Great Plains
- ▶ It reveals a troubling pattern across large swaths of the West. Annual rainfall is declining, dry spells are getting longer, and rainfall events are more erratic and unpredictable. Storms are getting bigger in some cases, but are also happening less frequently
- ▶ The desert SW, much of AZ and NM as well as parts of NV, UT, CO, and CA, has been struck by a triple whammy – less total rainfall, more variable rainfall, and longer dry spells in between
 - ▶ The average dry period has increased from 31 days to nearly 48 days since 1971
- ▶ “We were surprised to find widespread changes in precipitation have already occurred across large regions of the West.” said one researcher
- ▶ The last two decades mark the driest span the West has seen since the 1500’s. And its unlikely to be the last
- ▶ The risk of a megadrought, spanning at least 35 years, could rise above 90% by 2100, if humanity’s level of GHG’s continues at high levels. The new study provides more evidence that a hotter, drier future has already arrived for the American West

U.S. warns of drought along Rio Grande, EandE News 4/16/21

- ▶ Federal water management managers release their annual operating plan for the Rio Grande. Flows have been meager this year because of below-average snowpack along the CO-NM border that feed the river; and little spring precipitation
- ▶ Reservoirs are at a small fraction of their capacity and continue to shrink. There is no opportunity to replenish them because provisions of the water-sharing agreement with TX prevent NM from storing water upstream.
- ▶ That means the drought stricken state has no extra water in the bank to fall back on, as it had in previous years
- ▶ Matters are further complicated because of extremely low soil moisture levels. That means that most of the melting snow will be absorbed or evaporate before it reaches the river
- ▶ The Feds released a similar report indicating that releases of the Colorado River – which feeds several Western states, -- will continue to be limited because of a lack of water



Megadrought spurs first-ever federal Colorado River cutbacks, 8/14/21

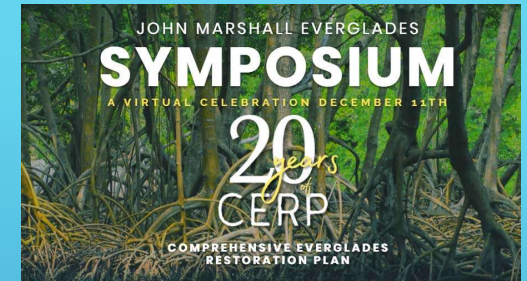
- ▶ The Biden administration will declare a water shortage on the Colorado River for the first time ever, triggering cutbacks in the SW U.S. due to a decades-long drought that experts say is a sign of what's to come
- ▶ Bureau of Reclamation officials will announce that water levels in the river's main reservoirs have dropped so low they have triggered mandatory delivery reductions in AZ and NV
 - ▶ AZ's share of the river's water will be cut by 18%
 - ▶ NV's share will be cut by 7%
 - ▶ More cuts could come if reservoir water continues to plummet
- ▶ A 20-year megadrought in the 7-state Colorado River Basin has caused Lake Mead and Lake Powell to drop to levels not seen since they were originally filled a half-century ago
- ▶ Many basin states (WY, CO, UT, NM, AZ, NV, CA) have taken proactive steps to conserve water supply for 40 million people and millions of acres of farmland
- ▶ Said one expert, *"At what point is it not a drought or dry period? Is it just the new normal?"*
- ▶ Upper basin states like CO, WY, and UT typically don't use their full allocation of Colorado River water under the river's 1922 compact
 - ▶ They are considering new projects to take more out of the river before it flows to lower basin states
- ▶ In the past two decades, the River's flows have dropped by about 20%
- ▶ In Southern CA, the water district is exploring a \$4 billion wastewater recycling facility, supported by NV



Receding water at
Lake Powell



FRESH WATER

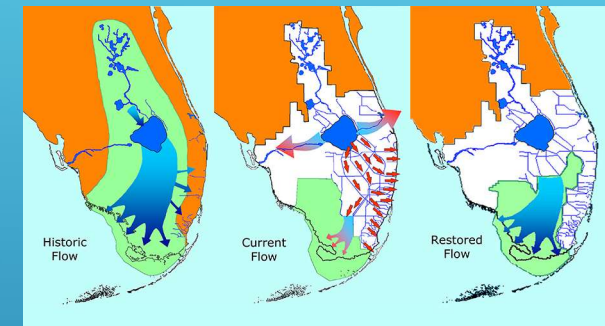


[Everglades] Restoration costs soar as seas rise and pythons slither in, EandE News, 1/4/21

- ▶ The Everglades rescue – one of the world's largest ecosystem restoration efforts – is in trouble, besieged by rising seas, rapacious developers, toxic algal blooms, and a python invasion
- ▶ The most recent cost estimate is \$23 billion, up from \$8 billion when the project started in 2000
- ▶ The Comprehensive Everglades Restoration Plan (CERP) extends over 18,000 sq. mi. – including pumps, marshes for filtering pollution from storm water, reservoirs, levees, and canals
- ▶ It's success will measure whether or not 8 million people in South Florida have enough drinking water

Coastal harm from invading saltwater 'happening right now,' AP, 11/23/20

- ▶ Four Native American tribes on Louisiana's Gulf Coast requested U.N. assistance this year to force action by the U.S. government on invading salt. Their formal complaint cited "climate-forced displacement" and said saltwater had poisoned their land, their crops and their medicinal plants.
- ▶ The landward movement of seawater threatens drinking water supplies, coastal farming and coastal ecosystems. Rising seas, more frequent storms, higher tides, drought and the pressure of pumping for drinking water are combining to accelerate the salt invasion.
- ▶ New scientific research along the East Coast and in California shows measurable and sometimes startling change, much of it from saltwater's unseen advance beneath the surface. The threat is widespread; roughly 40% of Americans live in coastal counties, according to the National Oceanic and Atmospheric Administration.
- ▶ Drinking water supplies in public aquifers and private wells from Long Island, NY, to the Florida Keys are increasingly threatened as some underground sources reach salinity levels nearly equal to seawater. In Miami-Dade County, Florida, homeowners and businesses can expect their water and sewer bills to rise 5% every year through at least the next decade,

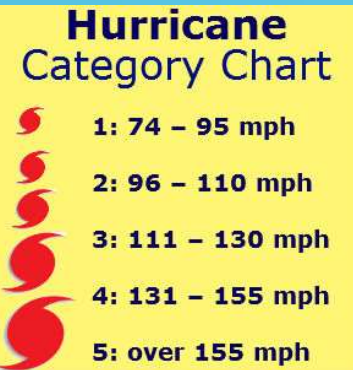


CERP

FRESH WATER (CONT.)



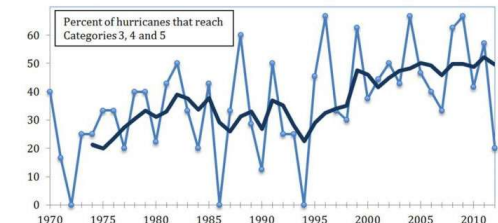
- ▶ The warmer the water temperatures, the more heat energy is available and the higher potential for tropical cyclones to develop
- ▶ In terms of frequency, studies have shown “no discernable trend in the global number of tropical cyclones,” and no human-caused signal in annual global tropical cyclone or hurricane frequency
 - ▶ However, another study showed a global increase in storm frequency of 9% and a 23% increase in the Atlantic basin by the end of the 21st century
- ▶ There is a substantial increase in the proportion of the strongest hurricane – Category 4 and 5 storms; an increase of 25-30% per 1C increase in global temperature
 - ▶ Simulations calculated a 28% increase in Category 4 and 5 storms globally, with a 42% increase in the North Atlantic
 - ▶ The same study, for just Category 5 storms, showed an 85% global increase and a 136% Atlantic basin increase
- ▶ Also found a decrease in Category 1 and 2 hurricanes
- ▶ Rapid intensification: models indicate human-caused warming significantly increases extreme tropical cyclone intensification
- ▶ There is a robust connection to increased rainfall. Simply: the warmer the air, the more moisture it can hold and the more rain it produces.
 - ▶ Models indicate 15%-38% more rain attributed to global warming
 - ▶ Extreme precipitation has become much more likely
 - ▶ Global rainfall increases in tropical cyclones predicted to increase by 14% by the end of the 21st century
- ▶ A 2018 NOAA study discovered a 10% global reduction in forward speed of tropical cyclones since 1949, including a heightened *slowdown over land areas*, 16% in the north Atlantic. No conclusion reached on the reason for increased stalling
- ▶ As oceans warm, hurricanes stay stronger longer, EandE News, 11/12/20
 - ▶ 1960's, a typical hurricane loses 75% of its power over land in 24 hours; today, only half of its power is gone over the same period



CLIMATE CHANGE AND HURRICANES

How climate change is making hurricanes more dangerous,
Yaleclimateconnections.org, 7/8/19

Atlantic Hurricanes Grow Stronger



World's food supplies slammed by drought, floods, and frost, EandE News, 7/26/21

- ▶ Extreme weather is slamming crops across the globe, bringing with it the threat of further food cost inflation
- ▶ Brazil's worst frost in two decades brought a deadly blow to young coffee trees to the world's biggest grower
- ▶ Flooding in China's pork region inundated farms and raised the threat of animal disease
- ▶ Scorching heat and drought crushed crops on both side of the U.S.-Canada border
- ▶ In Europe, torrential rains sparked the risk of fungal disease for grains and stalled tractors in soaked fields
- ▶ The series of misfortunes underscores what scientists have been warning about for years: Climate change and its associated weather volatility will make it increasingly harder to produce enough food for the world, and with the poorest nations hit the hardest
- ▶ "Things happening in one part of the world end up impacting all of us", said a U.N. envoy. "We've underestimated as a world just how frequently" weather would start to have serious impacts
- ▶ No other industry is more at the mercy of sun, rain, and heat than agriculture



Frost damage coffee
Trees: Brazil



Parched CA crops

CLIMATE CHANGE AND FOOD SUPPLY

- ▶ The Arctic is warming twice as fast as the rest of the planet
- ▶ Starting a few feet below the ground and extending tens or hundreds of feet down, the permafrost contains vast amounts of carbon in organic matter – plants that took CO₂ from the atmosphere centuries ago, died, and froze *before* they could decompose
- ▶ Worldwide, the permafrost is thought to contain twice as much carbon as is currently in the atmosphere
- ▶ Once this ancient layer thaws, microbes convert some of it to CO₂ and methane, which can then flow into the atmosphere
- ▶ Scientists have estimated that the process of permafrost melting could contribute as much as 1°C to global warming over the next several centuries, independent of anthropogenic GHG emissions
- ▶ In Alaska, temperatures 3 feet down are less than half a degree below freezing. *The area could lose much of its permafrost by midcentury (2050)*
- ▶ In addition to GHG emissions, permafrost melting wreaks havoc on the infrastructure which has been built on the permafrost, due to slumping of the land when ice loses volume as it turns to water
- ▶ If the decomposing permafrost is wet, there will be less O₂ available for the microbes, so they will produce more methane (via anaerobic digestion). If the permafrost is dry, the decomposition will lead to more CO₂
- ▶ One estimate is that GHG emissions from the melting permafrost over the rest of the century could average 1.5 billion tonnes of CO₂e per year, about that from annual fossil-fuel burning in the U.S.



John Schade



John Schade

Permafrost melting
Alaska

MELTING PERMAFROST?

40

NY Times

A new normal is settling over the Arctic: Temperatures are rising, ice is melting, snow is disappearing, and the region's delicate ecosystems are rapidly evolving *

- ▶ Temperatures in the Arctic are rising twice as fast as the global average
- ▶ 1. Melting sea ice: The 2020 September sea ice was at its second lowest level on record
 - ▶ This creates a vicious circle, as sea ice helps to reflect the sun's energy away from the earth's surface
- ▶ 2. Recent wildfires: 2020 was a record-breaking summer for wildfires in the Arctic, including blazes across Siberia
 - ▶ Scientists attribute this increase to rising temperatures and a drier fuel base (less rain and snowfall)
- ▶ Shifting ecosystems: Climate change is affecting plant and animal life in the Arctic Ocean, from the bottom of the food chain to the top

Warming has transformed the Arctic, Science News, 1/16/21

- ▶ Fifteen years of grading the impact of warming on the Arctic has made one thing clear: climate change has drastically altered the region in that short time period
- ▶ From sea ice lows to temperature highs, records keep popping up all over the arctic
 - ▶ In June, temperature a record-high temperature of 100F was set in the Arctic Circle
 - ▶ In 2018, winter ice on the Bering Sea shrank to a 5,500-year low
- ▶ Over the last 20 years, the arctic has warmed at a rate of 0.77C (1.4F) per decade, compared to the global average of 0.29C (0.41F) per decade



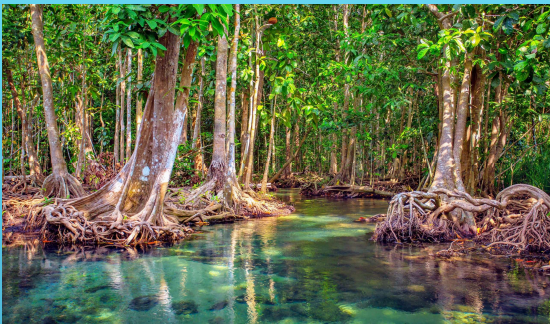
Bering Sea ice

3 SIGNS OF THE 'NEW ARCTIC'

* EandE News, 12/9/20
Based on NOAA report

Oceans offset emissions with 'blue carbon' – report, EandE News, 7/27/21

- ▶ According to climate scientists, countries must recognize the important role that oceans have in limiting climate change and enact policies to protect marine ecosystems
- ▶ More than half of the world's biological carbon is captured by animals and plants living in and around the oceans
- ▶ This so-called blue carbon and its associated ecosystems are mostly neglected in climate policy
- ▶ Mangrove forests store up to 4 times more carbon per hectare than tropical rainforests
- ▶ Seagrass meadows store nearly 20 gigatons of CO2 worldwide
- ▶ Up to 10 times more CO2 is stored in coastal habitats than in tropical rainforests
- ▶ Up to 200 million tonnes of CO2 could be captured annually by blue carbon sinks like mangroves, seagrasses, salt marshes, and kelp forests
- ▶ Yet those ecosystems and the creatures they support are threatened by rising water temperatures, acidification, overfishing, and commercial shipping
 - ▶ Seagrass releases nearly 300 million tonnes of CO2 per year based on rates of lost ecosystems
 - ▶ The figure is higher for coastal wetlands and mangroves
- ▶ “Unfettered human activities are turning these incredible carbon sinks into sources of GHG emissions,” said an advocate
- ▶ The report urges leaders to set targets for protecting and restoring marine ecosystems as part of their commitments under the Paris Agreement



Mangrove forests



Seagrasses



Kelp forest

GOOD NEWS – OCEANS OFFSET EMISSIONS

Paris Climate Agreement goal is still within reach, suggests new study, Science Daily, 2/11/22

- ▶ The Paris Agreement goal to limit global warming this century to 3.6F (2C) over pre-industrial temperatures is still within reach
- ▶ And apocalyptic worst-case scenarios are no longer plausible, suggests a new CU-Boulder study
- ▶ The new study finds that a subset of scenarios most in line with data from the IPCC project a warming to 2-3C by 2100, with a median of 2.2C
 - ▶ This compares to worst-case scenarios of as much as 4-5C by 2100, now implausible
- ▶ “This is cautiously optimistic good news with respect to where the world is today, compared to where we thought it would be,” said one of the researchers
- ▶ Why are the worst-case scenarios now less Plausible? Mainly, they were developed more than a decade ago, and a lot has happened since then
 - ▶ Renewable energy has become more affordable and more common than expected
 - ▶ Climate scenarios tended to overestimate growth in poorer countries
- ▶ “We’re getting close to [limiting] warming to 2C, but we definitely have a lot more work to do to get to 1.5C”
- ▶ And even 2C of warming will take a dramatic toll o the planet, and this is no time for complacency



THE GOOD NEWS: THE PARIS CLIMATE AGREEMENT GOAL IS STILL WITHIN REACH

- ▶ While we haven't reached a "tipping point" of no return yet, CO₂ emissions worldwide continue to increase. *There is still time to act*
- ▶ We are approaching the 1.5C limit on global temperatures set by the Paris agreement
- ▶ Tipping point possibilities, like melting permafrost, methane hydrate release, land-based ice sheet melting on Greenland and the Antarctic, are all showing signs of stress
- ▶ While there are still uncertainties in climate modeling, the *correlation* of GHG increases and global temperature increases is excellent and backed by scientific evidence, and even *causation* (over the period of human history) has been verified by analysis
- ▶ *All the world's nations, especially the U.S. and China, need to do something now to reduce GHG emissions*



CONCLUSIONS



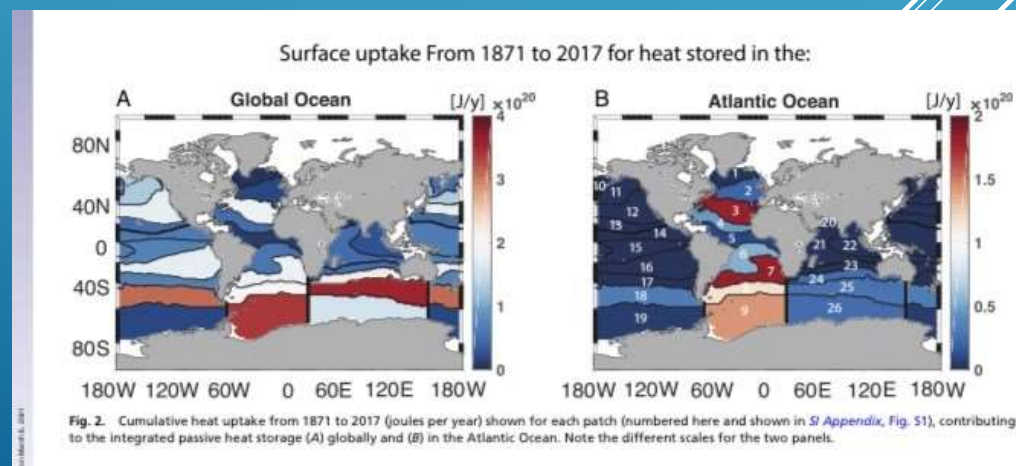
APPENDIX

The ocean has absorbed more than 90% of the heat gained by the planet, Climate Action, 1/8/19

- ▶ A new study found that the ocean has absorbed more than 90% of the heat gained by the planet between 1971 and 2010
- ▶ The process of the ocean absorbing this heat leads to increase in ocean temperatures and associated sea level rise
- ▶ The news follows a report by Princeton University researchers that the world's oceans absorbed 60% more heat energy between 1991 and 2016 than previous studies have indicated
- ▶ The study said: “Most of the excess energy stored in the climate system due to anthropogenic GHG emissions has been taken up by the oceans, leading to thermal expansion and sea-level rise.”



CLIMATE CHANGE MODELING



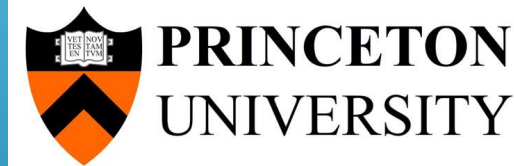
Lawmakers face 'brutal math of climate change', EandE News, 3/12/21

- ▶ Federal policy to reduce GHG emissions need to be paired with investments in resilience to deal with the effects of temperature rises already baked into the earth's climate system, experts told Congress today
- ▶ "While a sharp global reduction of CO₂ and other GHG's with the aim of achieving net-zero emissions by midcentury is necessary, it will not be sufficient to protect people and places unless accompanied by an aggressive program to adapt to unavoidable climate changes occurring now," said Michael Oppenheimer, a Princeton University professor and climate scientist
- ▶ "Even if the world hits the target of limiting warming to 2C laid out in the Paris Agreement, *coastal communities around the U.S. could see once-in-a-century floods every year – or more – by 2050.*"
- ▶ "How to respond needs to be decided well before 2050, essentially right now in many places, because building protection and retreating to higher ground could take decades."
- ▶ "CO₂ accumulates in the atmosphere over time, and until emissions reach net-zero, the world will continue to warm. *This is the brutal math of climate change.*"

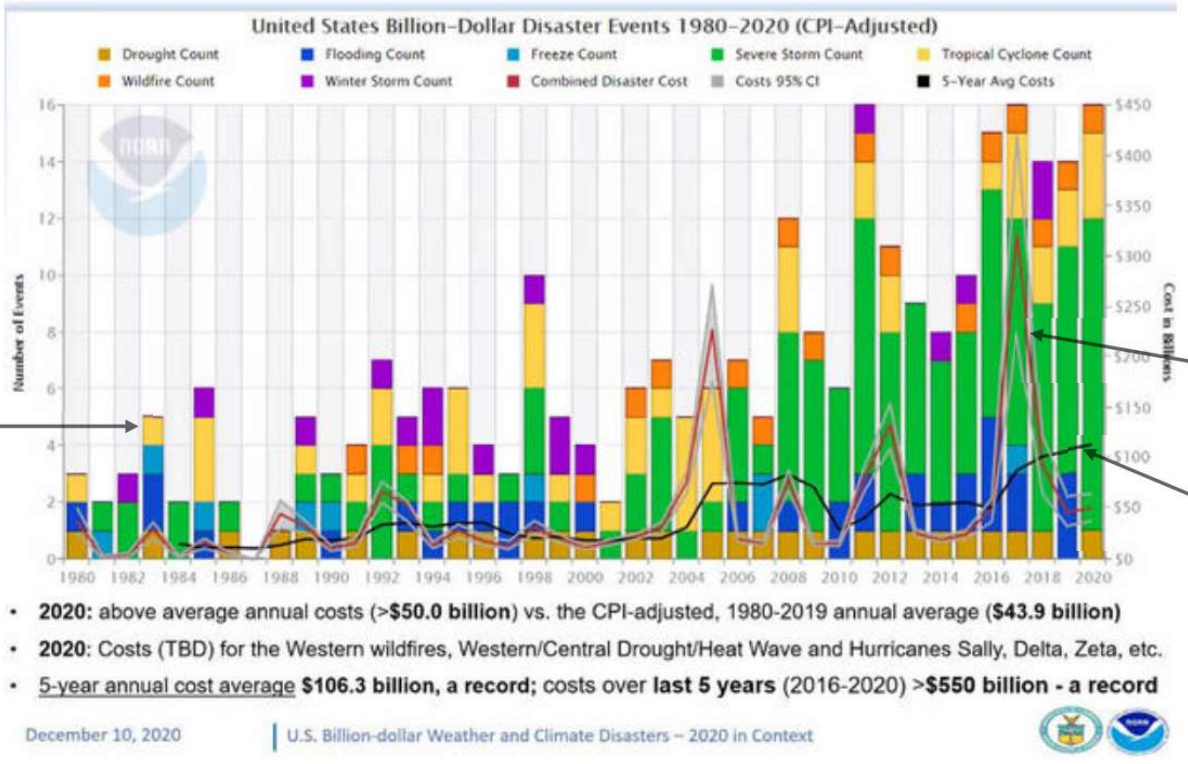
TOUGH CHOICES AHEAD



Oppenheimer



U.S. Billion-dollar event frequency, type, annual cost, 5-year cost average (January 1980–September 2020)



Frequency

Number of disasters

5-year cost average

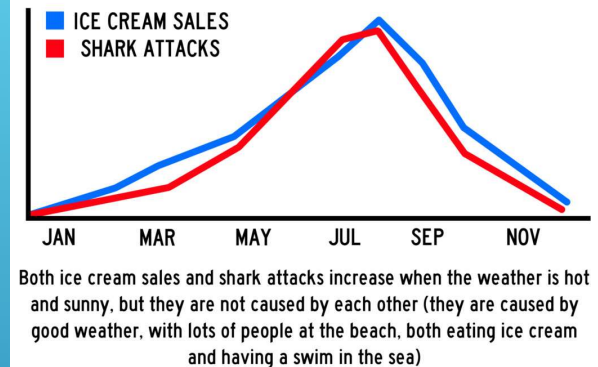
U.S. FREQUENCY OF CLIMATE-RELATED \$1B-DISASTERS IS INCREASING

CBS News, 12/10/20

Correlation or Causality: Drivers of the Earth climate

- ▶ The study analyzed recent measured data on global mean surface air temperature anomalies (GMTA) and various external forcing's covering the last 160 years using newly developed techniques that allow discrimination between correlation and causality.
- ▶ This evaluation is based on a new concept for calculating the information flow between time series.
- ▶ The strong correlation between the global CO₂ concentration and GMTA of 0.889 ± 0 is well known. But calculating the information flow in nat (natural unit of information) per unit time from the global CO₂ concentration to GMTA we get 0.348 ± 0.112 [nat/year] and -0.006 ± 0.003 [nat/year] in the reverse direction.
- ▶ Causality is expressed by an information flow significantly different to 0.0, whereas an information flow close to 0.0 indicates that the two time series are not causally related.
- ▶ Results demonstrate one-way causality in the sense that the *CO₂ increase is causing the temperature increase and not the other way around*. The positive value of the information flow indicates further that CO₂ has a positive feedback and therefore a destabilizing effect on GMTA; more CO₂ would lead to a stronger increase in GMTA.
- ▶ The results of investigating the information flow between the major radiative forcings and the GMTA time series clearly show that total GHG, dominated in particular by CO₂ forcing, is the main driver of changing global surface air temperature.
- ▶ Neither forcing by solar irradiance nor volcanic forcing contributes in a significant manner to the GMTA development.
- ▶ However on paleological time scales (800,000 years) the climate system seems to have behaved different, as on those time scales temperature changes seem to be the cause for subsequent changes in CO₂ concentration.
- ▶ This analysis reveals a surprising causal pattern: the increased anthropogenic forcing mainly originated in the northern hemisphere has especially strong warming effects in the southern hemisphere.

CORRELATION IS NOT CAUSATION!



CLIMATE CHANGE: CORRELATION VS CAUSATION

<https://ec.europa.eu/jrc/en/publication/correlation-or-causality-drivers-earth-climate> , 2015

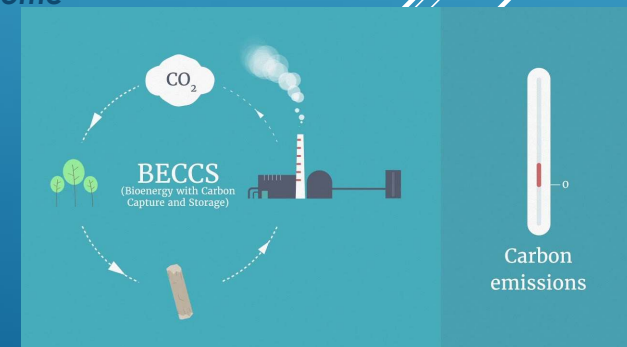
IPCC modelers' secret weapon: Negative emissions tech, EandE News, 12/22/20

- ▶ The IPCC and other modelers (e.g., oil companies) rely on a contentious strategy known as 'negative emissions' – the practice of pulling CO₂ out of the atmosphere
- ▶ In theory, negative emission technologies (NET) would buy the world a little more time to phase out of the use of fossil fuels, while they clean up extra emissions along the way
- ▶ *The danger is that governments fail to prioritize urgent action in hopes that technologies to remove CO₂ from the atmosphere come to the rescue in later decades*
- ▶ Some researchers say that the models' emphasis on NET give oil companies license to continue producing fossil fuels
- ▶ Many policymakers have concluded that NET are necessary for meeting the Paris Agreement's temperature benchmarks
- ▶ For instance, IPCC modeling includes bioenergy with carbon capture and sequestration, or BECCS, capturing 3-7 billion tonnes of CO₂. (BECCS is where organic matter is burned for energy and the GHG emissions are captured and stored underground.)
- ▶ "it's part of a least-cost solution to have some of these [NET] technologies out there."
- ▶ Other NET options include afforestation and direct air capture (where CO₂ is sucked out of the air and stored underground).
- ▶ Another solution used in the models is widespread CCS, which might take a carbon tax of \$100/tonne, difficult to achieve politically
- ▶ *So have climate change modelers been too optimistic in assuming NET technologies would become available?*



CLIMATE CHANGE MODELING UPDATE

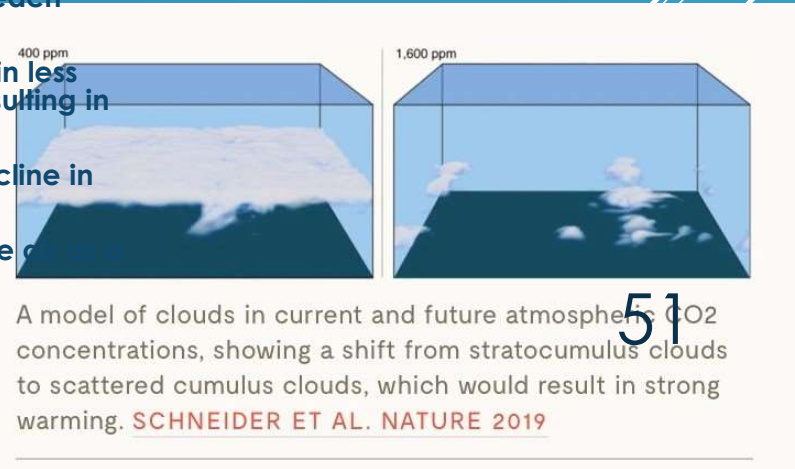
IPCC – Intergovernmental
Panel on Climate Change



Why clouds are the key to the new troubling predictions on warming, Yale Environment, 2/5/20

- ▶ New studies have changed how the climate models treat clouds and suggest that the ability of clouds to keep us cool could be drastically reduced as the world warms, pushing global heating into overdrive
- ▶ Clouds have been the biggest uncertainty in climate calculations. They can both shade the earth and trap heat
 - ▶ Which effect dominates depends on how reflective they are, how high they are, and whether it's day or night
- ▶ Clouds shade roughly a fifth of the oceans, reflecting 30%-60% of the solar radiation that hits them back into space
- ▶ In this way, they are reckoned to cut the amount of solar energy reaching the Earth's surface by 4%-7%
- ▶ But it seems increasingly likely that clouds could become thinner or even burn off entirely in a warmer world, leaving more clear skies through which the sun could add 1C or ore to global warming
- ▶ While during the day, low clouds shade the planet, at night they act as an insulating blanket, and high cirrus clouds predominantly act as heat traps, warming the air below them
- ▶ Generally global models have suggested that the warming and cooling effects cancel each other out, and this would continue in the warming future
- ▶ However, the latest analyses suggest otherwise. In a warmer world, clouds would contain less water than previously thought. Clouds would thin out, and may would not form at all, resulting in extra warming
- ▶ NASA found that a sharp rise in global temperatures since 2013 has coincided with a decline in cloud cover over the oceans.
 - ▶ Perversely, this could also be the result of fewer reflective aerosols released into the air as a result of smog controls

CLIMATE CHANGE MODELING (CONT.)



60 Minutes, The Guardian, and game-changing new climate science, 10/7/20

- ▶ Humanity, it turns out, may have a bit more time to prevent climate breakdown than previously believed
- ▶ Until recently, scientist believed the climate system carried a long lag effect
 - ▶ This lag effect was mainly a function of the CO2 remaining in the atmosphere and trapping heat for many decades after being emitted
- ▶ If humans “stop emitting carbon right now...the oceans start to take up carbon more rapidly,” said Michael Mann of Penn State
- ▶ *“The actual lag effect is not 25-30 years but “more like three to five years”*
- ▶ In short, humanity can turn down the heat almost immediately after slashing GHG emissions
- ▶ *Of course, this glimmer of hope is only empowering if humans actually act to reduce GHG emissions to zero*

Many scientists now say global warming could stop relatively quickly after emissions go to zero, Inside Climate News, 1/3/21

- ▶ Recent research shows that stopping GHG emissions will break the vicious cycle of warming temperatures, wildfires, and rising sea levels faster than expected just a few years ago
- ▶ “It is our best understanding that if we bring CO2 levels to net zero, the warming will level off; the climate will stabilize within a decade or two,” said Joeri Rogelj, a lead author of the next IPCC assessment
- ▶ The widespread idea that decades of additional warming were already “baked into” the system were based on an “unfortunate misunderstanding of experiments done with climate models that never assumed zero GHG emissions.”
- ▶ Those models assumed that concentrations of GHG in the atmosphere would remain constant
- ▶ The idea that global warming could stop relatively quickly after emissions go to zero was described as a “game changing new scientific understanding”



52

CLIMATE CHANGE MODELING (CONT.)

National Academies: Climate research needs fresh approach, EandE News, 3/17/21

- ▶ Experts say it's time for a new, more human approach to climate modeling
- ▶ The Global Change Research Program, a cornerstone of federal climate research, should shift its focus toward helping society understand and avoid the worst consequences of climate change
- ▶ The report recommends a greater focus on the unequal ways climate change affects different populations and how to reduce those inequalities
- ▶ Studies consistently suggest that people of color, women, and low-income communities are disproportionately vulnerable to the consequences of climate change
- ▶ Addressing these issues can drive smarter, faster societal response to climate change, but it requires a closer look at the ways that different sectors of human societies – energy, agriculture, and transportation among them – interact with each other and the natural world
- ▶ *"We're missing the deep interconnections across systems, and this is where we're starting to see failures and decreases in resilience in our societies,"* said one of the study's authors
- ▶ This leads to the recommendation to apply an integrated risk-framing approach to our research priorities over the next 10 years
- ▶ *It recommends a greater focus on climate extremes, thresholds, and tipping points – aspects of the Earth's climate system that could drive faster, more intense climate consequences*
 - ▶ Arctic permafrost thawing is one example

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

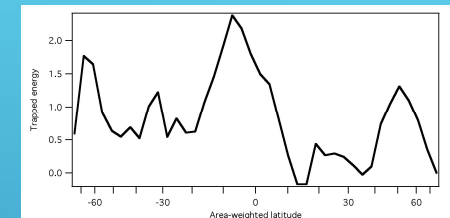
CLIMATE MODELING (CONT.)



- ▶ **Climate change: Threshold for dangerous warming will likely be crossed between 2027-2042, Science News, 12/21/20**
 - ▶ **The threshold for dangerous global warming will likely be crossed between 2027 and 2042 -- a much narrower window than the Intergovernmental Panel on Climate Change's estimate of between now and 2052.**
 - ▶ **Researchers introduce a new and more precise way to project the Earth's temperature. Based on historical data, it considerably reduces uncertainties compared to previous approaches.**

CLIMATE CHANGE THRESHOLD

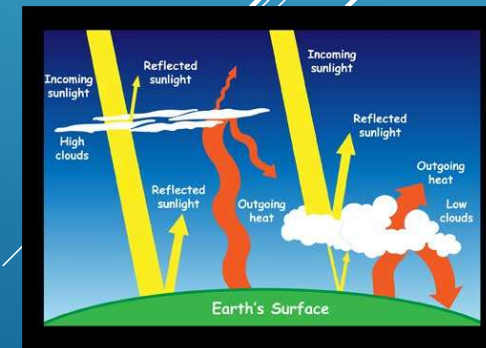
- ▶ Water vapor is known to be Earth's most abundant greenhouse gas (GHG), but the extent of its contribution to global warming has been debated. Using recent NASA satellite data, researchers have estimated more precisely than ever the heat-trapping effect of water in the air, validating the role of the gas as a critical component of climate change
- ▶ Andrew Dessler and colleagues from Texas A&M University confirmed that the heat-amplifying effect of water vapor is potent enough to double the climate warming caused by increased levels of CO₂ in the atmosphere.
- ▶ The answer can be found by estimating the magnitude of water vapor feedback. Increasing water vapor leads to warmer temperatures, which causes more water vapor to be absorbed into the air. Warming and water absorption increase in a spiraling cycle.
- ▶ Water vapor feedback can also amplify the warming effect of other GHGs, such that the warming brought about by increased carbon dioxide allows more water vapor to enter the atmosphere.
- ▶ "This new data set shows that as surface temperature increases, so does atmospheric humidity," Dessler said. "Dumping GHGs into the atmosphere makes the atmosphere more humid. And since water vapor is itself a greenhouse gas, the increase in humidity amplifies the warming from carbon dioxide."
- ▶ Specifically, the team found that if Earth warms 1.8 degrees F (1C), the associated increase in water vapor will trap an extra 2 W/m². "That number may not sound like much, but add up all of that energy over the entire Earth surface and you find that water vapor is trapping a lot of energy," Dessler said. "We now think the water vapor feedback is extraordinarily strong, capable of doubling the warming due to carbon dioxide alone."
- ▶ The biggest debate is about clouds. First, they reflect sunlight back into space, reducing *energy in*. Second they absorb IR emitted by the surface, decreasing *energy out*. In our present climate, the reflection of solar radiation is slightly larger than the heat-trapping effects, so clouds reduce net energy in by 25W/m²



Trapped energy
from water vapor

WATER VAPOR: GOOD OR BAD ACTOR IN CLIMATE CHANGE?

https://www.nasa.gov/topics/earth/features/vapor_warming.html



- ▶ Climate 'emulator' shows withering heat in global cities, EandE News, 1/5/21
 - ▶ Research published in *Nature Climate Change* found that urban regions across the globe – from the U.S. to Africa – could warm by more than 4C (7.2F) by 2100 under a high-emissions climate change scenario
 - ▶ Even with an intermediate scenario, average warming in cities would be 1.9C (3.4F)
 - ▶ Over half the world's population lives in urban environments, where concrete and asphalt absorb more heat and inhibit cooling
 - ▶ While urban areas encompass a large portion of the population of the world, they occupy only 3% of the land's surface, making them difficult to model
- ▶ Severe wildfires actually cooled globe, Washington Post, 1/5/21
 - ▶ Australia's disastrous 2019-2020 fire season blew so much smoke into the upper atmosphere that it blocked sunlight trying to reach the earth's surface, potentially causing a brief global cooling effect similar to a moderate volcanic eruption
 - ▶ The wildfires spawned a rash of rare fire-induced thunderclouds, injecting plumes of smoke into the stratosphere, some as high as 20 miles
 - ▶ This is the second time in modern history where a 'volcanic scale' outbreak has been documented
- ▶ America's GHG's see record fall, but nobody's celebrating, EandE News, 1/12/21
 - ▶ America's GHG emissions fell 10.3% in 2020 – the largest annual decline since WW2
 - ▶ The vast majority of the decline was attributable to Covid19-related behavioral changes, less driving and less flying
 - ▶ Driving plummeted by 40% in April; jet fuel demand remained 35% below 2019 levels in December
 - ▶ Overall U.S. GHG emissions were 5,160 MM tonnes in 2020; 21.5% below 2005 levels; on track to reach the previous U.S. goal of 26%-28% reduction by 2025
 - ▶ However, many analysts expect the U.S. to backtrack, with GHG emissions increasing in 2021 in a post-pandemic era
 - ▶ "The emissions decrease shows us the degree of effort necessary to get anywhere close to Paris [Agreement]"



CLIMATE CHANGE IN THE NEWS (CONT.)

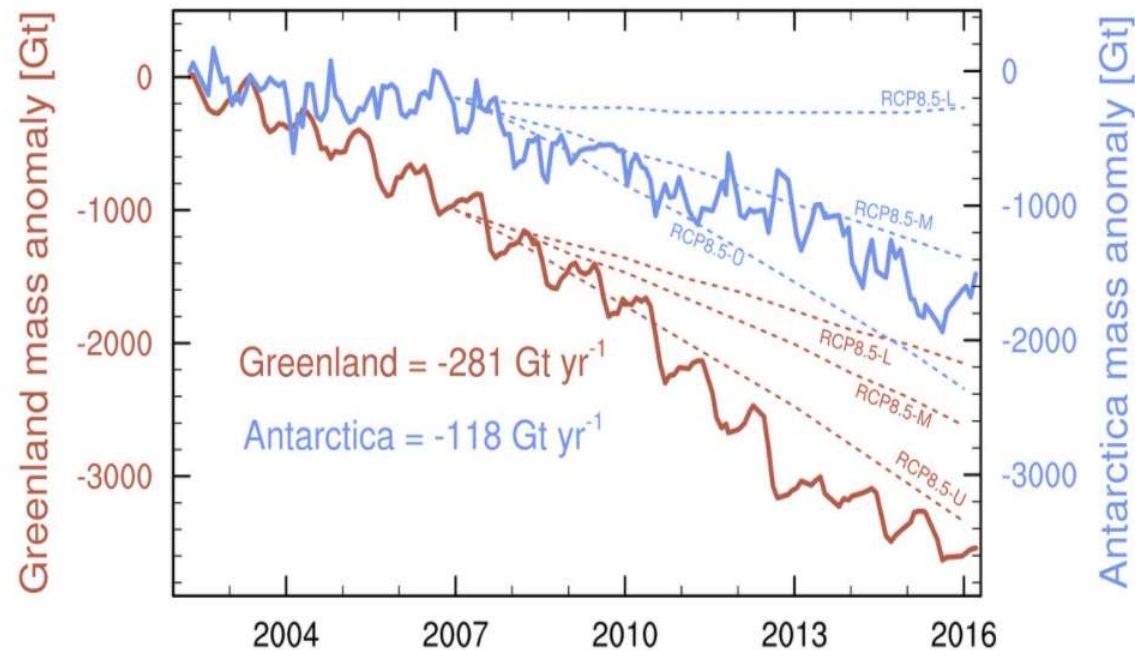


Figure 3. The mass loss of ice from Greenland and Antarctica ice sheets since 2002. Dashed lines show the ice loss predicted by different models starting in 2007 under the scenario of "business as usual" in terms of our continued greenhouse gas emissions. The mass loss is measured by the GRACE

1,000 Gt = 1 trillion tonnes

MELTING OF GREENLAND AND ANTARCTIC LAND-BASED ICE SHEETS

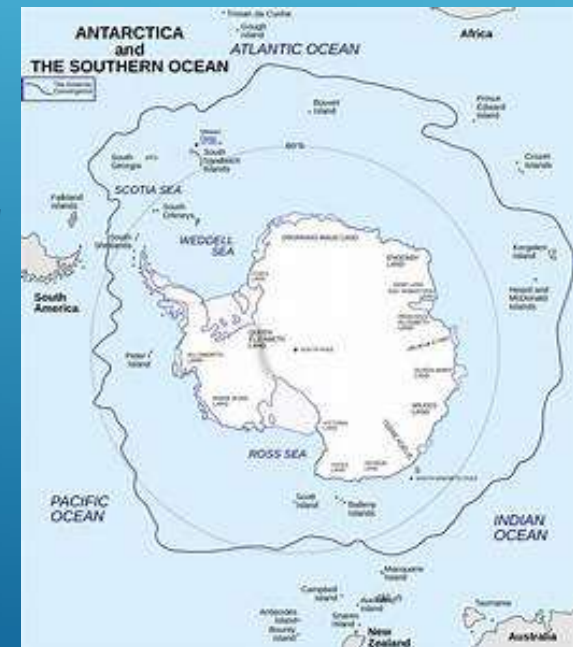
https://globalchange.umich.edu/globalchange1/current/lectures/dangerous_climate/dangerous_climate.html

Warming waters of Southern Ocean threaten Antarctic Ice, Washington Post, 2/2/21

- ▶ The Southern Ocean is one of the most important yet least explored and understood regions of the planet when it comes to determining how global warming will proceed, thanks to its *capacity to absorb huge quantities of CO₂ and melt swaths of the Antarctic ice sheet*
- ▶ In addition, this vast ocean is where global ocean currents get started
- ▶ A new study in Nature Communications finds that underneath the surface layers of waters circling Antarctica, the seas are warming much more rapidly than was previously known, at a rate 3 to 20 times higher than what was estimated
- ▶ *This means there is a greater potential for the Southern Ocean to help destabilize parts of the Antarctic Ice Sheet*
- ▶ There is a radical change from the Ocean's average state and is enough to threaten ice stability where glaciers empty into the sea via fragile floating ice shelves, which act as a dam to slow the flow of the land-based ice sheets into the sea
- ▶ *Sea-based ice shelves melting will not raise sea levels, but land-based ice moving more rapidly into the sea will do so*



ANTARCTIC ICE AND THE SOUTHERN OCEAN



A massive iceberg – larger than New York City – breaks off Antarctica, USA Today 3/1/21

- ▶ **A massive iceberg broke off Antarctica's Brunt Ice Shelf, British researchers announced.**
- ▶ **At 490 square miles, the berg is bigger than New York City, which is 302 square miles.**
- ▶ **A crack in the ice shelf widened several hundred meters Friday before the iceberg sheared off. The last major chunk to come off in this area was in the early 1970s, the BBC said.**
- ▶ **Ice shelves are floating sheets connected to a landmass, according to the National Snow and Ice Data Center. Since the ice is already floating, the newly created iceberg won't contribute to rising sea levels.**
- ▶ **Even so, the release said that changes in the ice at Halley is a "natural process," and there is "no evidence that climate change has played a significant role."**

Crack in Brunt ice sheet

ICE SHEET CALVING



The iceberg started to crack off of Antarctica's Brunt Ice Shelf in January 2021.

Scientists wrestle with sea level risks from Antarctic ice, Washington Post, 5/6/21

- ▶ Scientists struggling to understand the threat of sea level rise on a warming Earth found that amid lingering uncertainty, meeting the goals of the Paris climate agreement remains humanity's best hope for preserving current coastlines in the 21st century
- ▶ Two studies just published in Nature underscore how the answers to the complex puzzle of Antarctica remain unsettled
- ▶ In one study, experts found a relatively muted Antarctic response as the climate warms in the coming decades. That's largely because a rise in snow falling on the ice sheet could substantially offset the loss of ice to the ocean at the continent's perimeter
- ▶ In a second study, the model included an additional process known as "ice sheet instability" that factors in the potential for faster collapses of ice from the large glaciers perched against the ocean
- ▶ "The major uncertainty in global sea level rise is what the Antarctic ice sheet is going to do," said a researcher
- ▶ "These papers are a strong reminder that our understanding of the future of the ice sheet – our ability to estimate what its contribution to sea level rise is going to be – remains quite uncertain."
- ▶ "All we know is that we are headed into dangerous territory and we ought to back off."

www.recipesforfamilylife.com

Heading into Challenging Territory – Challenge A

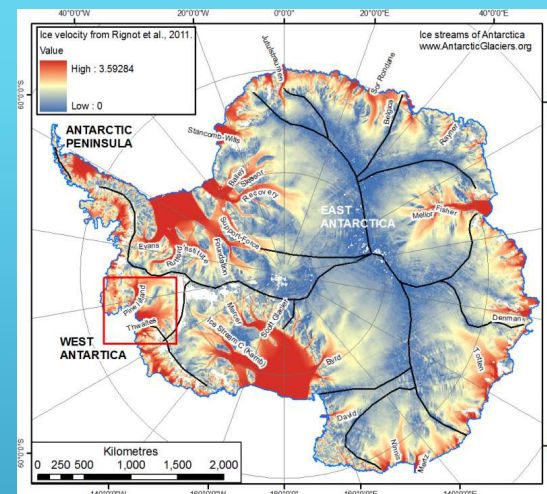
Antarctic ice sheet
melting

UNCERTAINTIES IN ANTARCTIC ICE MELTING



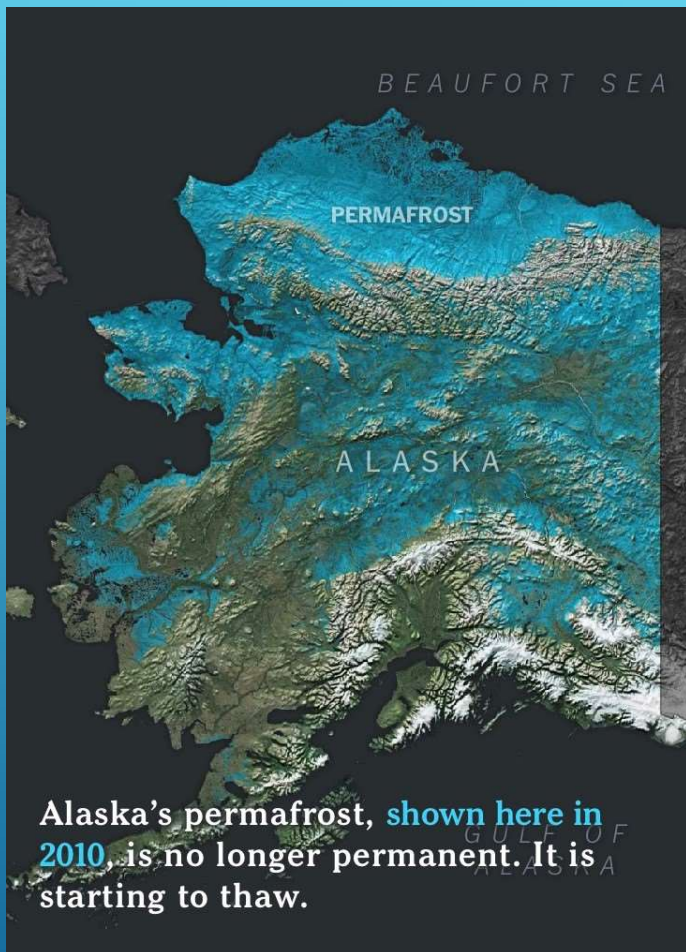
One of the world's fastest-melting glacier may raise sea level at alarming rate, Washington Post, 6/12/21

- ▶ The Pine Island glacier, a 160-mile long river of ice is known as the “weak underbelly” of West Antarctica.
- ▶ It contributes more to sea level rise than any other glacier on the continent and ranks among the fastest melting glaciers in the world
- ▶ Unlike other Antarctic glaciers, Pine Island is not sheltered from the warming ocean by a vast expanse of sea ice. The only thing preventing it from flowing directly into the ocean is a shelf of floating ice that sticks out from the glacier's edge. The shelf is like a cork in a bottle
- ▶ But the ice shelf is tearing itself apart. It has lost one-fifth of its mass in the past 5 years, shedding icebergs the size of cities
- ▶ Rifts have opened up in the center of the shelf, potentially adding to the instability
- ▶ Scientists have discovered that the glacier is flowing toward the ocean 12% faster than at the start of 2017 – a result of the weakened ice shelf's stability
- ▶ The glacier already adds a sixth of a millimeter (.006 inches) to sea level rise each year; but losing the ice shelf could double or triple that rate
- ▶ Pine Island contains 180 trillion tons of ice – *enough to cause 1.6 feet of sea level rise*
- ▶ Said one scientist, “I’m not a catastrophist, but the integrity of the ice shelf is definitely in question.”
- ▶ It appears that the rapid slide of the glacier is creating fractures in the ice shelf, which leads to more pieces breaking off, or “calving”
- ▶ “It’s not inconceivable to say the rest of the ice shelf could be gone in a decade.”



Ice shelf in front of Pine Island glacier

ICE SHEETS (CONT.)

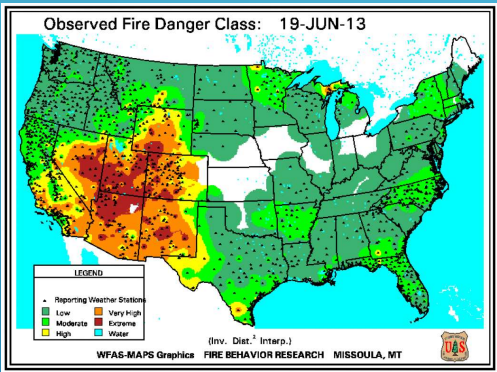
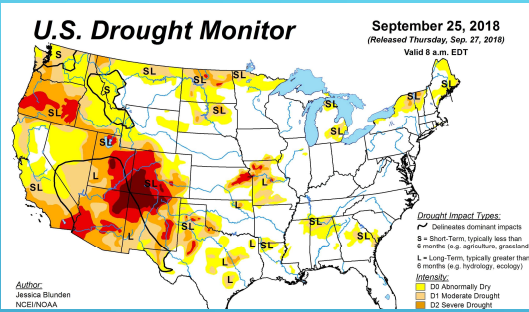


MELTING PERMAFROST? (CONT.)

NY Times, 8/23/17

Climate fuels huge drought in West, increasing risk of fire, N.Y. Times, 5/20/21

- ▶ Severe drought – largely connected to climate change – is ravaging not only New Mexico but the entire Western half of the U.S., from the Pacific Coast, across the Great Basin and desert Southwest, and up through the Rockies to the Northern Plains
- ▶ The most significant and potentially deadly effect of a drought that is as severe and widespread as any seen in the West is the wildfires that are raging amid hot and dry conditions. And this is well before the full blast of summer’s heat arrives
 - ▶ CA, AZ, and NM each had two large blazes, unusual for this early in the year
 - ▶ Officials are predicting the this fire season, damage could exceed 10.3 million acres (16,000 square miles) (Maryland is only 12,407 square miles)
- ▶ Water shortages are affected by population and economic growth, as well as pumping of groundwater for agriculture
- ▶ The situation in some states is dire, with the two most severe categories of drought encompassing 90% of UT, 87% of AZ, 85% of ND, 80% of NM, and 73% of CA
- ▶ The winter’s lack of snowfall didn’t help matters. Snowpack across the West is well below normal (CA’s snowpack is only 59% of historical averages.)
- ▶ Climate scientists now talk of a “megadrought,” one that may rival those that occurred over the past thousand years. Those SW megadrought lasted decades, in one case, 80 years








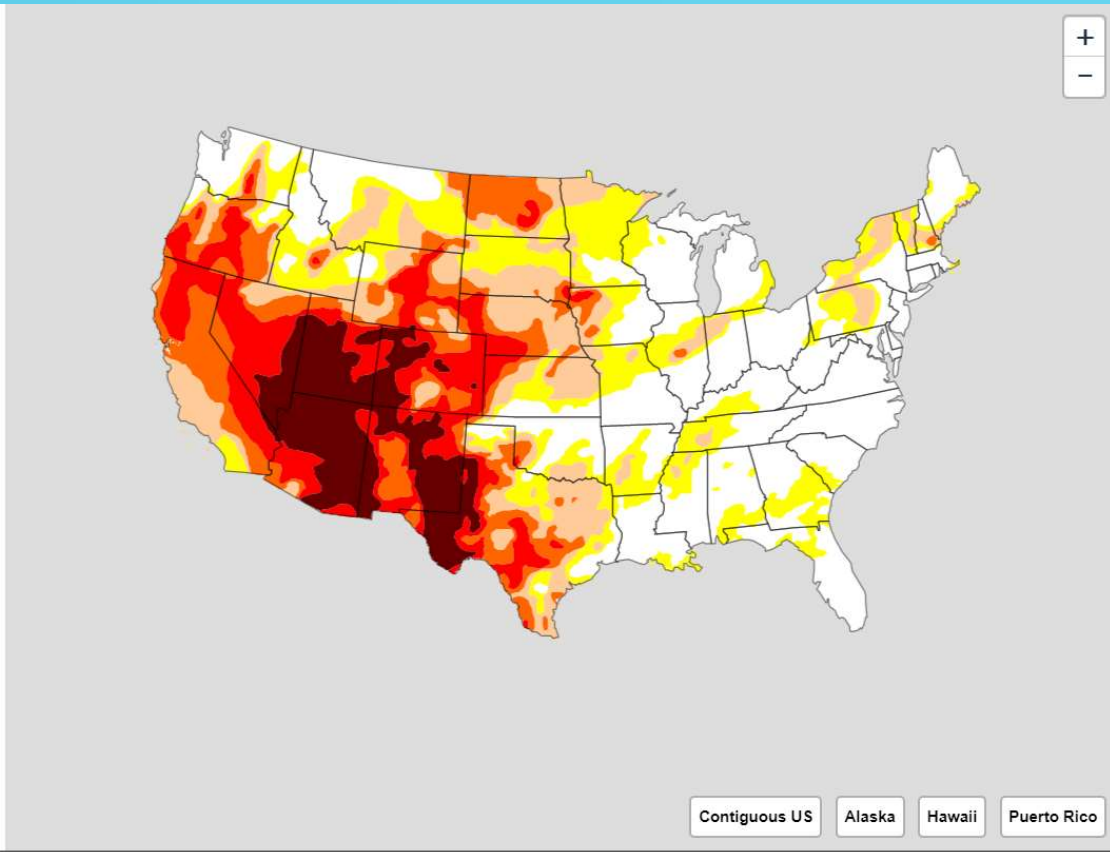
DROUGHT AND THE WEST (CONT.)

Drought and fire danger monitors

The U.S. Drought Monitor (USDM) is a map that shows the location and intensity of drought across the country. The data is updated each Tuesday and released on Thursday. This map shows the drought conditions on December 15, 2020.

Learn more about the US Drought Monitor

	D0 - Abnormally Dry <ul style="list-style-type: none"> • Short-term dryness slowing planting, growth of crops • Some lingering water deficits • Pastures or crops not fully recovered 	16.5% of U.S.	57.7% D0-D4
	D1 - Moderate Drought <ul style="list-style-type: none"> • Some damage to crops, pastures • Some water shortages developing • Voluntary water-use restrictions requested 	12.7% of U.S.	41.2% D1-D4
	D2 - Severe Drought <ul style="list-style-type: none"> • Crop or pasture loss likely • Water shortages common • Water restrictions imposed 	10.1% of U.S.	28.5% D2-D4
	D3 - Extreme Drought <ul style="list-style-type: none"> • Major crop/pasture losses • Widespread water shortages or restrictions 	10.1% of U.S.	18.4% D3-D4
	D4 - Exceptional Drought <ul style="list-style-type: none"> • Exceptional and widespread crop/pasture losses • Shortages of water creating water emergencies 	8.3% of U.S.	

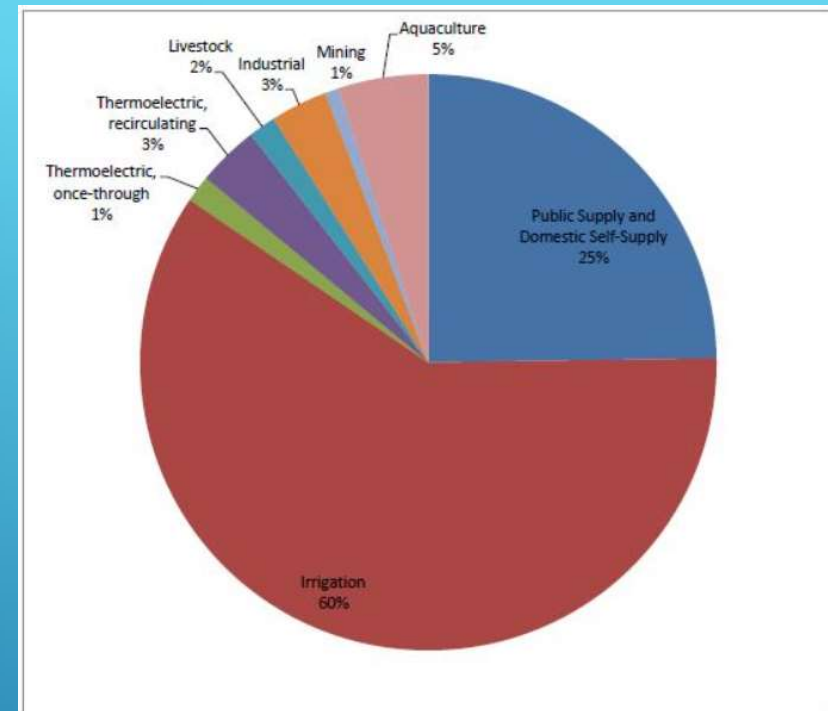


DROUGHT MONITOR

<https://www.drought.gov/drought/>

► Fresh water statistics

- Only 23% of the total volume of water withdrawals in the U.S. is *consumptively* used. The rest goes back to a water source, available for further use or to support ecosystem health.
- Withdrawals of water used to cool electricity-generating power plants account for 41% of the total withdrawals in the U.S., but only a tiny fraction is consumed (lost to evaporation). As a result, electricity generation accounts for less than 5% of total consumptive water use.
- The largest consumptive user of water is irrigated agriculture, accounting for nearly two-thirds of all water depleted from freshwater sources.
- U.S. fresh water use is *322 billion gallons per day (117.5 trillion gallons per year)*
 - U.S. water use for shale gas fracking: *31 billion gallons per year, less than 0.026% of fresh water consumption*



U.S. water consumption

FRESH WATER STATISTICS

<https://blog.nationalgeographic.org/2014/03/28/to-understand-water-learn-the-math/>

Country	Water use per person (gallons/day)
United States	1,002
Australia	481
France	329
Germany	226
U.K.	92



- The U.S. has one of the highest fresh water use per person of any industrialized country in the world (China is 308, Japan is 459)
- *What can we do to conserve fresh water?*

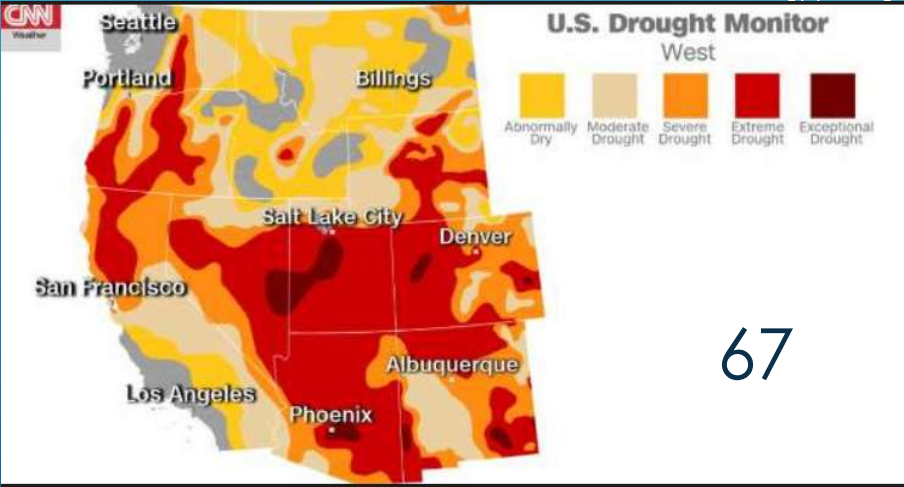
FRESH WATER USE PER PERSON

<https://www.worldometers.info/water/>

- ▶ **West faces reckoning over water but avoids cuts for now, EandE News, 8/14/20**
 - ▶ The Bureau of Reclamation is expected to release projections that Lake Powell and Lake Mead – the 2 largest manmade reservoirs in the U.S. -- will dip slightly in 2021
 - ▶ Despite the dip, Lake Mead's levels are expected to stay above the threshold that triggers mandatory water cuts to AZ and NV, giving officials throughout the SW U.S. more time to prepare for a future where the Colorado River flow will slow
 - ▶ The Colorado supplies 7 states (AZ, CA, CO, NM, NV, UT, and WY) in growing cities like Denver, Las Vegas, and Phoenix and nourishes enough farmland to yield 15% of total U.S. crop output and 13% of its livestock production
 - ▶ "The future of the River is going to be drier than the past. All the climate models and the current drought suggest that."
 - ▶ Since 1990, the population has more than tripled in Las Vegas, which gets nearly 90% of its water from the Colorado. But by treating and recycling almost all water used indoors – for flushing toilets and running dishwashers – and replacing 305,000 square miles of grass with desert-friendly landscaping. The area has been able to consume far less water than it's allocated. And NV is able to treat and then store recycled wastewater in Lake Mead.
 - ▶ This can't be done in places with less storage capacity, like Southern California
 - ▶ In AZ, where nearly 40% of its water comes from the Colorado, officials need to aggressively pursue alternative sources, including underground aquifers and ocean water desalination, to serve customers in the long term
- ▶ **Reclamation: More must be done to protect against drought, EandE News, 12/21/20**
 - ▶ A set of guidelines for managing the Colorado River, helped seven states through a dry spell, but it's not enough to keep key reservoirs in the American West from plummeting amid persistent drought and climate change
 - ▶ Millions of people in seven states and Mexico rely on the river for drinking water and growing crops.
 - ▶ "We all need to work more efficiently and faster than we typically have in the past." This year "has taught us, if we know anything, that we cannot take time for granted."



Millions of people in seven states and Mexico rely on the Colorado River for drinking water and growing crops.



FRESH WATER

Invading seawater jeopardizes South Florida's drinking water, but we can lessen the threat, Sun Sentinel, 6/8/18

- ▶ Sea-level rise isn't just a flooding threat to South Florida. The invading sea is also seeping in underground and coming for the drinking water
- ▶ Decades of too much pumping and draining to provide both drinking water and flood control leave South Florida susceptible to saltwater intrusion, when the ocean moves in and contaminates underground fresh water sources
- ▶ Now, in some of South Florida's most vulnerable spots, sea-level rise is expected to push that underground line of saltwater inland at twice the rate it would otherwise move
 - ▶ Cities from Jupiter to Ft. Lauderdale to Miami already sit within or near the line of *saltwater pushing further inland* into the Biscayne Aquifer, which most communities rely on for drinking water
 - ▶ Broward County within 50 years expects to lose 42% of its coastal fresh water field capacity to the underground push of saltwater
 - ▶ Miami-Dade County already relies on western wells to keep providing fresh water
- ▶ South Florida's sea level is projected to rise about 2 feet by 2060. As the seas rise, the saltwater front moves further inland
- ▶ More must be done to limit saltwater contaminating drinking water, including:
 1. Move wells (to western fields) and build better treatment plants, including desalination units
 2. Develop alternative water sources, including storing and using more rainwater, building new fresh water reservoirs, Everglades restoration, and making better use of Lake Okeechobee water
 3. Increase water conservation, including planting less-water-using plants and shrubs and lawn watering restrictions
 - ▶ Half of South Florida's public water supply goes to watering lawns
 4. Pursue regional collaboration to share the costs of new reservoirs, well fields, and treatment plants



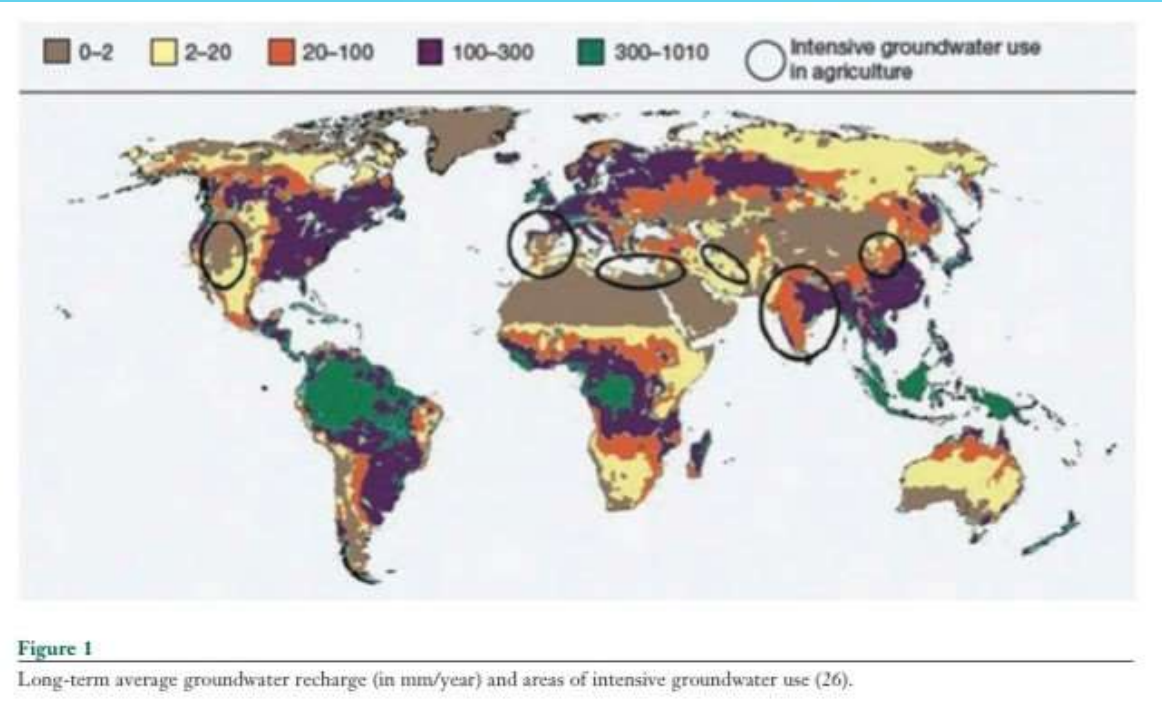
OPINION

Map: Saltwater intrusion in South Florida

FRESH WATER (CONT.)

Stressed aquifers around the globe, N.Y. Times, 6/21

- ▶ As the worst drought in decades continues to afflict the West, it's straining a precious commodity far beneath the Earth's surface: groundwater
- ▶ The Ogallala aquifer, for example, which underlies 8 states from NE to TX, and helps irrigate fields of corn, soybeans, and corn, is overextended
- ▶ Such aquifers are being depleted at an unsustainable rate in the long term, as a study of 700 aquifers worldwide indicates
- ▶ The analysis showed that groundwater supplies in the Upper Ganges of India and Pakistan, the Central Valley of CA, and the North China plain are heavily overexploited
- ▶ Also, aquifers in Iran, western Mexico, and Saudi Arabia are quickly being depleted
- ▶ Water management could help by limiting how much groundwater is drawn or encourage farmers to use groundwater more efficiently when irrigating their crops
- ▶ Altogether, 1.7 billion people live in areas with overextended groundwater supplies
- ▶ But in an interconnected world where food travels thousands of miles, the impact stretches further



FRESH WATER (CONT.)

Hurricanes got stronger. Now they're getting closer to land, EandE News, 1/29/21

- ▶ Research released in the journal Science examines where tropical cyclones hit their peak intensity as they move across the ocean – and how far they are from land when that happens
- ▶ The study found that tropical cyclones are hitting their maximum strength closer to shore as time goes by. The average distance to land has been decreasing by about 18 miles every decade
- ▶ Research has also found that tropical cyclones are shifting westward and further north in many regions around the world
 - ▶ This combination of poleward and westward migration may be part of the region that hurricanes are inching closer to land; and the cyclones may end up impacting coastal areas that are not used to the events
- ▶ “Coastal communities may need stronger protection and better preparation for future storms,” said one scientist



Hurricane Eta
Approaching Nicaragua
with 145 mph winds

CLIMATE CHANGE AND HURRICANES

▶ **Water limitations in the tropics offset carbon uptake from Arctic greening, 12/21/20**

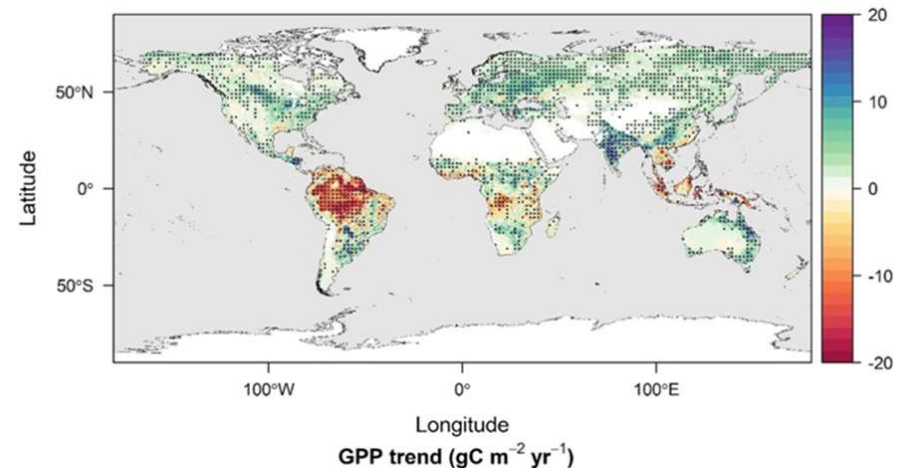
- ▶ More plants and longer growing seasons in the northern latitudes have converted parts of Alaska, Canada, and Siberia to deeper shades of green; translating to greater global carbon uptake
- ▶ Recent studies show that as Earth's climate changes, increased carbon absorption by plants in the Arctic is being offset by a corresponding decline in the tropics
- ▶ Plant productivity in the Arctic is limited by the lengthily periods of cold. As temperatures warm plants in these regions have been able to grow more densely and extend their growing season, leading to an increase in photosynthetic activity and hence greater carbon absorption
- ▶ However, as global temperatures have risen, the atmosphere in the tropics (where plant productivity is limited by the availability of water) has become drier.
- ▶ Recent increases in drought and tree mortality in the Amazon rainforest is one example of this, and carbon absorption over land near the equator has gone down over the same period as Arctic greening
- ▶ *This has cancelled out any net effect on global productivity of carbon absorption by plants*

CARBON UPTAKE BY PLANTS DURING GLOBAL WARMING

Climate.nasa.gov



Satellite image of North America showing where plants are greening the terrain. Credit: NASA



A map of the world shows the changes in global gross primary productivity (GPP), an indicator of carbon uptake, from 1982–2016. Each dot indicates a region with a statistically significant trend. Credit: NASA/Nima Madani

Thawing permafrost releases GHG's from depth, Science Daily, 8/2/21

- ▶ Geologists found that methane concentrations in the air over northern Siberia after last year's heat wave indicate increased gas emissions came from limestone formations
- ▶ Permafrost soils, which cover large areas in northern Asia and North America, pose dangers if they thaw in a warming world, because CO₂ and methane are released during thawing
- ▶ Previous projections have showed a 0.2C rise in global temperatures by 2100 due to this permafrost thawing effect
- ▶ IN the current study, scientists have found significantly elevated methane concentrations in Siberian air, where the bedrock is a limestone foundation
- ▶ There was very little soil in these areas, making methane from the permafrost soil from decaying plant matter very unlikely. Scientists have suggested that instead the methane comes from fractures in the underlying limestone system, that was previously clogged by a mixture of ice and methane hydrates (methane trapped in ice crystals)
- ▶ As a result, methane from natural gas reservoirs beneath the earth's surface can reach the atmosphere



Thawing Siberian
permafrost

MELTING PERMAFROST

Surfside collapse exposes an overlooked threat: Saltwater rising from underground, NBC News, 2/17/22

- ▶ Some scientists believe that the Champlain Towers South condo tower may have been damaged by saltwater seeping into the underground foundation
- ▶ During the natural tidal cycle, including king tides, underground seawater and the freshwater layer above it – called a ‘lens’ – probably mixed
- ▶ The frequency of mixing increases as sea level rises
- ▶ “Ultimately, it will all go to salt. The ocean will be so high and will flood the area so there will be no freshwater lens.” Said one of the scientist
- ▶ The saltwater acts on the concrete, creating spalling, and will eventually corrode the steel rebar with the concrete pillars
- ▶ The number of times groundwater rose above the level of the Towers garage increased from 244 times a year from 1994-2006 to 636 times a year from 2007-2020

Illustration of
Saltwater intrusion

SURFSIDE CONDO COLLAPSE LINKED TO SALT WATER INTRUSION

