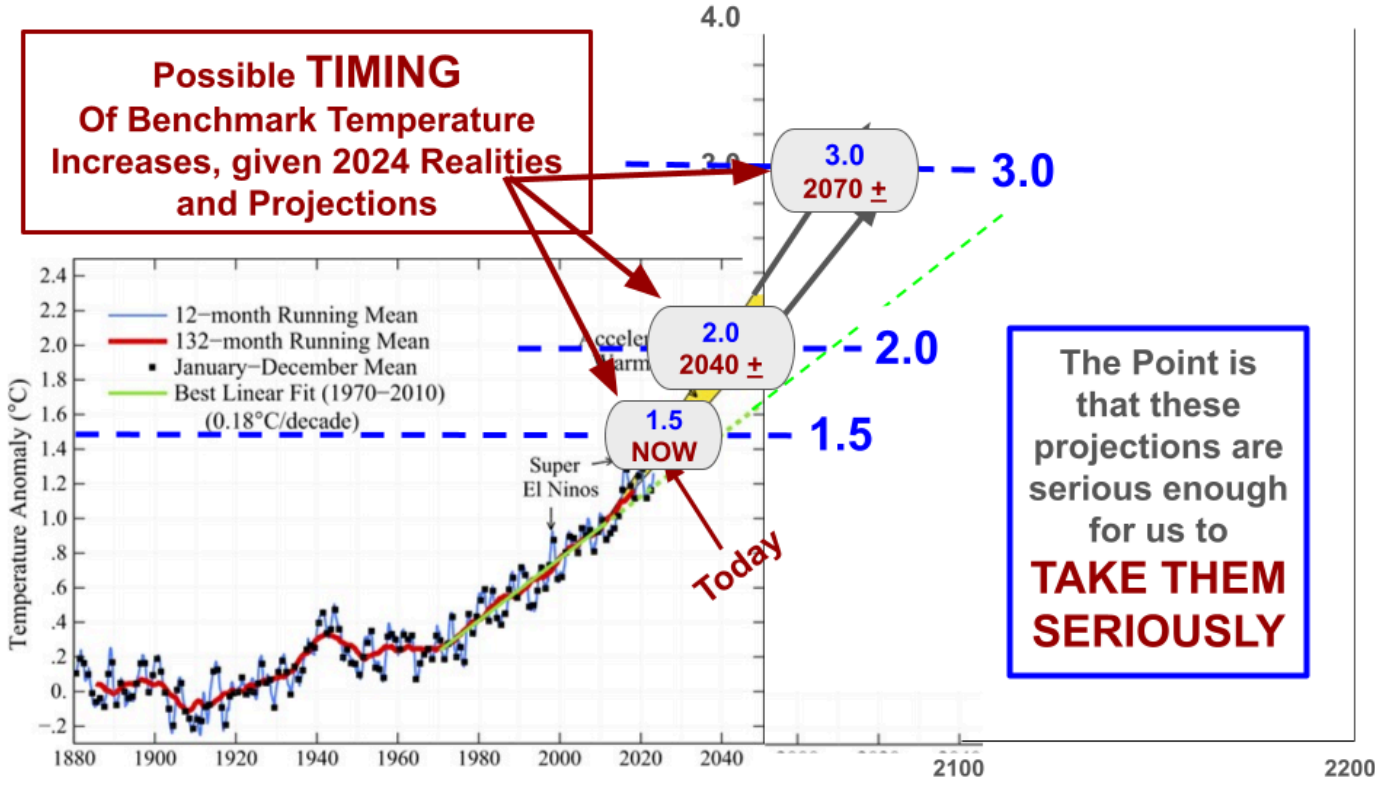
IMPACTS of Global Warming at 1.5 ^{0}C

Timing of Benchmark Temperatures (from last meeting)

In **CSSG-2.26,** we began the study of potential **TIMING** and **IMPACTS** of Global Warming by addressing TIMING. Given our current practice of dumping greenhouse gas (GHG) and aerosols (particulate pollutants) into the atmosphere, the planet will certainly continue to get hotter. We addressed: the historic buildup of emissions, how the planet has responded, our current emission trajectory, estimates of the remaining carbon "budgets" before we hit certain temperatures, and best estimates of how the planet might respond to our behavior (including likely and/or evident accelerations in planetary response). I suggested the following was a reasonable **estimate for TIMING of key temperature increases**:



maclankford@gmail.com

Approximate "Cheat Sheet":

1 meter → 3 feet **1 degree Celsius (^{0}C)** → 2 degree Fahrenheit (^{0}F)
ppm = parts per million **CO_2** = Carbon Dioxide
1 tonne = 1000 kilograms = 2205 pounds **1 gigatonne (1 Gt)** = 1 billion tonnes
1 trillion tonnes (1Tt) = 1000 gigatons

IMPACTS of Global Warming at 1.5 ^{0}C

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The most comprehensive compilation of the best science on potential impacts was assembled by the **IPCC** in their **2023 Synthesis Report** https://www.ipcc.ch/report/ar6/ , based in part on their Reports from 2021 “Climate Change - The Physical Science Basis” and 2022 “Climate Change - Impacts, Adaptation, and Vulnerability”.

First, I have selected some more **general findings** which set the stage for understanding impacts which unfold over a range of specific temperatures.

Selected General Findings by the IPCC

- **Global Warming** - It is unequivocal that human influence has warmed the planet on a scale unprecedented over many centuries to many thousands of years.

- **Climate Change** - This human-caused warming has already caused widespread and rapid changes in the atmosphere, (frozen areas), and biosphere (living things).

- **Further warming** depends on future greenhouse gas (GHG) emissions. Projections for the latter part of this century are as high as 4.4 ^{0}C, and above for greater planetary sensitivities or feedbacks.

- **More warming will result in continuously worsening global conditions**
  - Further amplification of thawing of sea ice, glaciers and permafrost
  - Increases in irreversible changes, especially in the ocean and ice sheets
  - Further intensification of the global water cycle - quantity and intensity
  - More frequent and intense marine (underwater) heatwaves
  - Increased extremes and compounding changes in every region.
  - Impacts and risks will become increasingly complex and more difficult to manage.

- **Only deep, rapid, and sustained GHG reductions** can limit the global temperature rise to less than 2 ^{0}C by the end of the century. If achieved, air quality will also be improved.

- **Sea level rise is unavoidable for centuries to millennia** and sea levels will remain elevated for thousands of years. However, deep, rapid, and sustained GHG emissions reductions would limit further sea level rise acceleration and projected long-term sea level rise commitment.

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IMPACTS of Global Warming at 1.5 ^{0}C

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At each benchmark temperature we will investigate:

Selected TRENDS
and
SPECIFIC FINDINGS

In each section I have included:

1. the graphic depiction of the **main TRENDS for the full range of temperatures** which are possible for this century (typically up through 4 ^{0}C).
2. Bullets addressing the temperature of interest - in this case **today's 1.5 ^{0}C actual situation**.

There are so many components and participants at every level of our planet, atmosphere (air), hydrosphere (water), cryosphere (ice), biosphere (everything living), geosphere (the material of the planet), human-o-sphere (?)! Global Warming will affect, and is affecting every part.

There is no way to adequately capture these impacts. The IPCC has touched on, among many many others:

1. **Temperatures and Precipitation**
2. **Moisture Change in the soil and Food Production**
3. **Heat-Humidity Risks to Human Health**
4. **Risks of Species Losses**
5. **Sea Level Rise**
6. **Tipping Points**

While I can point interested folks to all the details you can stand, for our purposes here we will stick with these.

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So, let's get our heads around the first benchmark:

IMPACTS of Global Warming

at

1.5 ^{0}C

What has Already Happened to our Planet from Human-Caused Global Warming

IMPACTS of Global Warming at 1.5 ^{0}C

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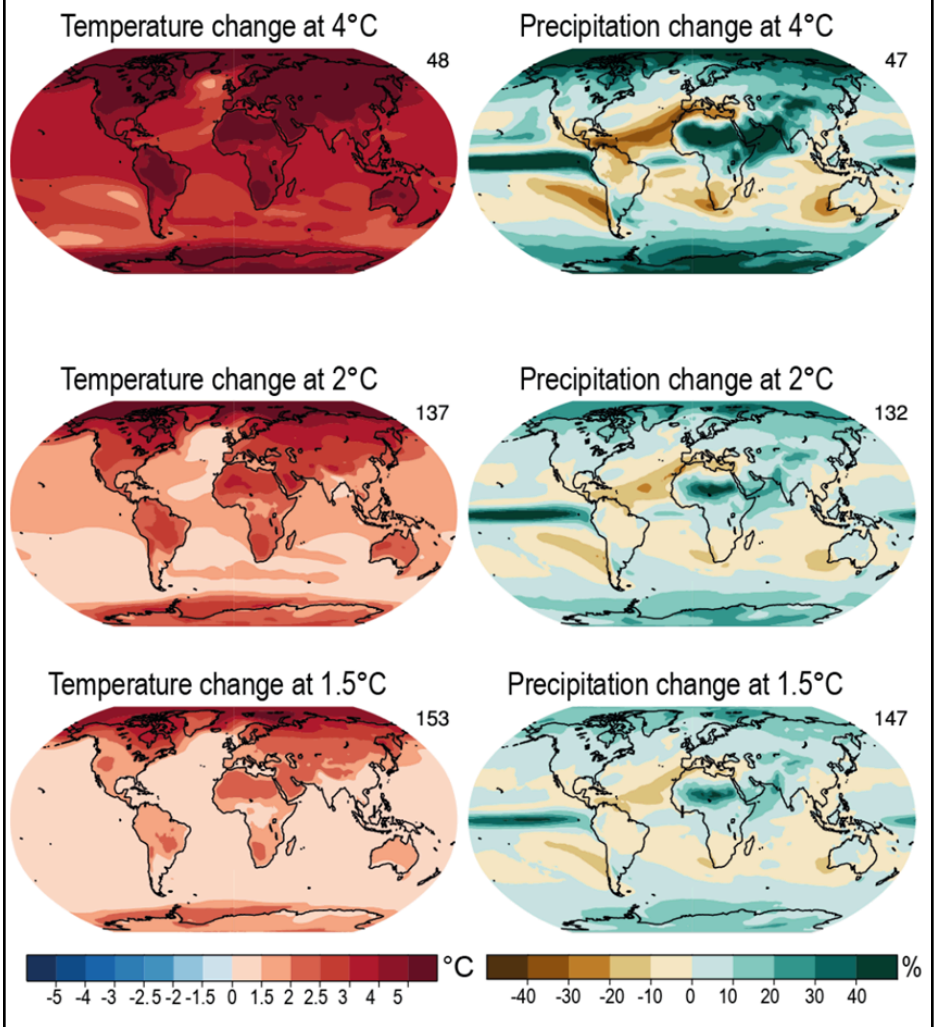
1. SURFACE TEMPERATURE and PRECIPITATION CHANGES

→ THE TRENDS

Average Warming (relative to the period 1850-1900) is shown, with even greater warming toward the poles and specific areas. Dramatic climate changes are projected all over the globe as temperatures rise. **The 1.5 ^{0}C chart can be considered our current condition.**



AverageTemperatures: Note that, locally, the annual **<u>maximum</u> temperatures** experienced can be much higher than these averages shown - typically increasing by up to 8 ^{0}C in the 4 ^{0}C global warming scenario.

Precipitation: At the same time as these major changes in temperature are occurring, rainfall is also expected to modify in **intensity and total precipitation.** These changes can be strongly increasing or strongly decreasing total rainfall.

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IMPACTS of Global Warming at 1.5 ^{0}C

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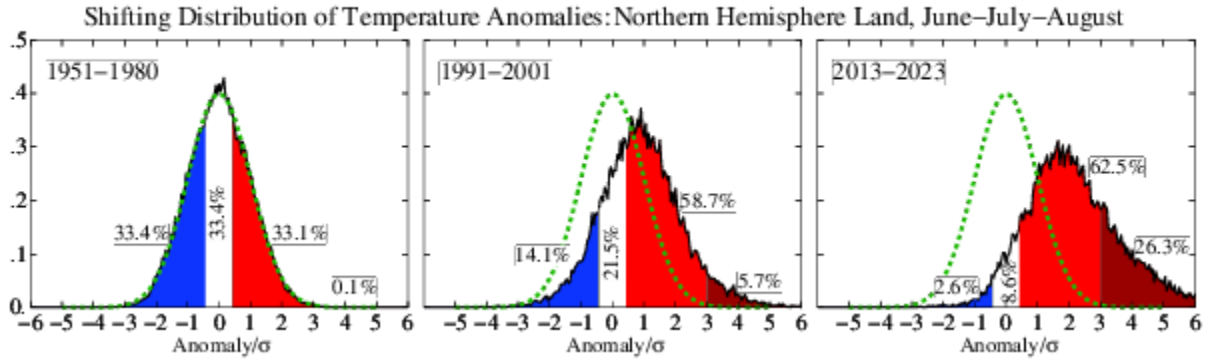
SURFACE TEMPERATURE and PRECIPITATION

→ Specific Impacts already here today at 1.5 ^{0}C

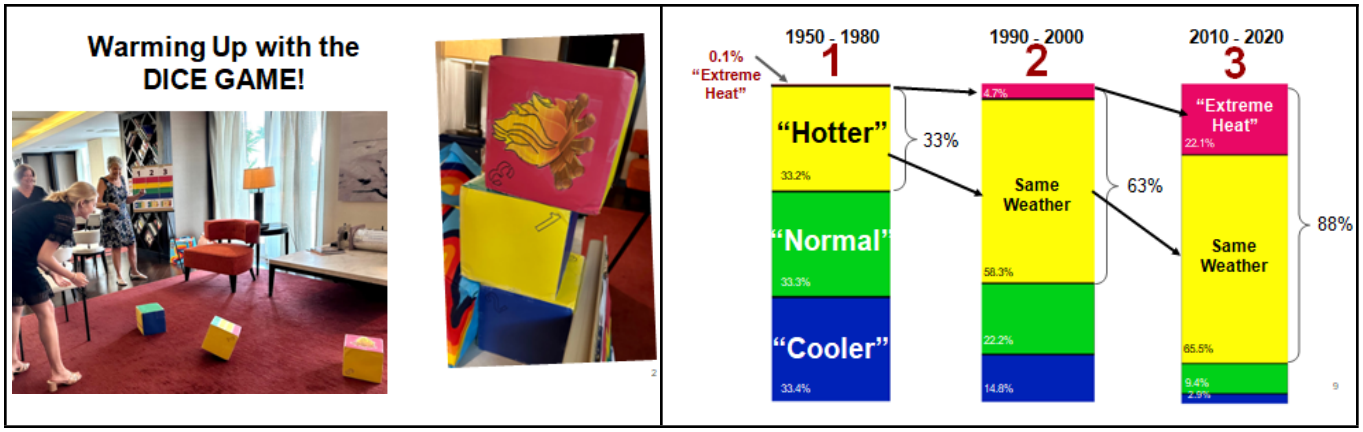
■ **Steady increases of temperatures of annual hottest days,** particularly in some mid-latitude and semi-arid regions, and in the South American Monsoon region. Strong evidence that these **increases in global average temperatures are accelerating**.

The following chart is directly from data for Northern Hemisphere land in the summers. The type of "normal weather" ⅓ of days in the 1951-1980 period (white band in center) is rare 4 decades later. The extremely hot 0.1% days in the first period are 26% of the days in our most recent 2013-2023 decade. **The 33% "warmer" and "extreme" days in the first period now are experienced 89% of the summer.** As we saw in our **"Roll of the Dice" game last September** (see attachment), WEATHER is a roll of the dice, but you have to now use the dice for the current decade's CLIMATE!

Figures in Warm/Cool Dice Colors [for NH Land]



https://www.columbia.edu/~mhs119/PerceptionsAndDice/



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IMPACTS of Global Warming at 1.5 ^{0}C

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■ Evidence of observed changes in extremes such as **heatwaves, heavy precipitation, droughts, and tropical cyclones**, and, in particular, their attribution to human influence, has strengthened.

heatwaves that, on average, arose once every 10 years in a climate with little human influence will likely occur 4.1 times more frequently with 1.5 degrees C

■ Human influence was the main driver of the **global retreat of glaciers** since the 1990s and the decrease in Arctic sea ice area between 1979-1988 and 2010-2019 (very likely). Human influence contributed to **decreased Northern Hemisphere spring snow cover** and **surface melting of the Greenland ice sheet** (very likely).

■ **Heavy precipitation and flooding events** intensified and became more frequent in most regions in Africa, Asia, North America, and Europe. Notable regions with respect to **loss of precipitation** are the Amazon and, especially, the Mediterranean countries.

At least one ice-free summer per 100 years in the arctic. 6.6.million km^2 of arctic permafrost that will melt (38% increase from 1.5 C impact).

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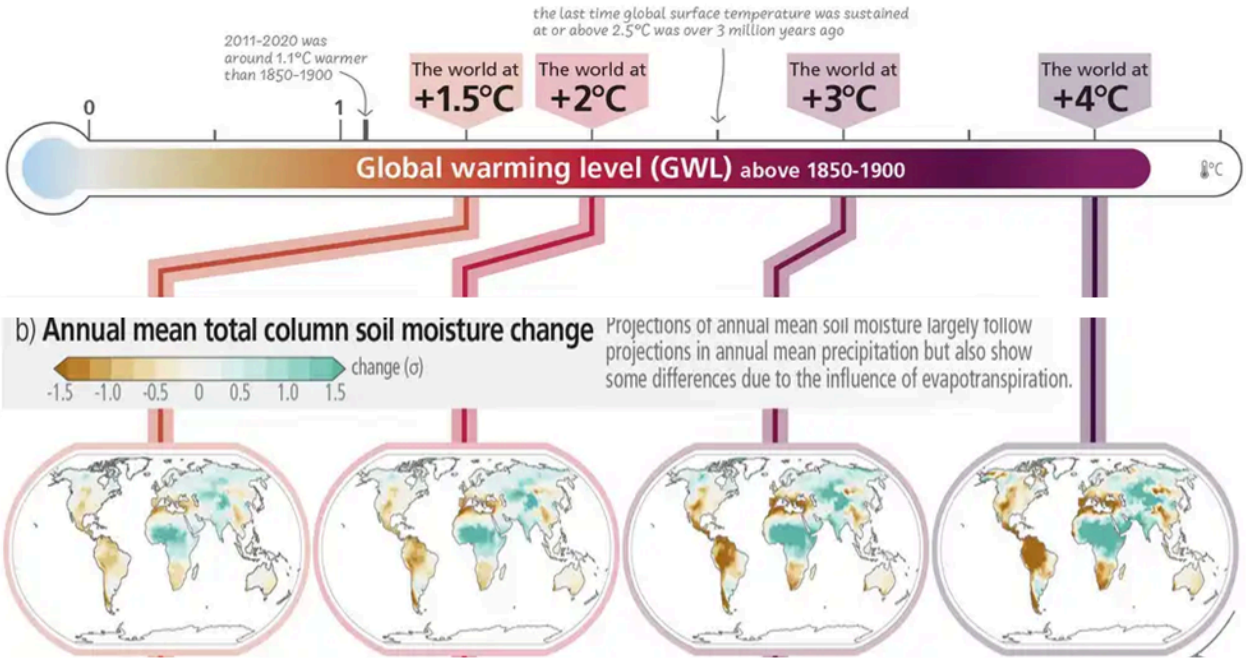
IMPACTS of Global Warming at 1.5 ^{0}C

2. SOIL MOISTURE and FOOD PRODUCTION

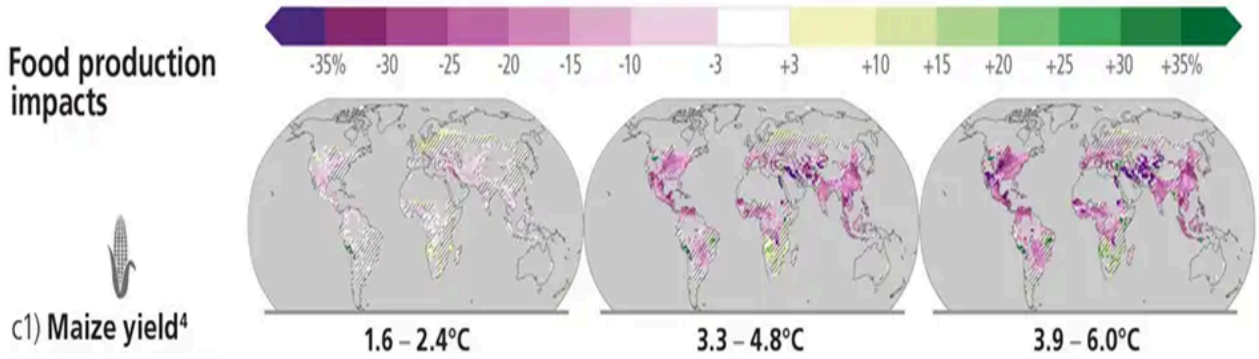
→ THE TRENDS

SOIL MOISTURE: With major changes in rainfall, in combination with the increased heat, the moisture in the soil for plant growth can take significant hits. (Note that small absolute changes may appear as large changes in dry regions, e.g., the Sahara.)



Notable regions include the US Southwest, Europe and the Mediterranean, Central America, and the Amazon.

FOOD PRODUCTION: As more regions become less habitable to humans and diverse species, food production will be more challenging. The change in % yield of Maize provides one example.



IMPACTS of Global Warming at 1.5 ^{0}C

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SOIL MOISTURE and FOOD PRODUCTION

→ Specific Impacts already here today at 1.5 ^{0}C

■ Warming is associated with **moderate risks from increased dryland water scarcity** (high confidence).

■ **Intensifying changes in annual mean total column soil moisture**.

■ Climate change has **contributed to desertification and exacerbated land degradation**, particularly in low lying coastal areas, river deltas, drylands, and in permafrost areas (high confidence). 3% corn harvest reduction in the tropics.

■ Many **low-elevation and small glaciers** around the world **will lose most of their mass or disappear within decades to centuries** (high confidence)

■ Regions at **disproportionately higher risk include Arctic ecosystems, dryland regions, small island development states, and Least Developed Countries** (high confidence)

1.5. Million tonnes reduction in sea fishing.

https://www.foodbusinessnews.net/articles/19120-drought-heat-wreak-havoc-on-western-crops

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IMPACTS of Global Warming at 1.5 ^{0}C

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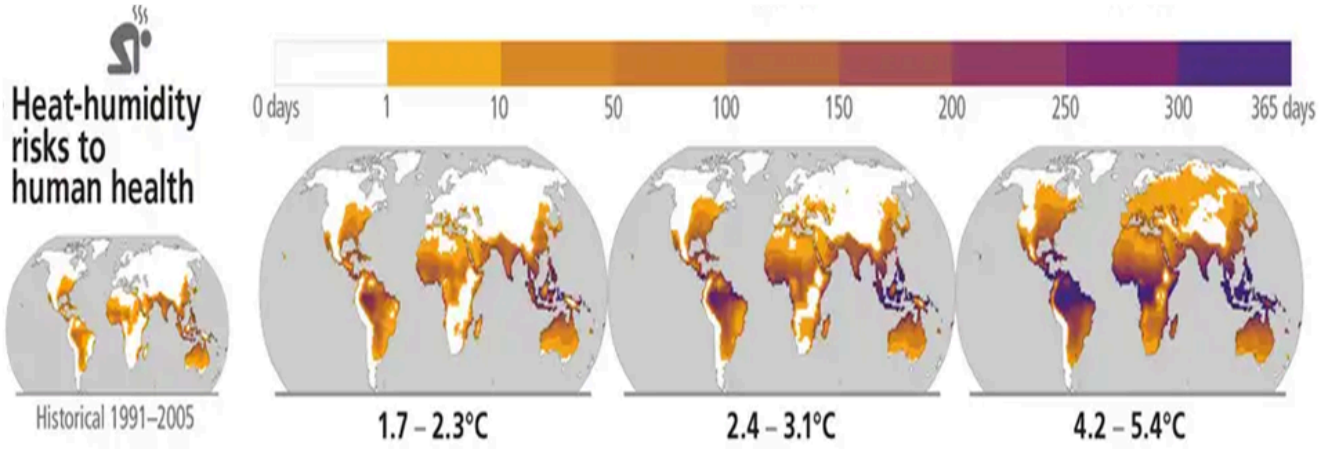
3. HEAT-HUMIDITY RISKS TO HUMAN HEALTH

→ THE TRENDS

These temperature increases, combined with humidity, will have direct effects on humans. More areas will become less habitable as the number of dangerous days in the year increase, posing a risk of mortality increase.

Days per year where combined temperature and humidity conditions pose a risk of mortality to individuals:



HEAT-HUMIDITY RISKS TO HUMAN HEALTH

→ Specific Impacts already here today at 1.5 ^{0}C

■ **Human mortality and morbidity have increased in all regions** from increases in **extreme heat** (very high confidence). 14% of the population exposed to heatwaves and their consequences at least every 5 years.

■ **Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change** (high confidence).

■ Between 2010 and 2020, **human mortality from floods, droughts, and storms was 15 times higher in highly vulnerable regions** (high confidence).

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IMPACTS of Global Warming at 1.5 ^{0}C

- Increasing weather and climate extreme events have **exposed millions of people to acute food insecurity and reduced water security** (high confidence).

- Climate change has adversely affected **human physical health** globally and **mental health** (very high confidence), and is **contributing to humanitarian crises** where climate hazards interact with high vulnerability (high confidence).

- **Severe water scarcity is currently experienced by roughly half of the world's population** for at least part of the year due climatic and non-climatic drivers (medium confidence). 350 million persons in urban settings exposed to droughts and water shortages.

- The occurrences of **climate-related food-borne and water-borne diseases** (very high confidence) and challenges are associated with increasing temperature (high confidence).

- **Climate and weather extremes are increasingly driving displacements**. Through displacement and involuntary migration from extreme weather and climate events, climate change has generated and perpetuated vulnerability (medium confidence).

- Due to **unavoidable sea level rise**, risks for coastal ecosystems, people, and infrastructure will continue to increase beyond 2100 (high confidence).

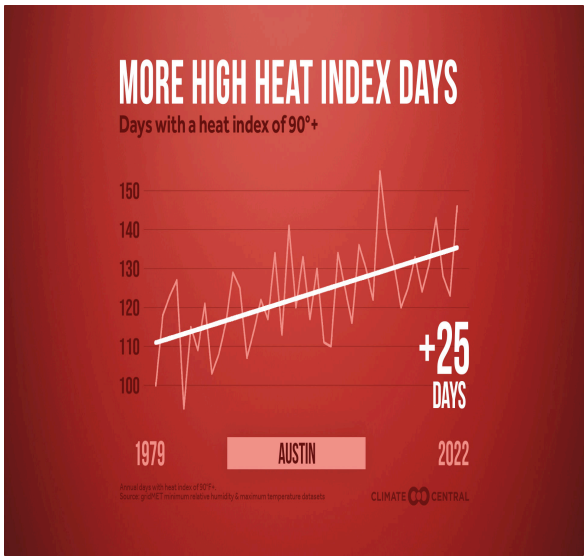
- Climate-related **risks to health, livelihoods, food security, water supply, human security, and economic growth** are projected to increase

higher temperatures are enabling the spread of vector-borne diseases, such as malaria, West Nile virus and Lyme disease

since 2008, extreme floods and storms have forced over 20 million people from their homes every year.

At this level of warming, for example, 950 million people across the world's drylands will experience water stress, heat stress and desertification, while the share of the global population exposed to flooding will rise by 24%.

IMPACTS of Global Warming at 1.5 ^{0}C



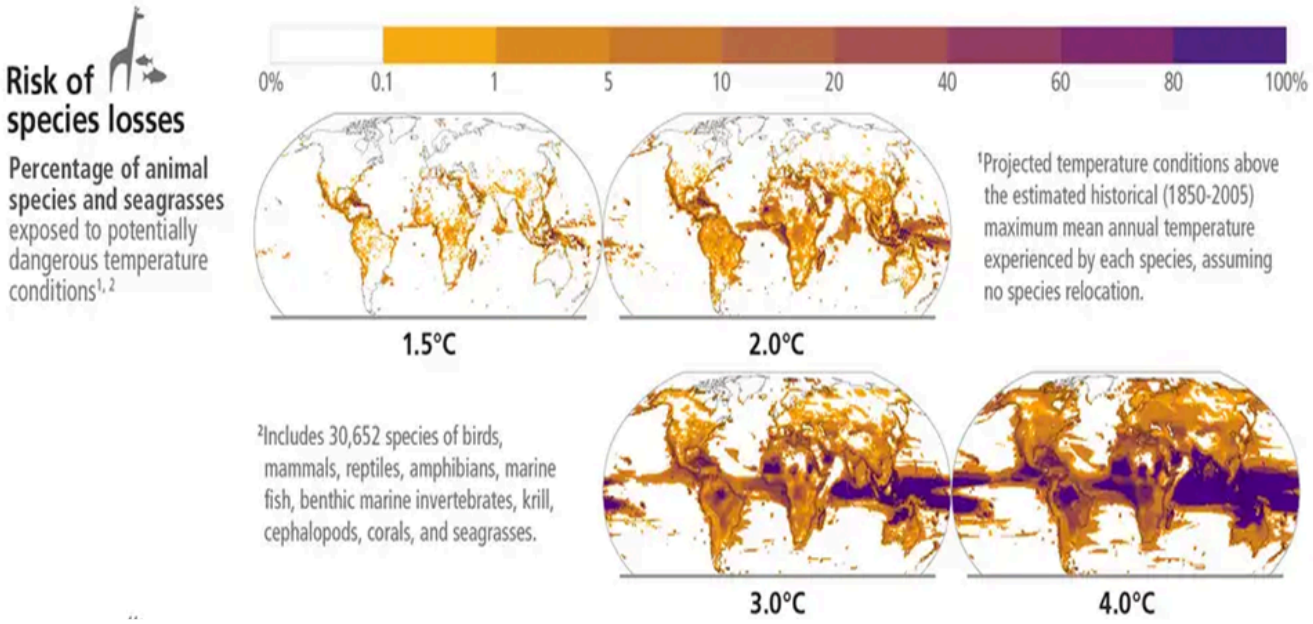
https://www.climatecentral.org/climate-matters/high-heat-index-days-2023

https://www.upi.com/Science_News/2023/04/27/Somalia-Africa-drought-climate-change/3331682606599/

4. SPECIES EXTINCTIONS

→ THE TRENDS

Not only will humans be displaced, but rising temperatures will increasingly require **species to relocate or die**.



IMPACTS of Global Warming at 1.5 ^{0}C

SPECIES EXTINCTIONS

→ Specific Impacts already here today at 1.5 ^{0}C

■ **3-14% of the 30,652 species assessed likely face a very high risk of extinction. Approximately 4% of vertebrate animal species would be halved.**

■ **Hundreds of local losses of species** have been driven by increases in the magnitude of heat extremes (high confidence) with **mass mortality events** on land and in the ocean (very high confidence). 8% of plants will lose half their numbers. 6% of insects will lose half their numbers. 7% of land area where ecosystems would change their characteristics, flora and fauna.

■ **Approximately half of the 30,652 species** assessed globally **have shifted polewards** or, on land, **also to higher elevations** (very high confidence).

■ **Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater, cryospheric, and coastal and open ocean ecosystems** (high confidence).

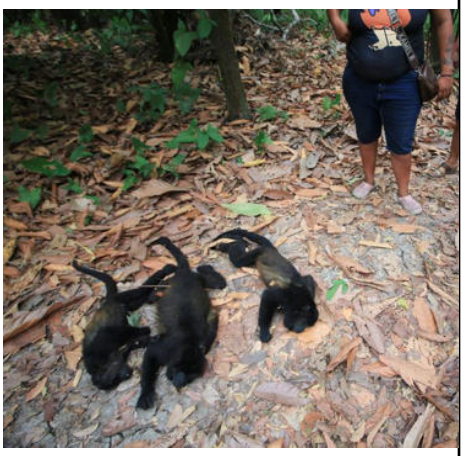
■ **Coral reefs are projected to decline by a further 70-90%** (high confidence)

■ Ocean warming in the 20th century and beyond has contributed to an **overall decrease in maximum catch potential** (medium confidence), compounding the impacts of overfishing for some fish stocks (high confidence).

IMPACTS of Global Warming at 1.5 ^{0}C

https://www.wilderness.org/articles/blog/what-extinction-crisis-5-key-facts

Heat and humidity can have a direct and devastating effect

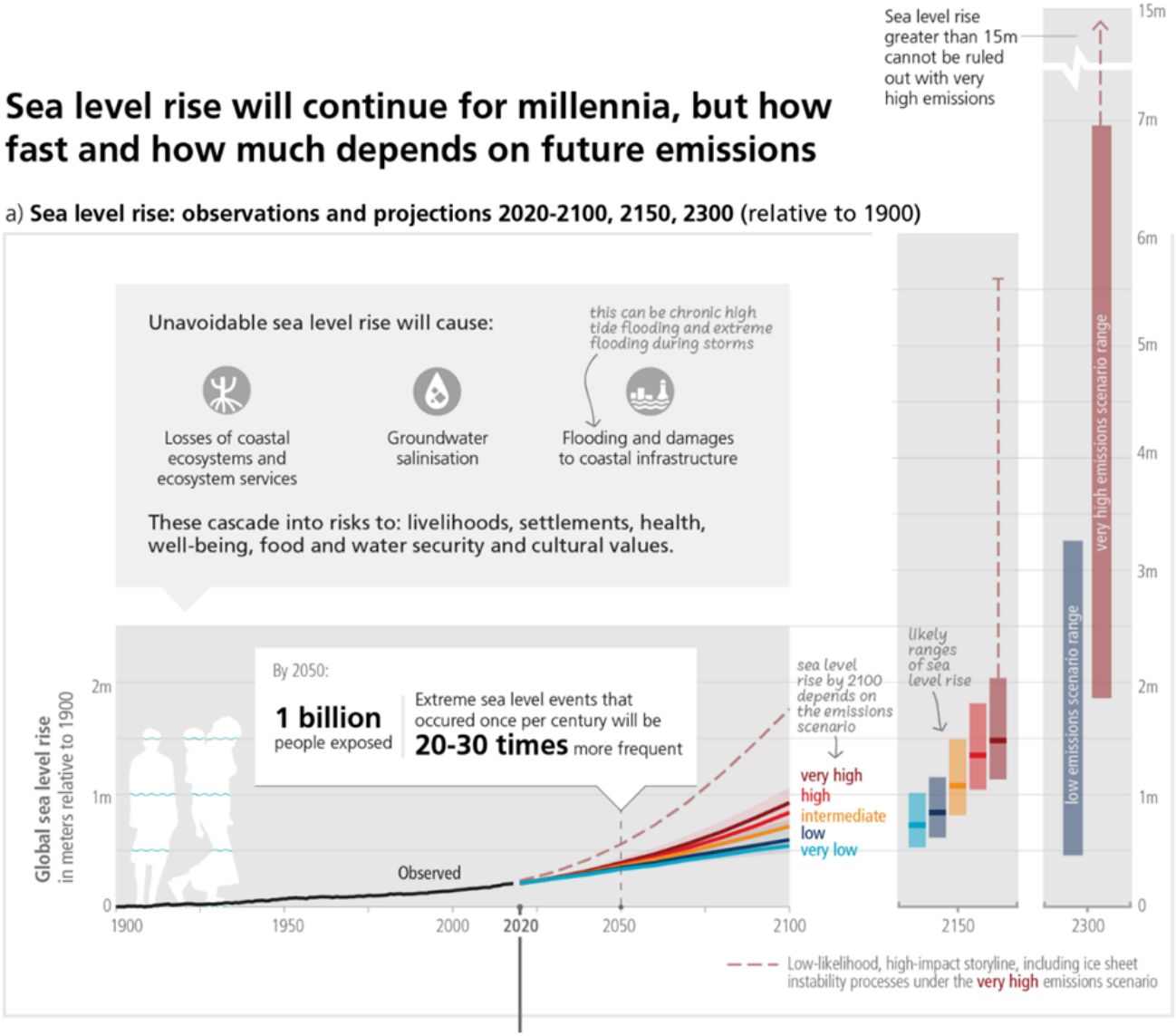


https://www.msn.com/en-us/news/world/mexico-s-howler-monkeys-dropping-dead-as-heat-toll-mounts/ar-BB1mK0BQ

IMPACTS of Global Warming at 1.5 ^{0}C

5. SEA LEVELS
→ THE TRENDS

Finally, for this very-abbreviated summary, sea level rise is very much in our future.



Recent publications have documented faster-than-expected melting in Greenland and Antarctica. Also, improved understanding of ancient (paleo) processes have been articulated. These raise the possibilities that the planet is more sensitive to changes in greenhouse gas concentrations. If so, sea levels may be significantly higher in this century than shown above.

IMPACTS of Global Warming at 1.5 ^{0}C

SEA LEVELS

→ Specific Impacts already here today at 1.5 ^{0}C

■ Due to **unavoidable sea level rise**, risks for coastal ecosystems, people, and infrastructure will continue to increase beyond 2100 (high confidence).

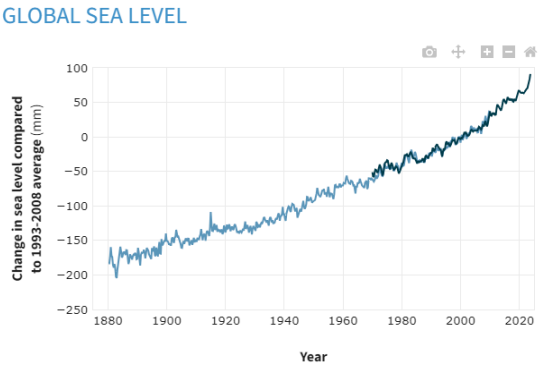
■ Global mean sea level increased by **0.2 meters between 1901 and 2018**. The **rate of rise has tripled** since 1950 (high confidence). Approx 40 cm of sea level rise is expected by 2100.

■ **Current 1-in-100 year extreme sea level events** are projected to **occur at least annually** in **more than half of all tide gauge locations by 2100** under all considered scenarios (high confidence).

■ The global upper ocean (0-700 m) has warmed since the 1970s (virtually certain) and human influence is the main driver (extremely likely). **Ocean warming accounted for 91% of the heating in the climate system** (high confidence).

■ Human-caused CO_2 emissions are the main driver of current **global acidification of the surface open ocean** (virtually certain). Ocean warming and ocean acidification have adversely affected food production from fisheries and shellfish aquaculture in some oceanic regions (high confidence).

■ **Nearly 50% of coastal wetlands have been lost over the last 100 years**, as a result of the combined effects of localized human pressures, sea level rise, warming, and extreme climate events (high confidence).



https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

IMPACTS of Global Warming at 1.5 ^{0}C

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6. TIPPING POINTS

→ THE TRENDS

On Dec 6, 2023, a major study on Tipping Points by more than 200 climate scientists was published. The announcement is at: https://www.nature.com/articles/d41586-023-03849-y. The 500 page report, and its constituent sections and summaries, can be accessed at: https://global-tipping-points.org/. We covered a lot of this report in **CSSG-2.11, 12, 13, and 17**.

The reason for including these tipping points as IMPACTS is obvious from the authors' statement:

> **"THESE TIPPING POINTS POSE THREATS OF A MAGNITUDE NEVER BEFORE FACED BY HUMANITY. These threats could materialize in the coming decades, and at lower levels of global warming than previously thought. They could be catastrophic, including global-scale loss of capacity to grow major staple crops. Triggering one Earth system tipping point could trigger another, causing a domino effect of accelerating and unmanageable damage. Tipping points show that the overall threat posed by the climate and ecological crisis is far more severe than is commonly understood."**

26 Earth system tipping points were identified from evidence of past changes, observational records and computer models.

- **In the cryosphere,** six Earth system tipping points are identified, including large-scale tipping points for the Greenland and Antarctic ice sheets. Localized tipping points likely exist for glaciers and permafrost thaw. Evidence for large-scale tipping dynamics in sea ice and permafrost is limited.
- **In the biosphere,** 16 Earth system tipping points are identified, including forest dieback (e.g. in the Amazon), savanna and dryland degradation, lake eutrophication (relates to human activities where the artificial introduction of plant nutrients has led to community changes and a deterioration of water quality in many freshwater systems), die-off of coral reefs, mangroves, and seagrass meadows, and fishery collapse.
- **In ocean and atmosphere circulations,** four Earth system tipping points are identified, in the Atlantic Meridional Overturning Circulation (AMOC), the North Atlantic Subpolar Gyre (SPG), the Southern Ocean Overturning Circulation and the West African monsoon.

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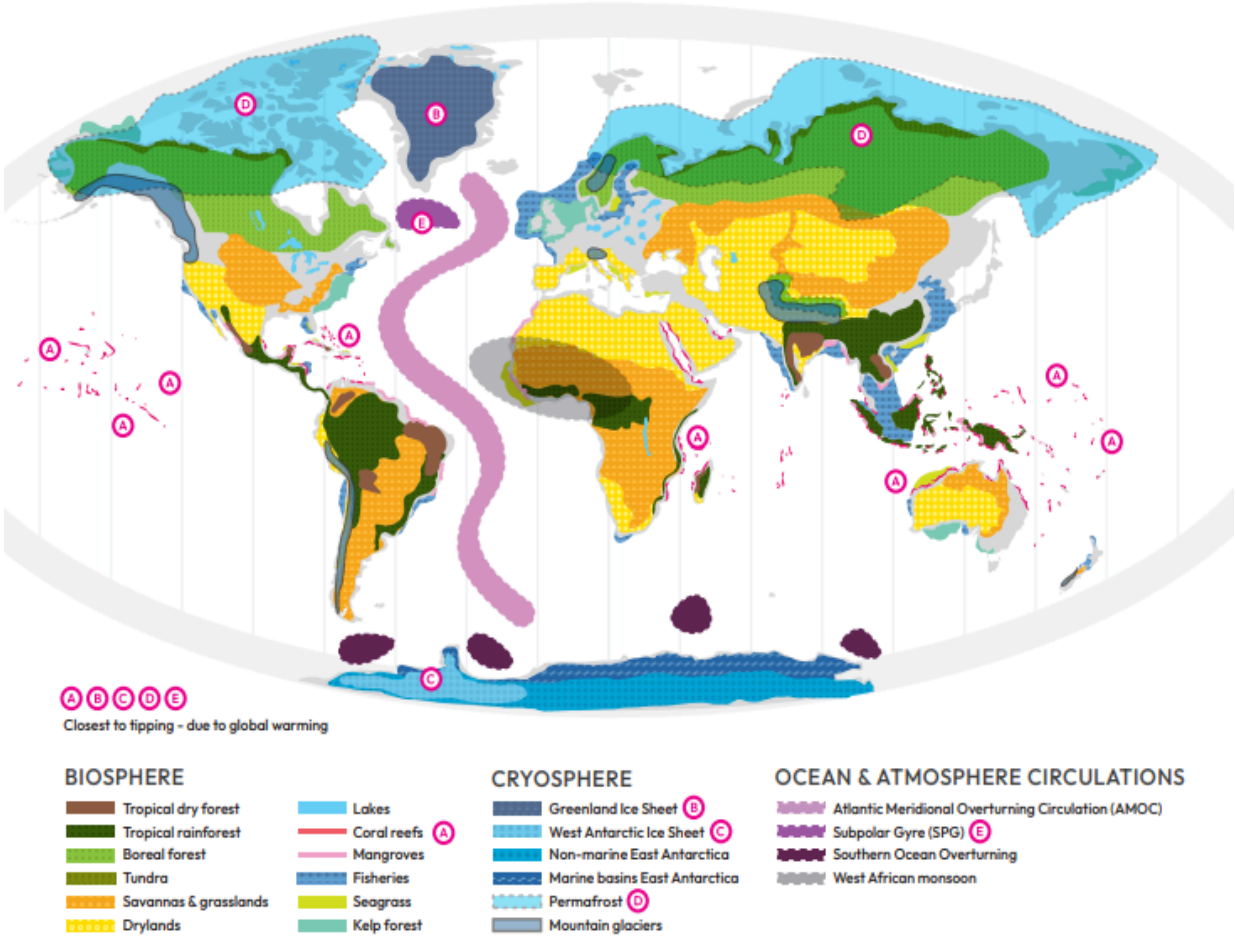
IMPACTS of Global Warming at 1.5 ^{0}C

Some Earth system tipping points are no longer high-impact, low-likelihood events, they are **rapidly becoming high-impact, high-likelihood events**.

The chart below catalogs the 26 potential tipping points of most concern.



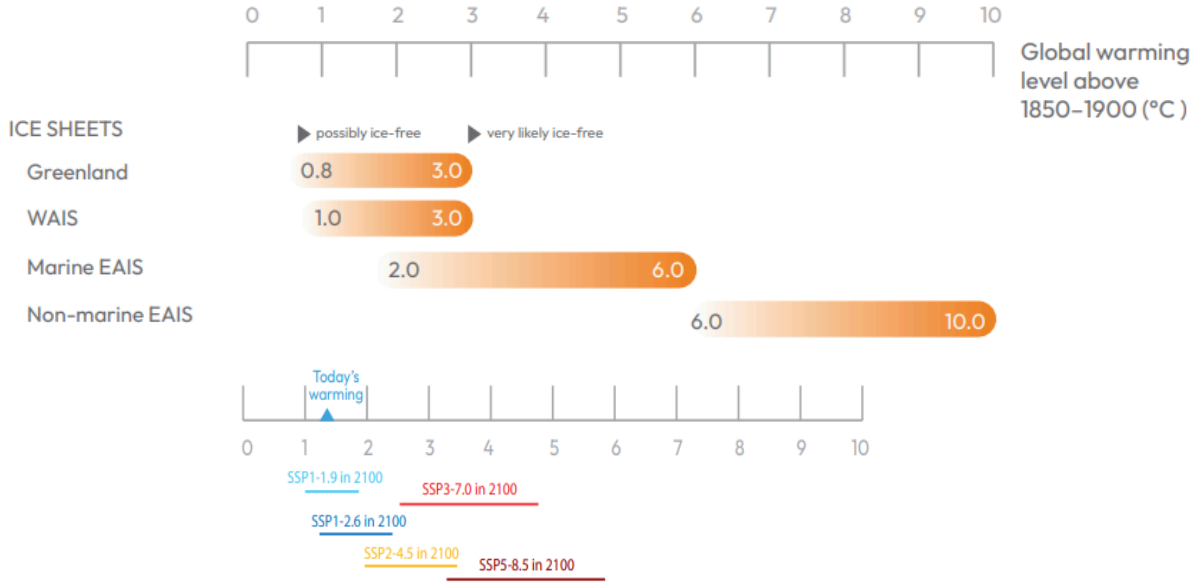
https://global-tipping-points.org/

Five of the 26 potential tipping points (A) - (E) were flagged as being **already at risk** of crossing tipping points at the present level of global warming**:**

- warm-water coral reefs (A),
- Greenland (B) ice sheet [7m sea level rise potential over centuries to millennia]
- West Antarctic (C) ice sheets [3m],
- permafrost regions (D), and
- North Atlantic Subpolar Gyre circulation (E).

IMPACTS of Global Warming at 1.5 ^{0}C

For the tipping points of the **ice sheets**, Greenland and West Antarctica have both entered the range of instability:



The "SSP" bars immediately above reference IPCC scenarios varying from very aggressive action against global warming up to "business as usual" increases in emissions.

TIPPING POINTS

→ Specific Impacts already here today at 1.5 ^{0}C

- **Already,** tipping of warm-water **coral reefs** is likely and we **cannot rule out that the other four** systems may pass tipping points

- **Early warning signals** have been detected that are consistent with the Greenland Ice Sheet, AMOC, and Amazon rainforest heading towards tipping points. Loss of resilience (the ability to recover from perturbations) is expected before reaching a tipping point, but does not directly reveal how close a tipping point is.

- **The AMOC has weakened by approximately 15% since 1950** – that's around three million cubic metres less water being shifted per second. A weaker AMOC means a slowdown in the conveyor belt effect in the North Atlantic that pulls warm water up towards Europe.

https://www.carbonbrief.org/atlantic-conveyor-belt-has-slowed-15-per-cent-since-mid-twentieth-century/#:~:text=The%20implication%20of%20this%20is,warm%20water%20up%20towards%20Europe.

IMPACTS of Global Warming at 1.5 ^{0}C

■ **The Western Antarctic Sheet** is directly threatened by unpredicted loss of sea ice and greater-than-anticipated intrusion of warmer waters beneath the Thwaites Glacier, per a very recent study. This glacier alone, if it is released to flow out to sea by the emerging conditions could contribute 0.6 m of global sea level rise. Such conditions may be evolving in other Antarctica sites.

https://www.pnas.org/doi/full/10.1073/pnas.2404766121
https://www.washingtonpost.com/climate-environment/2024/05/20/thwaites-glacier-melt-sea-level-rise/

Brown sediment marks rapidly melting ice on the Greenland ice sheet (and, being darker, the sediment absorbs even more sunlight, further **accelerating thawing - towards a Tipping Point?**).

IMPACTS of Global Warming at 1.5 ^{0}C

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Punchlines
for our Situation at 1.5 ^{0}C

1. SURFACE TEMPERATURE and PRECIPITATION CHANGES

- **Global temperatures are steadily increasing and are now accelerating.**
- **Climates around the world have strongly shifted to much warmer conditions** than even 40 years ago, including the loss of glaciers and surface snow. As an example, in the most recent decade (2013-2023), 89% of Northern Hemisphere summer days were as hot or hotter than the hottest 33% of summer days in the period 1950-1980. That means that only 11% of these recent days were as cool as the cool and "average" 66% in the earlier period.
- **Weather events** (storms, precipitation, droughts, heatwaves, heavy precipitation, tropical cyclones, flooding events, etc.) **are more intense than in previous decades.**

2. SOIL MOISTURE and FOOD PRODUCTION

- Climate change has **contributed to desertification and exacerbated land degradation**, particularly in low lying coastal areas, river deltas, drylands, and in permafrost areas (high confidence).

3. HEAT-HUMIDITY RISKS TO HUMAN HEALTH

- **Human mortality and morbidity have increased in all regions** from increases in **extreme heat** (very high confidence). **Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change** (high confidence).
- **Climate and weather extremes are increasingly driving displacements**.

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IMPACTS of Global Warming at 1.5 ^{0}C

4. SPECIES EXTINCTIONS

- **3-14% of the 30,652 species assessed likely face a very high risk of extinction.**

- **Approximately half of the 30,652 species** assessed globally **have shifted polewards** or, on land, **also to higher elevations** (very high confidence). **Climate change has caused substantial damages, and increasingly irreversible losses, in** terrestrial, freshwater, cryospheric, and coastal and open ocean **ecosystems** (high confidence).

5. SEA LEVELS

- Global mean sea level increased by **0.2 meters between 1901 and 2018**. The **rate of rise has tripled** since 1950 (high confidence).

- **Ocean warming accounted for 91% of the heating in the climate system** (high confidence). Human-caused CO_2 emissions are the main driver of current **global acidification of the surface open ocean** (virtually certain).

- **2023 was a year of climate disasters and ice loss.** A glacial lake outburst flood devastated Sikkim in India. Swiss glaciers lost 10% of their remaining ice over just two years. Sea ice around Antarctica hit all-time-low summer and winter records. Unprecedented fires raged across Canadian permafrost. Parts of the Arctic and North Atlantic saw water temperatures 4–6°C higher than normal. It rained far inland on Antarctica, and Greenland saw its second-highest surface melt ever. https://iccinet.org/statecryo23/

6. TIPPING POINTS

- **Already,** tipping of warm-water **coral reefs** is likely and we **cannot rule out that the other four** systems (Greenland Ice sheet, West Antarctic ice sheets, permafrost regions, and the North Atlantic Subpolar Gyre circulation) may pass tipping points

- **Early warning signals** have been detected that are consistent with the Greenland Ice Sheet, AMOC, and Amazon rainforest heading towards tipping points. **The AMOC has weakened by approximately 15% since 1950, and new research documents faster than anticipated deterioration of the Thwaites Glacier.**

IMPACTS of Global Warming at 1.5 ^{0}C

Figure 1.1.1: Illustration of the Earth system, showing the different 'spheres'.

The **Earth system** describes the interconnected complex system at the surface of the planet that sustains life (Figure 1.1.1). It is comprised of multiple subsystems (or spheres), including the

- **cryosphere (ice-related systems** , including ice sheets, sea ice, glaciers and permafrost) (from Greek *krios* 'cold' + *sphaira* 'ball, globe'),
- **biosphere (global ecosystems)** (*bio* 'of living things') ,
- **Atmosphere**, (*atmos* 'vapor')
- **hydrosphere (water-based systems**, including oceans, rivers and lakes) (*hydro* 'water'), and
- **lithosphere (the Earth's solid surface)** (*lithos* 'stone').

IMPACTS of Global Warming at 1.5 ^{0}C

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Together **these subsystems and their interactions determine the climate** (the average long-term weather conditions at a place or across the Earth, usually measured over 30 years).

GOOD NEWS CORNER

Reduce EMISSIONS - EMISSIONS - EMISSIONS!!!! That's the only way to slow the accelerating heating of the planet in the next decades.

Here's some good steps in that specific direction, **BUT NOTE THEY ARE FOR THE FUTURE !** These are NOT actual Emissions cuts:

The U.S. just took its biggest step yet to end coal mining

washingtonpost.com

https://www.washingtonpost.com/climate-environment/2024/05/16/coal-leasing-powder-river-basin-climate/

And a hopeful forecast:

"U.S. CO_2 **emissions in our forecast** decline by 1% from 2024 to 2025. Small reductions in CO_2 emissions are mostly a result of continued changes in the electricity generation mix. **Continued decreases in coal-fired generation** reduce emissions in 2Q24 and 4Q24, and **decreasing natural gas-fired generation** reduces emissions in 3Q24."

www.eia.gov - short-term energy outlook May 7, 2024

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