KAIST | MetaEarth Lab
KAIST Moon Soul Graduate School of Future Strategy

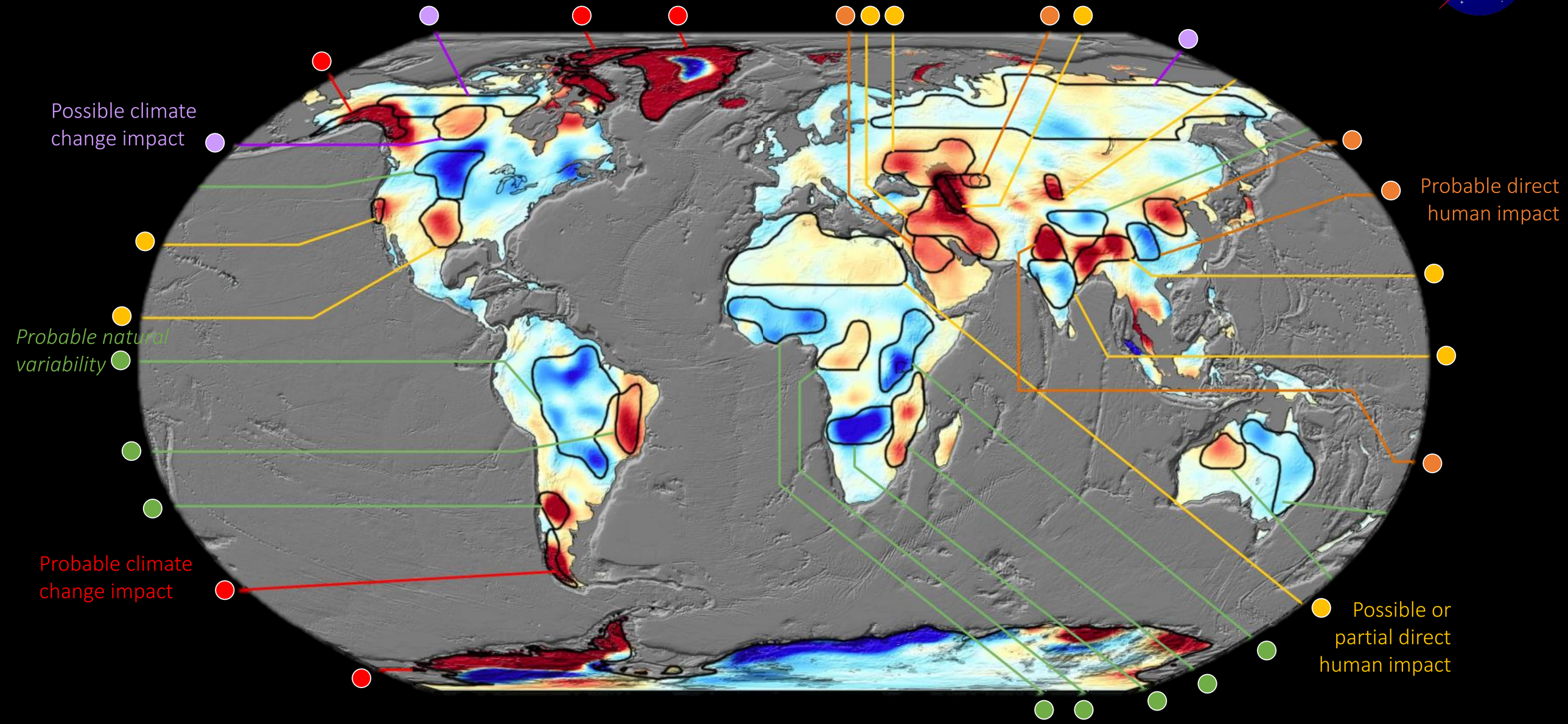
Navigating Climate Crisis

Understanding Coupled Earth-Human System

Hyungjun Kim
Moon Soul Graduate School of Future Strategy
& Dept. of Civil and Environmental Engineering
& Graduate School of Green Growth and Sustainability
& Graduate School of Data Science
| KAIST

APEC Climate Symposium 2025 | 2025.08.08

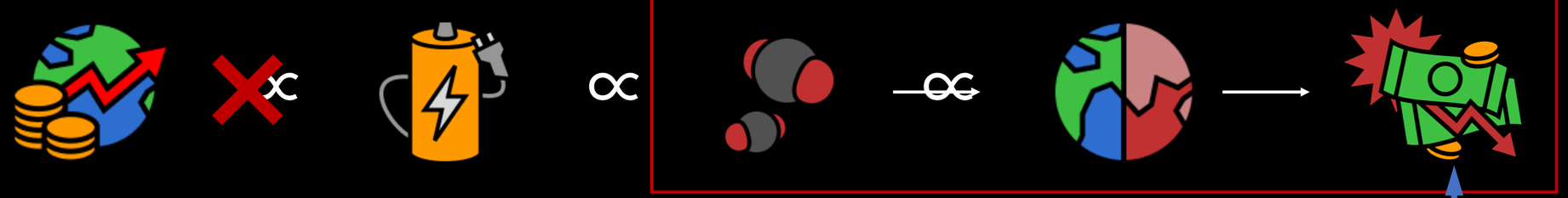
Changing Global Water Availability



Observed by GRACE satellite (2002-2016)

Rodell et al., 2018, Nature

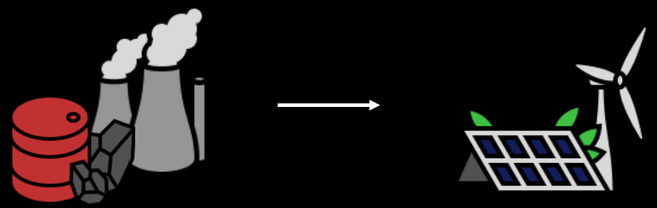
Adaptation



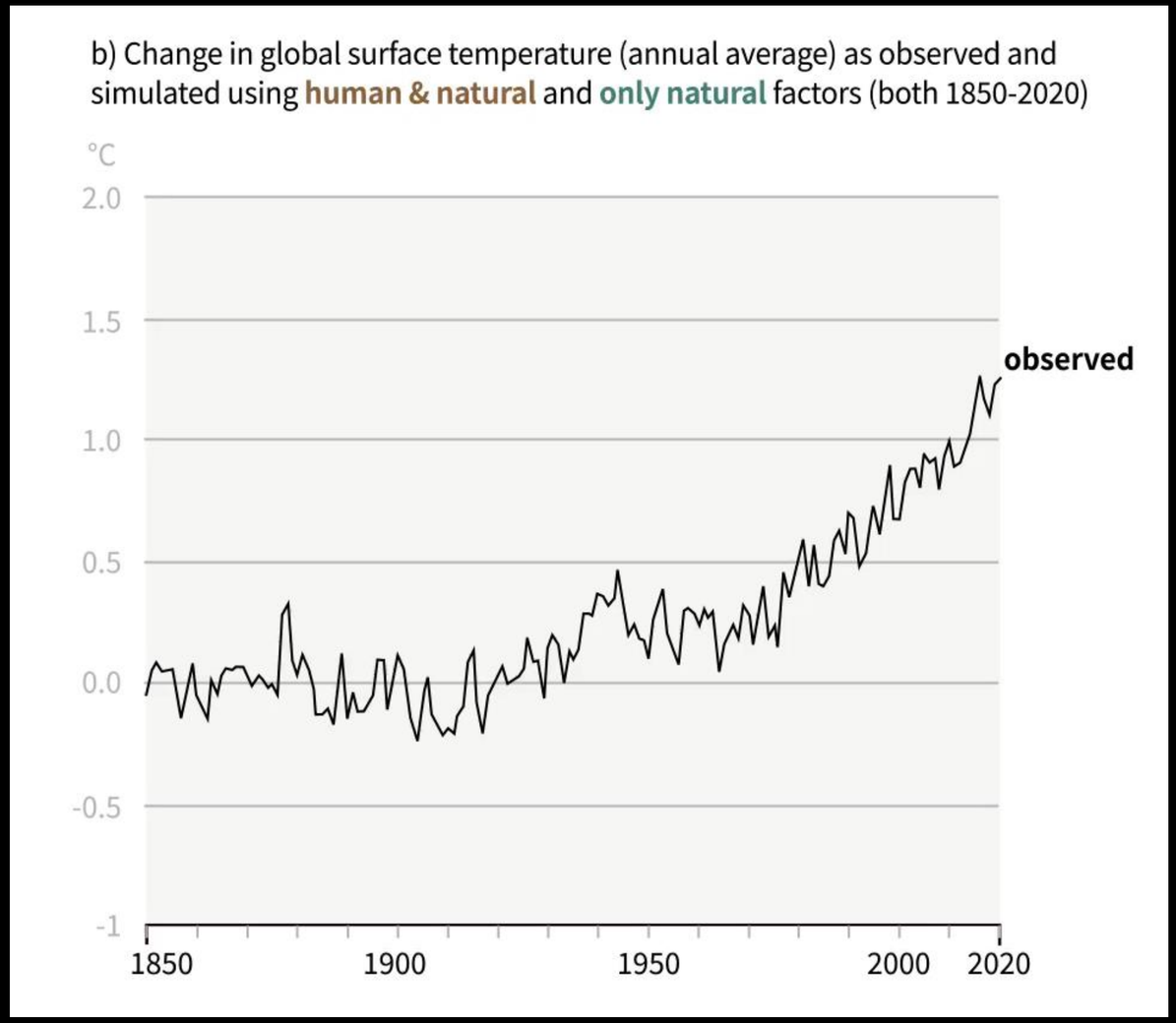
Climate Crisis

Mitigation

~ Carbon Neutrality



IPCC AR6 Update after AR5



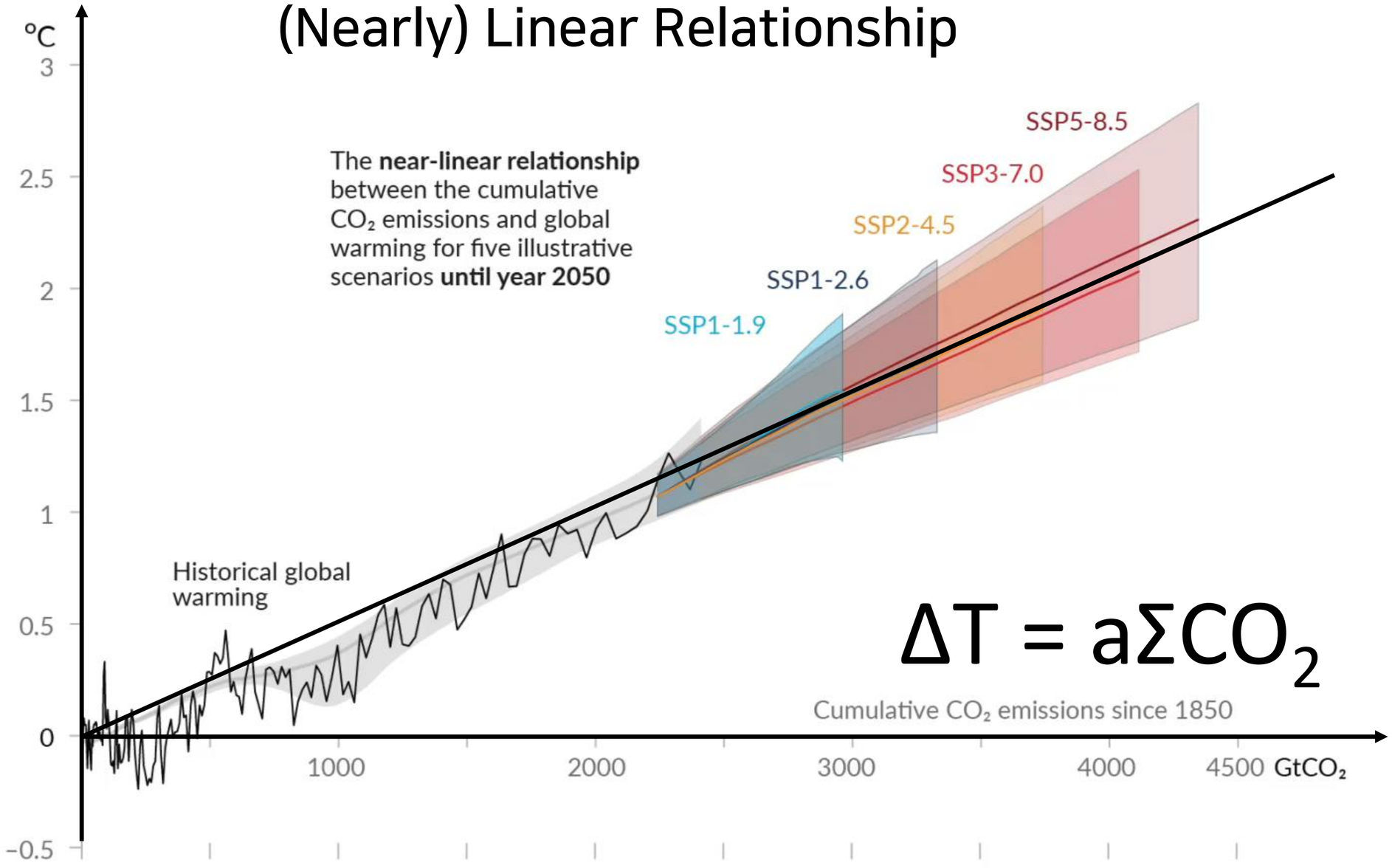
The Current State of the Climate

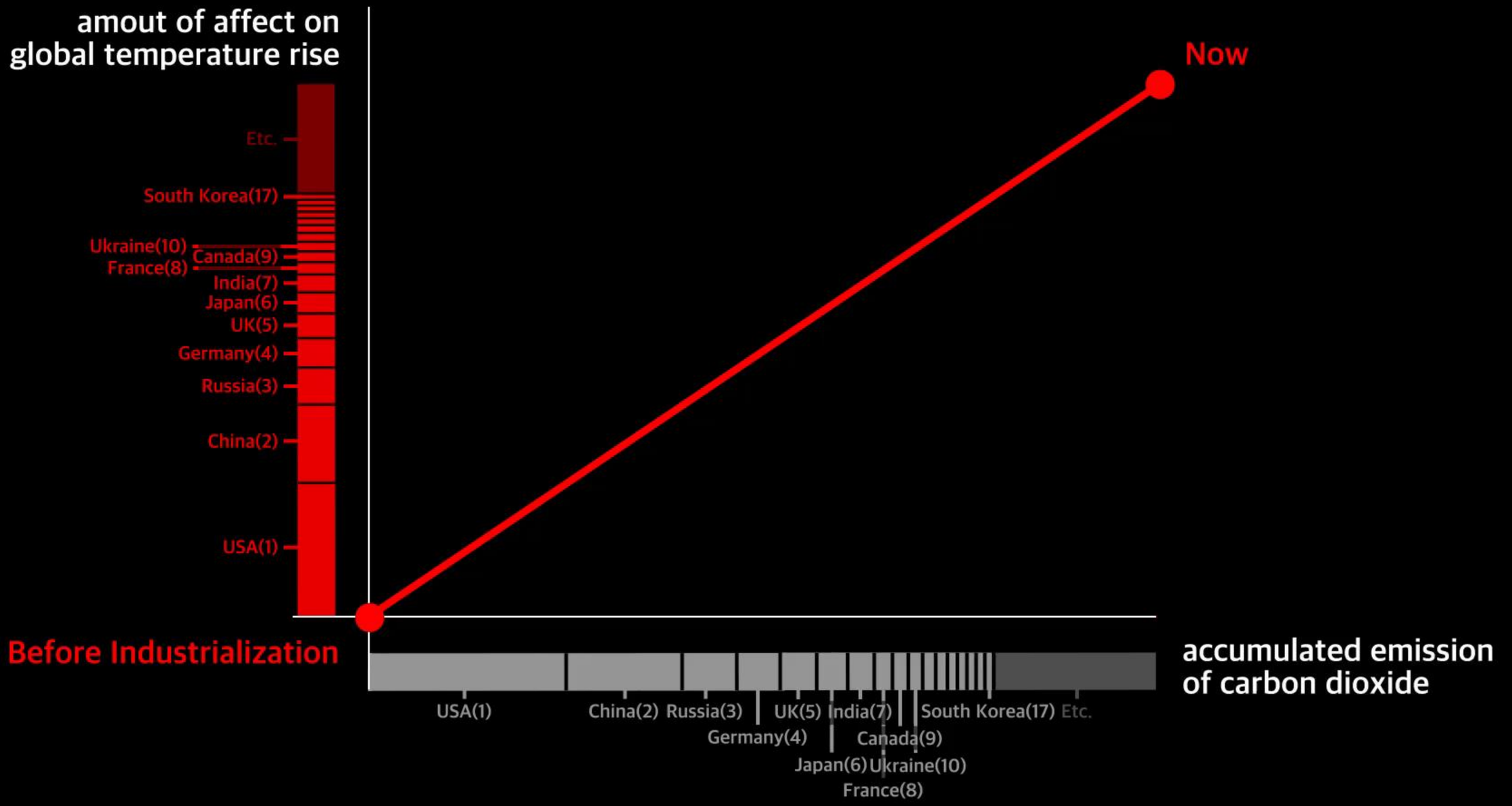
It is **unequivocal** that human influence has warmed the atmosphere, ocean and land.

Human-induced climate change is already affecting many weather and climate extremes in every region across the globe.

- IPCC AR6 WG I SPM

(Nearly) Linear Relationship

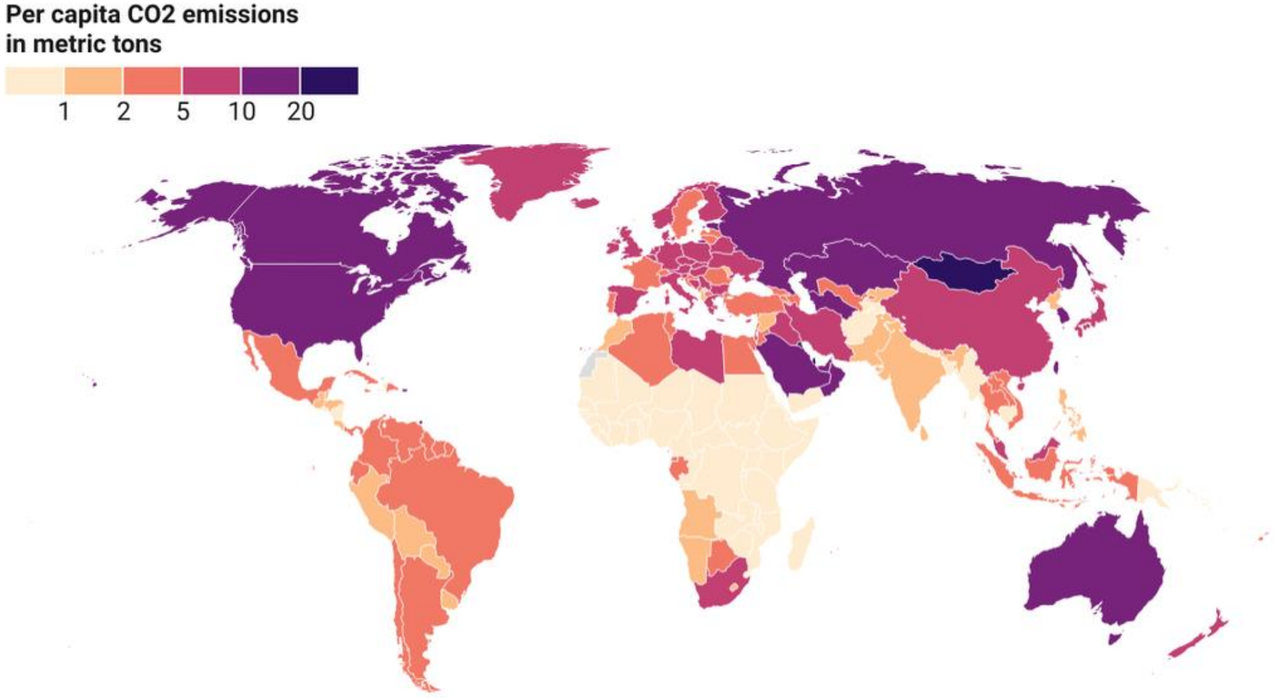



amout of affect on
global temperature rise
Etc.
South Korea(17)
Ukraine(10)
Canada(9)
France(8)
India(7)
Japan(6)
UK(5)
Germany(4)
Russia(3)
China(2)
USA(1)
Now
Before Industrialization
accumulated emission
of carbon dioxide
USA(1)
China(2)
Russia(3)
Germany(4)
UK(5)
Japan(6)
India(7)
Canada(9)
Ukraine(10)
France(8)
South Korea(17)
Etc.

Offender & Victims – Geographical

Annual carbon dioxide emissions produced per capita

Africa produced about 1.1 metric tons of climate-warming carbon dioxide emissions per person in 2019, well below the global average of 4.7. The U.S. produced 16.1 metric tons per capita.

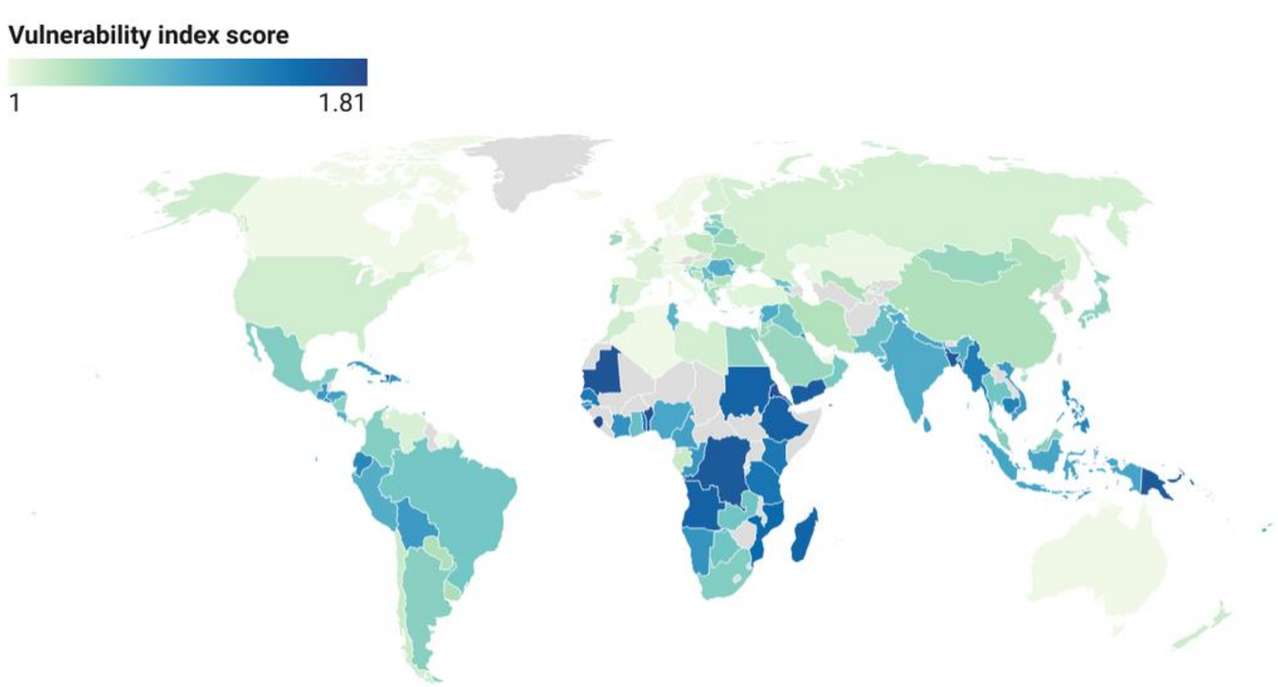


Data from 2019, production-based CO2 only, does not account for emissions embedded in traded goods

Map: The Conversation/CC-BY-ND • Source: Our World in Data, Global Carbon Project

The countries most vulnerable amid climate change

Scientists assessed countries' vulnerability based on food security, water availability, human health and living conditions, ecosystem services and infrastructure, including energy. The most vulnerable are in sub-Saharan Africa, South Asia and small island states.



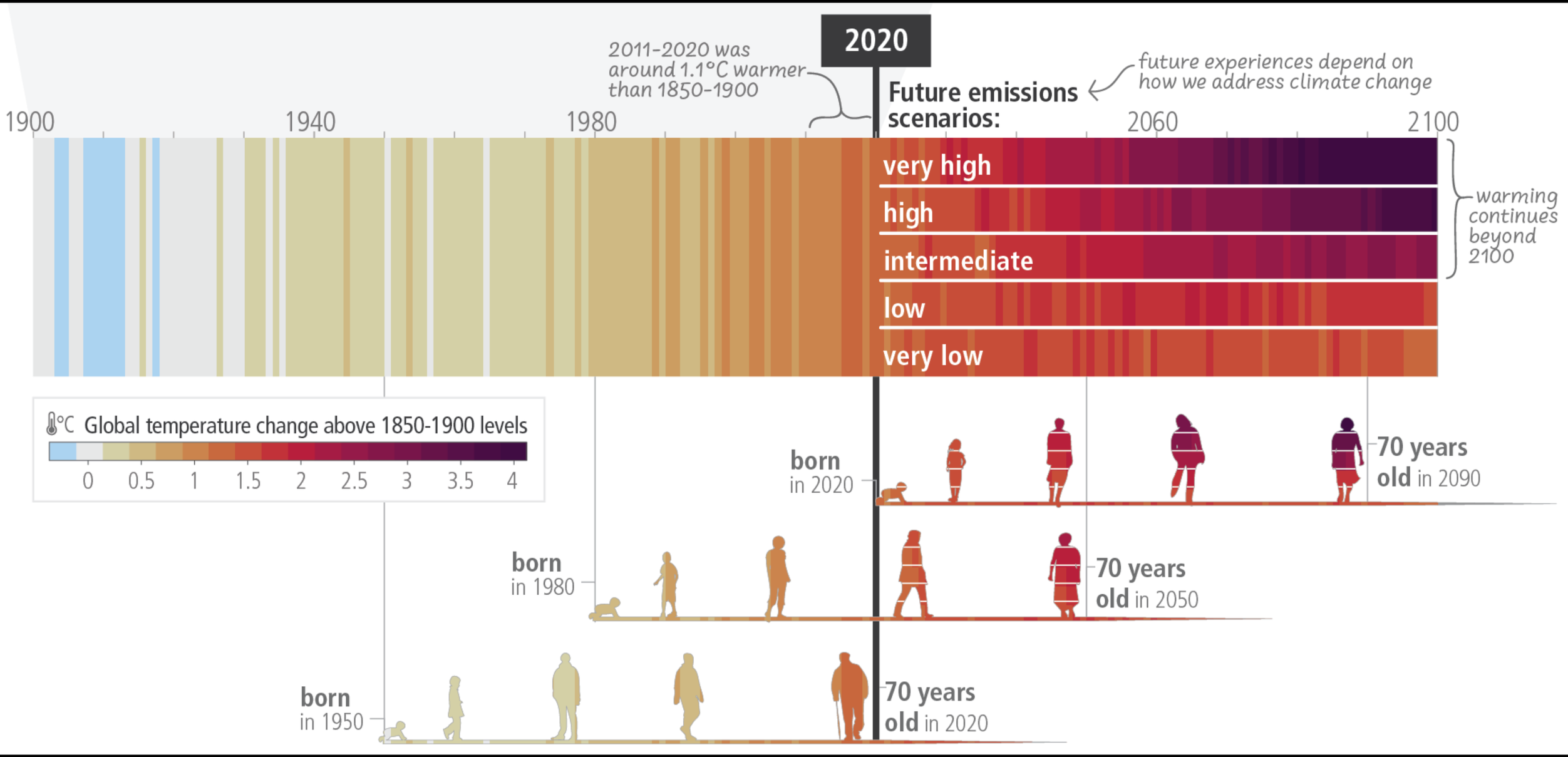
Vulnerability rises with higher scores. Data not available for regions in gray.

Map: The Conversation/CC-BY-ND • Source: Edmonds, Lovell and Lovell, 2020

+ The top 10% rich have emitted ~40% of total GHGs, while the bottom 50% have emitted <15%.

= The less wealthy half of the world is responsible for only a 0.15°C global temperature rise.

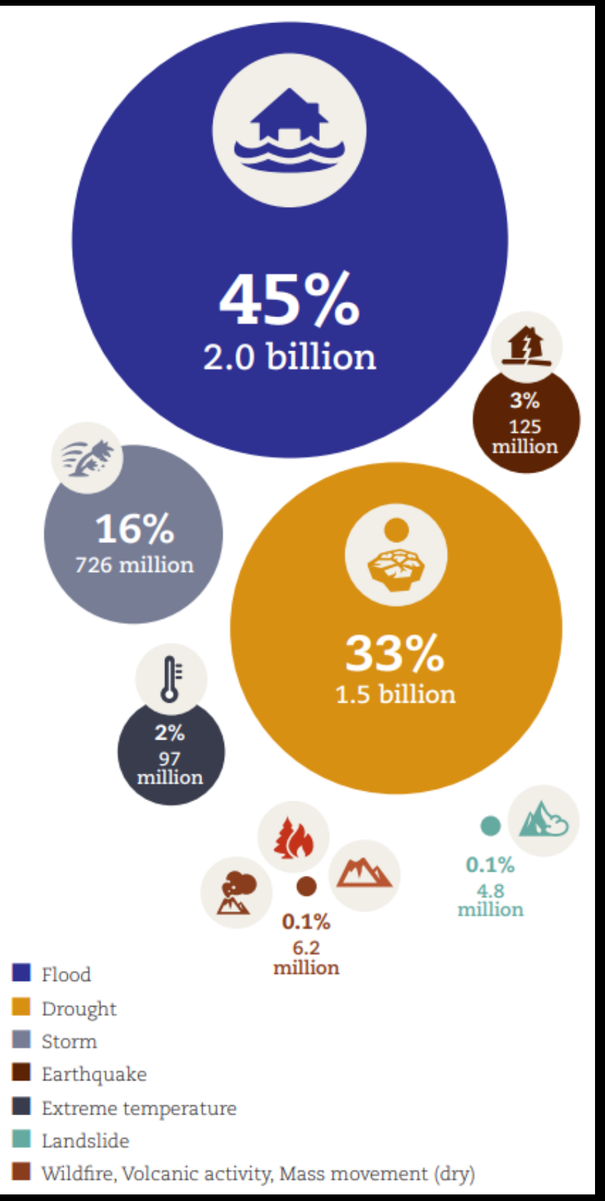
Offenders and Victims – Generational




50


50
Dodgers
17

Climate-Induced Disasters & Losses



"Between 1998 and 2017 ***climate-related and geophysical disasters killed 1.3 million people … 91% of all disasters were caused by … extreme weather events."***

- Economic Losses, Poverty & Disasters 1998-2017, UNDRR

In 1998-2017,
Direct economic losses: 2,908 b$; Climate-related disasters: 77% (2,245 b$)
251% increased from 1978-1997

---

nature

Explore content ⌄ About the journal ⌄ Publish with us ⌄ Subscribe

nature › editorials › article

EDITORIAL | 08 November 2022

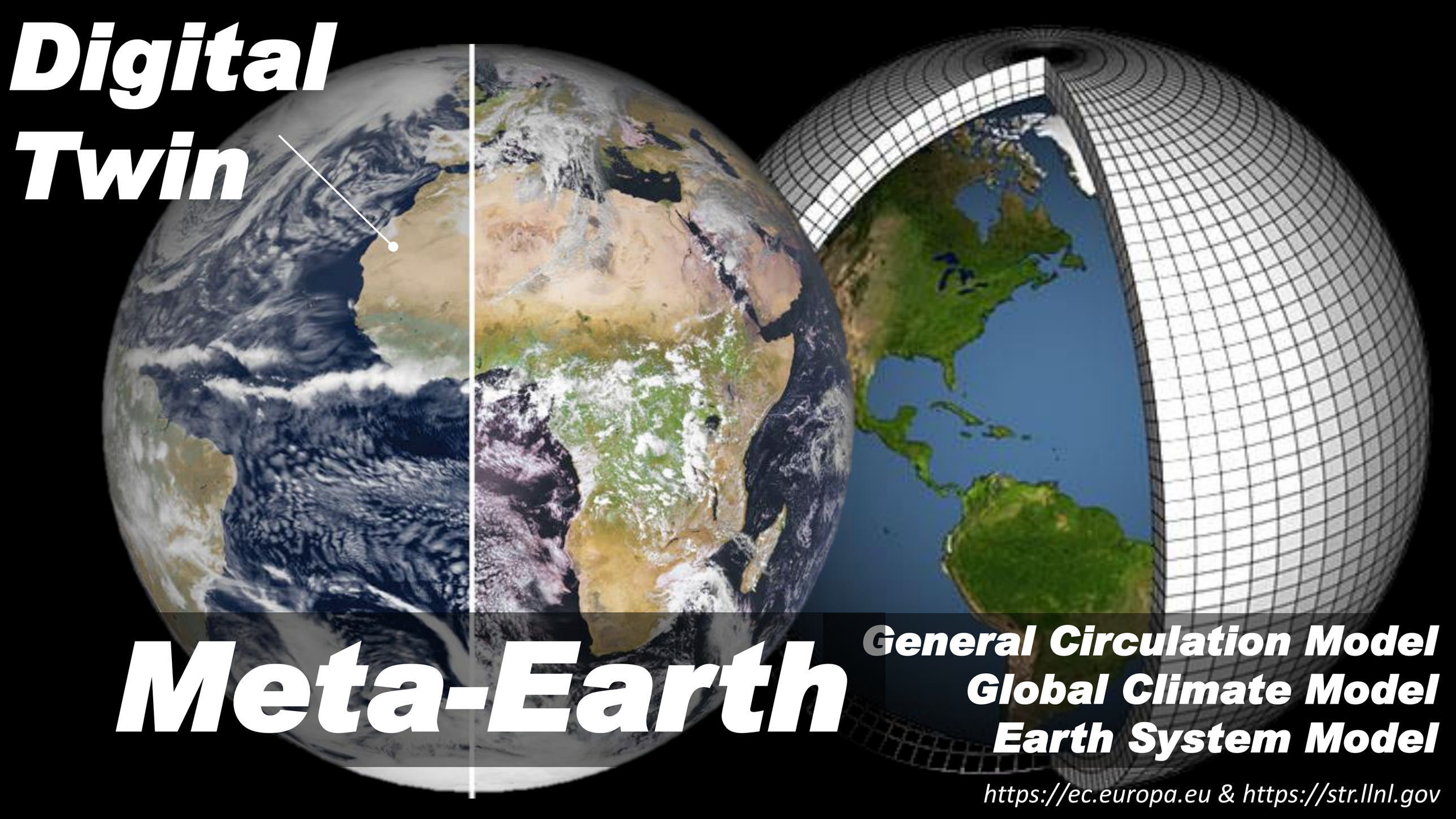
COP27: Rich countries must stop stalling talks on climate loss and damage compensation

The issue of loss and damage needs to be discussed honestly, but it must not derail progress at the crucial climate summit.

The poorest, most vulnerable people who have done the least to cause global warming (Africa and Pakistan emit < 4% of CO2) who are left paying the bill when their homes are destroyed in floods, or their fields are left dry for years.

a need for "Global Shield" a global agreement to ensure that those responsible for climate change help pay for the losses and damages

Digital Twin

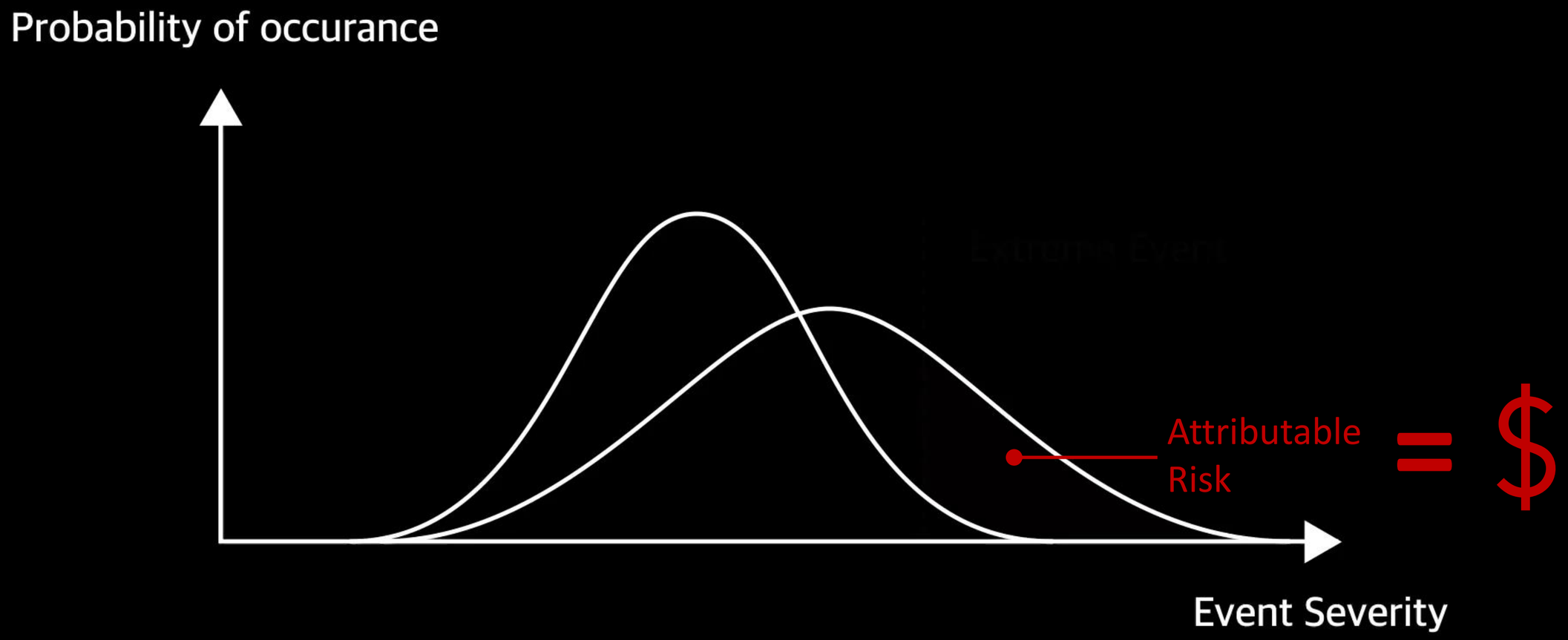


Meta-Earth

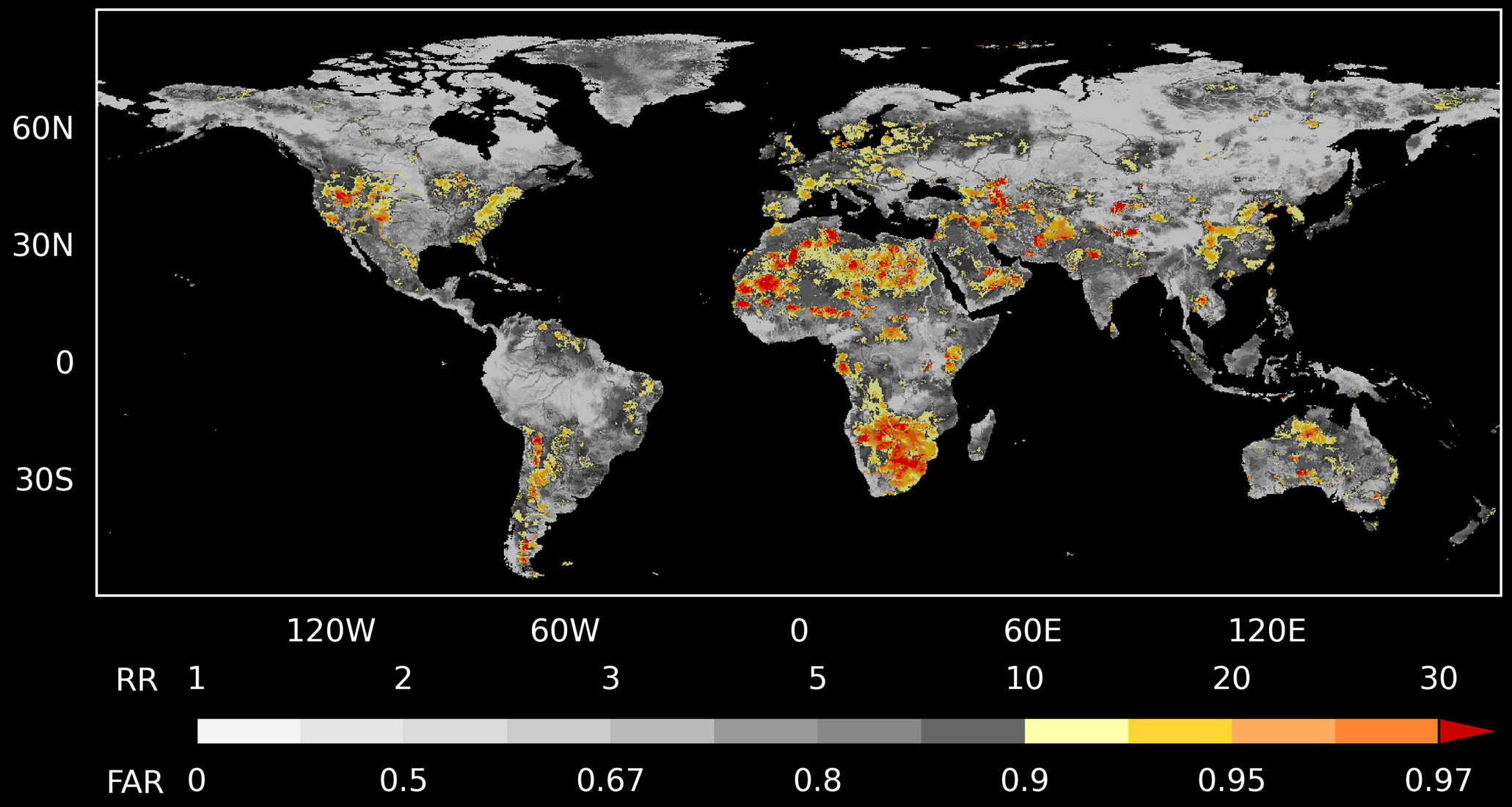
General Circulation Model
Global Climate Model
Earth System Model

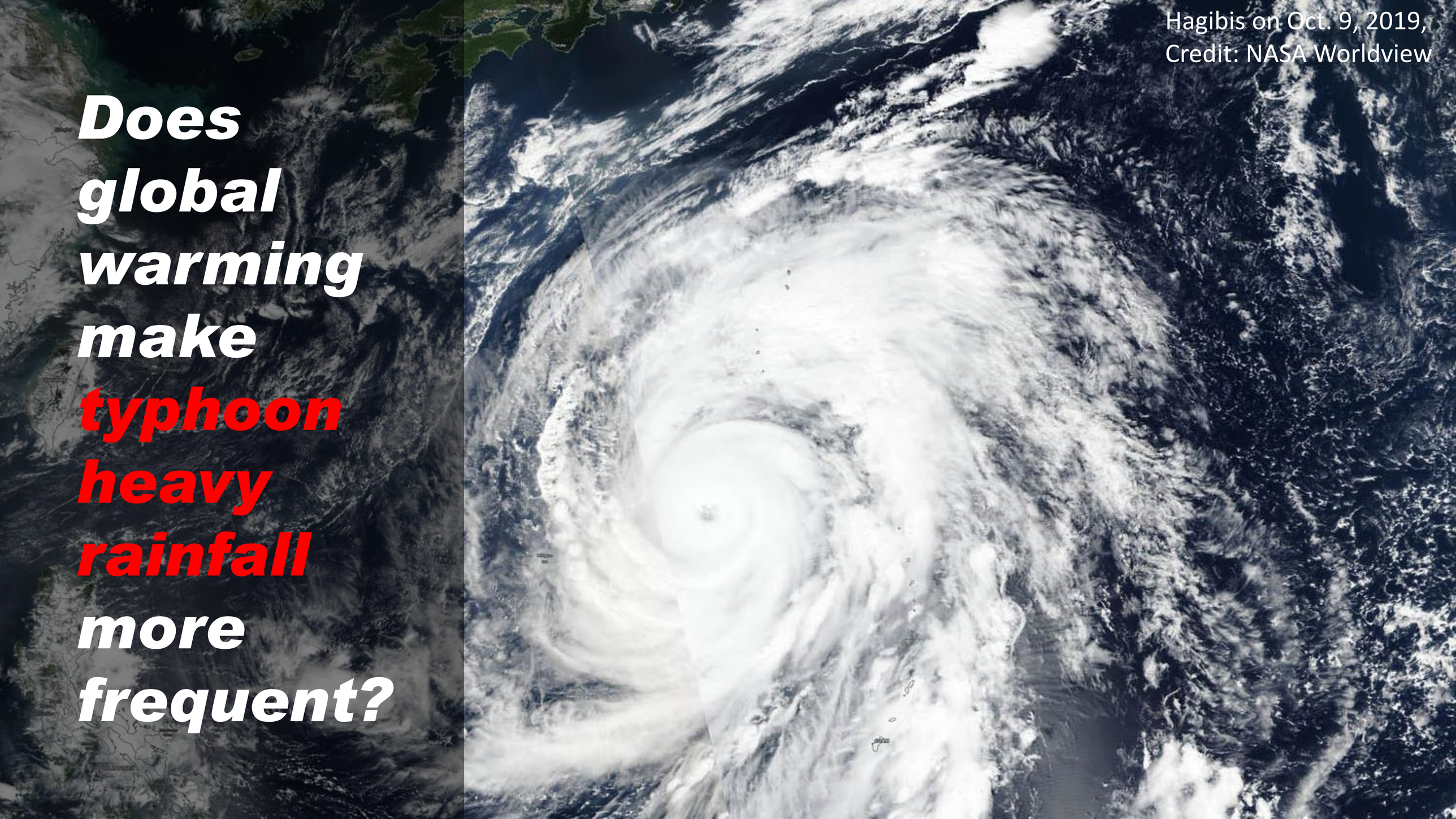
https://ec.europa.eu & https://str.llnl.gov

Mean Shift & Larger Variance



Quantification of Human Influence of the 2022 Droughts

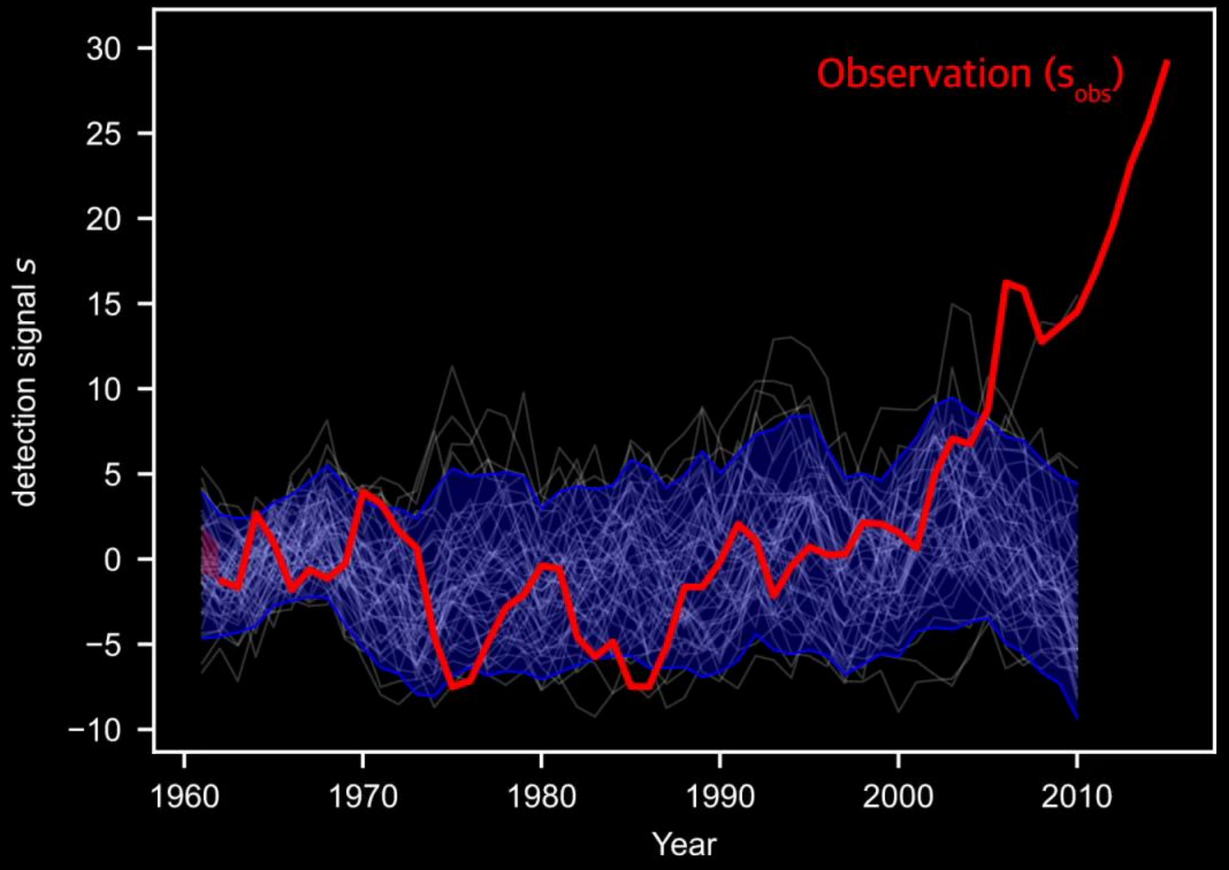




Hagibis on Oct. 9, 2019,
Credit: NASA Worldview

Observed Influence of Anthropogenic Climate Change on Tropical Cyclone Heavy Rainfall

Similarity between observations and human-occupied Earth models
(Standard Deviation 95%, 2 standard deviation)



Utsumi & Kim, 2022

Δ freq. of typhoon heavy rain
(once-in-10year since 1961)

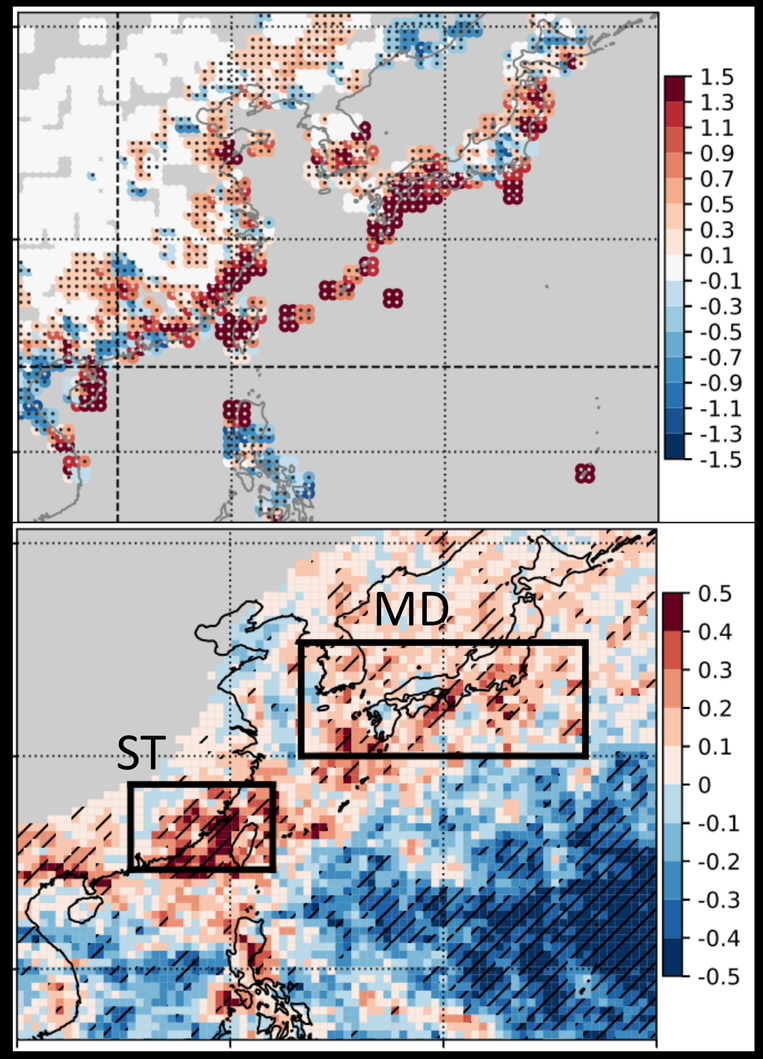
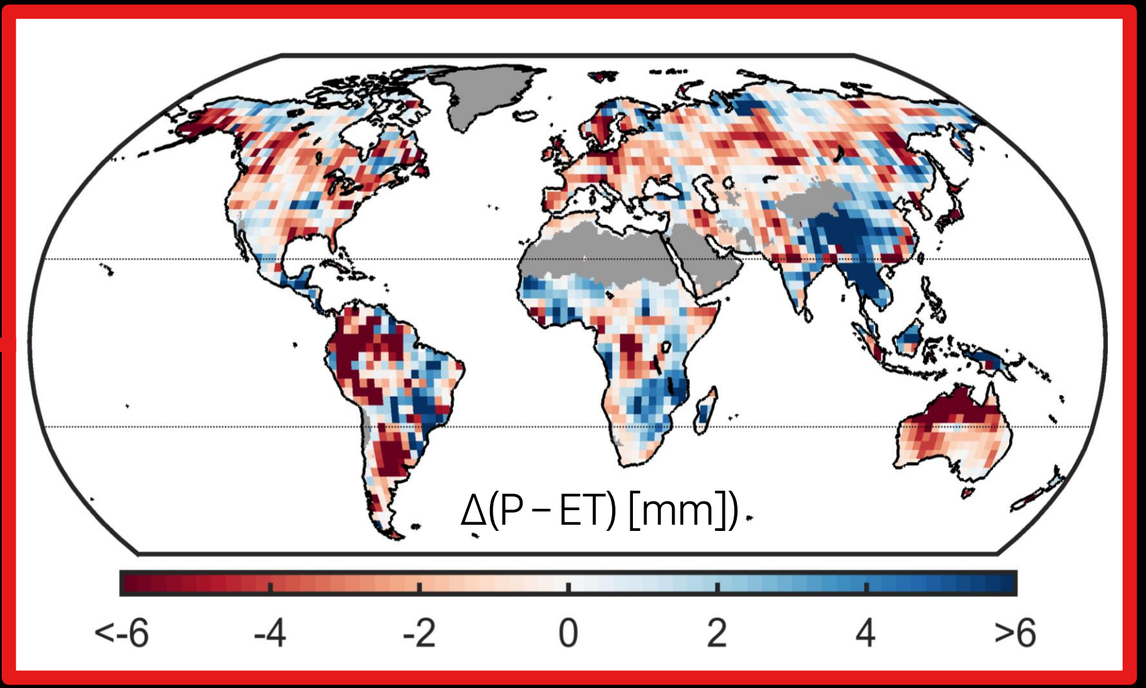
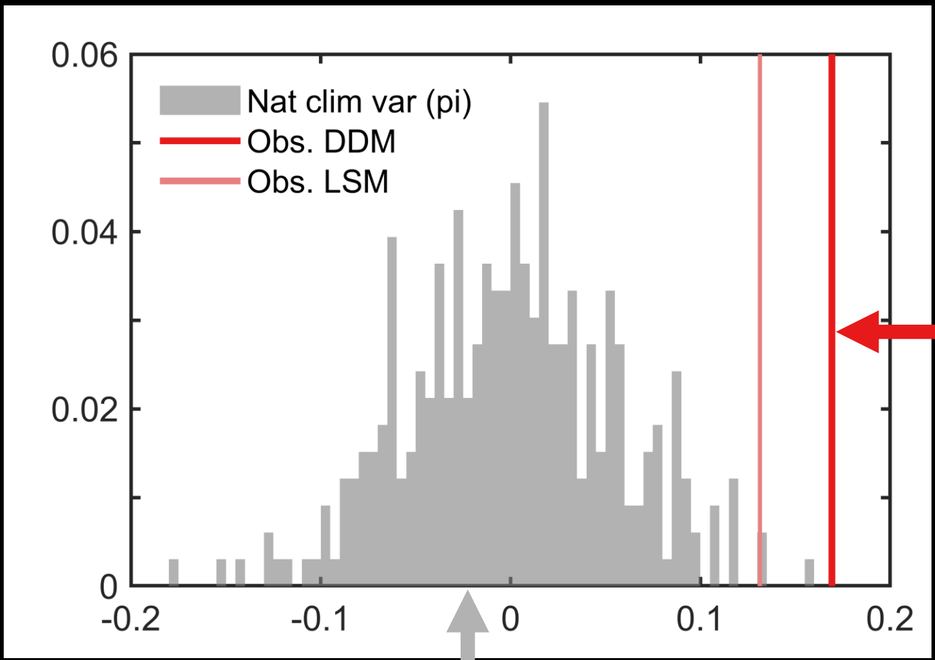


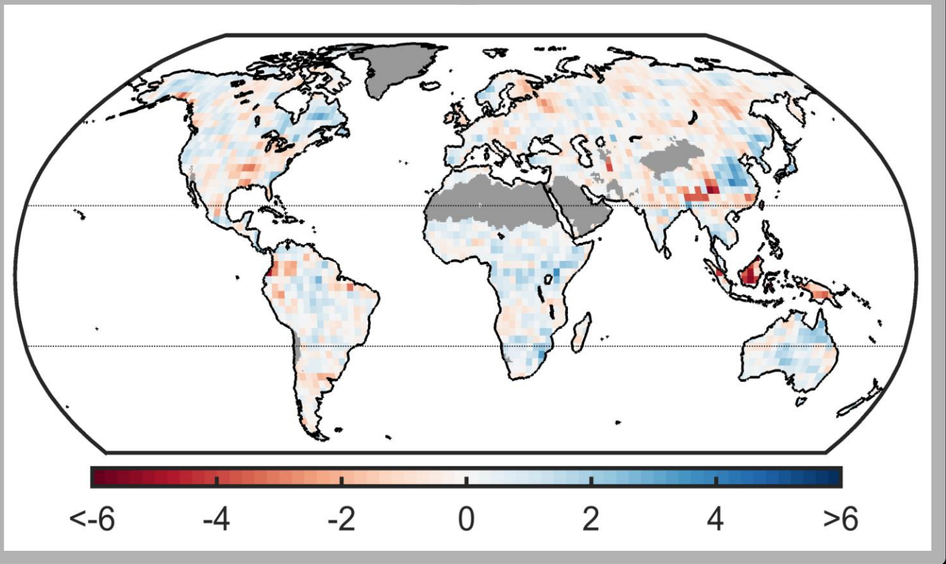
Image Courtesy of https://unsplash.com

Real World





Natural Earth



Decrease in Available Water Resources during 20th Century

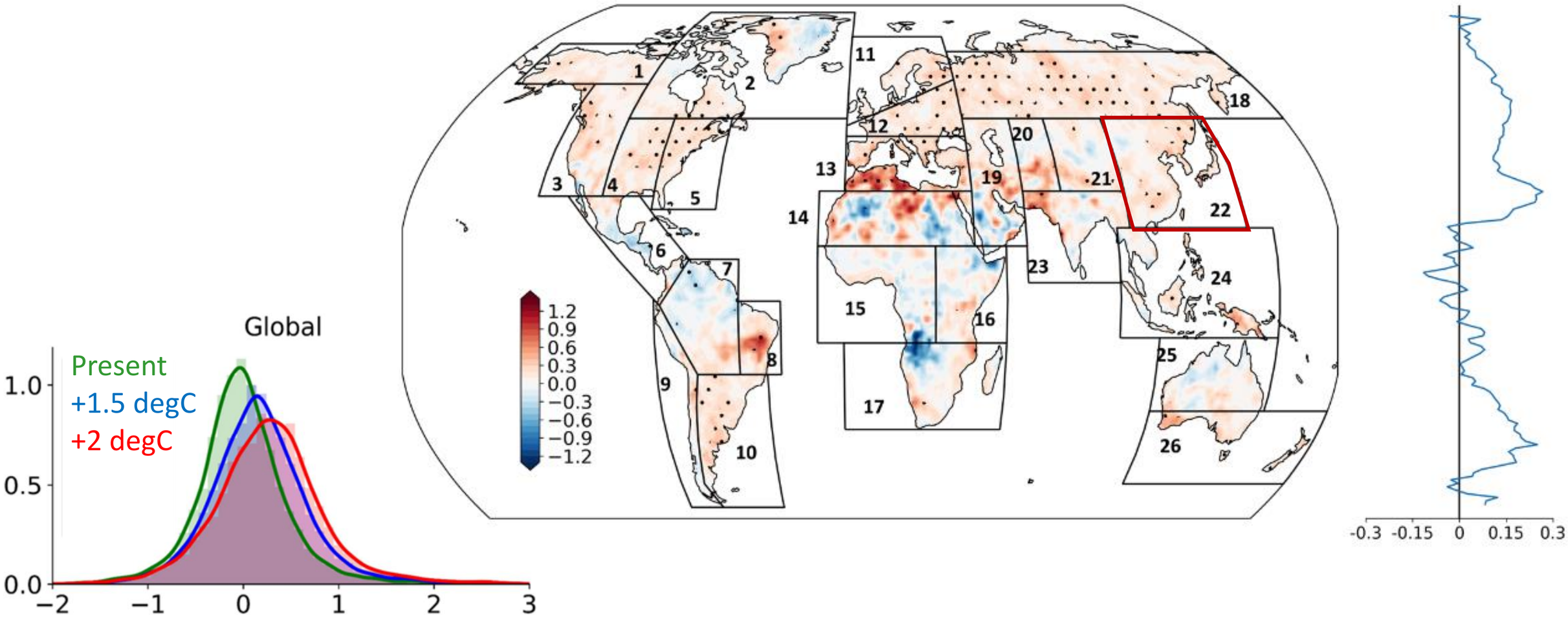
is extremely likely with anthropogenic warming.

Padrón, Kim et al., 2020

Is wet & hot swing getting more severe in future?

Japan, July & August 2018
Image from a broadcast service in Japan

Event-To-Event Intensification of the Hydrologic Cycle

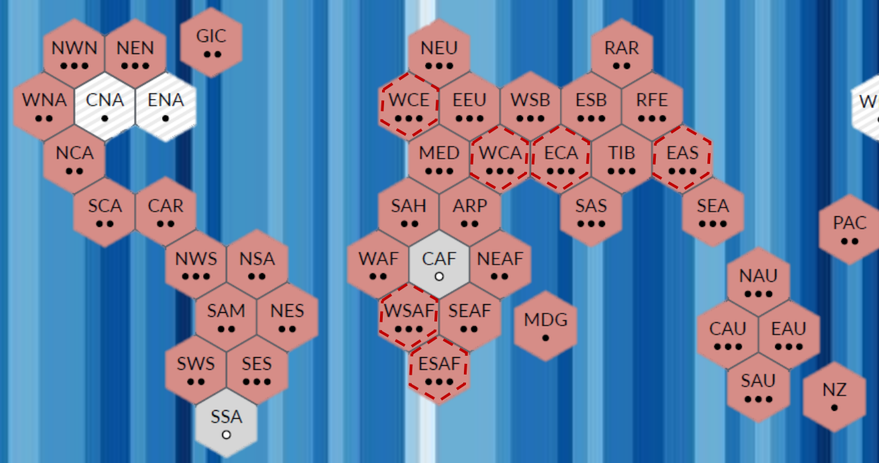


+ In mid-high latitudes “wet-dry swing” will be significantly intensified by 0.5° additional warming after 1.5°.

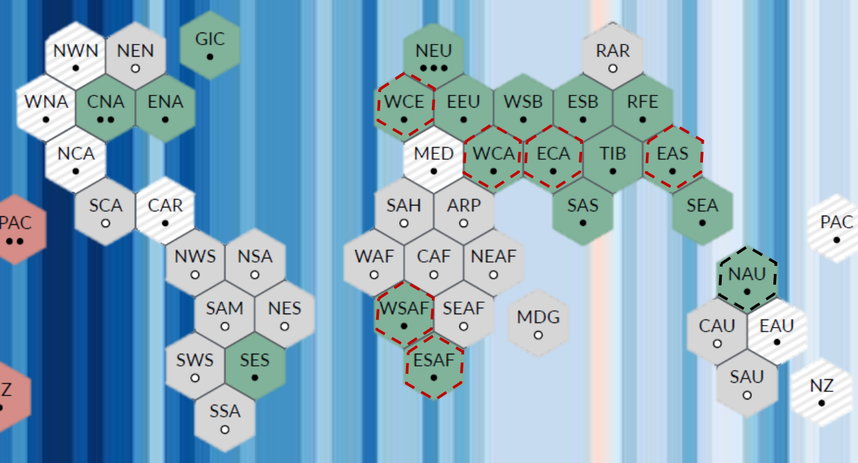
Madakumbura, Kim et al., 2019

Climate Inequality

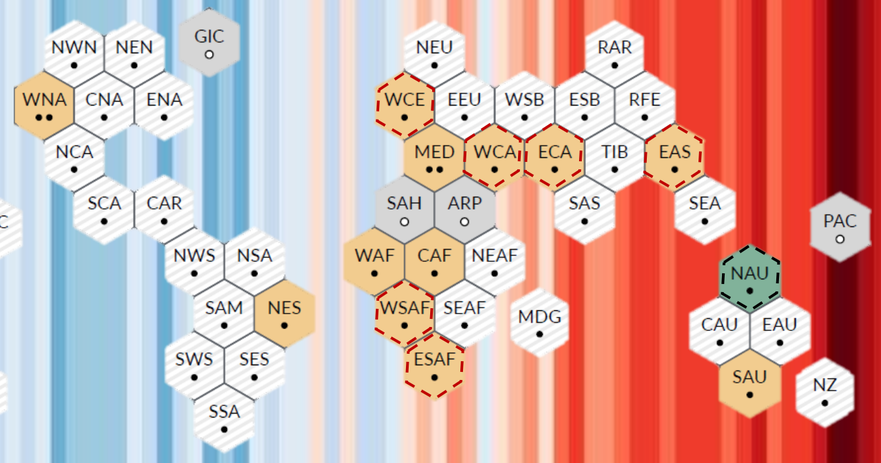
Heatwave

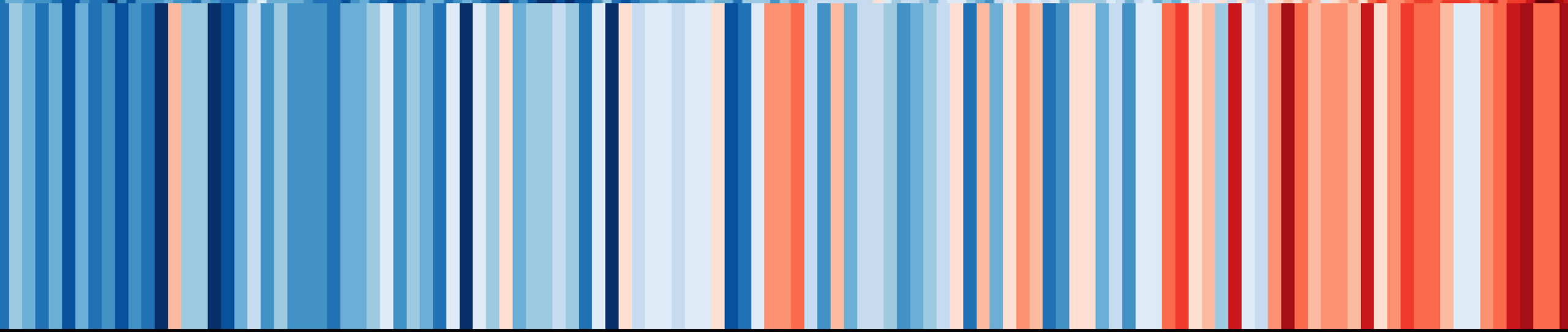


Heavy Rainfall



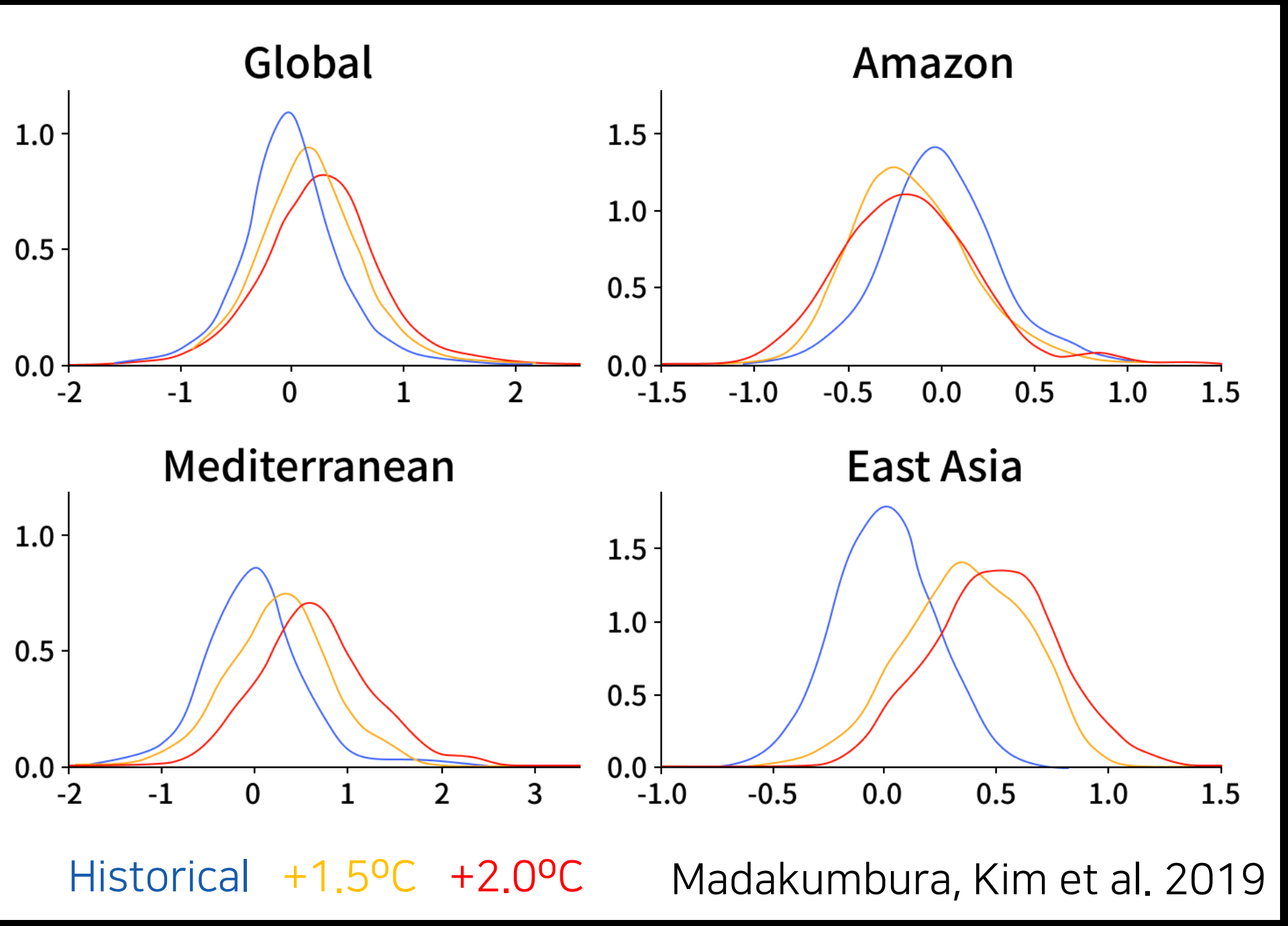
Drought





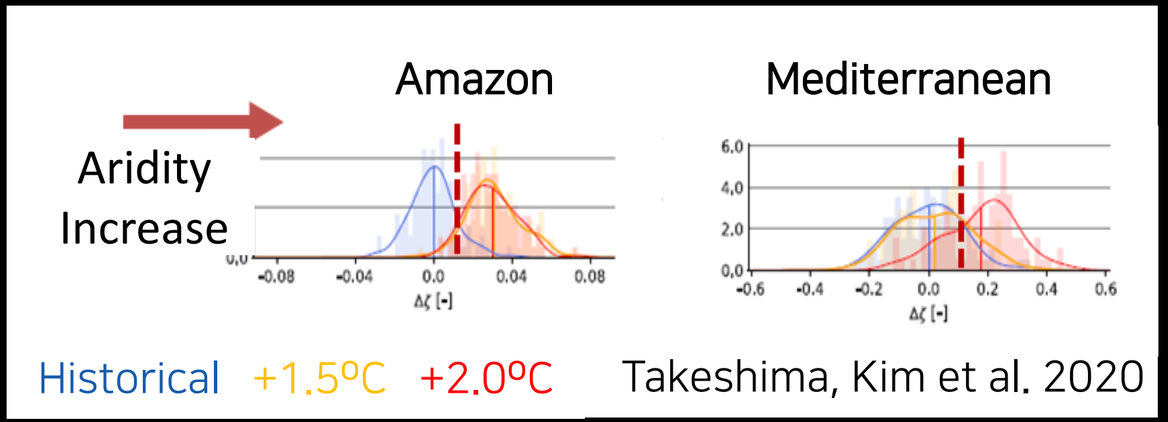
Tipping Point

Extreme Wet-Dry Swing

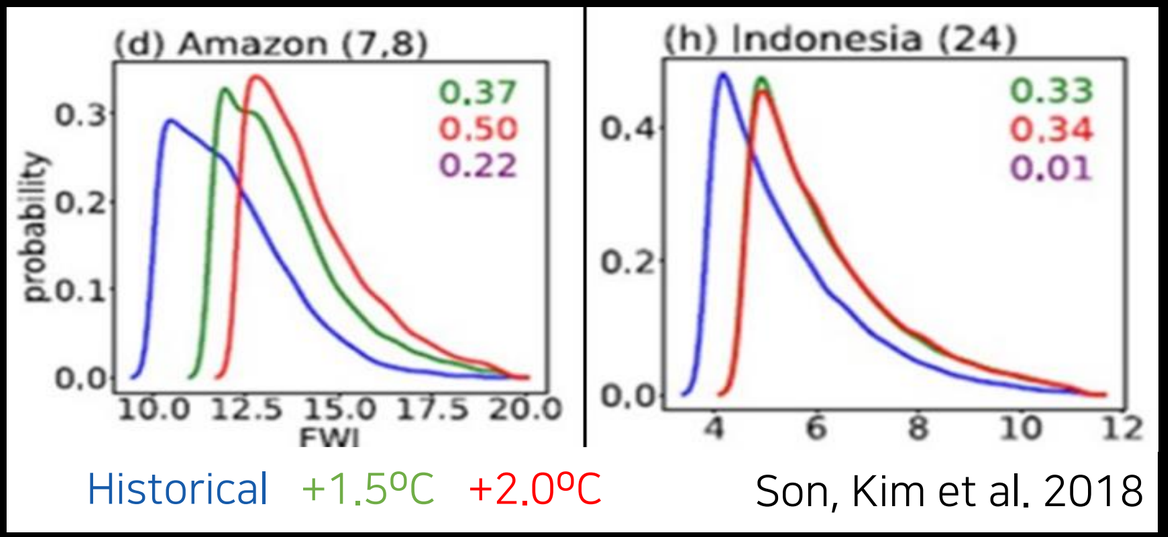


Tipping point varies for different climate extremes and global regions.

Aridity



Wildfire



Water – Food – Energy Nexus

Irrigation, Virtual water

Runoff, GW Recharge, Water Quality

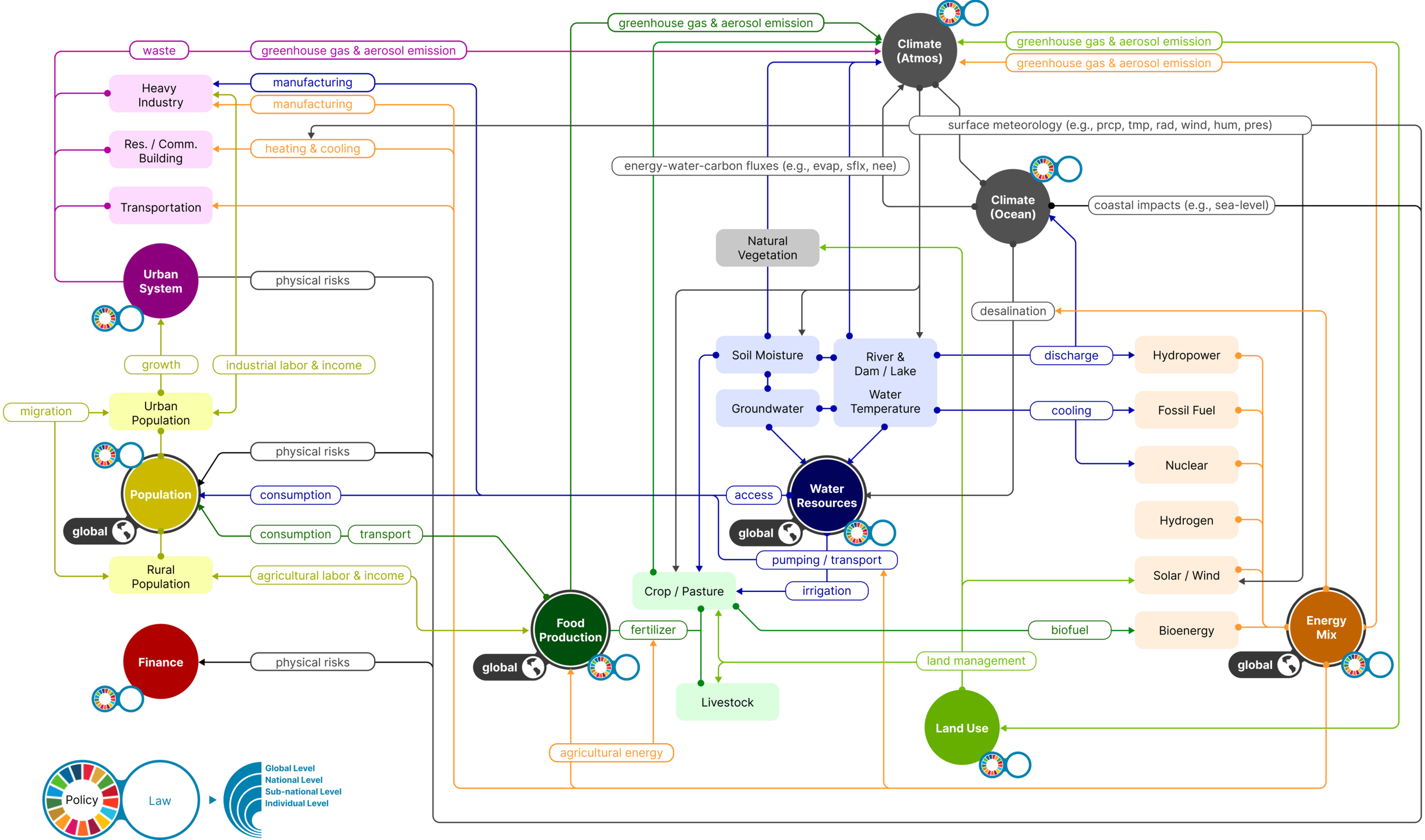
Hydropower, Power Plant Cooling

GW Pumping, Desalination

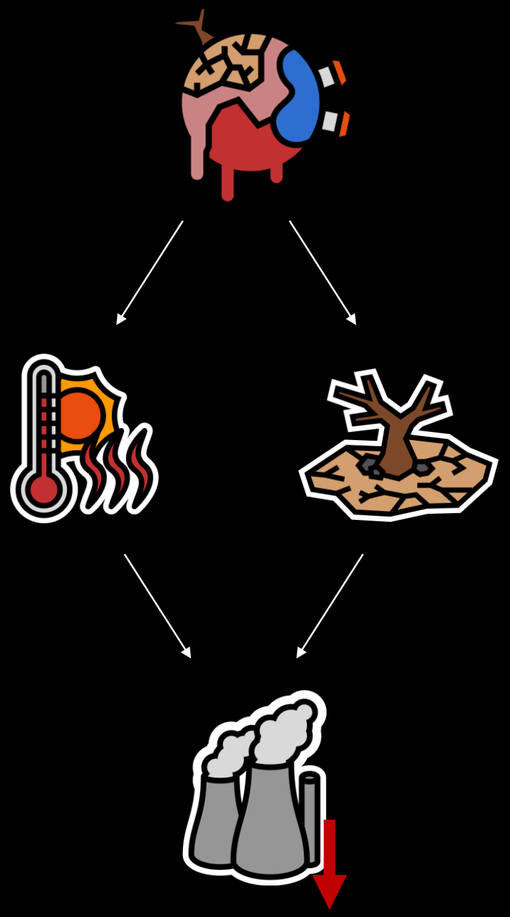
Integrated Assessment & System Thinking

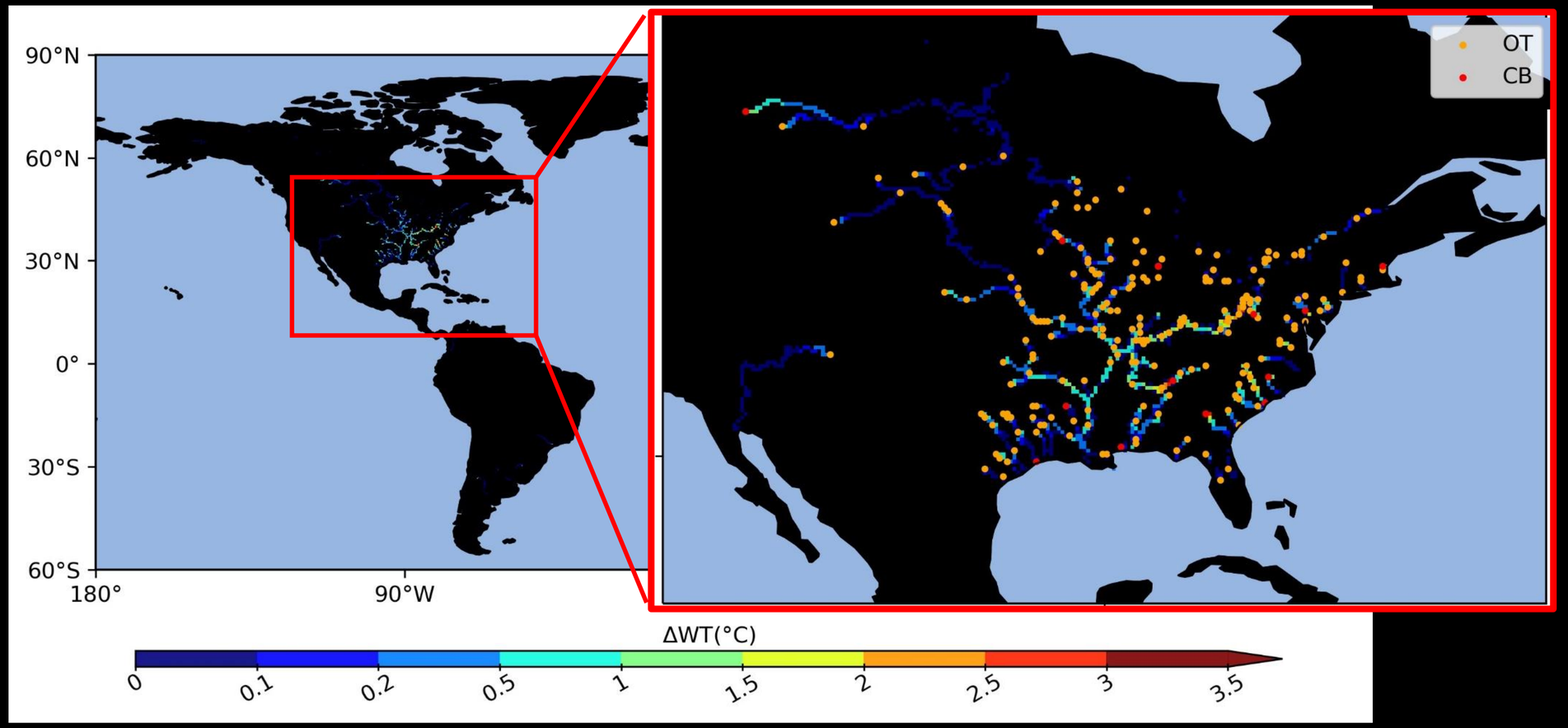
Bio Fuel, Land Use

Irrigation, Groundwater Pumping


greenhouse gas & aerosol emission
Climate (Atmos)
waste
greenhouse gas & aerosol emission
greenhouse gas & aerosol emission
greenhouse gas & aerosol emission
Heavy Industry
manufacturing
manufacturing
surface meteorology (e.g., prcp, tmp, rad, wind, hum, pres)
Res. / Comm. Building
heating & cooling
energy-water-carbon fluxes (e.g., evap, sflx, nee)
Climate (Ocean)
Transportation
coastal impacts (e.g., sea-level)
Natural Vegetation
Urban System
physical risks
desalination
Soil Moisture
River & Dam / Lake
discharge
Hydropower
growth
industrial labor & income
Groundwater
Water Temperature
cooling
Fossil Fuel
migration
Urban Population
Nuclear
physical risks
Population
consumption
access
Water Resources
Hydrogen
global
consumption
transport
global
pumping / transport
Rural Population
agricultural labor & income
Crop / Pasture
irrigation
Solar / Wind
Food Production
fertilizer
biofuel
Bioenergy
Energy Mix
Finance
physical risks
land management
global
global
Livestock
Land Use
agricultural energy
Policy
Law
Global Level
National Level
Sub-national Level
Individual Level

Thermal power plants under climate change & Temperature rise due to TPP cooling





+ Temp. increases due to TPP cooling travels to downstream area.
+ Such impacts are piled up within river basin networks.

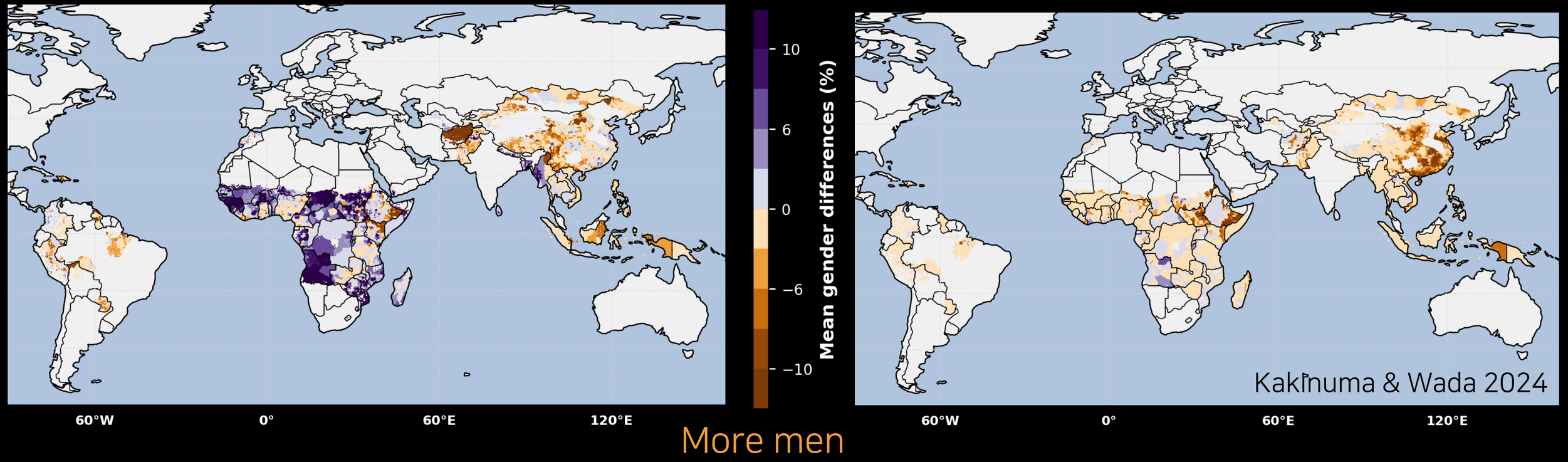
Otta, Kim et al., in prep.

Gender Inequality in Poor Water Access

Working Age

More women

Children

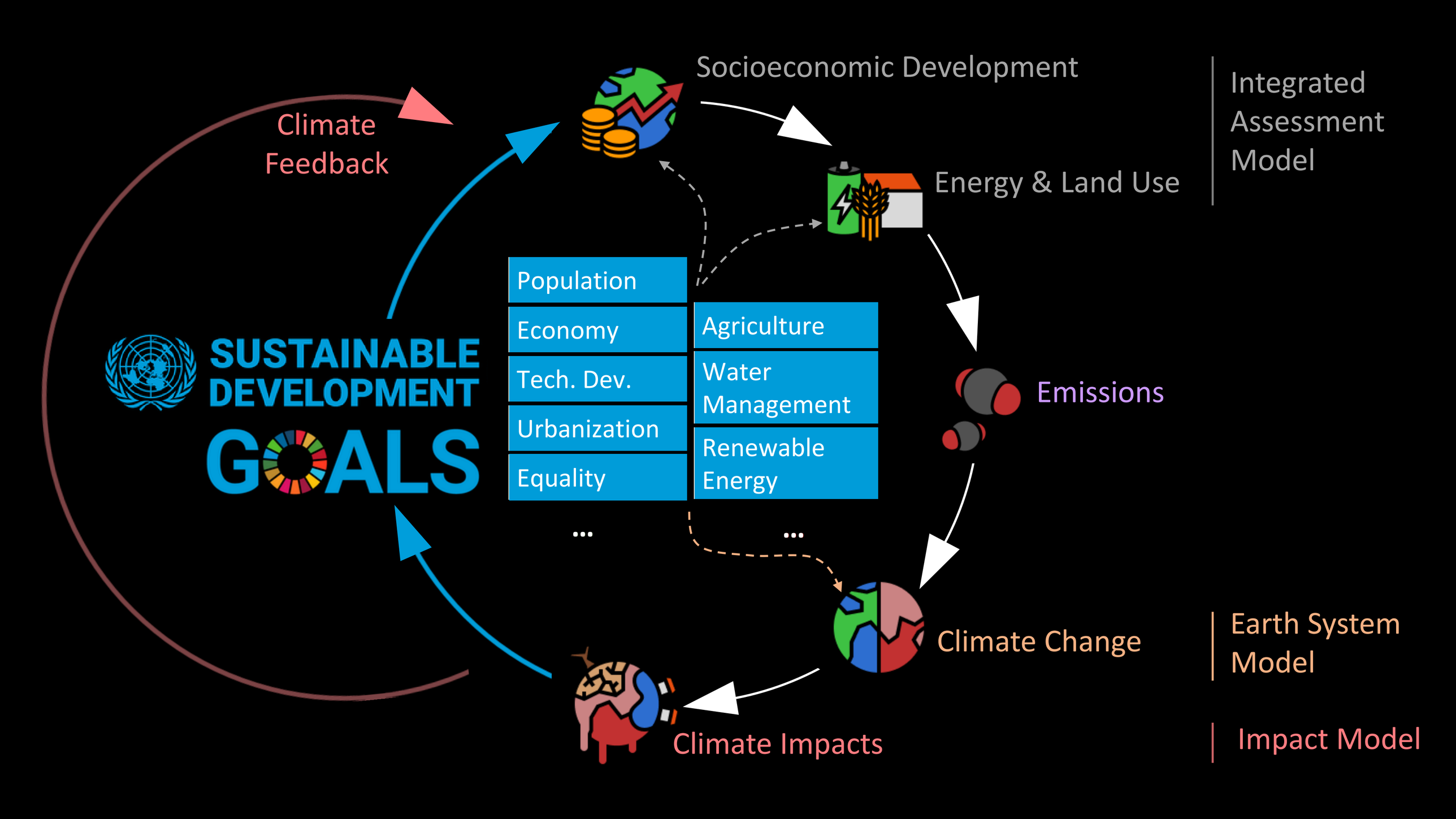


More men

+ Women often bear responsibility for water collection spending more than 30min/day on this task.

+ More women are in poor water access than men especially in Africa.

+ Education and work opportunities may be lost as a result


Socioeconomic Development
Energy & Land Use
Emissions
Climate Change
Climate Impacts
Climate Feedback
SUSTAINABLE DEVELOPMENT GOALS
Population
Economy
Tech. Dev.
Urbanization
Equality
...
Agriculture
Water Management
Renewable Energy
...
Integrated Assessment Model
Earth System Model
Impact Model

KAIST | MetaEarth Lab
KAIST Moon Soul Graduate School of Future Strategy

Thank You

Hyungjun Kim
Moon Soul Graduate School of Future Strategy
& Dept. of Civil and Environmental Engineering
& Graduate School of Green Growth and Sustainability
& Graduate School of Data Science
| KAIST
| hyungjun.kim@kaist.ac.kr
| https://melab.kaist.ac.kr

APEC Climate Symposium 2025 | 2025.08.08