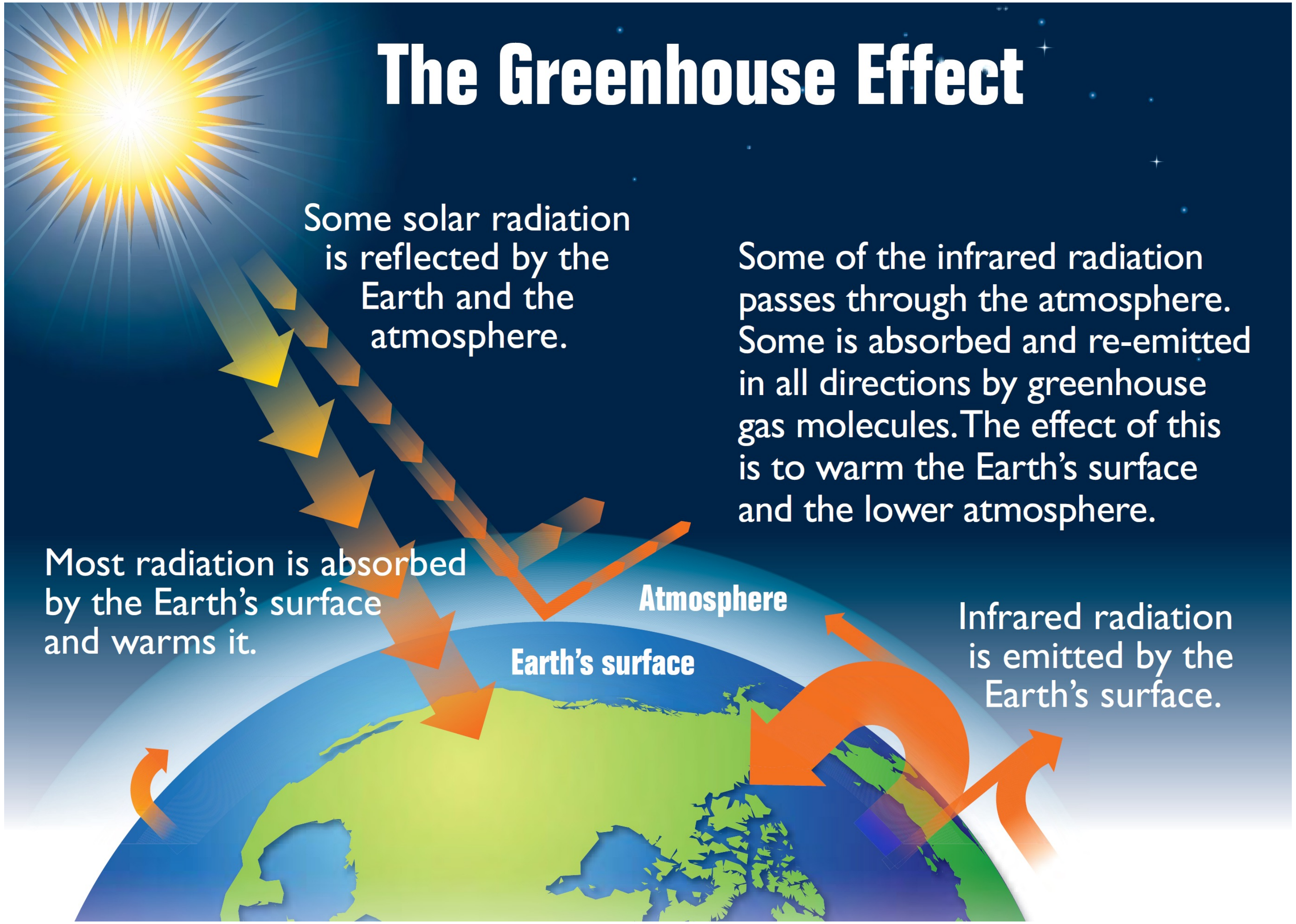
Climate and Health Data Science Workshop

April 29

Accra, Ghana

Kintampo Health Research Centre, Columbia University, Mount Sinai, Montana State University

The Greenhouse Effect Basics



The Impact of Climate Change on Human-Environment Interactions

- Earth absorbs the sun's shortwave radiation and then emits longwave radiation, creating **sensible heat**, the temperature we feel around us.

- Naturally occurring **greenhouse gases** in the troposphere absorb some longwave energy from Earth and reradiate it back to the surface

The Impact of Climate Change on Human-Environment Interactions

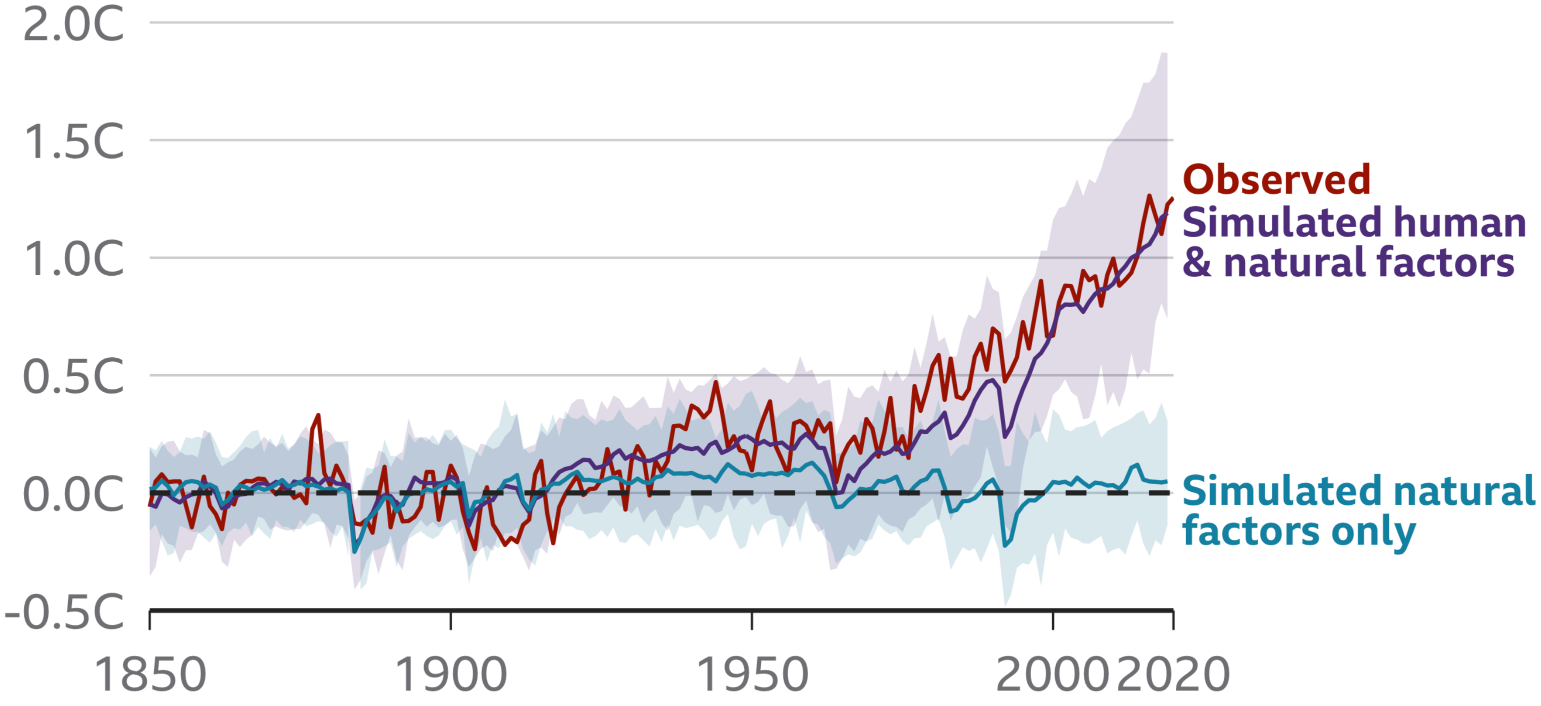
The basic premise of climate change science is that humans are burning hydrocarbons, which releases greenhouse gases that intensify the greenhouse effect.

How much have we warmed the planet?

- Global average - about 1.2°C or 2.2°F over pre-industrial levels.

Human influence has warmed the climate

Change in average global temperature relative to 1850-1900, showing observed temperatures and computer simulations



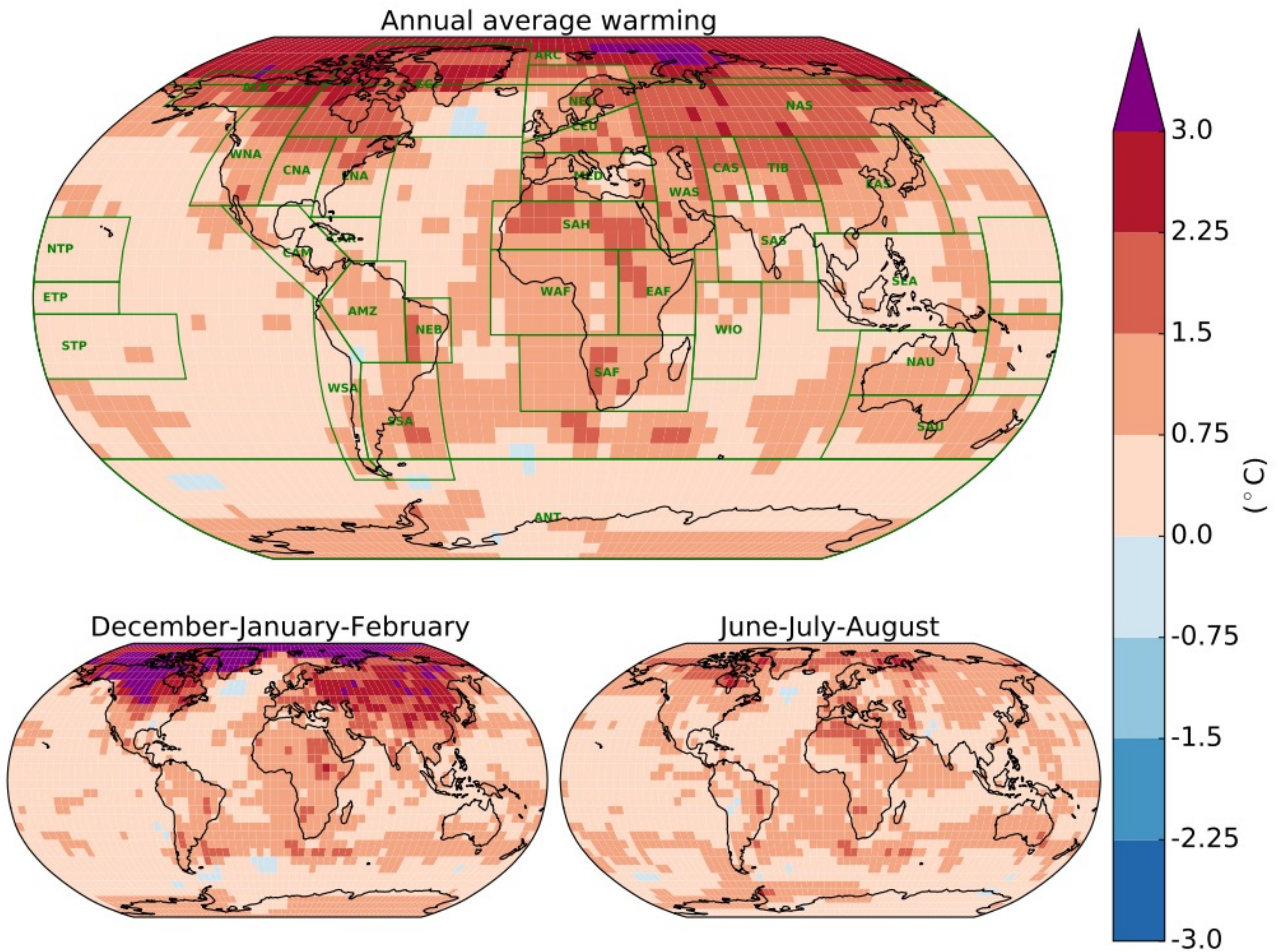
Note: Shaded areas show possible range for simulated scenarios

Source: IPCC, 2021: Summary for Policymakers

BBC

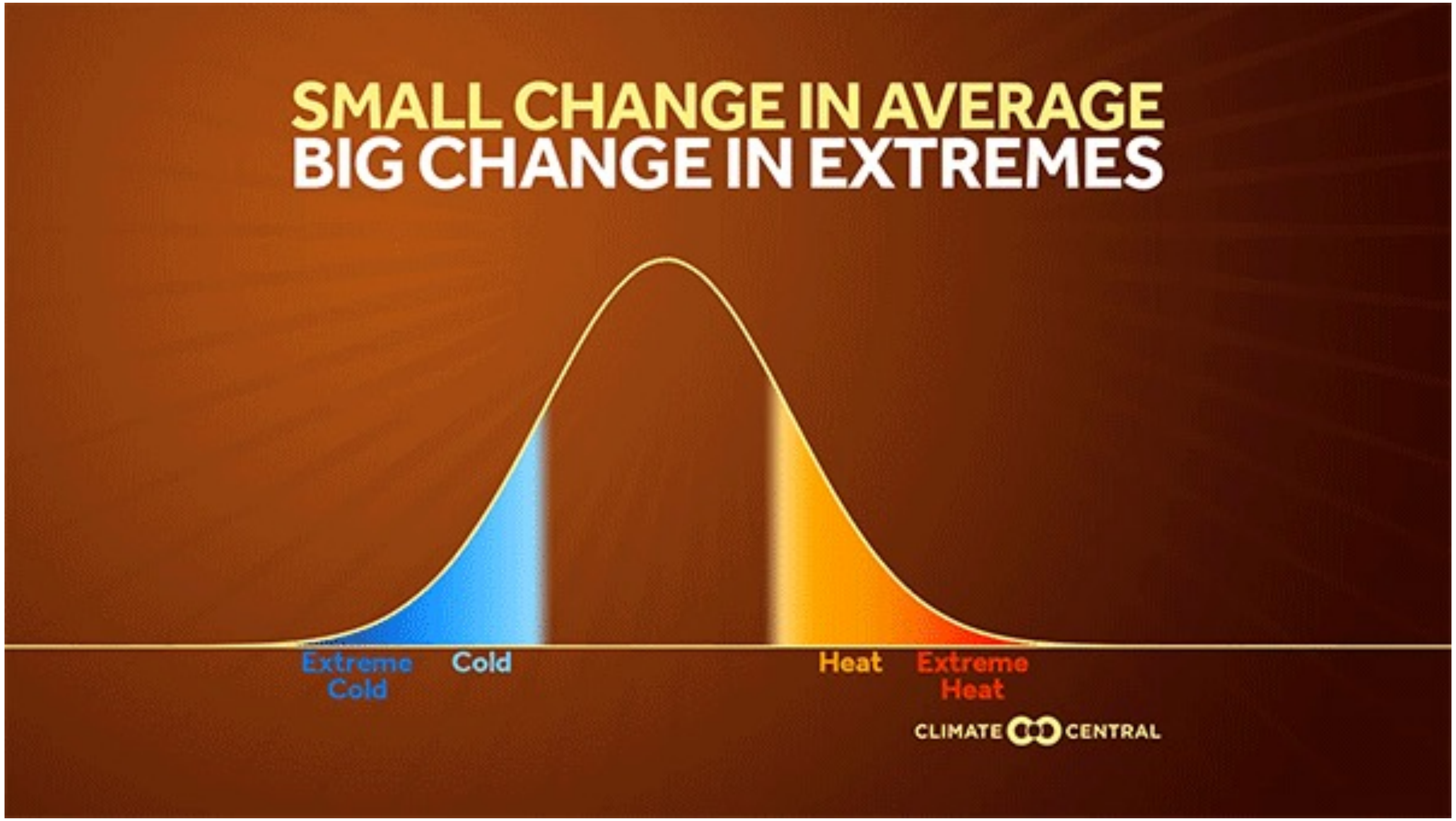
How much have we warmed the planet?

- Global average - about 1.2°C or 2.2°F over pre-industrial levels.
- But warming is not evenly distributed over space or time.
- The poles are warming much faster than the tropics and winters are warming faster than summers in Northern latitudes.



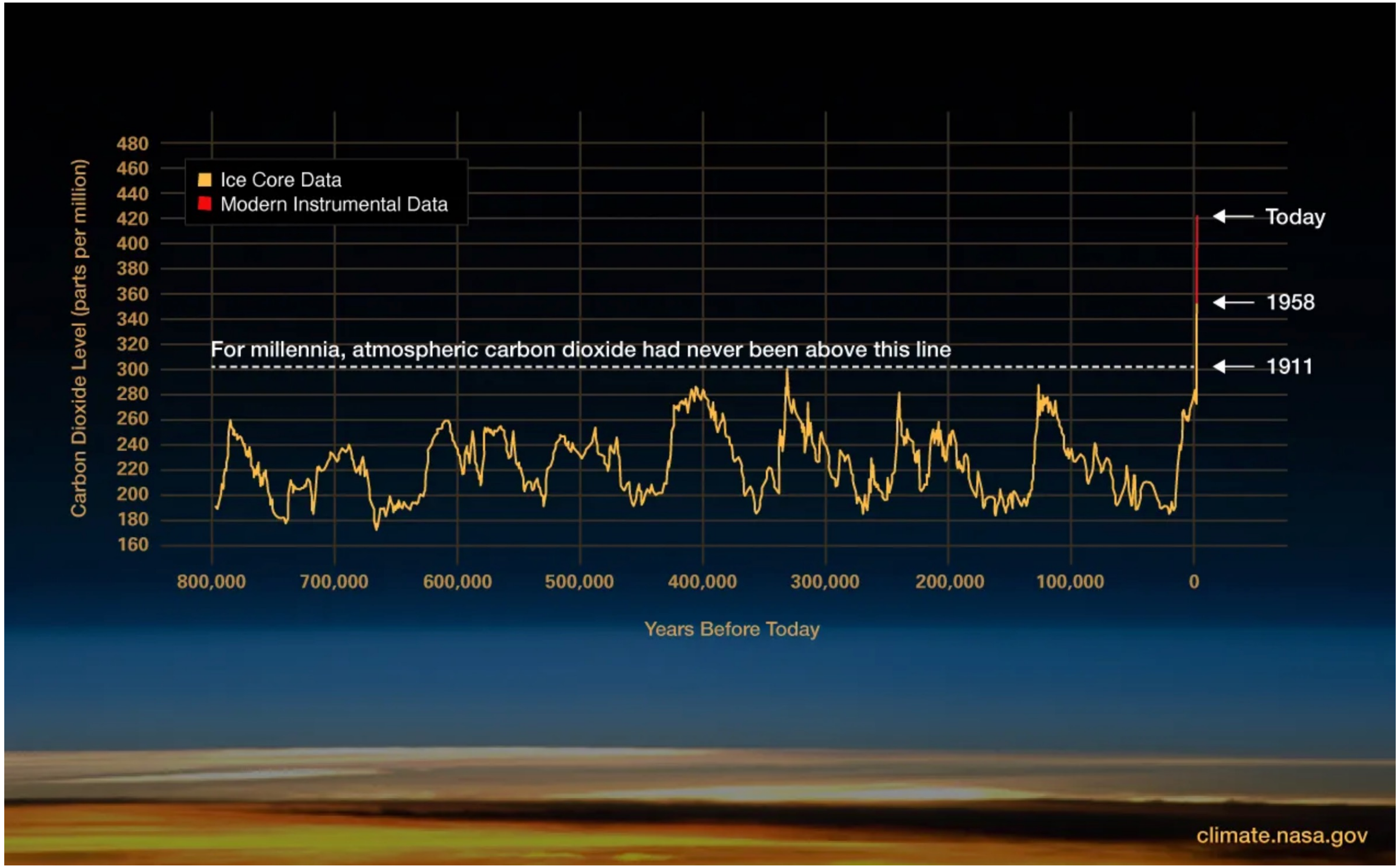
How much have we warmed the planet?

- A shift in average warming, means heat extremes are getting more extreme.



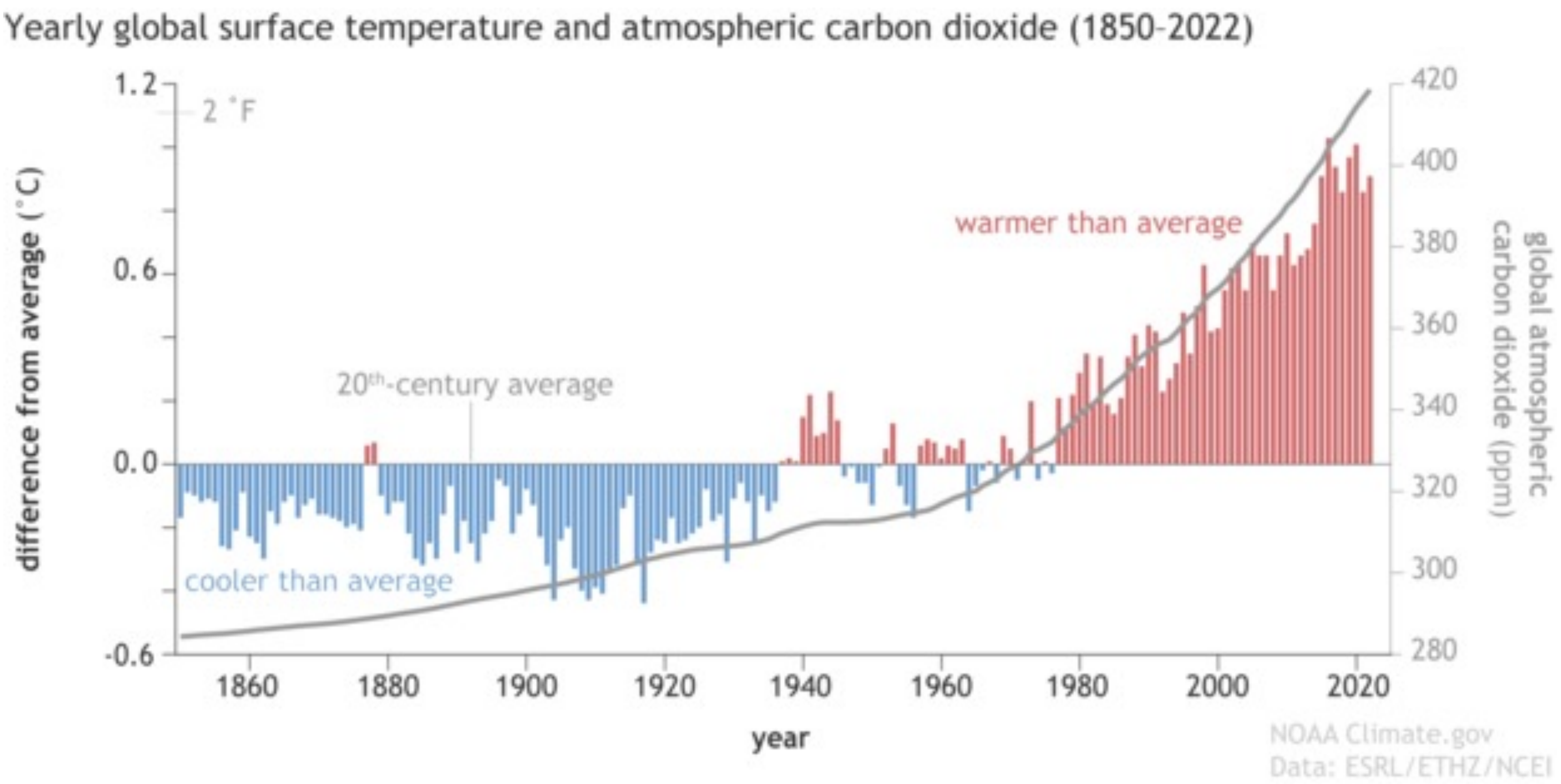
How do we know we are warming the planet?

- Paleo-climate record: ice cores, tree rings, sediments, etc.



How do we know we are warming the planet?

- Paleo-climate record: ice cores, tree rings, sediments, etc.
- Recent observational record ~1800 to present.



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- Paleo-climate record:
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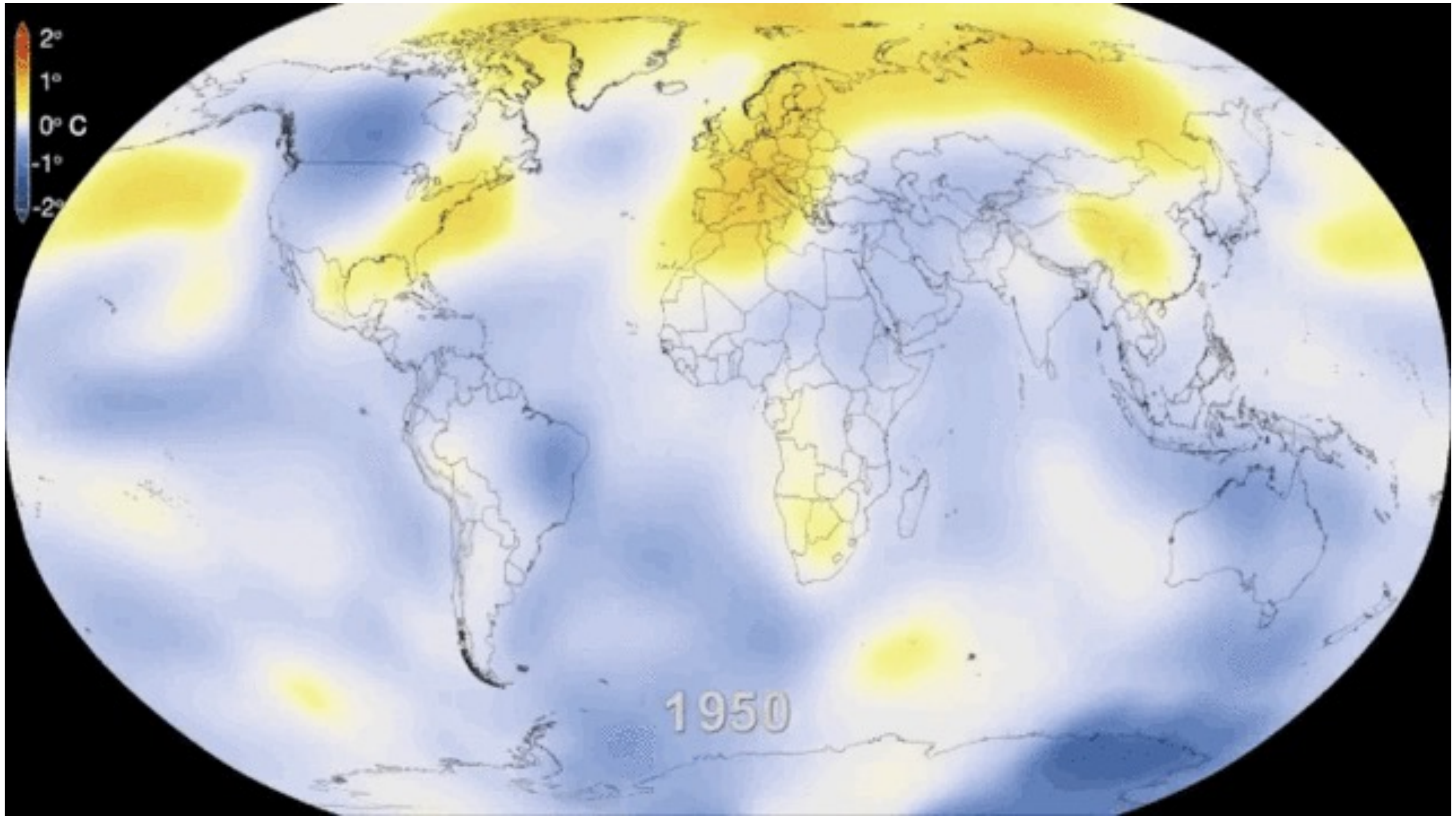
- Recent observational record ~1800 to present.
- Observations of climate change impacts like ice melting, more extreme weather, etc.
- Climate Models



What is a climate model?

- Equations to represent the processes (land, ocean, & atmospheric) the drive the Earth's climate in four dimensions.
- Based on "laws" that determine the physical, chemical, and biological processes on Earth (e.g. first law of thermal dynamics).
- Many of the processes are partial differential equations with no known solution. So, they are approximated.
- Models have gotten more complex as computing processing power has increased.

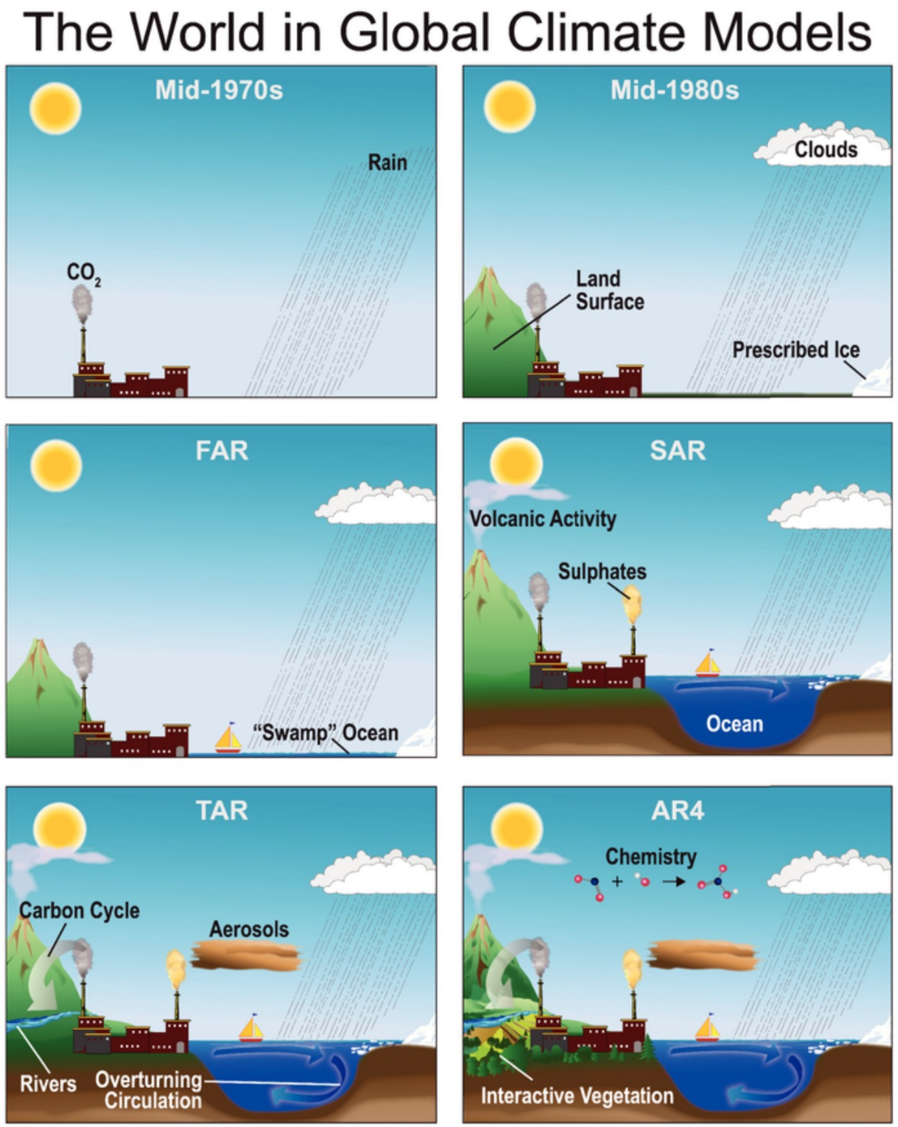


Illustration of the processes added to global climate models over the decades, from the mid-1970s, through the first four IPCC assessment reports: first ("FAR") published in 1990, second ("SAR") in 1995, third ("TAR") in 2001 and fourth ("AR4") in 2007. (Note, there is also a fifth report, which was completed in 2014). Source: IPCC AR4, Fig 1.2

https://www.carbonbrief.org/qa-how-do-climate-models-work/

What is a climate model?

- Often millions of lines of code in Fortran or C for fast processing.
- Require the largest computers on Earth to run.
- Global climate models are produced course-grained (100-250km) because they are so computationally expensive.
- They cannot approximate future climates at fine (5-km) spatial scales.

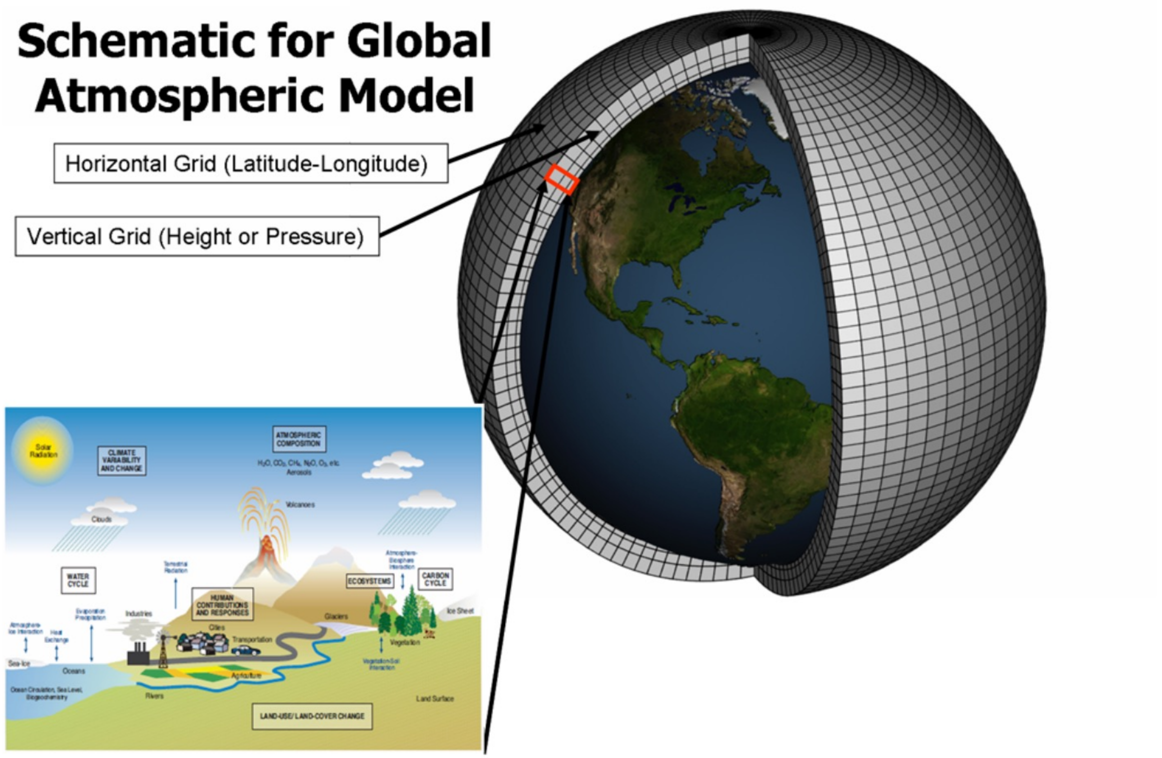


Illustration of grid cells used by climate models and the climatic processes that the model will calculate for each cell (bottom corner). Source: NOAA GFDL

https://www.carbonbrief.org/qa-how-do-climate-models-work/

What is a climate model?

- Scientists set “initial conditions”, like a coach setting up a play for a football team.
- But, like football, the we cannot predict the outcome of the “model run”.
- In short, climate models are extremely complex.
- They are always wrong, but they have skill.

https://www.carbonbrief.org/qa-how-do-climate-models-work/

What is a climate model?

- Modern global circulation models (GCMs) model the physical processes of the earth's climate.
- Early GCMs only focused on one aspect (e.g. ocean systems), but now GCMs are "coupled" (e.g. atmosphere-ocean GCMs - AOGCM)
- Now we have earth system models (ESMs) that include things like the carbon cycle, nitrogen cycle, atmospheric chemistry, ocean ecology and changes in vegetation and land use.
- We also have regional climate models (RCMs), down-scaled GCMs for a specific region of the planet.
- Integrated assessment models (IAMs) include societal decisions that impact the future which are applied to an ESM to estimate things like the "social cost of carbon"

https://www.carbonbrief.org/qa-how-do-climate-models-work/

What is a climate model?

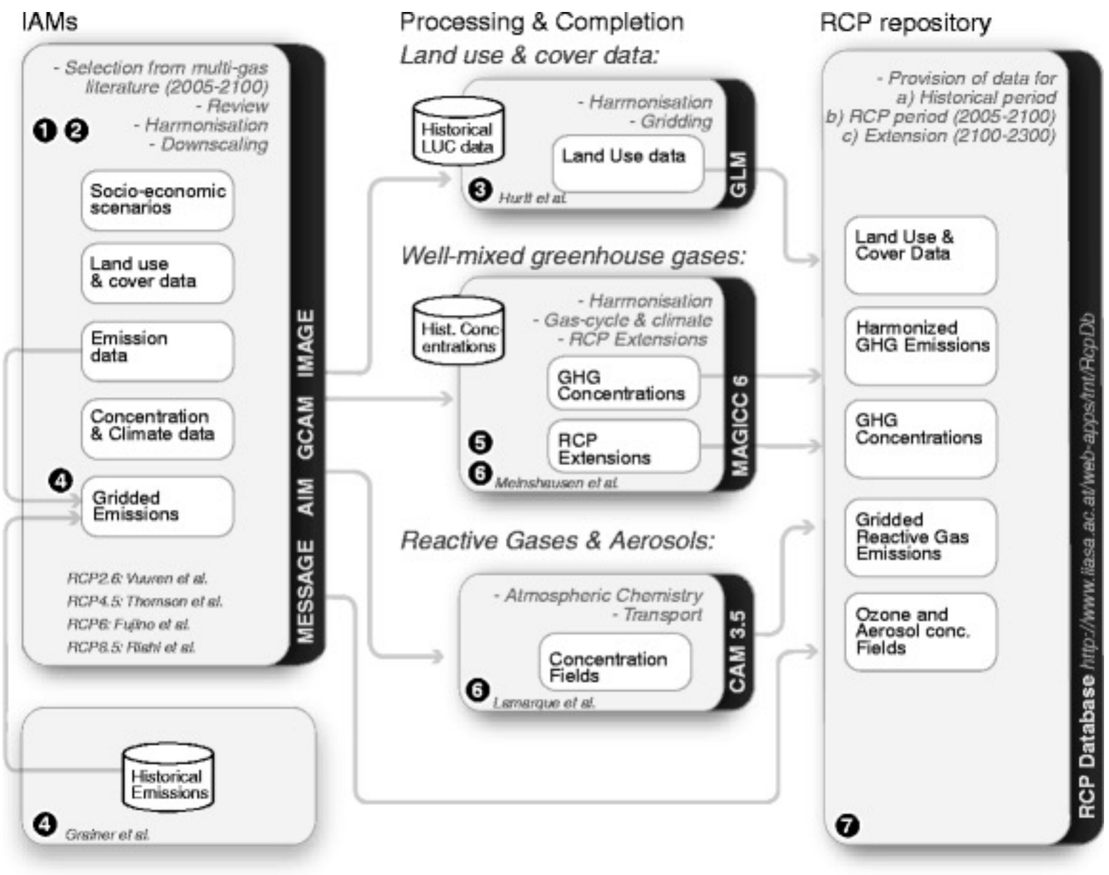
- Inputs: CO_2 emissions, methane emissions, and other green house gases, but also land cover change, aerosols and other
- Called "radiative forcing", means the amount of energy trapped by adding GHG to the system.
- Forcing scenarios follow the representative concentration pathways (RCPs) radiative forcing levels of 8.5, 6, 4.5 and 2.6 W/m2.
- Time period is 1850 – 2100, with 1750 "year zero".

Home > Climatic Change > Article

The representative concentration pathways: an overview

Open access | Published: 05 August 2011

Volume 109, article number 5, (2011) Cite this article



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What is a climate model?

Table 2 Overview of representative concentration pathways (RCPs)

From: The representative concentration pathways: an overview

	Description[a]	Publication—IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_2 eq) by 2100.	(Riahi et al. 2007)—MESSAGE
RCP6	Stabilization without overshoot pathway to 6 W/m^2 (~850 ppm CO_2 eq) at stabilization after 2100	(Fujino et al. 2006; Hijioka et al. 2008)—AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_2 eq) at stabilization after 2100	(Clarke et al. 2007; Smith and Wigley 2006; Wise et al. 2009)—GCAM
RCP2.6	Peak in radiative forcing at ~3 W/m^2 (~490 ppm CO_2 eq) before 2100 and then decline (the selected pathway declines to 2.6 W/m^2 by 2100).	(Van Vuuren et al., 2007a; van Vuuren et al. 2006)—IMAGE

[a] Approximate radiative forcing levels were defined as ±5% of the stated level in W/m^2 relative to pre-industrial levels. Radiative forcing values include the net effect of all anthropogenic GHGs and other forcing agents

Van Vuuran et al. 2011. Climatic change.

What is a climate model?

- Important to remember that climate models are experiments based on scenarios: past, present and future model runs.

- Coupled Model Intercomparison Project ("CMIP"): international effort to coordinate comparison of climate models.

- CMIP6: 53 modeling groups and 134 climate models.

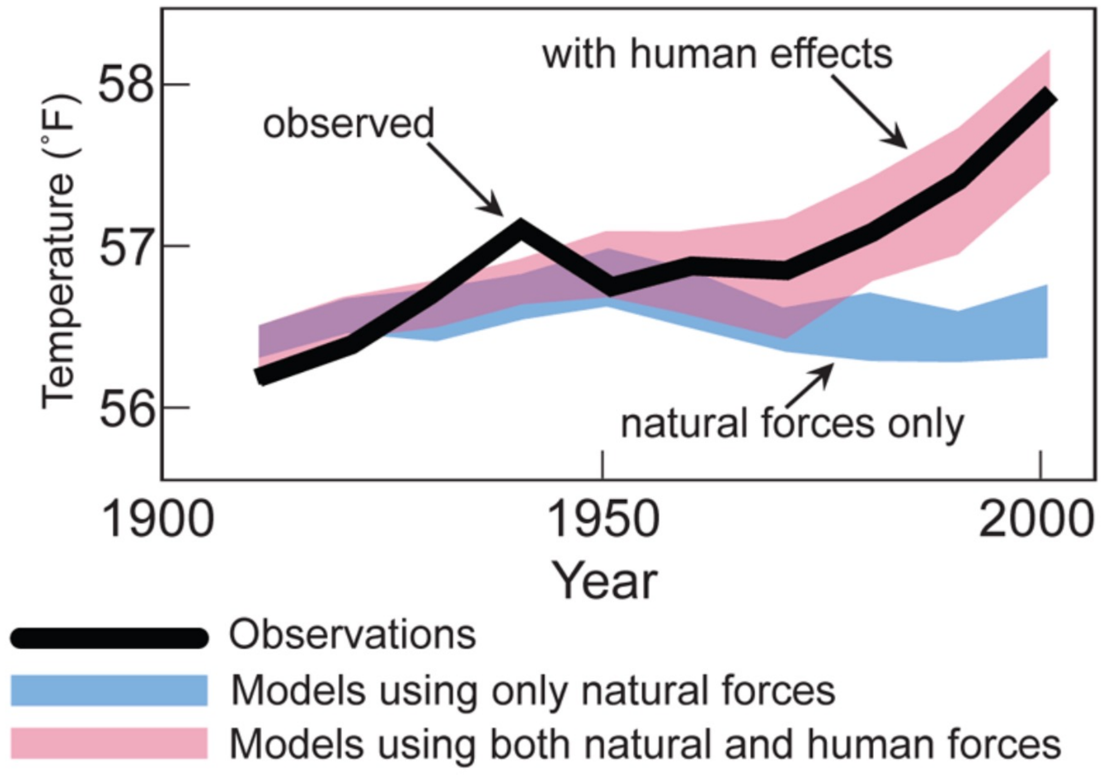
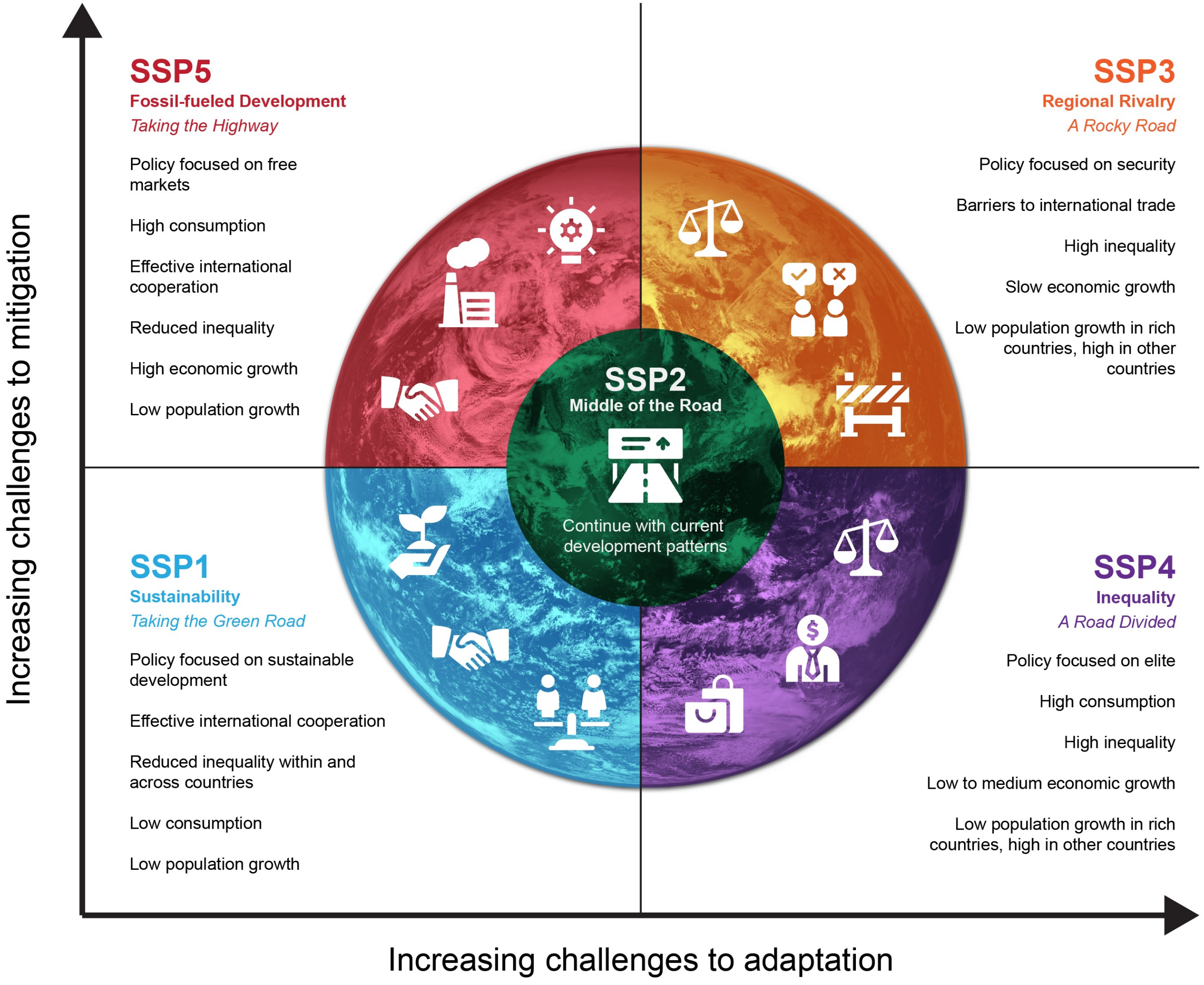


Figure from the IPCC's Fourth Assessment Report (Hegerl et al 2007).

Van Vuuran et al. 2011. Climatic change.

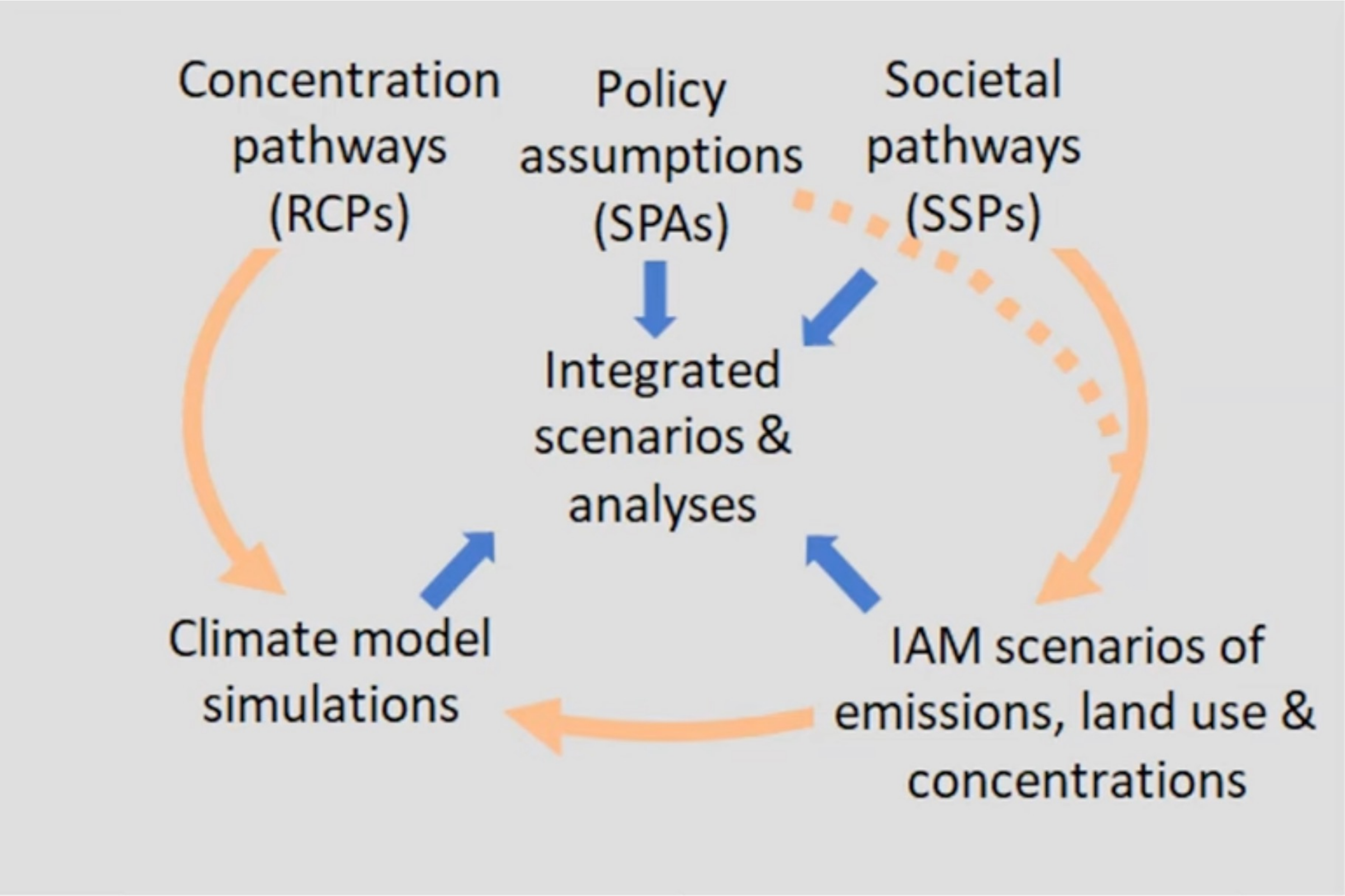
The SSPs

- CMIP6 models: SSP-RCP coupling.
- Shared Socioeconomic Pathways (SSP): baseline future socioeconomic scenarios that **do not** account for new climate change policies.
- SSP project future based on demographic, economic, and political pathways that influence **energy use**, thus GHG emissions.
- Future assumptions: population, education, urbanization, and GDP.
- Each pathway can have mitigations "applied" to test different outcomes.



https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/

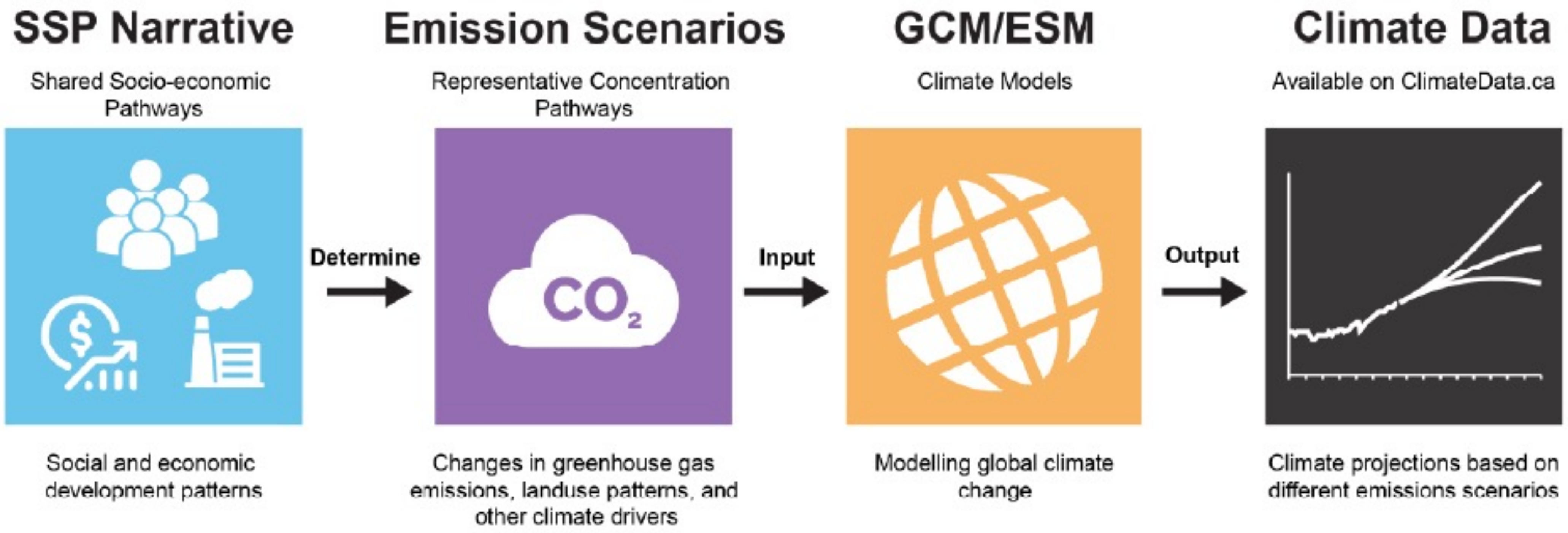
The SSPs



O'Neill et al., 2020.

https://www.youtube.com/watch?v=0l2ToWAiC0U

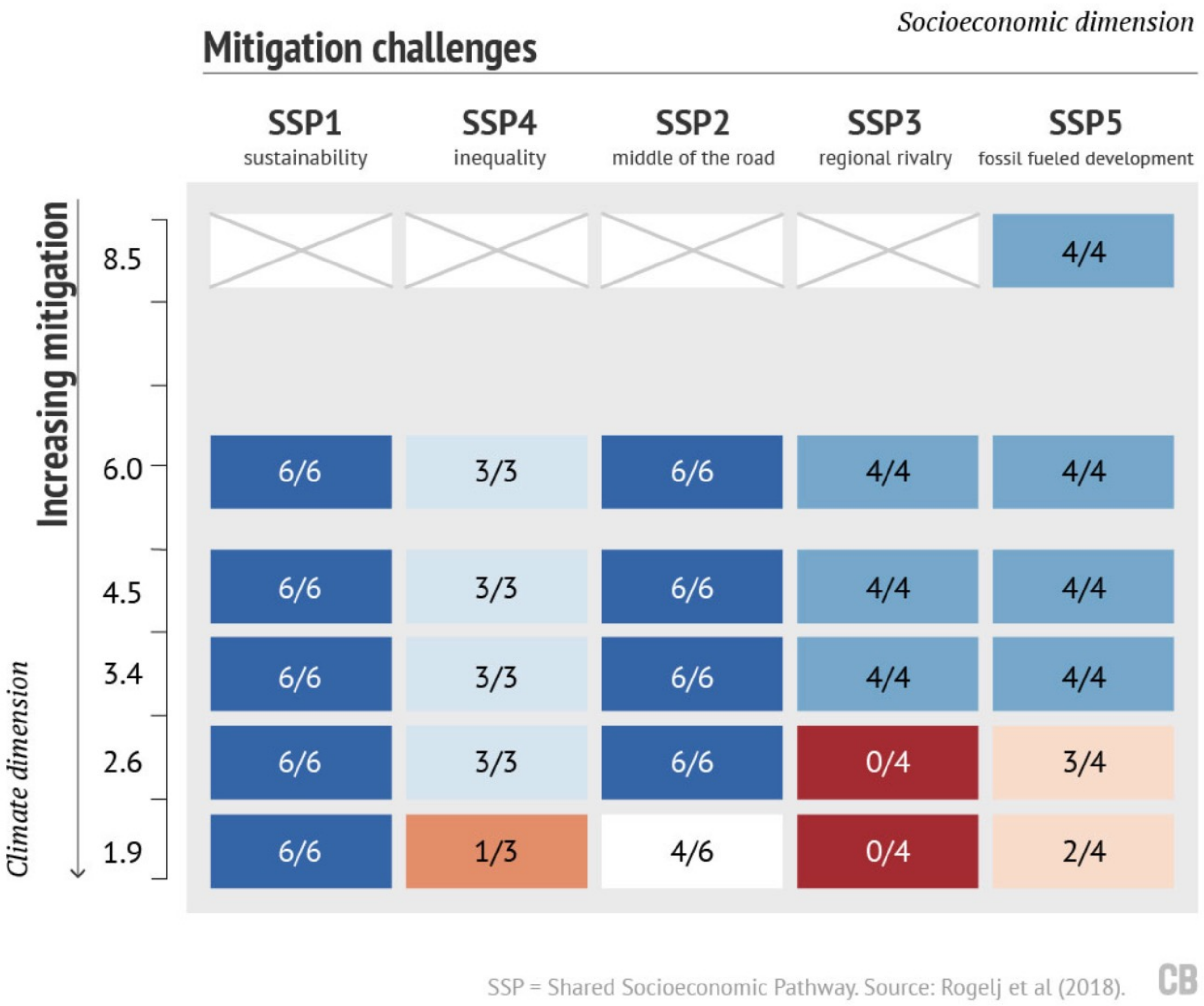
The SSPs



SSP are used for integrated assessment models of future land use energy, emissions:
f(emissions) = f(land use, energy) = pop X ed X urban X gdp

https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/

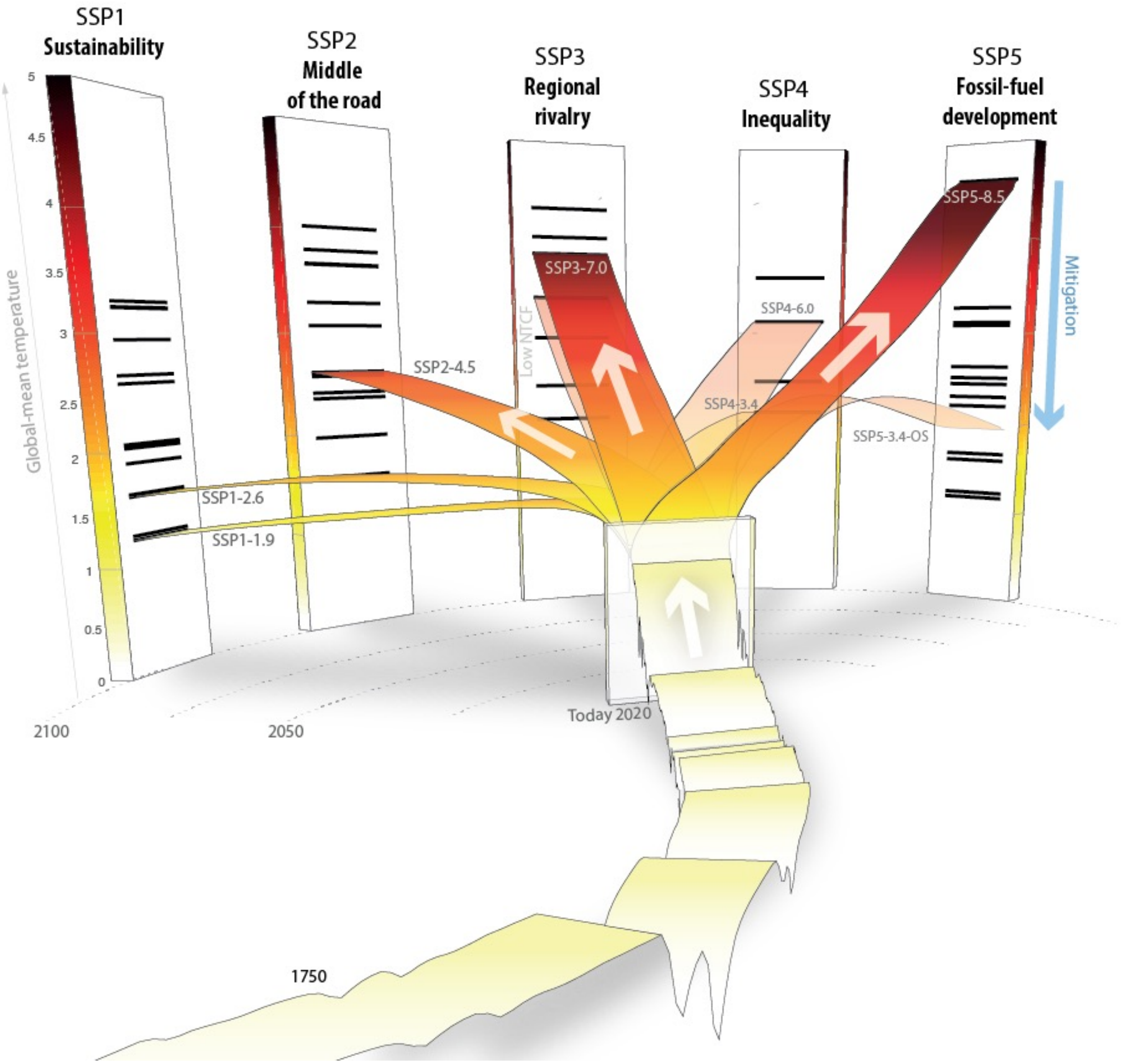
The SSPs



Combination of SSP and RCP model runs in the SSP database, with RCPs listed in order of increasing mitigation and SSPs in the (rough) order of increasing mitigation difficulty. Ratios in cells indicate the number of models that succeeded in making the scenario "work" out of the total number of models available for the SSP. Chart by Carbon Brief, adapted from Figure S1 in Rogelj et al (2018).

https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change/

The SSPs



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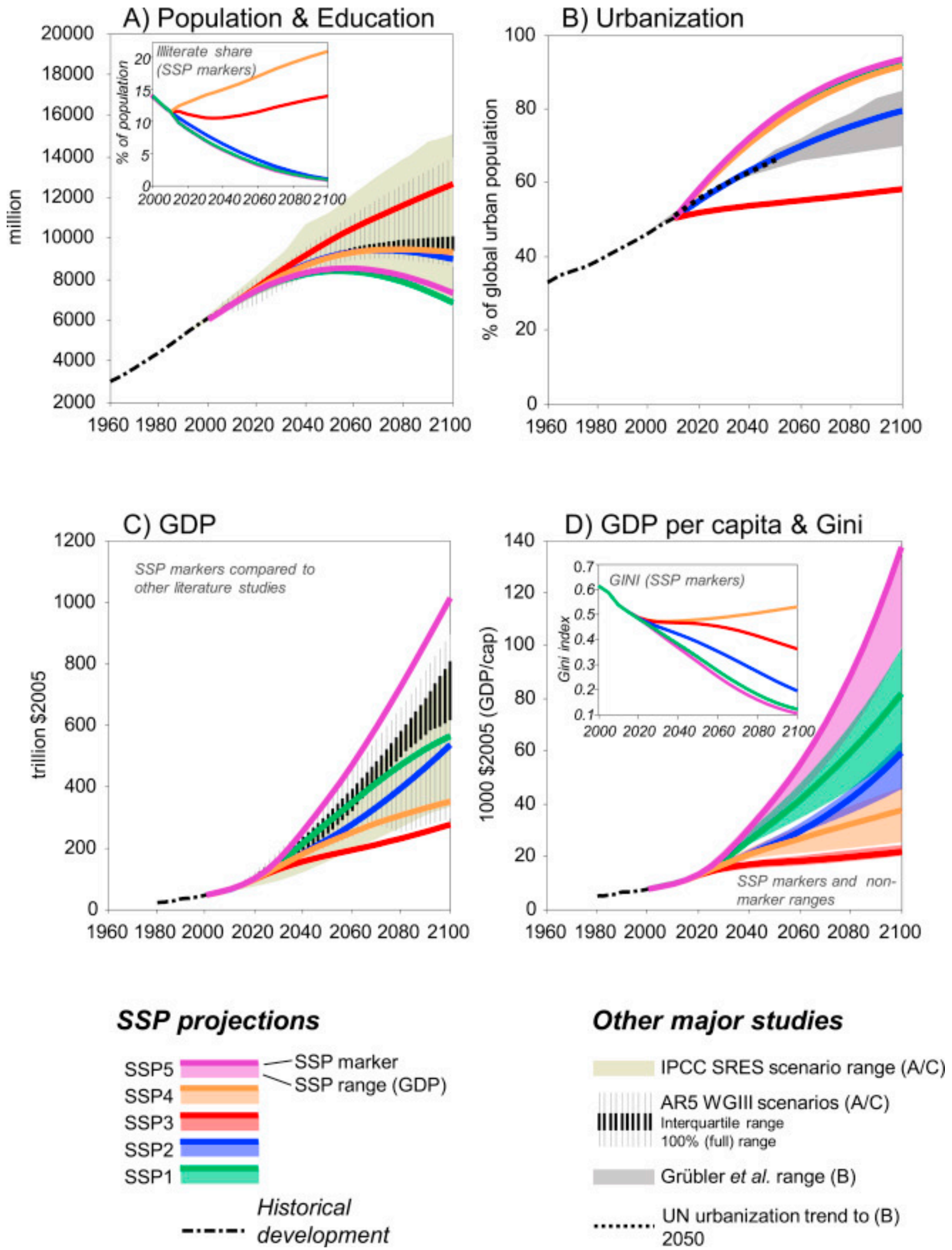


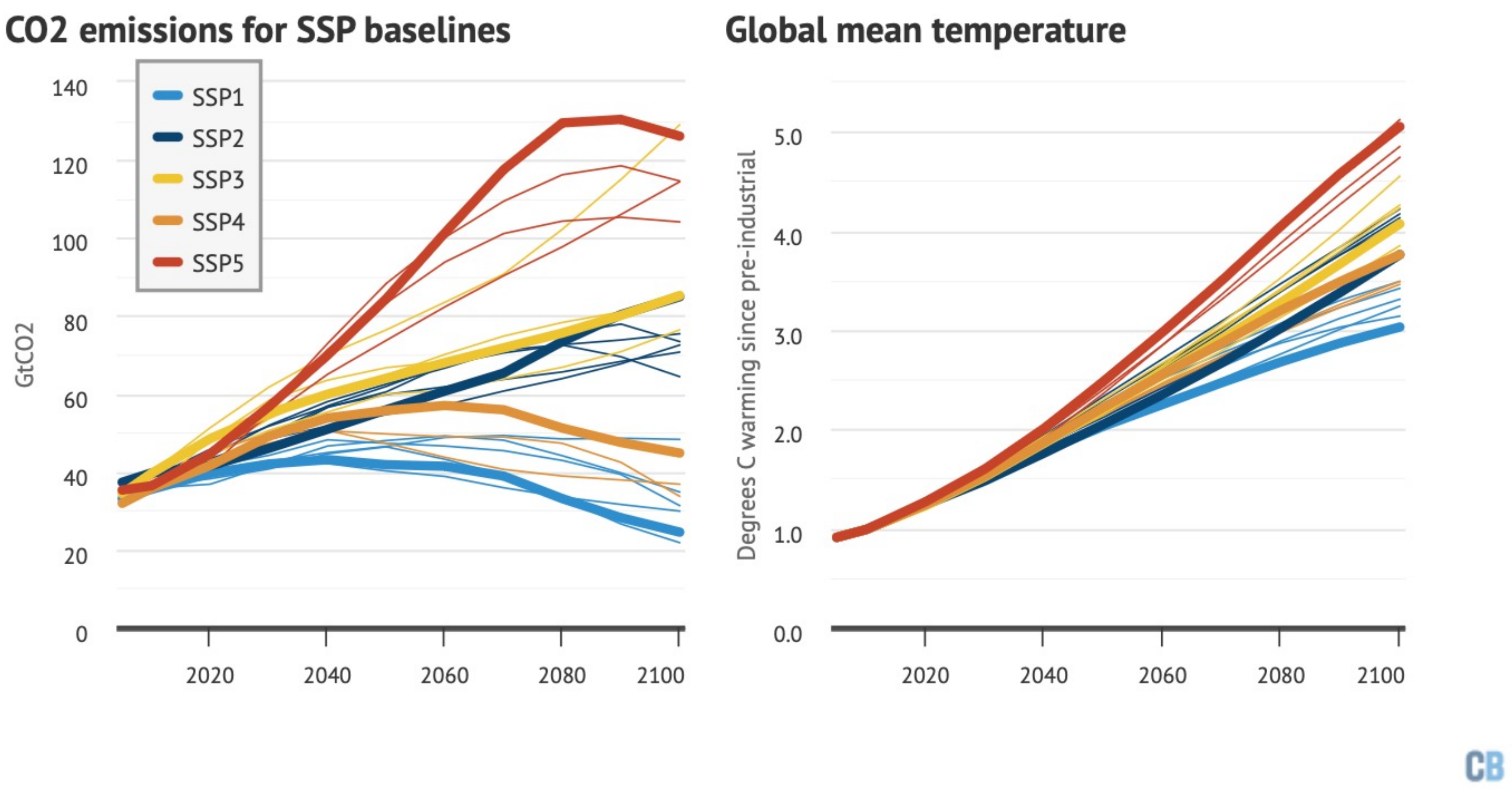
SSP narratives

SSP1	**Sustainability – Taking the Green Road (Low challenges to mitigation and adaptation)** The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and the emphasis on economic growth shifts toward a broader emphasis on human well-being. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Consumption is oriented toward low material growth and lower resource and energy intensity.
SSP2	**Middle of the Road (Medium challenges to mitigation and adaptation)** The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly and challenges to reducing vulnerability to societal and environmental changes remain.
SSP3	**Regional Rivalry – A Rocky Road (High challenges to mitigation and adaptation)** A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. Policies shift over time to become increasingly oriented toward national and regional security issues. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialized and high in developing countries. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions.
SSP4	**Inequality – A Road Divided (Low challenges to mitigation, high challenges to adaptation)** Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor intensive, low-tech economy. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. The globally connected energy sector diversifies, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas.
SSP5	**Fossil-fueled Development – Taking the Highway (High challenges to mitigation, low challenges to adaptation)** This world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy, while global population peaks and declines in the 21st century. Local environmental problems like air pollution are successfully managed. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary.

Narratives for each Shared Socioeconomic Pathway, from Riahi et al 2017.

Riahni et al. 2017

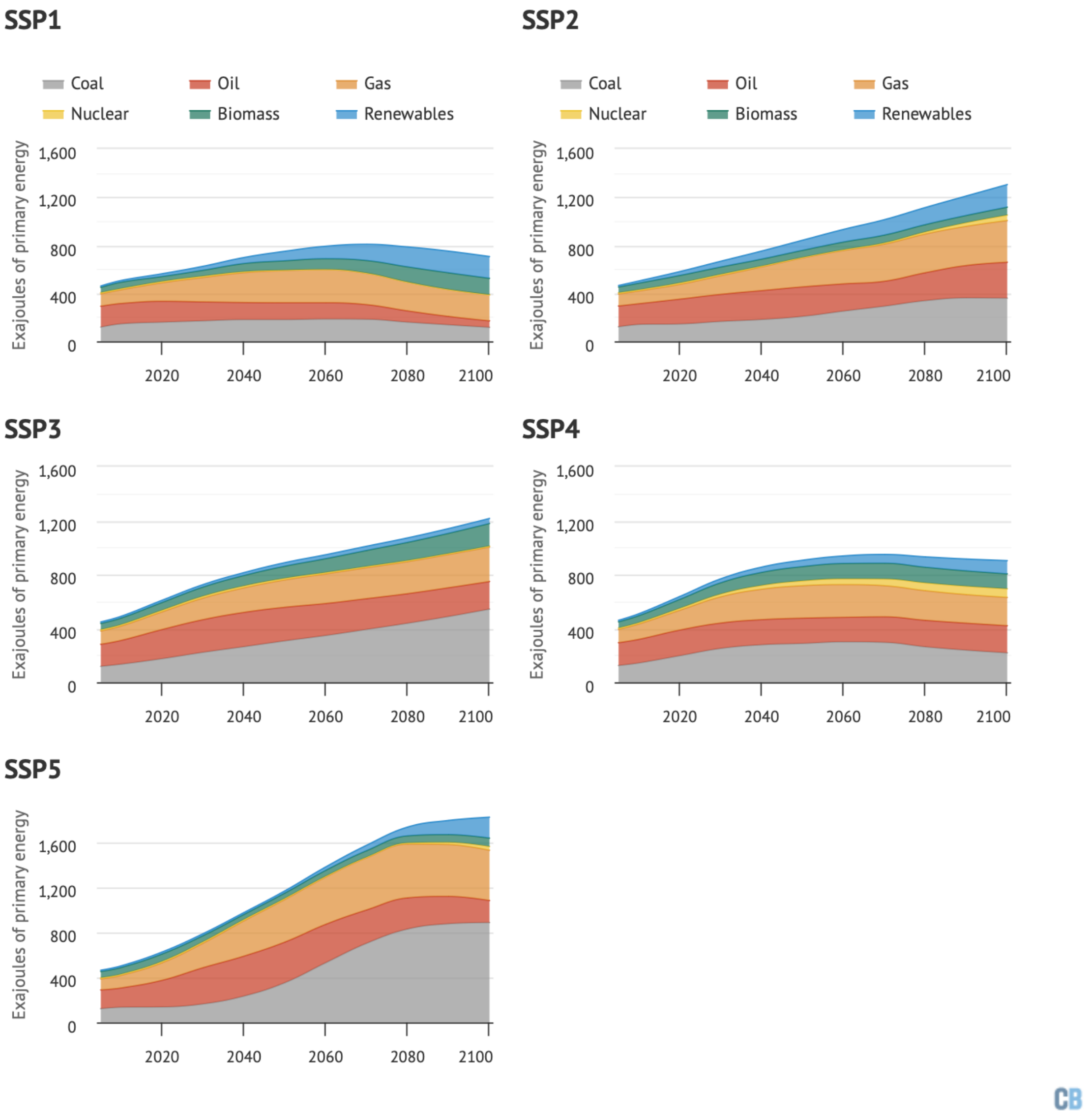
The SSPs



CO2 emissions (left) in gigatonnes (GtCO2) and global mean surface temperature change relative to pre-industrial levels (right) in degrees C across all models and SSPs for baseline no-climate-policy scenarios. The "marker" model for each SSP is shown by a thicker line, while all other model runs for that SSP have thin lines. Data from the SSP database; chart by Carbon Brief using Highcharts.

https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change/

The SSPs



Global primary energy use by fuel type between 2005 and 2100 in exajoules (EJ) for each SSP baseline marker scenario (IMAGE for SSP1, MESSAGE for SSP2, AIM for SSP3, GCAM for SSP4, and REMIND for SSP5). Data from the SSP database and Riahi et al 2017; chart by Carbon Brief using Highcharts.

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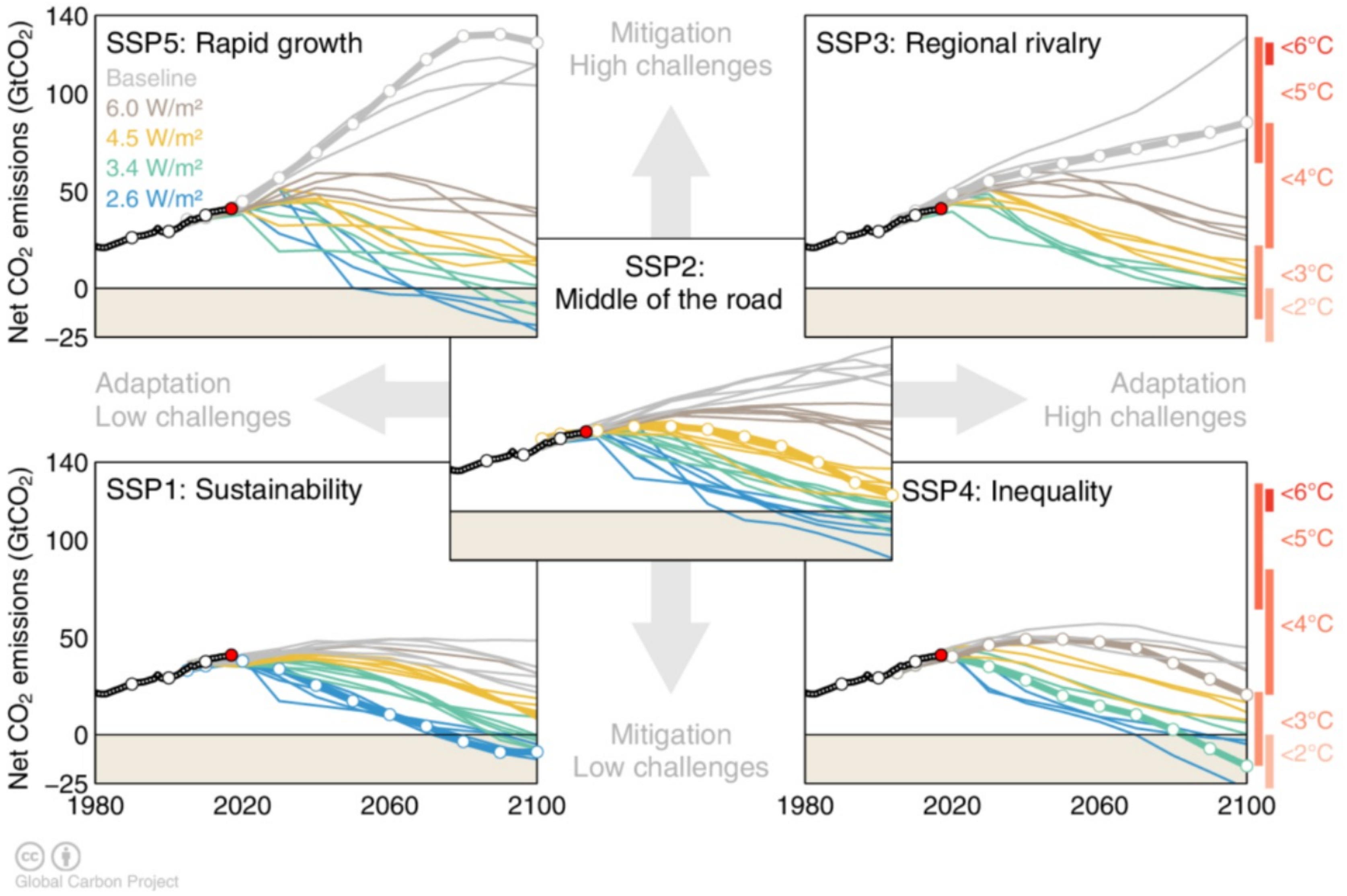

Global CO2 emissions (GtCO2) for all IAM runs in the SSP database separated out by SSP. Chart via Glen Peters and Robbie Andrews and the Global Carbon Project.

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Climate Observational Data

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Climate Data

The ***Climate Data Guide*** is a high-traffic expert knowledge portal providing concise and reliable information on the climate data that are essential for measuring and predicting physical climate risk.

Currently, the ***Climate Data Guide*** curates expert insights on over 200 observational datasets and climate indices, searchable or browseable in the list below.

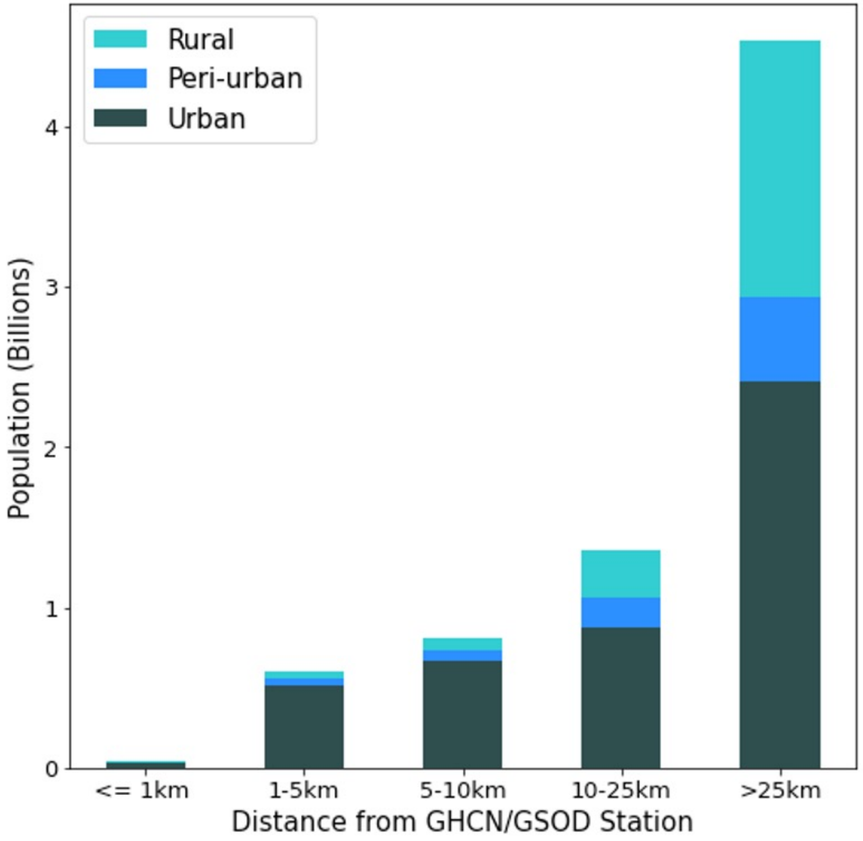
To find a specific dataset or climate variable, jump to the the search box. For only the datasets paired with guidance written by experts, select the "Datasets with guidance" button when using the search box.

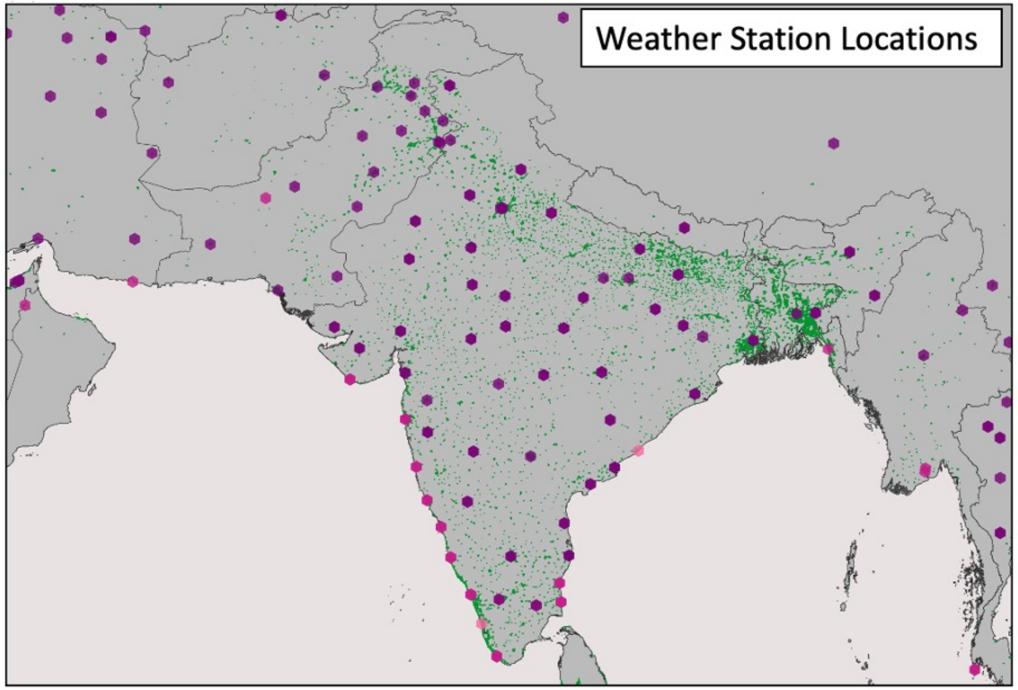
Data creators, data publishers, and scientists who use climate data are invited to join our Network of Experts by contributing commentaries on data strengths and limitations to the ***Climate Data Guide***. What type of data are included? See this discussion.

With the exception of about 25 climate indices, **the Climate Data Guide does not host datasets. Data cannot be downloaded from this site**. However, links are provided to download locations under the "Data Access" section of each dataset page.

https://climatedataguide.ucar.edu/climate-data

Climate Observational Data

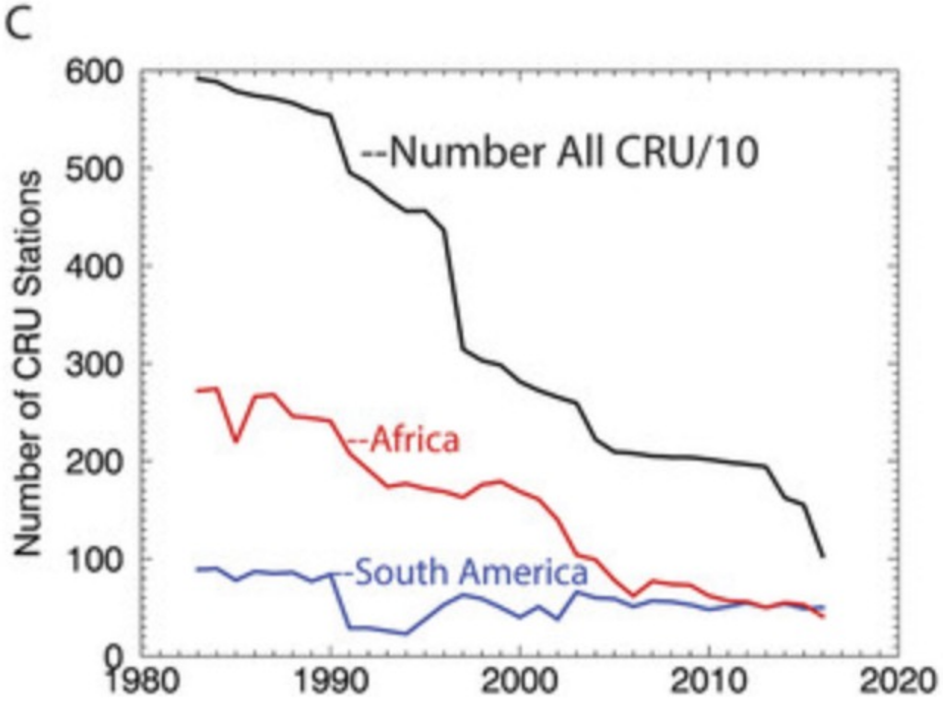




Tuholske *et al.* 2021; Zaitchik & Tuholske 2021;
Verdin *et al.* 2020; Funk *et al.* 2019

Due to declining number of weather stations, we have lacked accurate, high-resolution weather/climate data across most populated regions worldwide.

Climate Observational Data

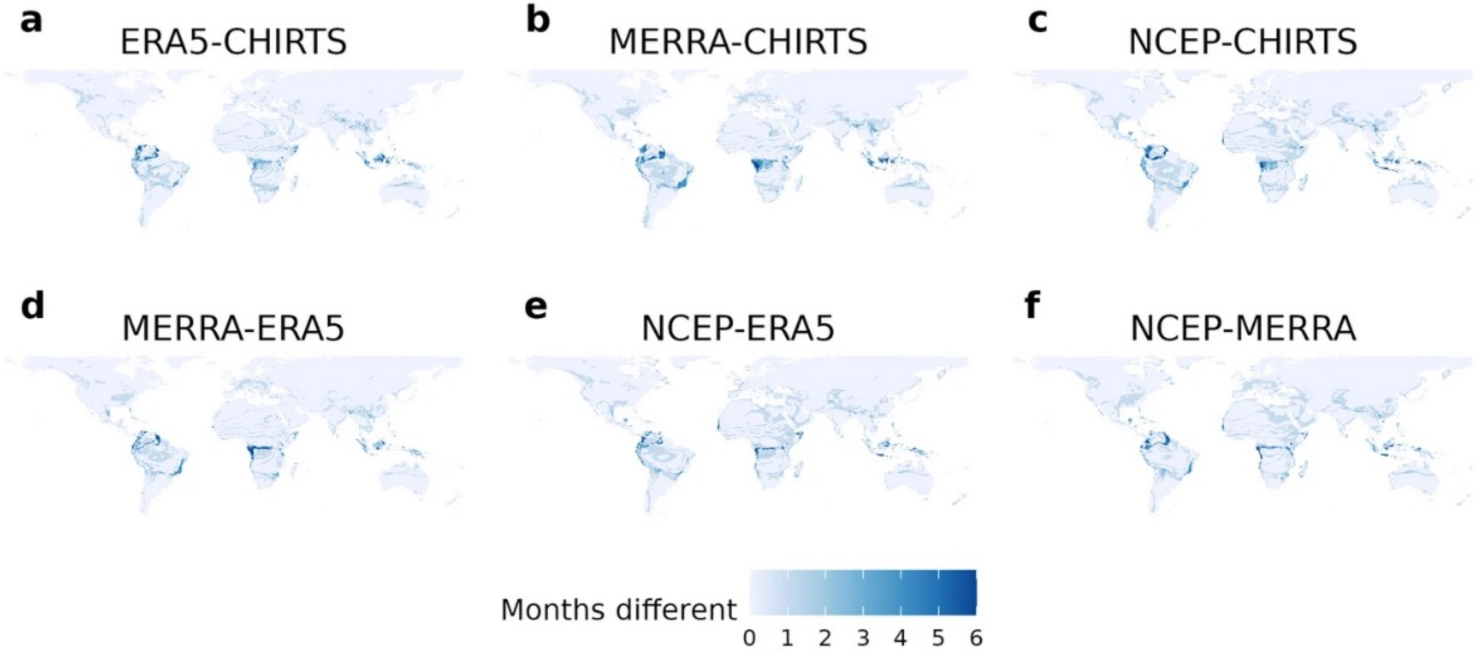


Climate Observational Data

- Climate reanalysis products don't agree in the tropics, where the majority of humans live.
- Summer = Winter
- Only 2 "heat waves" documented in Africa since 1900 (Harrington & Otto 2020)

Fig. 5

From: Challenging the universality of heatwave definitions: gridded temperature discrepancies across climate regions



Difference in monthly climatologies of Tmax (1983–2015). Each map depicts the number of months difference between the hottest month in the two datasets being compared

Coughlan de Perez *et al.* 2023

Weather Station Data

- Berkeley Earth
  - https://berkeleyearth.org/data/
  - About 50,000 Individual station data with to produce monthly record.

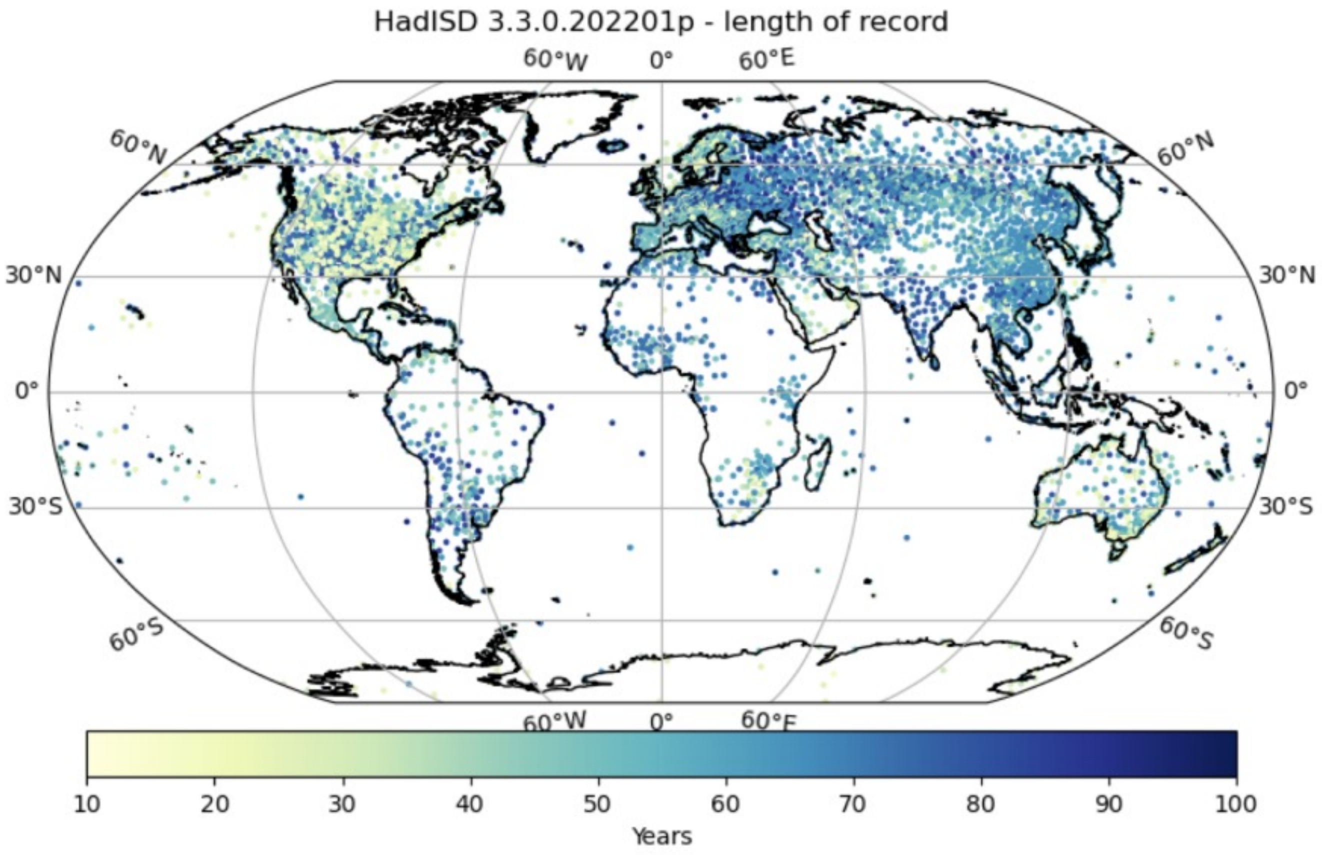
- HadISD Stations:
  - https://www.metoffice.gov.uk/hadobs/hadisd/index.html
  - Quality controlled sub-daily data from NOAA NCEI's Integrated Surface Database.
  - About 10,000 stations.
  - 1931 – present
  - Few stations for Africa

- CRUTEM5 Temperature station data:
  - https://www.metoffice.gov.uk/hadobs/crutem5/data/CRUTEM.5.0.2.0/download.html
  - monthly-mean temperature records from 10639

Weather Station Data

- Weather station data is not usually available in a use-friendly format.

- Quality control is important.
  - Station go offline
  - Stations don't all have the same reporting time-period
  - Stations get moved.



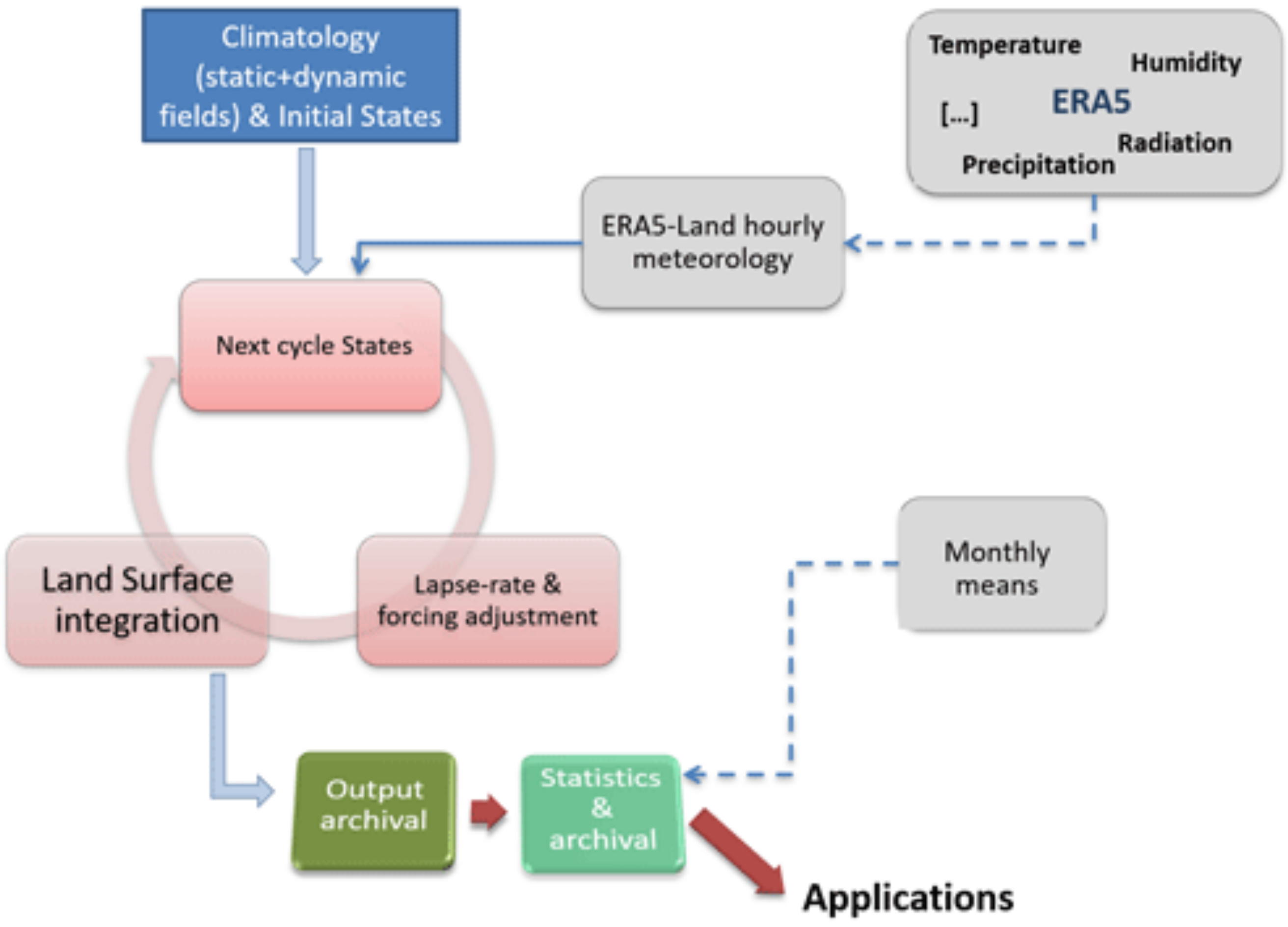
Gridded Observation Datasets

- NOAA Climate Prediction Center Global Unified Temperature
  - https://psl.noaa.gov/data/gridded/data.cpc.globaltemp.html
  - 0.5° spatial resolution (very course-grained)
  - 1979 – present
  - Daily min & max 2m air temperature

- CHIRTS-daily
  - https://www.chc.ucsb.edu/data/chirtsdaily
  - Blends satellite data and station data to down-scale ERA5 (more later)
  - 0.05° (about 5km) spatial resolution
  - Daily min & max 2m air temperature
  - 1983 – 2016 (experimental version to present available)

Climate Reanalysis Data

- Weather models use “initial conditions” (e.g. observations) to forecast the near-term weather.
- Reanalysis products use “initial conditions” to hindcast the weather.
- Produce sub-daily (hourly) ocean, land, and atmospheric conditions.



Climate Reanalysis Data

There are four main global reanalysis products:

- ERA5 & ERA5-Land produced by the European Union
  - https://www.ecmwf.int/en/research/climate-reanalysis
  - Since 1950, Hourly at 25 and 9 km respectively
- MERRA2 produced by NASA:
  - https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/
  - Since 1980 6 hours, 0.5° latitude × 0.625°
- NCEP/NCAR Reanalysis:
  - https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html
  - Since 1948, 6 hours, 1.875 × 1.904129 gaussian grid
- JRA-55:
  - https://data.ucar.edu/dataset/jra-55-japanese-55-year-reanalysis-daily-3-hourly-and-6-hourly-data
  - 1958 onward, 3-hour, 1.55°

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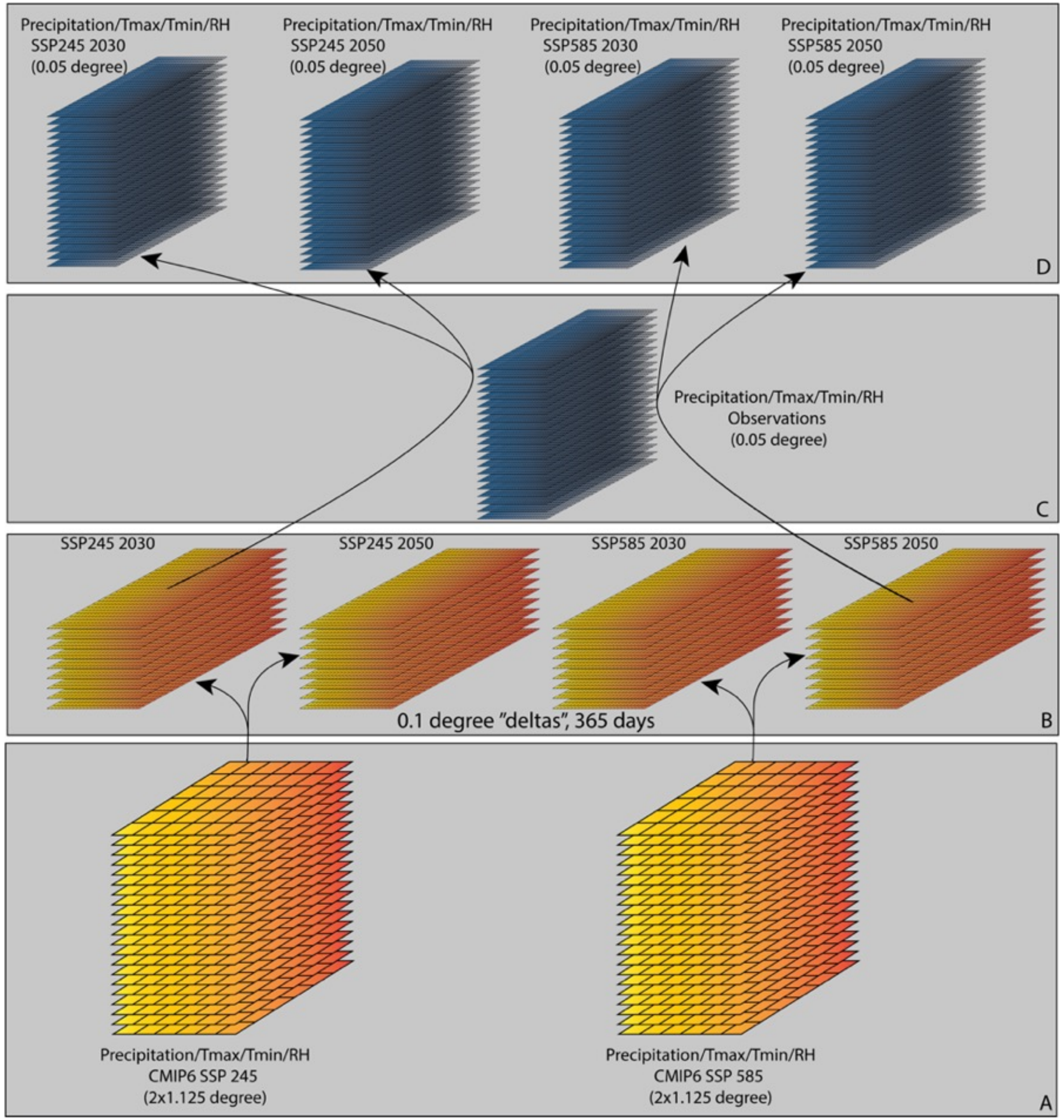
  - 1958 onward, 3-hour, 1.55°

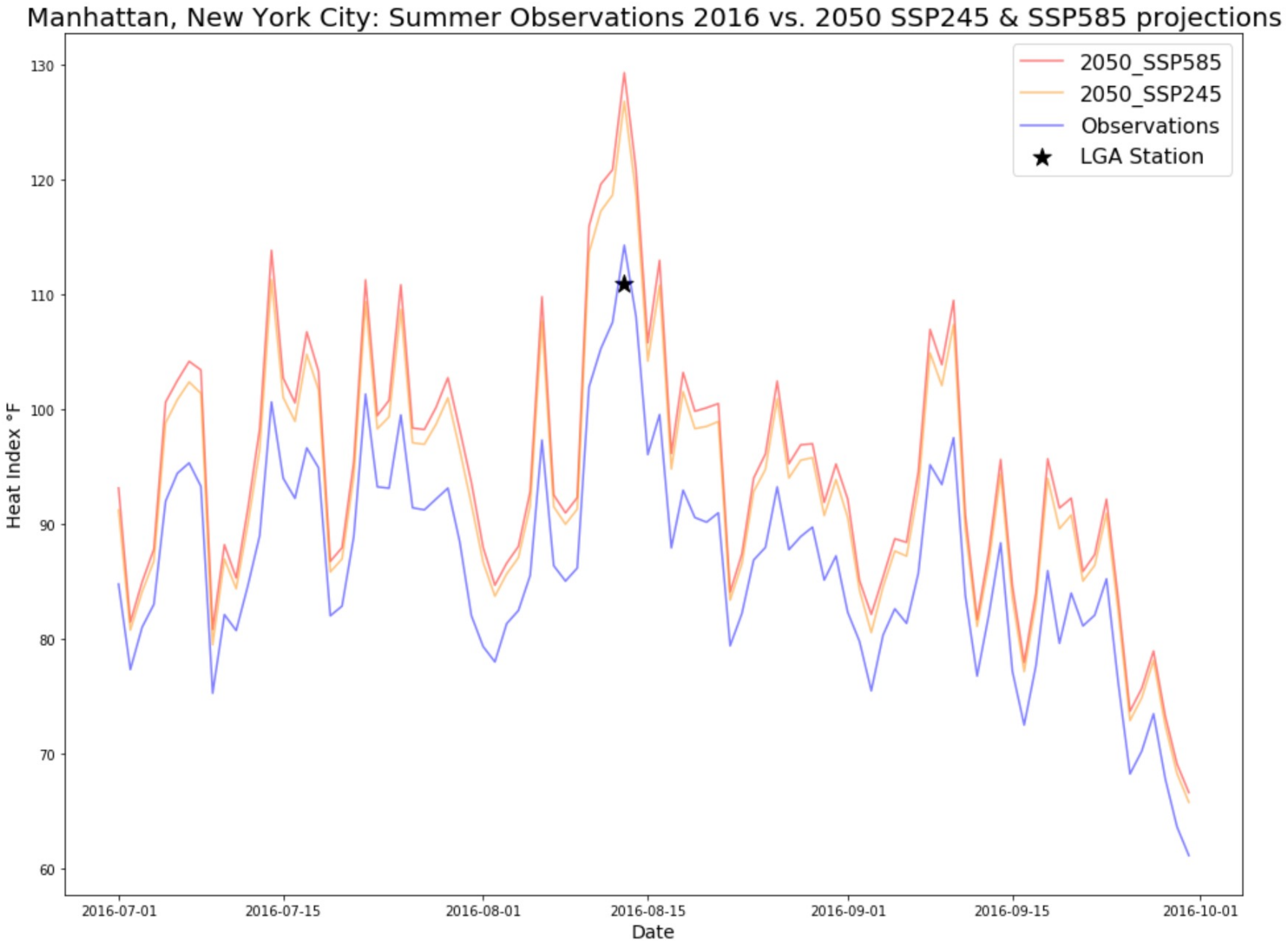
CHC-CMIP6 Projections



- CHIRTS-daily: 5km daily maximum air temperature record.
- Leverages weather stations & satellite record.
- CHC-CMIP6 **5-km** temperature, precipitation, vapor pressure deficit, etc. projections.
- SSP245 and SSP585 for 2030 and 2050.
- Figure by Chris Funk, UCSB.

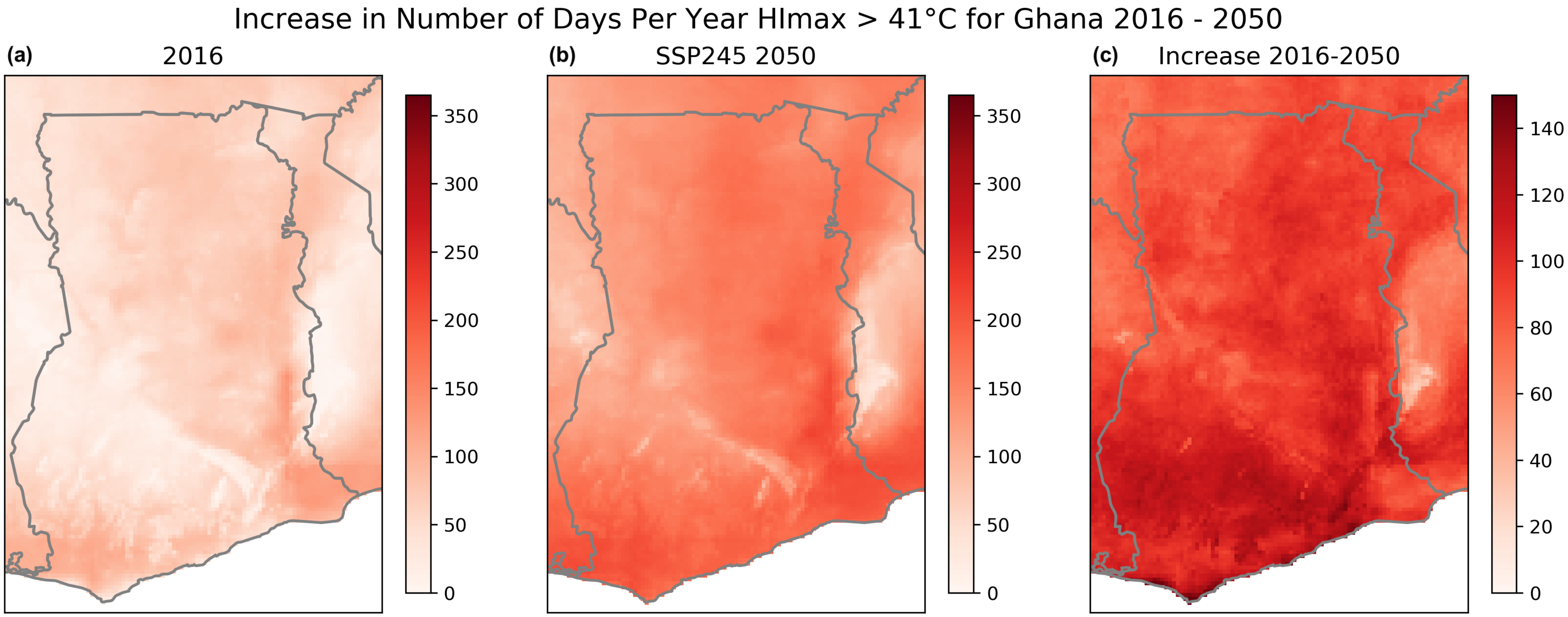
Williams *et al.* 2024

CHC-CMIP6 Projections



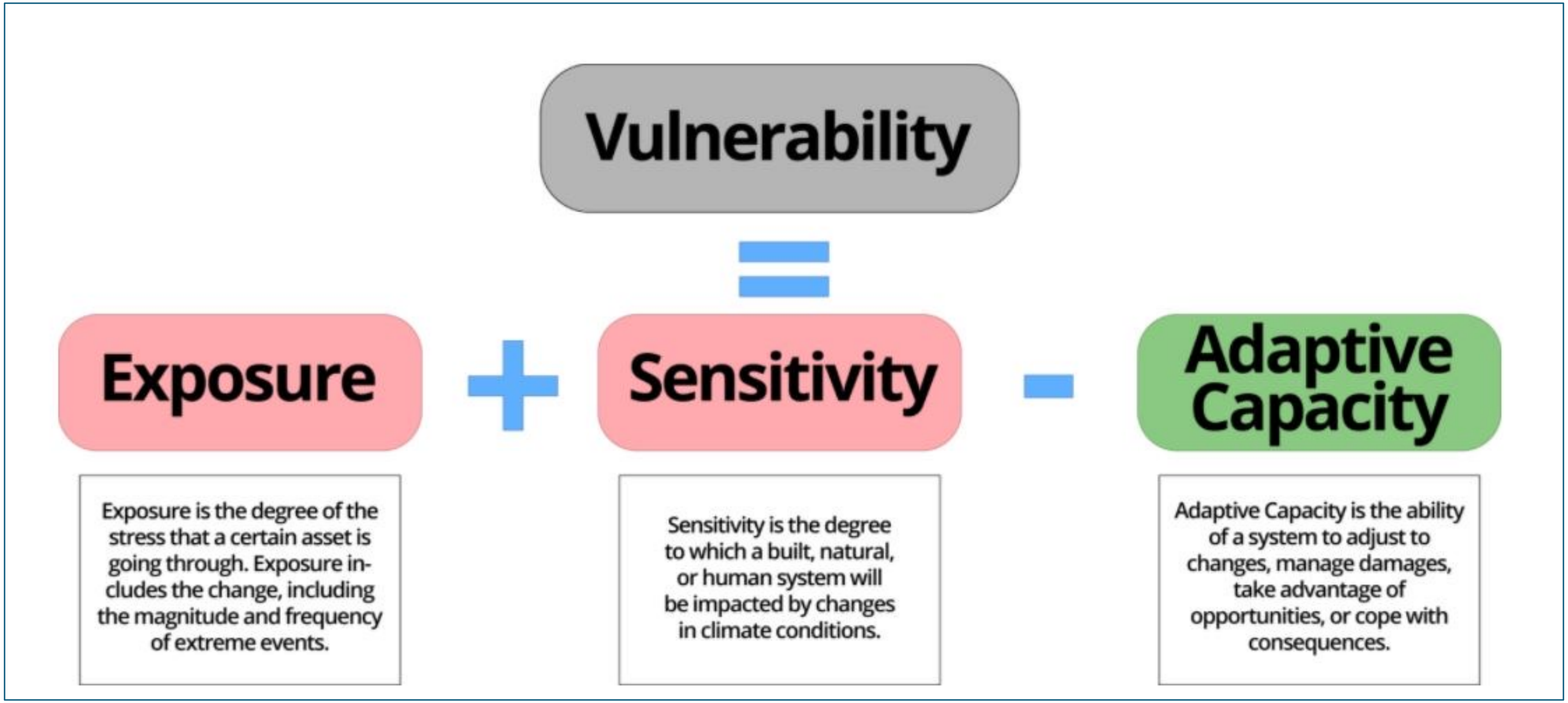
Data from Williams *et al.* 2024

Ghana CHC-CMIP6 Heat Index Projections

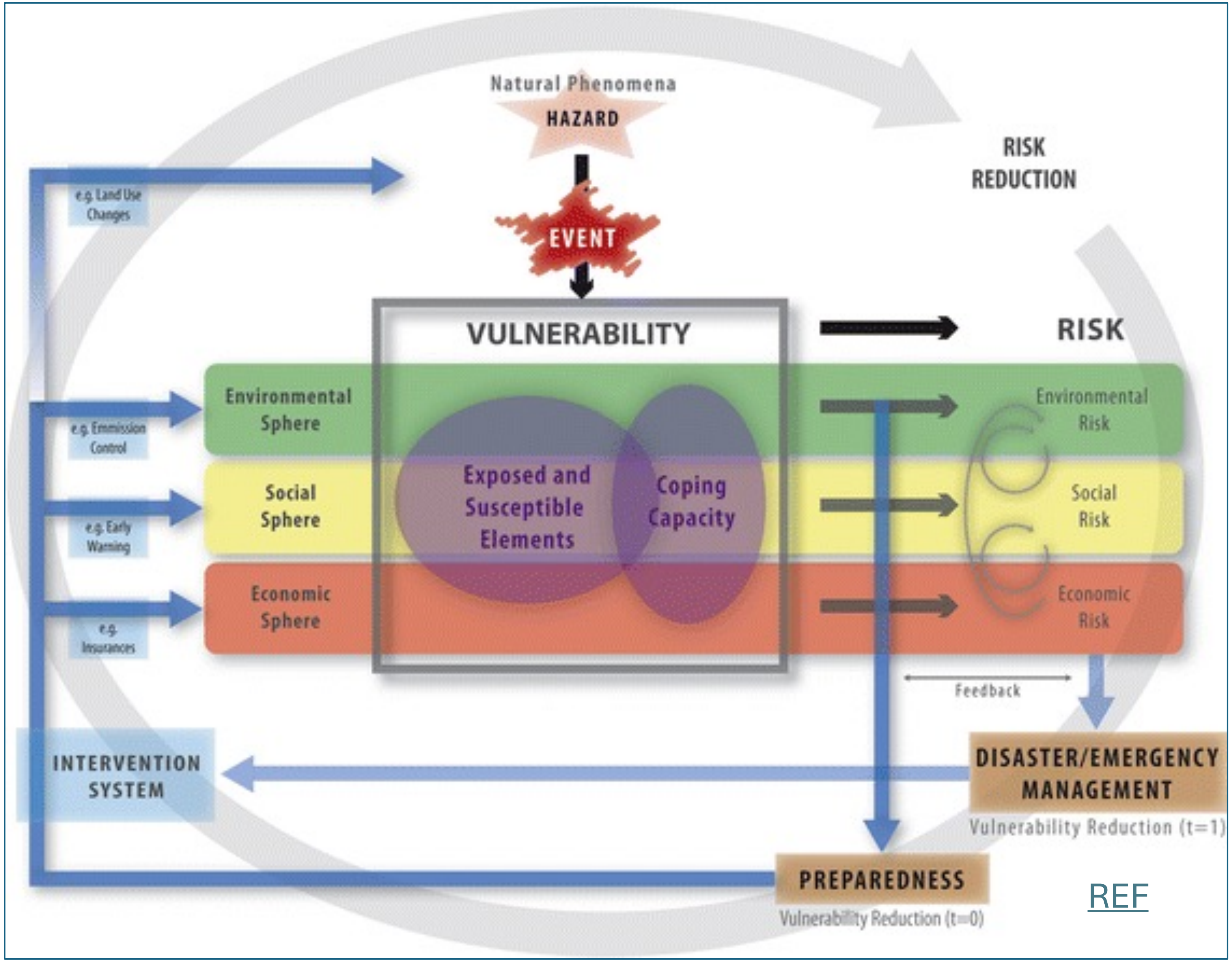


Data from Williams *et al.* 2024

How to model **vulnerability** to climate change impacts.

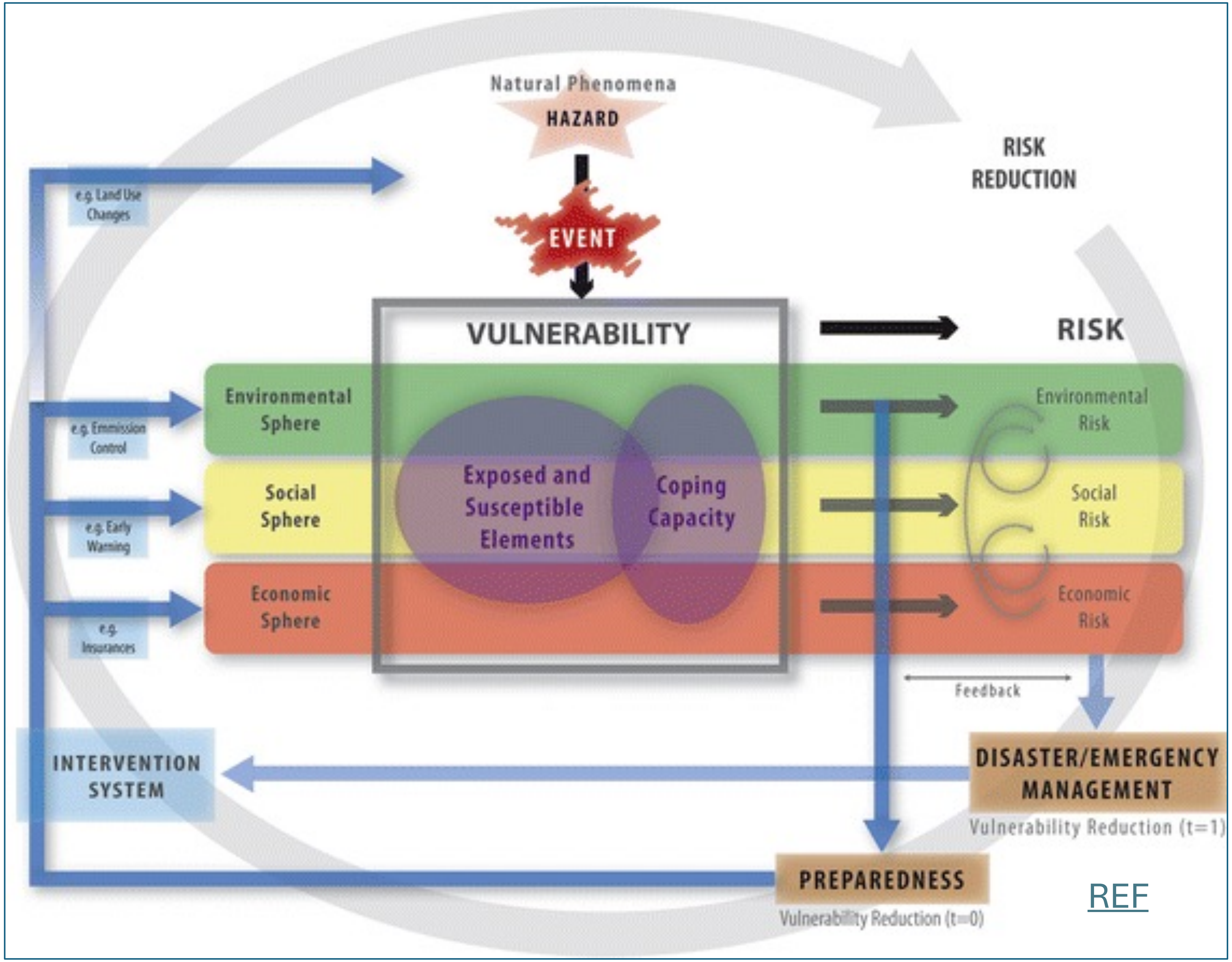


- Complex socio-ecological system.



[REF](REF)

- Complex socio-ecological system.
- Spatial scale is really important.
    - Is the risk of hazard over a large geography?
    - Is the vulnerable population concentrated in a small area?
    - What level of government will respond (e.g. local? National? International?)



REF

Spatial Resolution

100 x 100 km

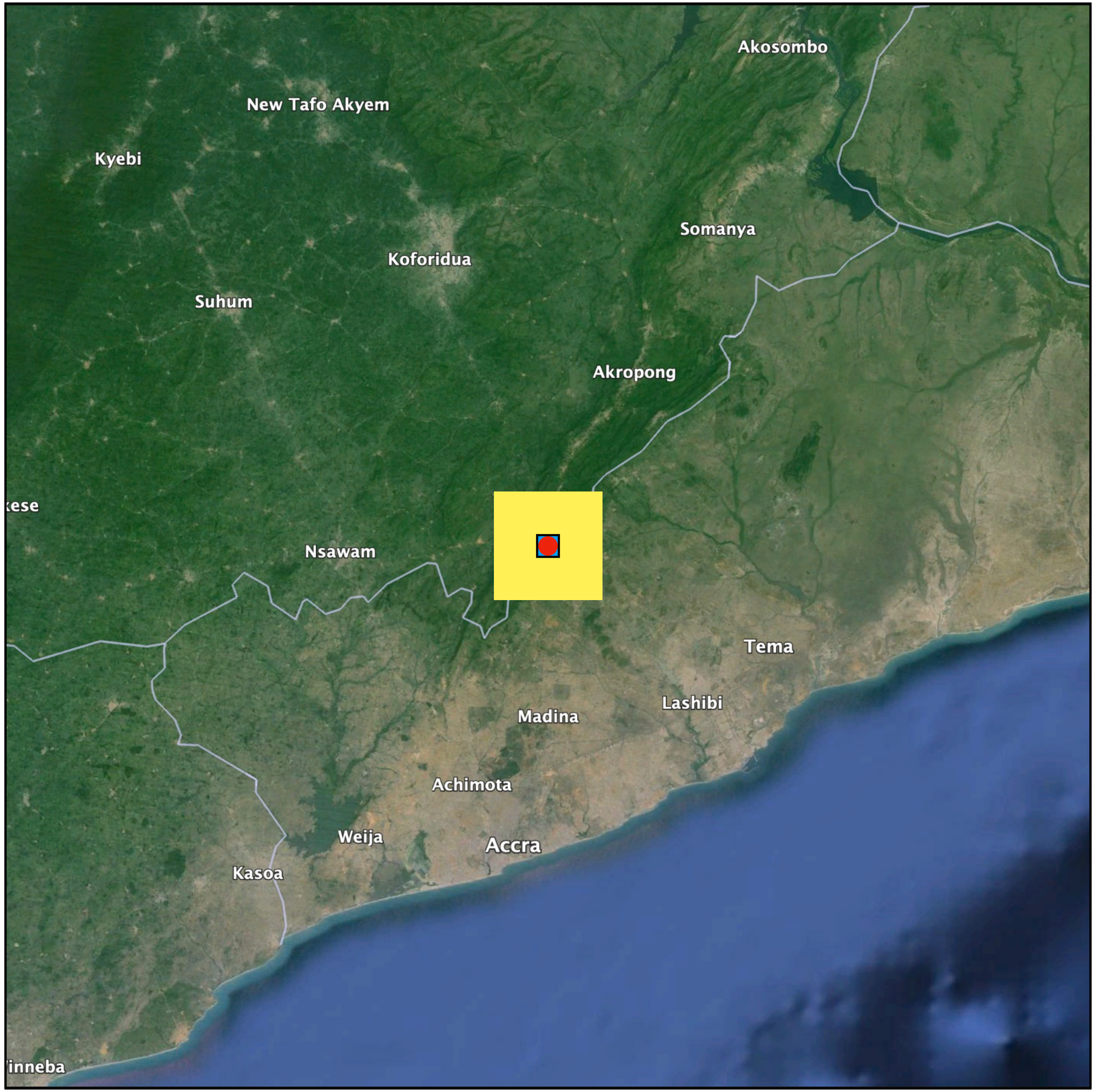
Spatial Resolution

100 x 100 km

Person location (if you're lucky) Point data

ERA-5 Temperature Record 25 x 25 km

Spatial Resolution



100 x 100 km

Person location
(if you're lucky)
Point data

ERA-5
Temperature
Record
25 x 25 km

CHIRTS-Daily
5 x 5 km

Verdin *et al.* 2020

Heat Impacts to Human Health

Heat Impacts to Human Health

There are 300+ “heat stress” metrics used to study how temperature affects human health and well-being, according to the World Meteorological Organization.

Heat Impacts to Human Health

Physiologists

Vanos *et al.* 2023; Baldwin *et al.* 2023

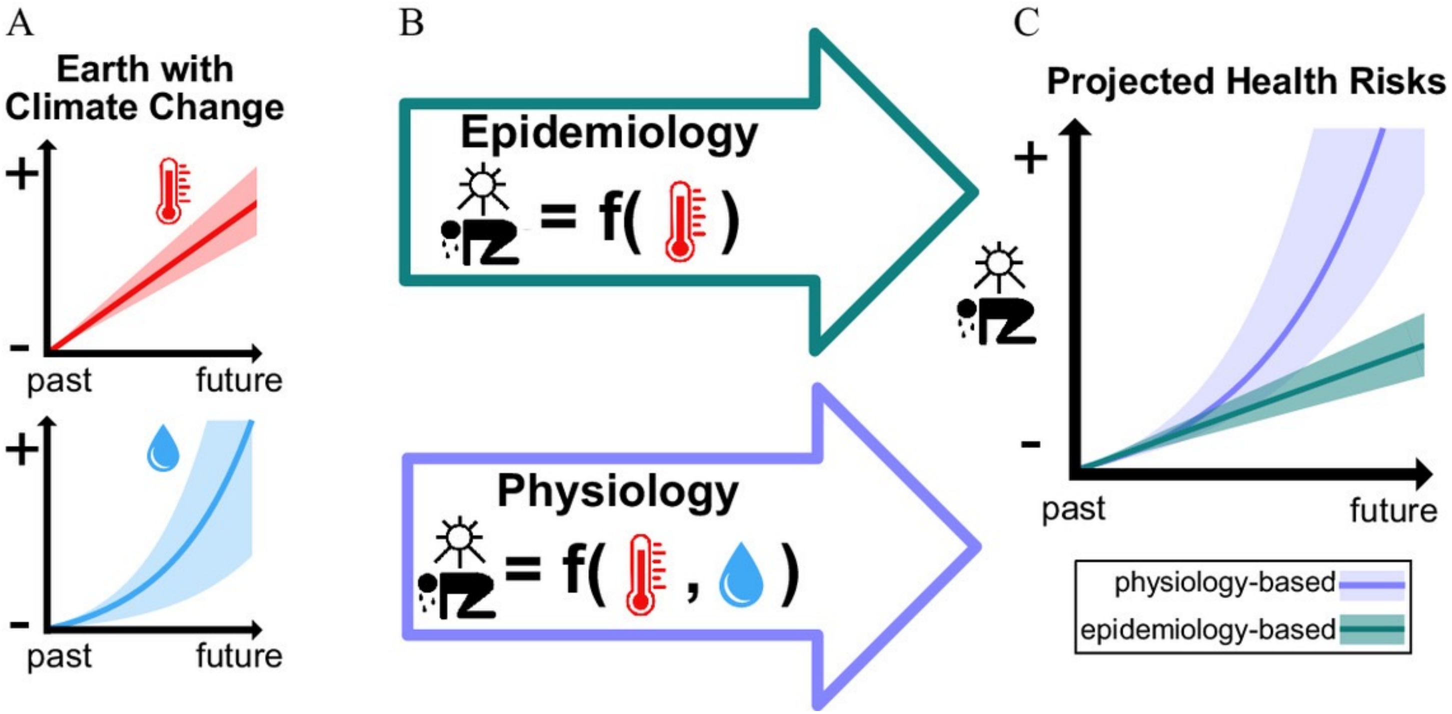
Heat Impacts to Human Health

Physiologists

Epidemiologists (& Economists)

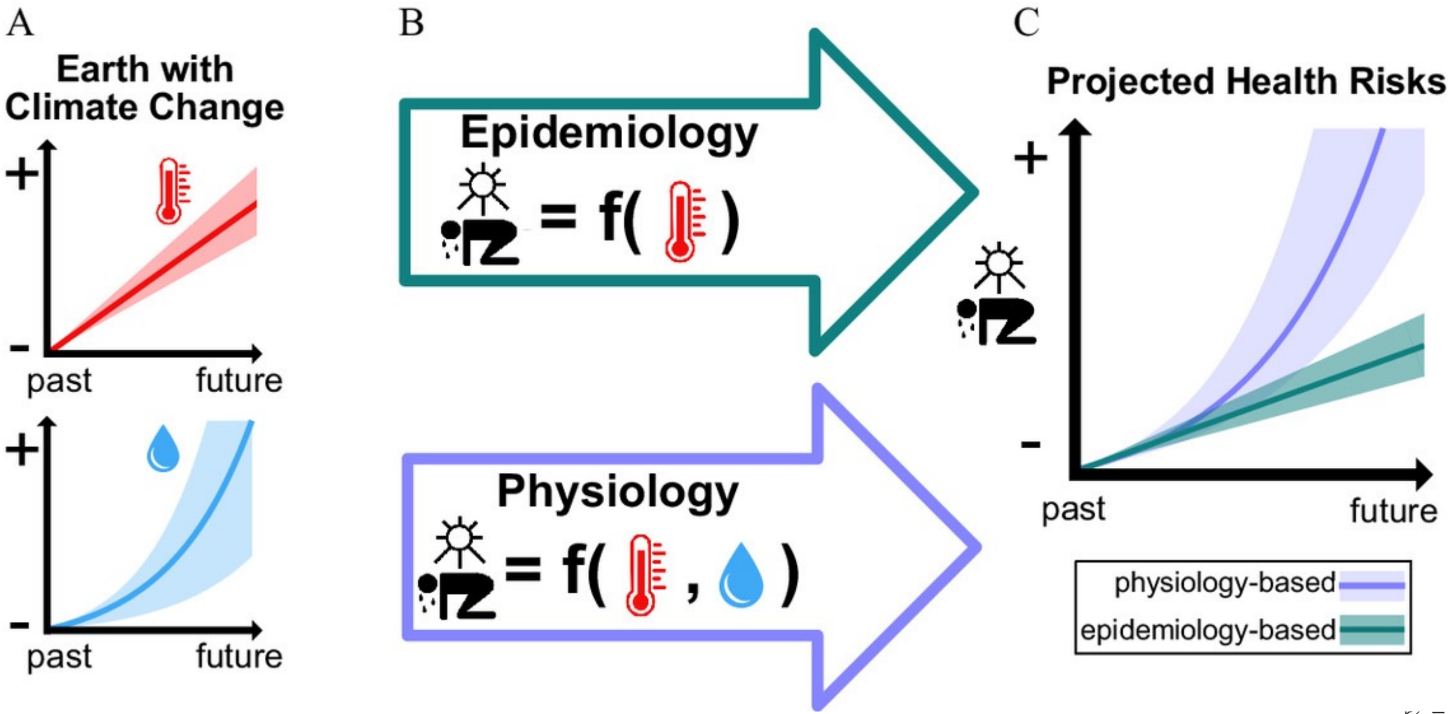
Vanos *et al.* 2023; Baldwin *et al.* 2023

Heat Impacts to Human Health

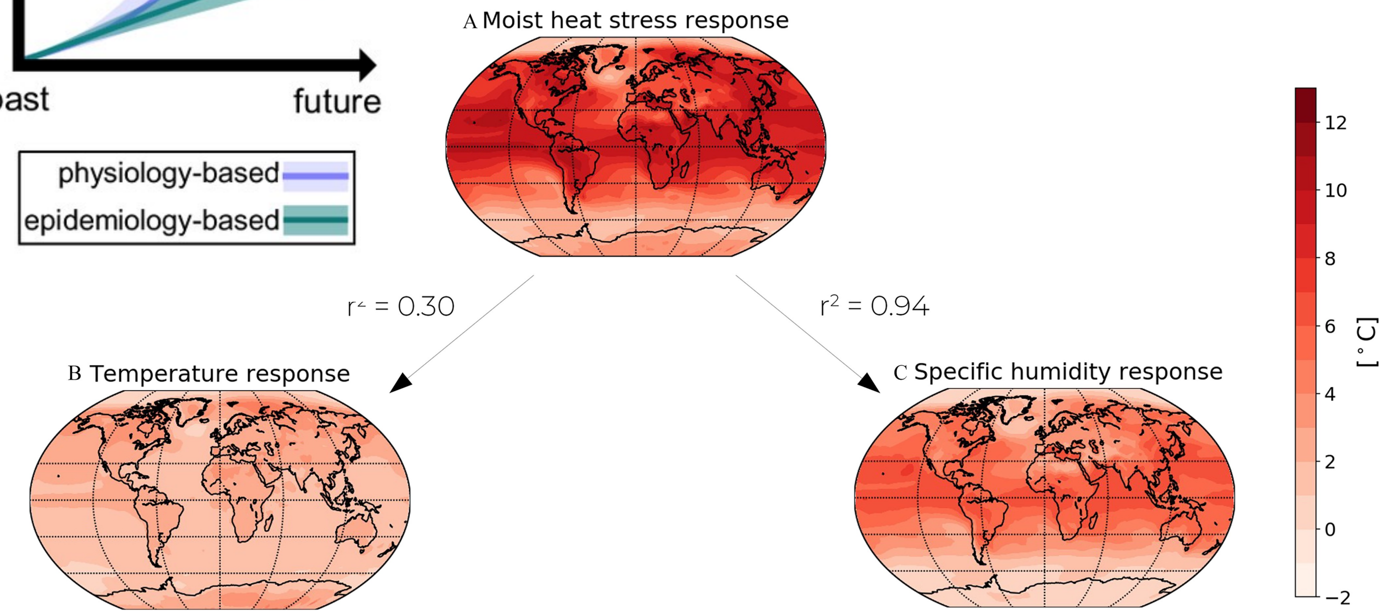


Baldwin *et al.* 2023

Heat Impacts to Human Health



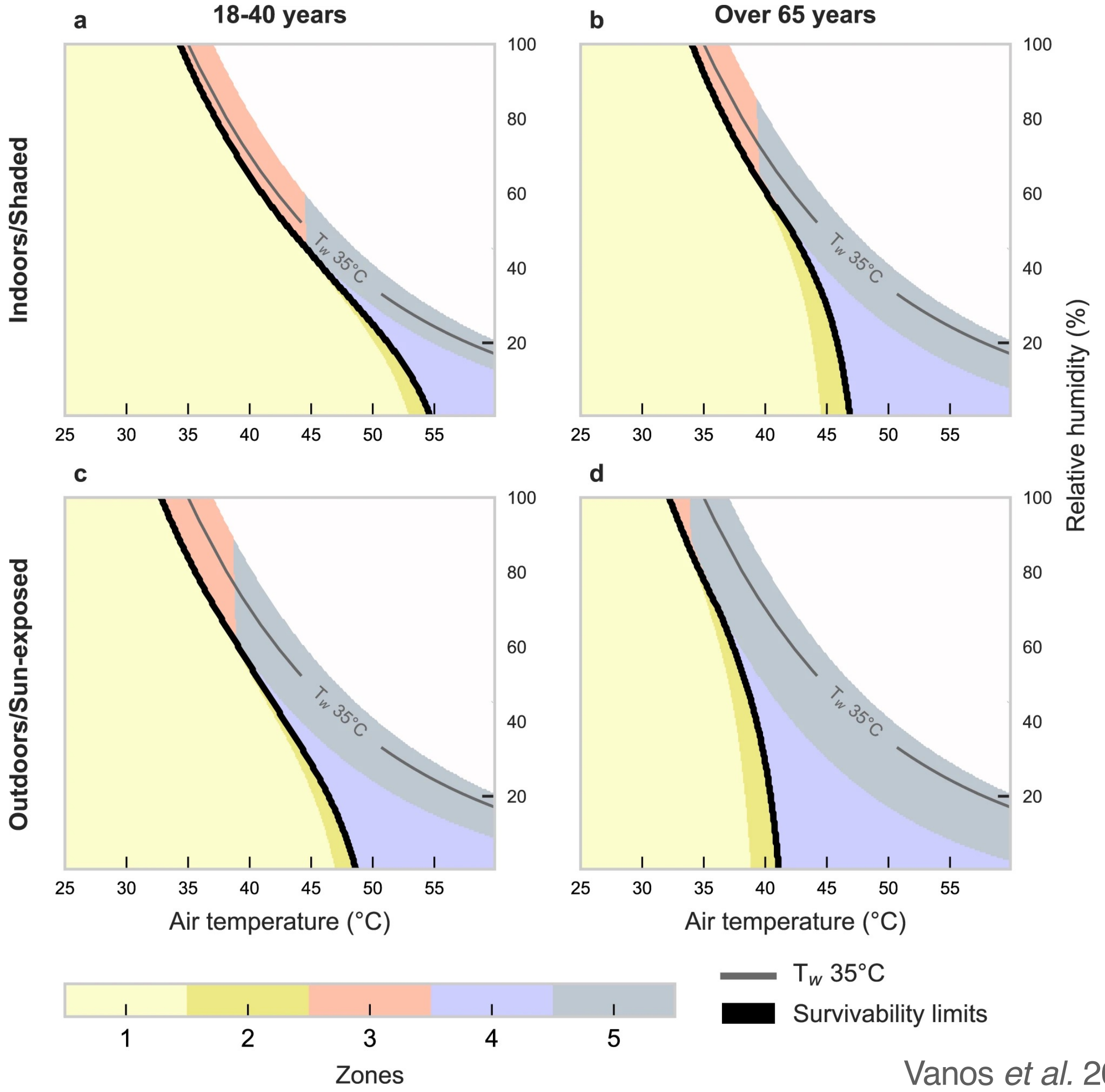
The relationship between moisture and temperature is really important for climate projections due to **<u>exponential scaling of humid-heat.</u>**



Baldwin *et al.* 2023

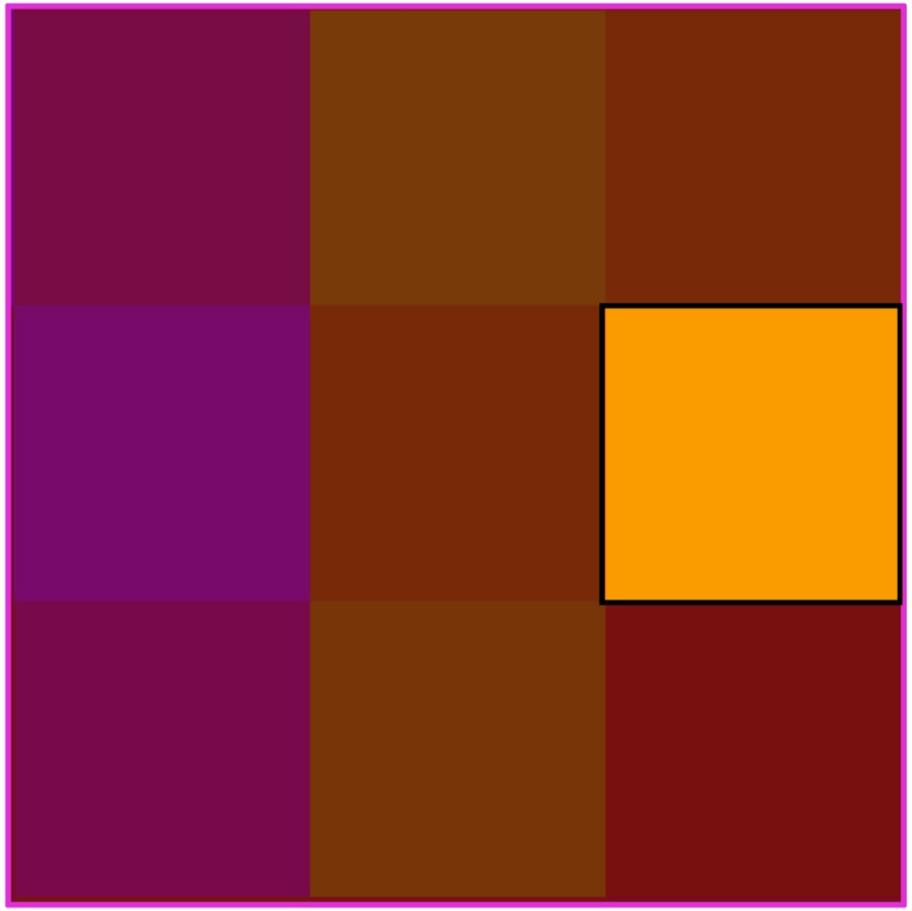
Heat Impacts to Human Health

- Wet Bulb Temperature (WBT) of 35°C has been proposed to be lethal with 6 hours of exposure (Sherwood, S. C. and Huber 2010) … may be as low as 31°C (Vecellio *et al*. 2022).
- WBT ≠ Wet Bulb Globe Temperature
- Research published this week attempts to reconcile dangerous dry air vs. dangerous moist air temperatures for different demographics (Vanos *et al*. 2023).



Vanos *et al.* 2023

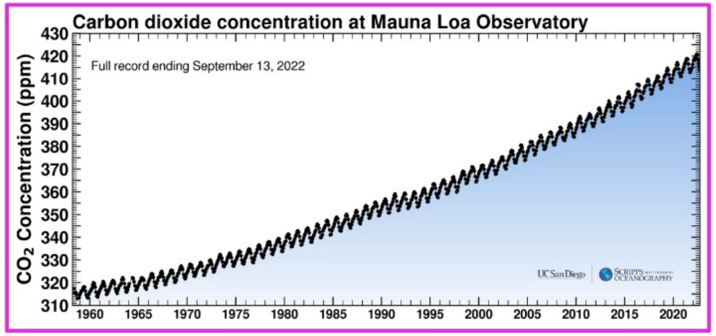
Interactions with Land-Cover and Land-Use Change



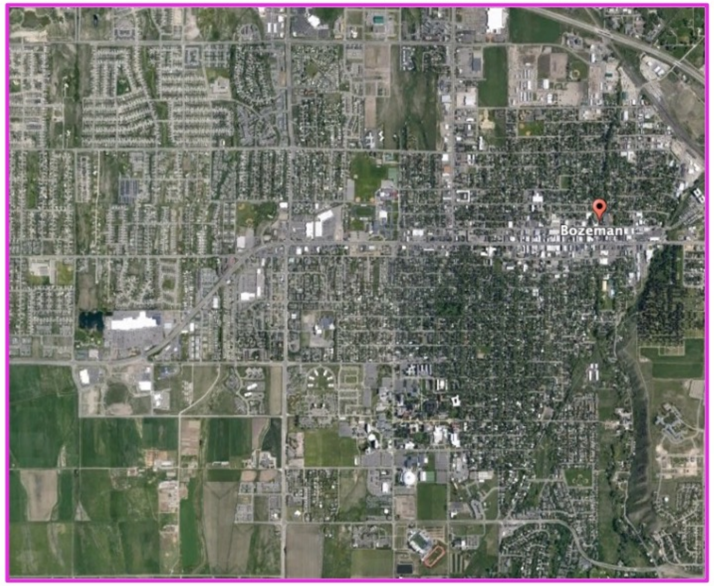
Annual Increase In Hot-Humid Days

Humidity

Ambient Temperatures

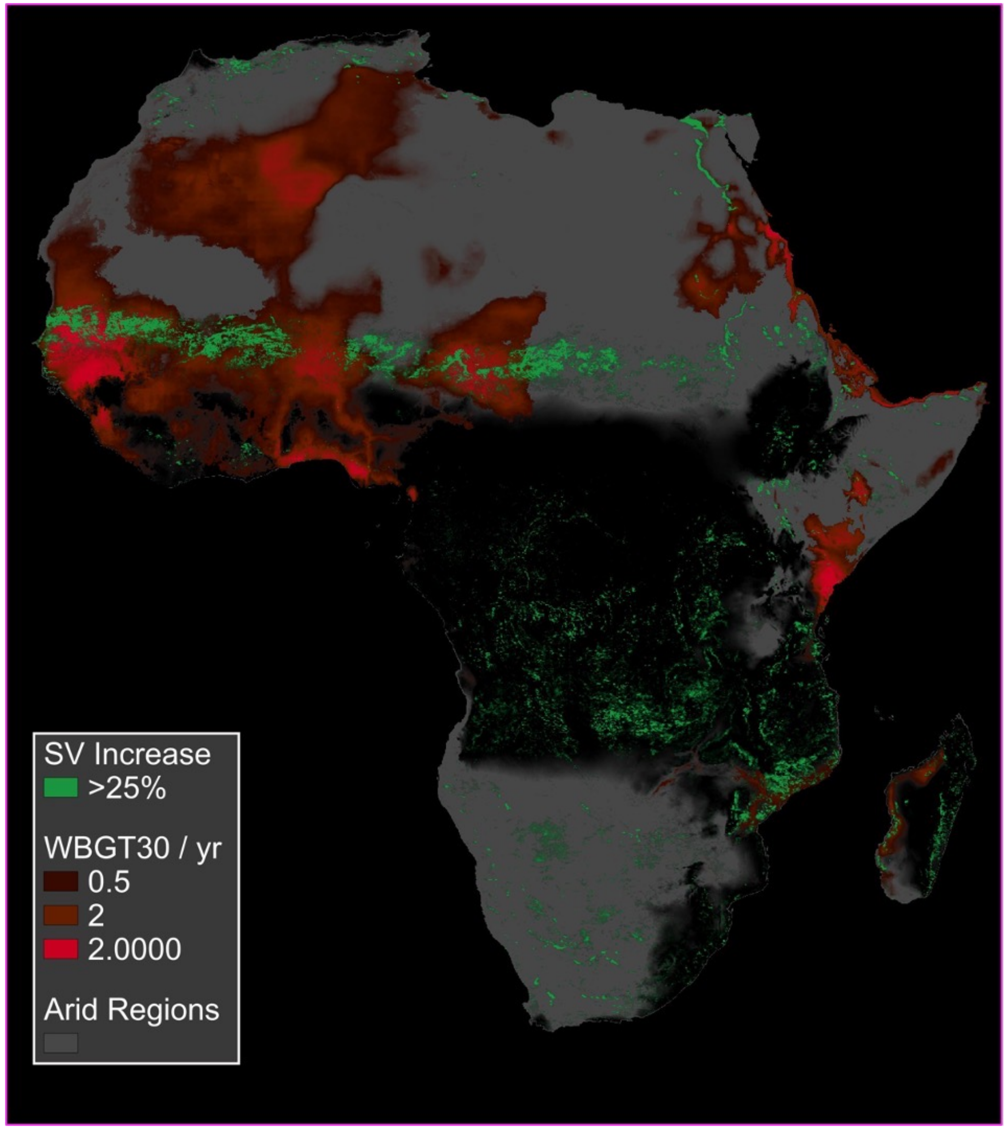


Climate Change

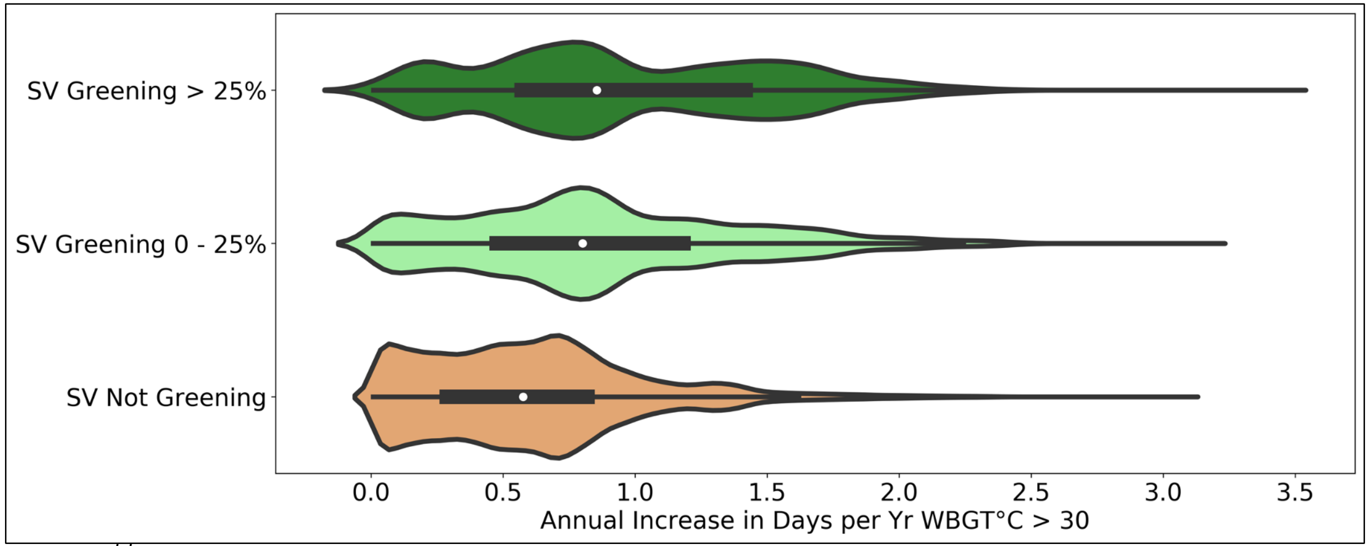


LCLUC

Interactions with Land-Cover and Land-Use Change



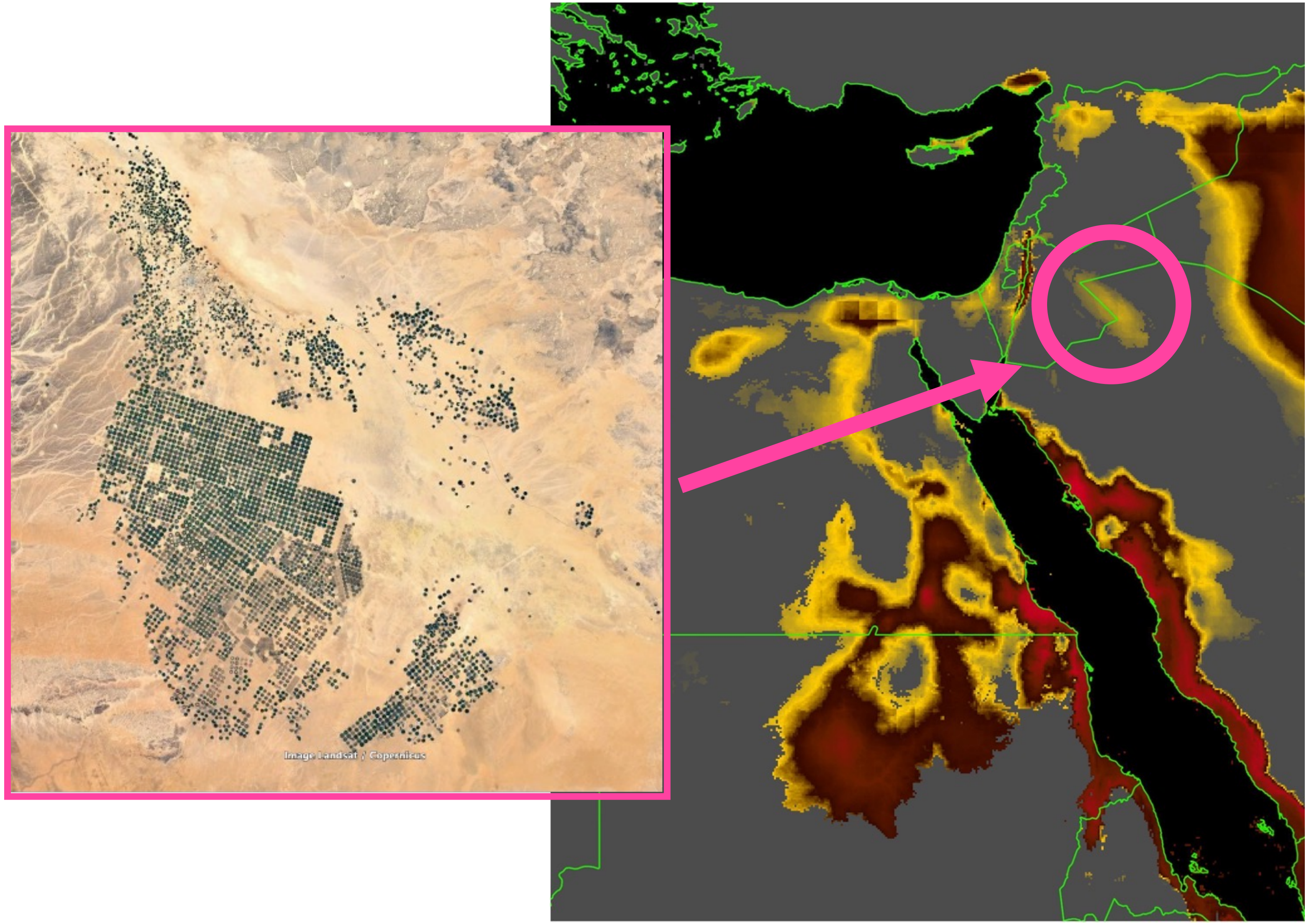
- Evidence that **dangerous heat is increasing across Africa's "Great Green Wall"** faster than surrounding arid regions.
- Implications for poverty reduction efforts and human health outcomes.



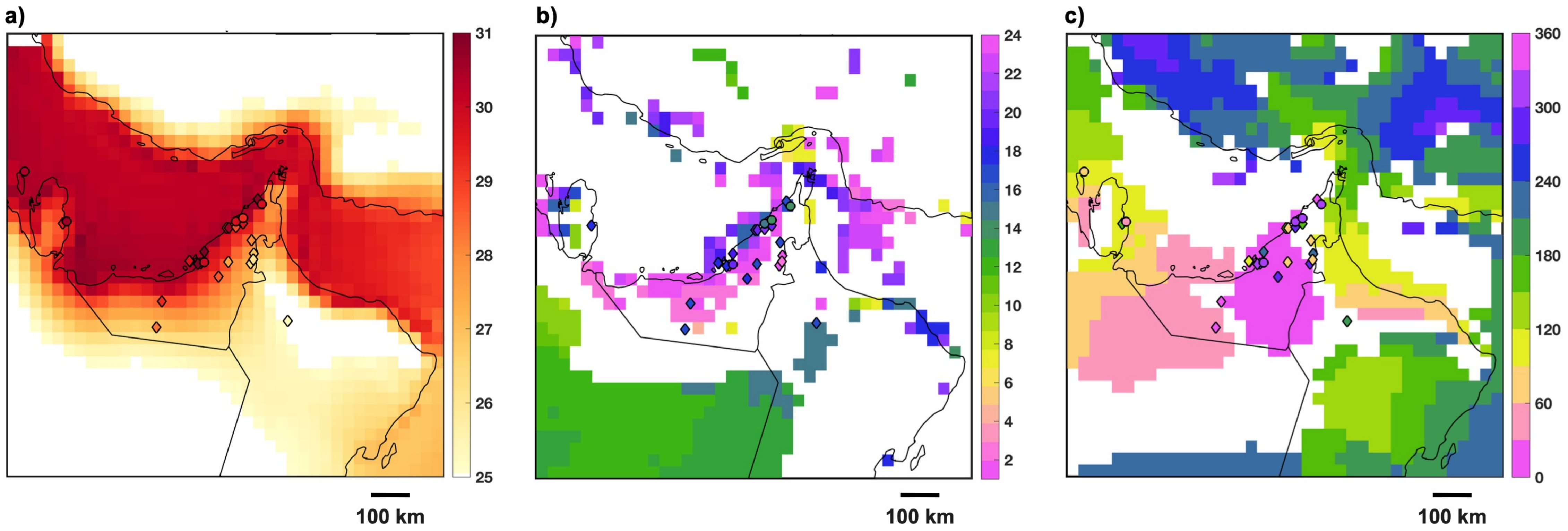
Interactions with Land-Cover and Land-Use Change

- Emerging Agricultural "Humid-Heat" Heat Islands in Arabian desert.

- Eqi Luo, is investigating the relationship between LCLUC, humid-heat, and population change in the region.



Timing of heat stress matters



Evidence that most dangerous extreme heat occurs in the evening or at night, bucking conventional wisdom that day temperatures are hottest…Key for heat adaptations.

Figure by Colin Raymond, UCLA

Raymond *et al.* In Review. Communications Earth & Environment.

Heat Impacts to Human Health

	Chronic	Acute
Direct		
Indirect		

Heat Impacts to Human Health

	Chronic	Acute
Direct	Kidney Disease	Heat Stroke
Indirect	Labor productivity decrease reduce ability to pay for healthcare	Child wasting due decrease food availability due to crop damage

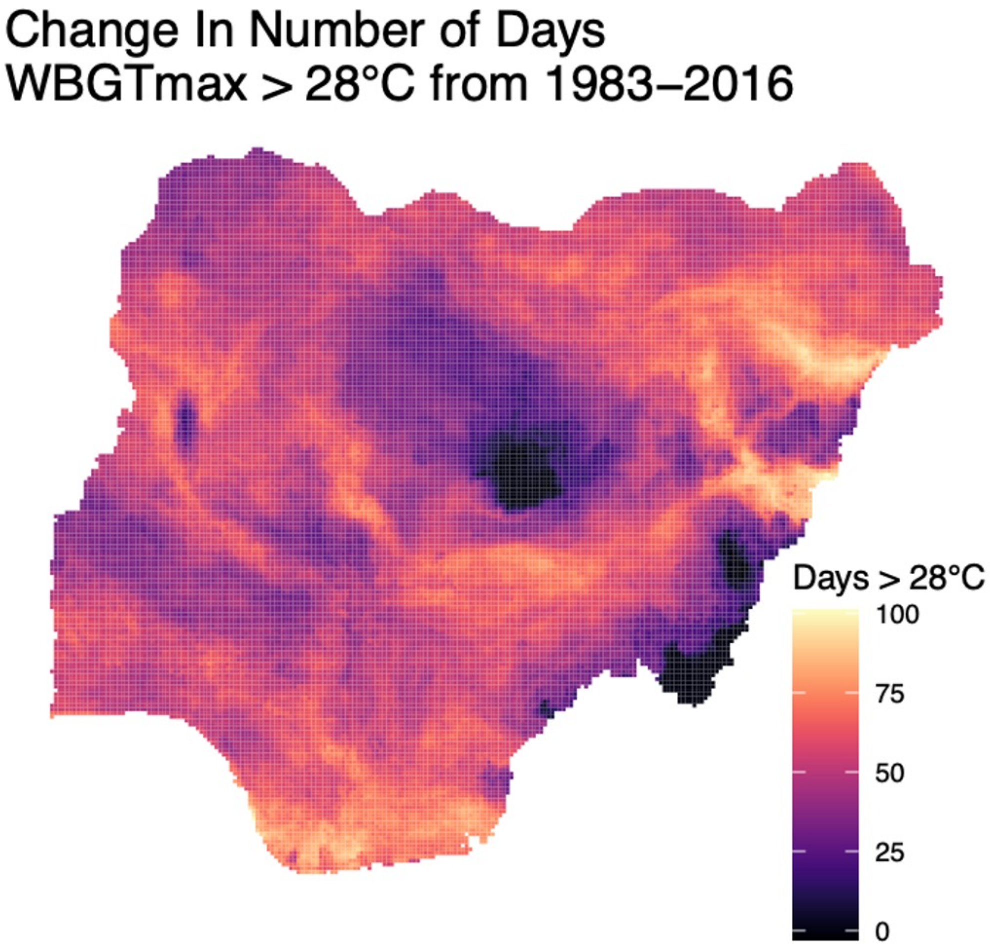
(Towards) Impacts: Nigeria Fertility

- Climate change is increasing the intensity, frequency, and severity of extreme heat events in Nigeria.

- **Impacts to fertility are understudied** relative to other demographic processes but link directly to climate change

- Low-income, tropical countries, like **Nigeria, face a triple burden**: (1) Climate vulnerability, (2) high population growth, (3) many poor people, with weak health systems.

- Figure by Nina Brooks, Boston U.



Brooks, Tuholske, *et al.* In Review. PNAS

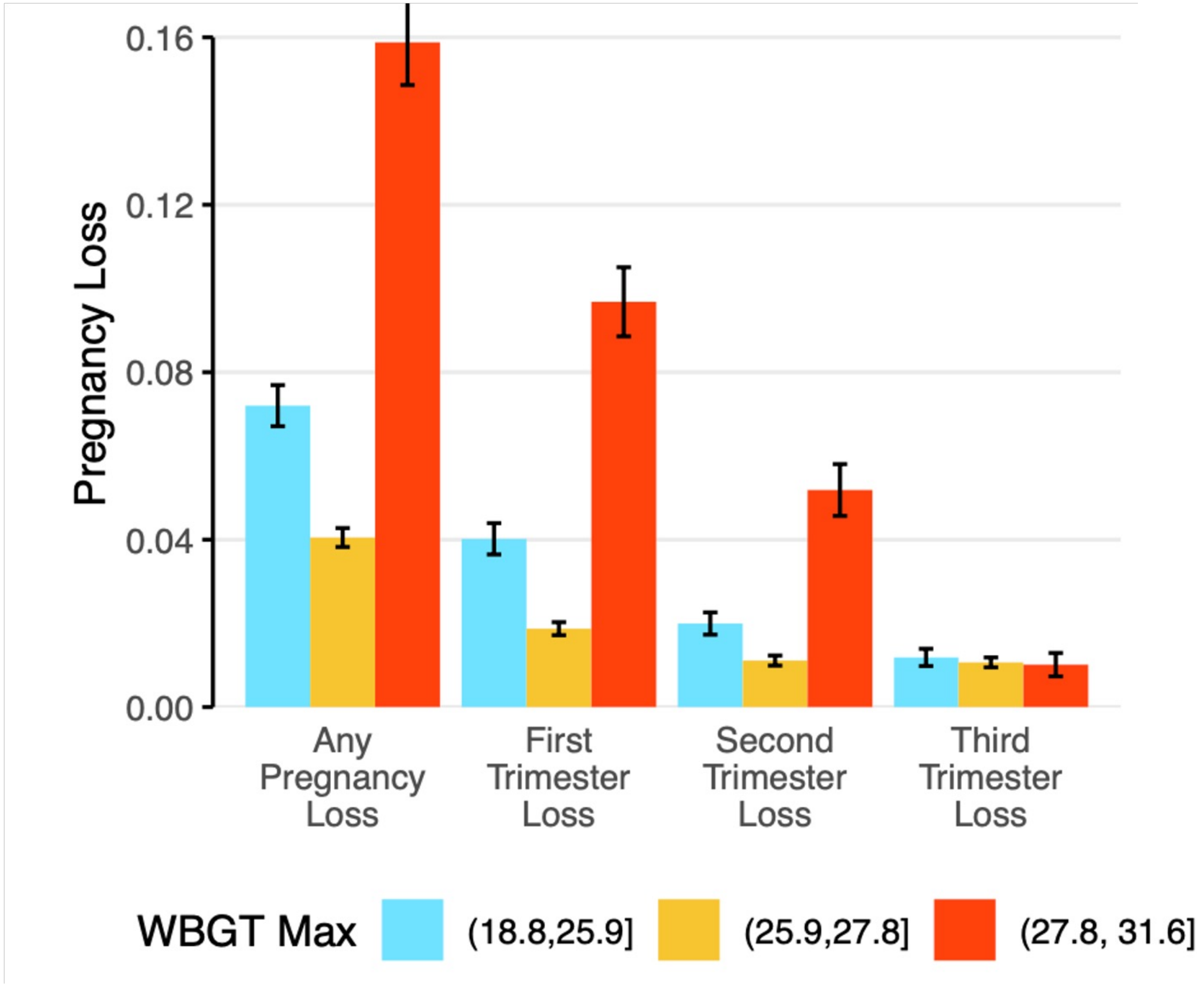
(Towards) Impacts: Nigeria Fertility

- Log-odds models employed with fixed “exposure windows” because we don’t have daily outcome data.

- A 1°C increase WBGT is associated with a **33.8% decrease in the odds** of conception.

- Overall, a 1°C increase in WBGT during gestation is associated with a **28% increase in odds of pregnancy loss** at any point during gestation.

- Figure by Nina Brooks, Boston U.



Brooks, Tuholske, *et al.* In Review. PNAS

Thank you!
Questions?

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