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Life Expectancy at Risk: The Enduring Impact of El Niño on Human Mortality

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Joint work with Yanbin Xu, Benjamin P. Horton, and Dhruvajyoti Samanta



Agenda

- Background
- ENSO & Research Questions
- Methodology
- Results
- Conclusions

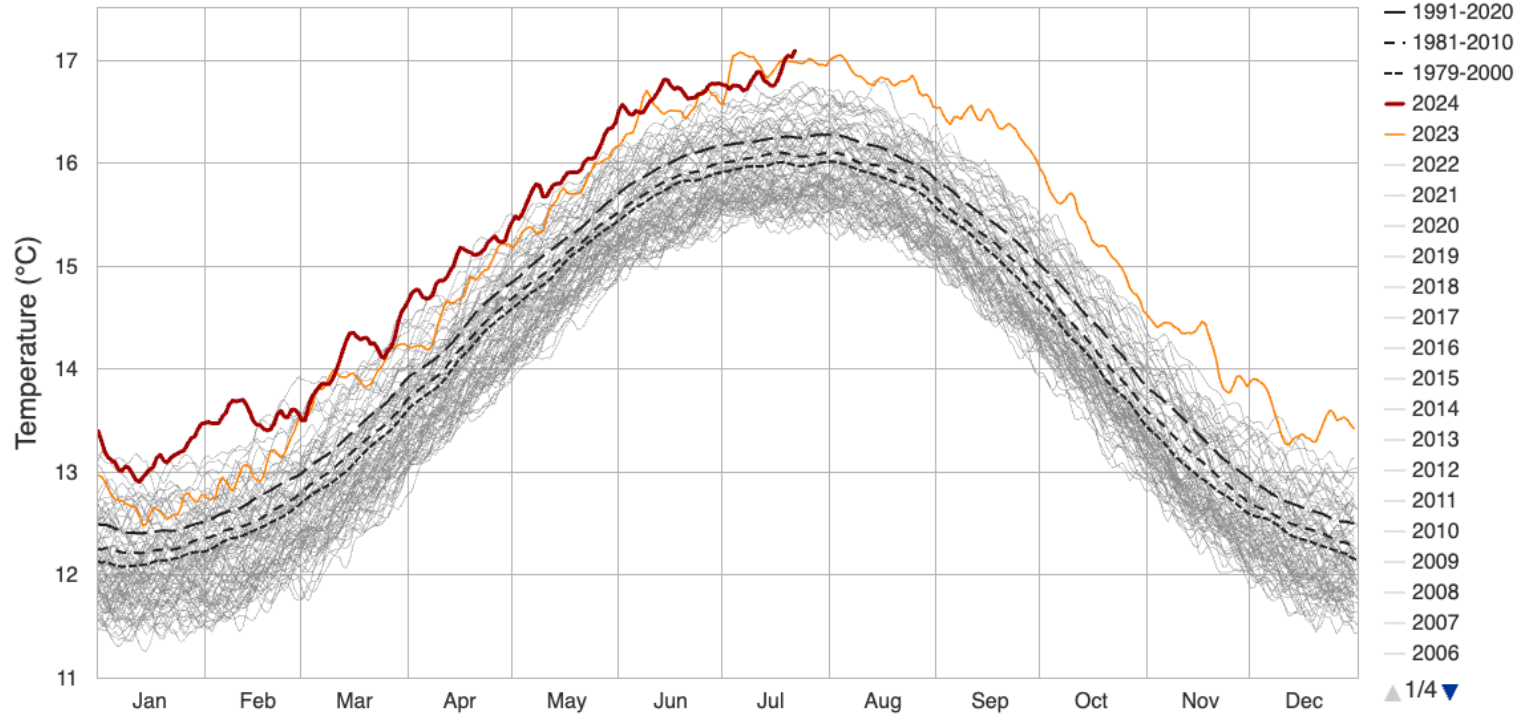
BACKGROUND



Records Keep Being Broken

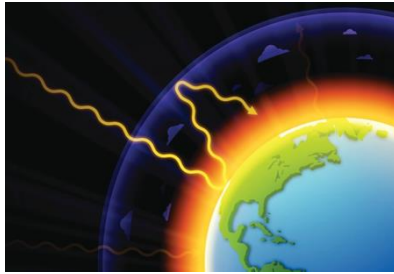
Daily Surface Air Temperature, World (90°S–90°N, 0–360°E)

Dataset: ECMWF Reanalysis v5 (ERA5) downloaded from C3S | Image Credit: ClimateReanalyzer.org, Climate Change Institute, University of Maine



Source: ERA5

Climate Change Risk



Greenhouse gas concentrations



Increasing temperature



Sea level rise



Extreme weather



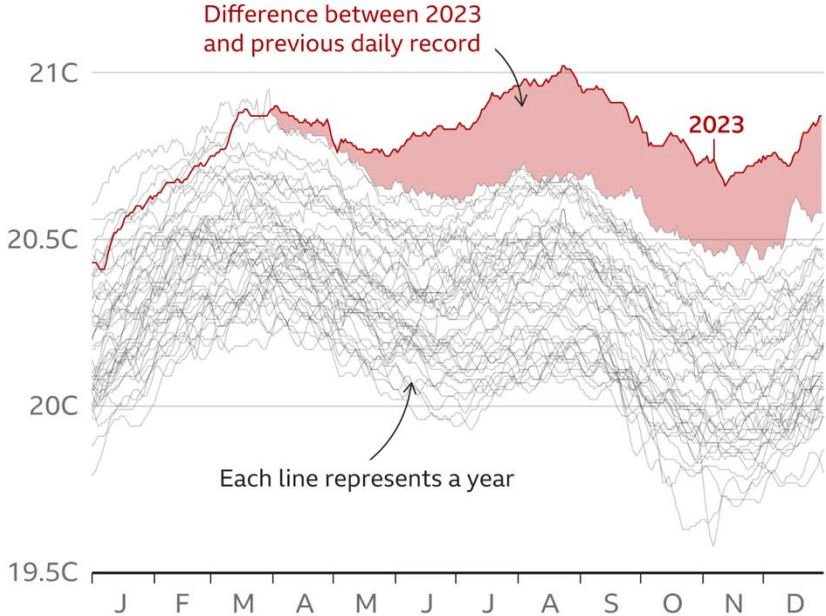
Melting ice and glacier

Source: MIT News; Google earth; BBC

Climate Change Risk

Ocean temperatures highest on record

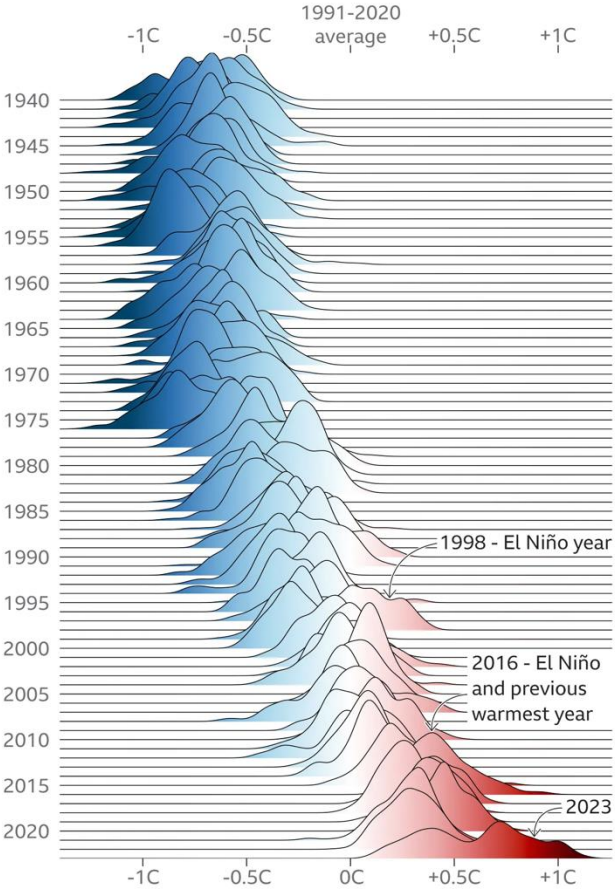
Daily average sea surface temperature, 1979-2023



Note: Temperatures between latitudes 60° North and 60° South

More days at the highest temperatures in 2023

Daily global air temperature compared with the 1991-2020 average, by year



Source: ERA5, C3S/ECMWF

Extreme Weather and Climate Events



- **Floods:** Mediterranean Cyclone Daniel caused deadly flooding in Greece, Bulgaria, Turkey, and Libya.
- **Tropical Cyclones:** Cyclone Freddy, one of the longest-lived cyclones, impacted Madagascar, Mozambique, and Malawi. Cyclone Mocha was among the most intense in the Bay of Bengal.
- **Extreme Heat:** Southern Europe and North Africa faced severe heatwaves, with record temperatures in Italy, Tunisia, Morocco, and Algeria.
- **Wildfires:** Canada's wildfire season was unprecedented, burning over six times the 10-year average area.

Economic Impact of Climate Change

- Global temperature rises will negatively impact GDP in all regions by mid-century.
- Asian countries, including Advanced Asia and Economies in southeast Asia (ASEAN) countries would be hardest hit.

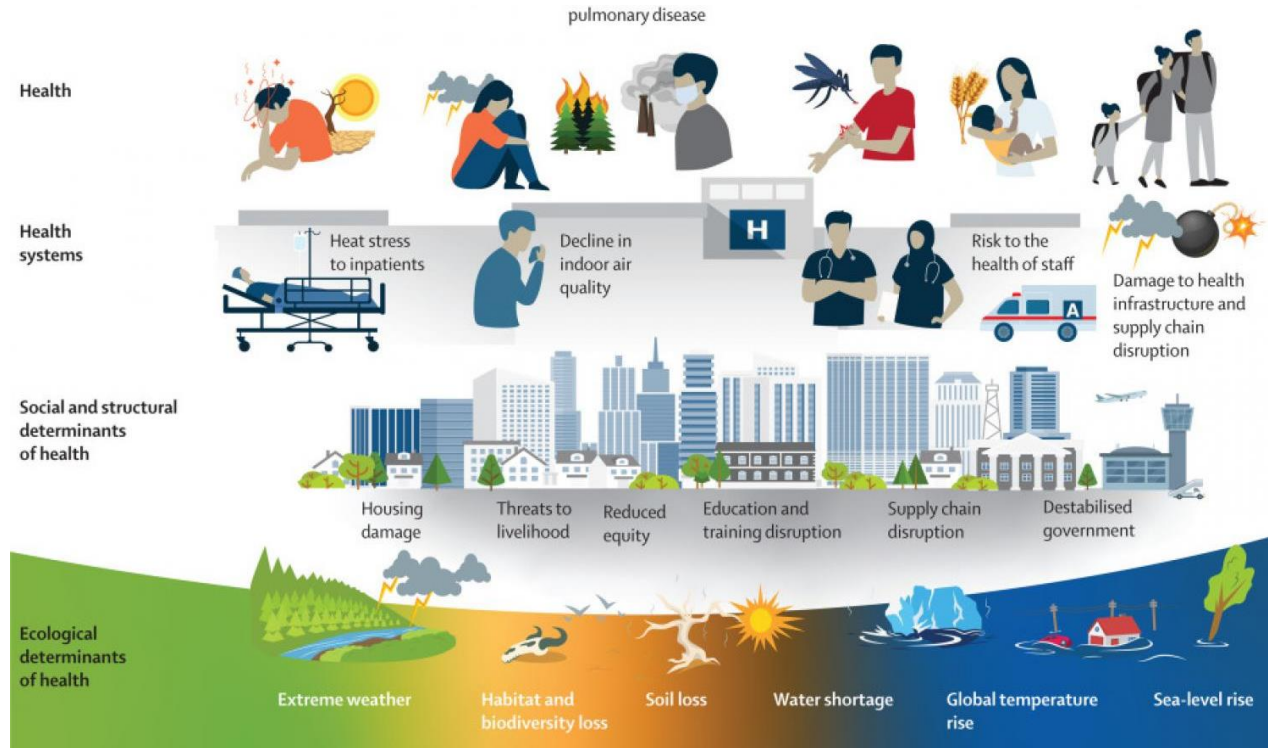
	Temperature rise scenario, by mid-century			
	Well-below 2°C increase	2.0°C increase	2.6°C increase	3.2°C increase
	<i>Paris target</i>	<i>The likely range of global temperature gains</i>		<i>Severe case</i>
Simulating for economic loss impacts from rising temperatures in % GDP, relative to a world without climate change (0°C)				
World	-4.2%	-11.0%	-13.9%	-18.1%
OECD	-3.1%	-7.6%	-8.1%	-10.6%
North America	-3.1%	-6.9%	-7.4%	-9.5%
South America	-4.1%	-10.8%	-13.0%	-17.0%
Europe	-2.8%	-7.7%	-8.0%	-10.5%
Middle East & Africa	-4.7%	-14.0%	-21.5%	-27.6%
Asia	-5.5%	-14.9%	-20.4%	-26.5%
Advanced Asia	-3.3%	-9.5%	-11.7%	-15.4%
ASEAN	-4.2%	-17.0%	-29.0%	-37.4%
Oceania	-4.3%	-11.2%	-12.3%	-16.3%

Source: Swiss Re Institute (2021)

Health/Mortality Impact of Climate Change



Impact of Climate Change on Health



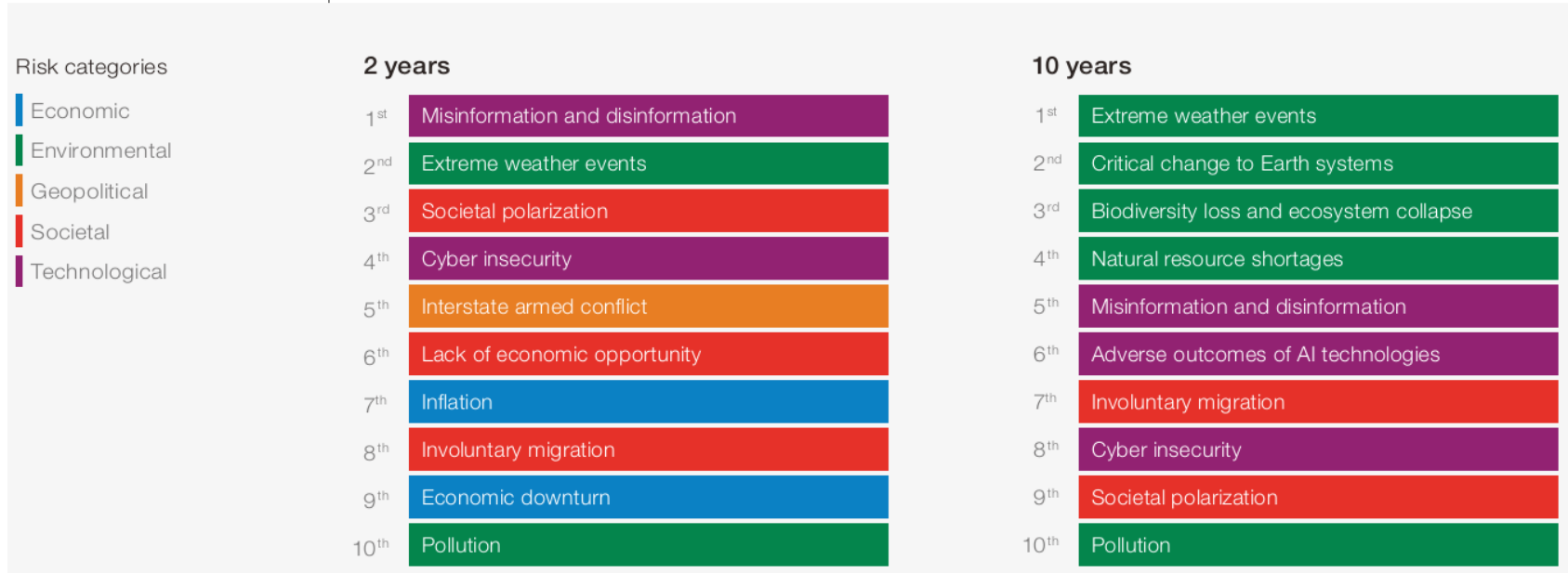
Source: The Lancet Planetary Health, Volume 7, March 2023

Global Risk Ranks by WEF

FIGURE C

Global risks ranked by severity over the short and long term

"Please estimate the likely impact (severity) of the following risks over a 2-year and 10-year period."

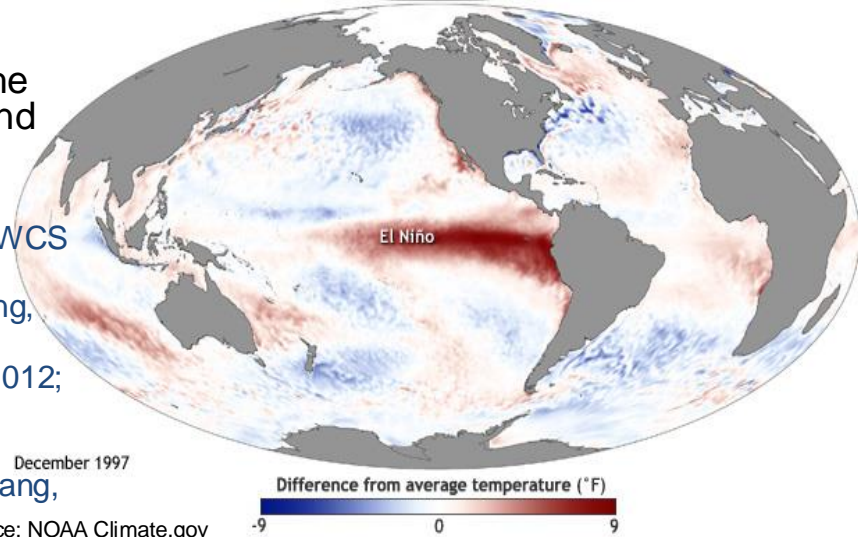
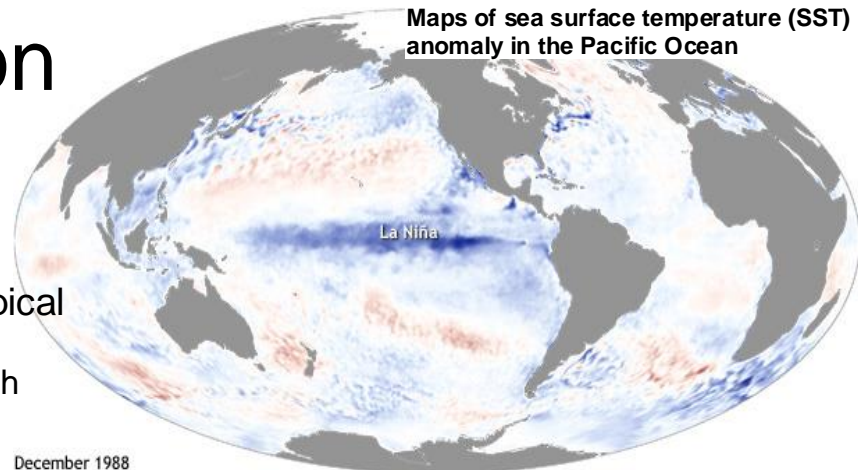


Source: World Economic Forum Global Risks Perception Survey 2023-2024.

ENSO AND RESEARCH OBJECTIVES

El Niño-Southern Oscillation (ENSO)

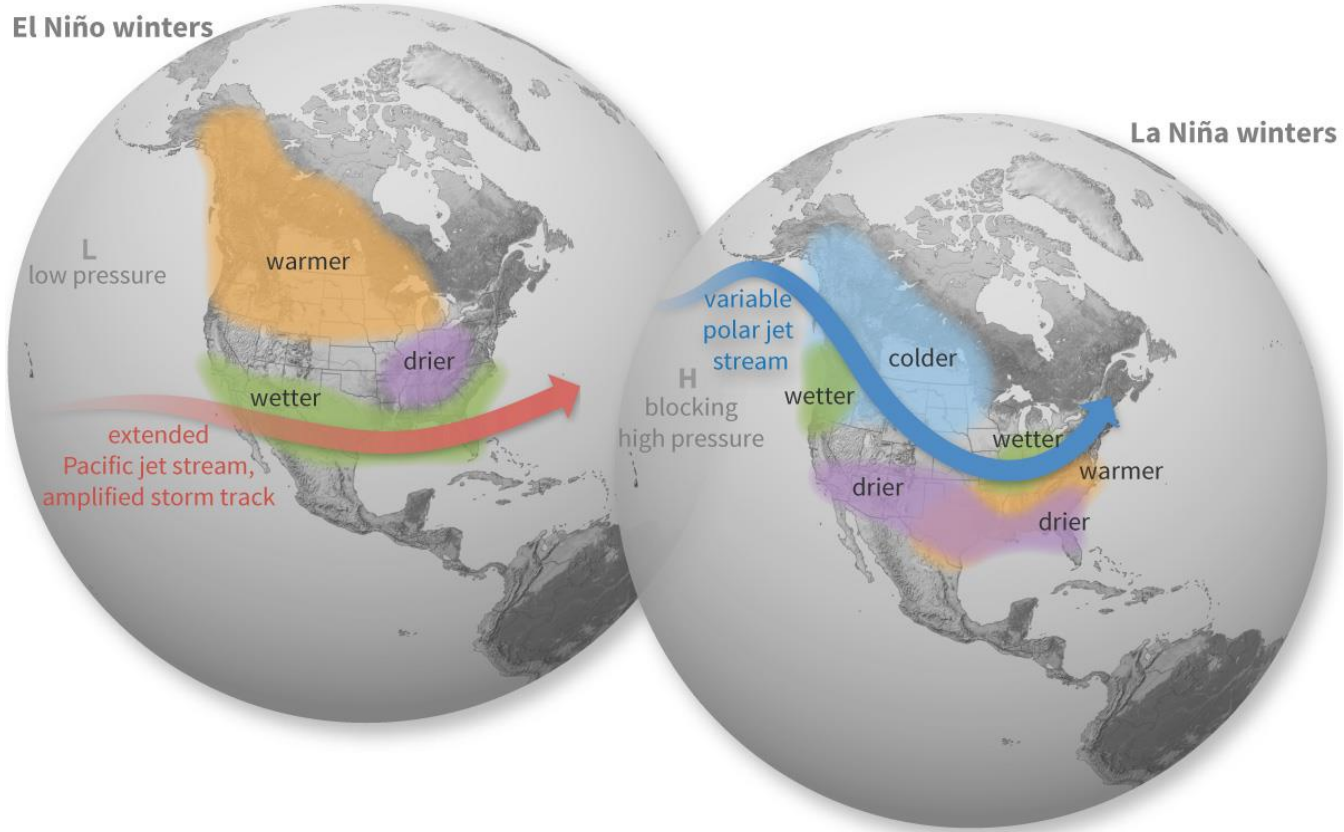
- **ENSO:** A complex climate pattern in central - eastern tropical Pacific Ocean
 - A leading mode of interannual climate variability on Earth
- Two opposite phases:
 - **El Niño (warm phase)**
 - **La Niña (cold phase)**
- Climate anomalies: Lead to significant differences from the average ocean temperatures, winds, surface pressure, and rainfall across the globe
- Impacts
 - Flooding (Magilligan et al, Geology, 2001; Corringham et al, WCS 2019)
 - Crop yields (Lizumi et al, Nat. Commun. 2014; Hsiang & Meng, AER 2015)
 - Commodity price fluctuations (Brunner, RES 2002; Ubilava 2012; Ubilava 2017)
 - Civil conflicts (Hsiang & Meng Nature 2011)
 - Socioeconomic losses (short-term and long-term; Burke, Hsiang, Miguel, Nature 2015; Liu et al, Nat. Commun. 2022)



Source: NOAA Climate.gov

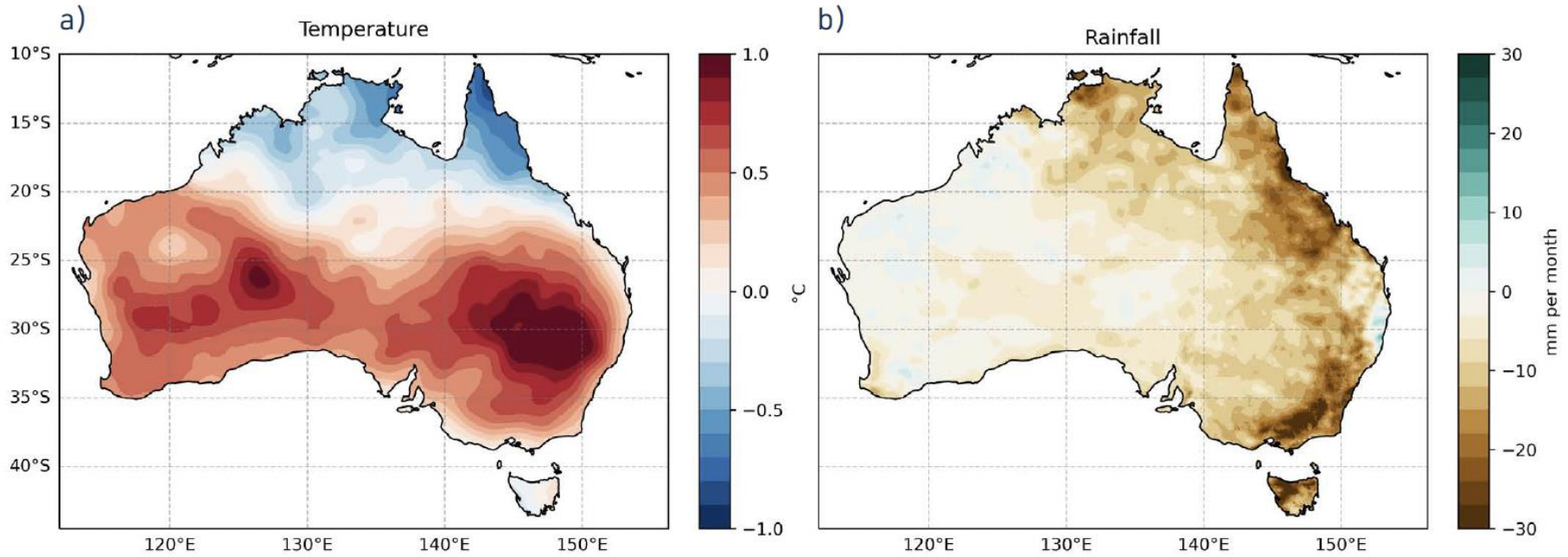


El Niño/La Niña and US Climate



Source: NOAA Climate.gov

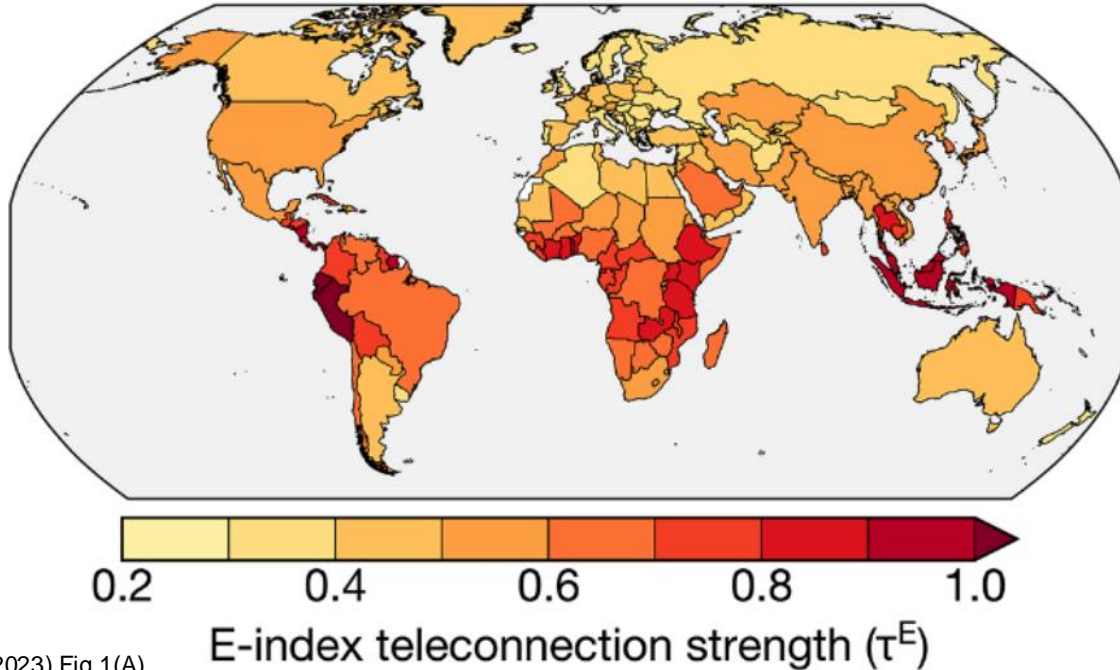
El Niño/La Niña and Australia Climate



ENSO Teleconnection

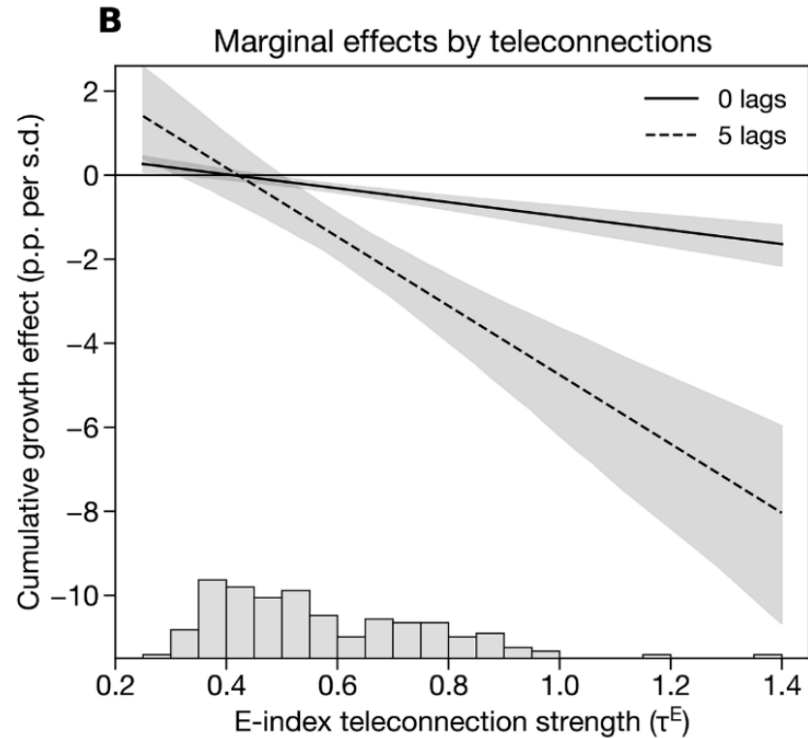
A

ENSO teleconnections



Source: Callahan and Mankin (2023) Fig 1(A)

ENSO and Economic Growth



Source: Callahan and Mankin (2023) Fig 1(B)

Research Question

- Does ENSO have significant impact on human mortality?
- If so, is the impact short-term or persistent?
- What is the impact on a decadal time scale?
- What are the possible channels of the impact?

METHODOLOGY

Methodology: Data

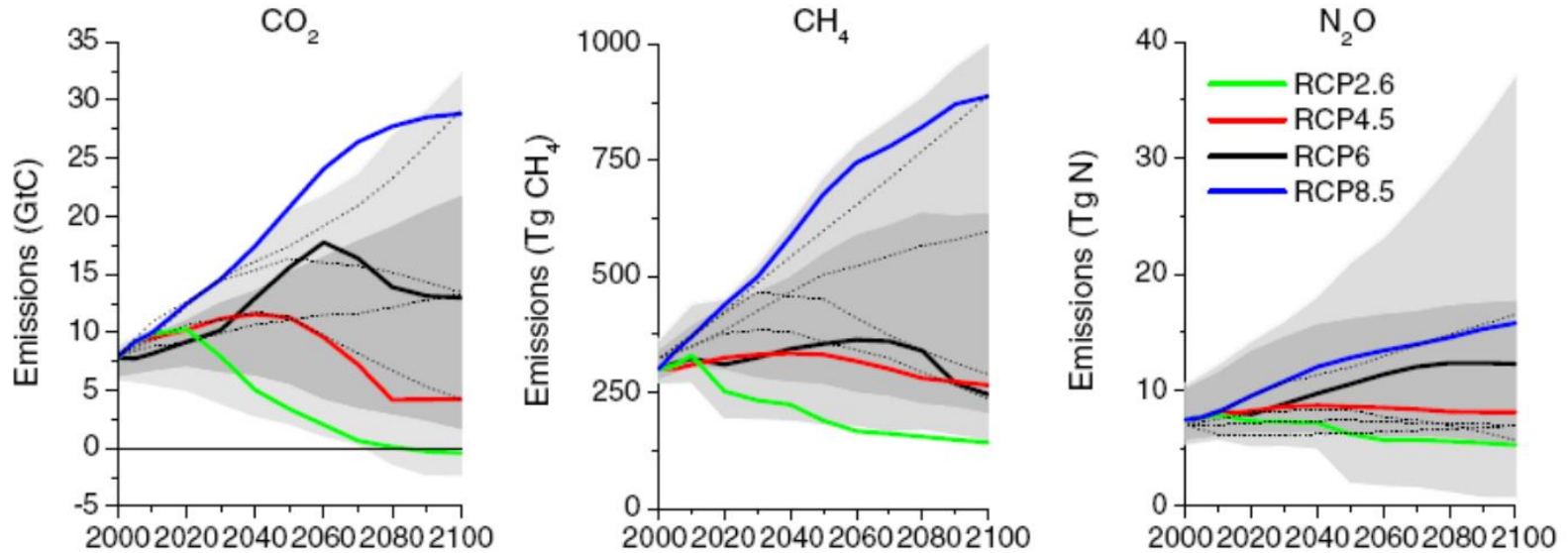
- **Mortality Data:** Total population mortality for Asia-Pacific regions
 - Australia, Canada, Chile, Japan, New Zealand, the Republic of Korea, Taiwan, the U.S., Singapore, and Hong Kong
 - HMD, USMDB, and Singapore Department of Statistics
- **Economic Data:** control for impacts of economic slowdowns
 - GDP per capita; CPI; GDP per capita; unemployment, etc. from OECD
 - business confidence index (BCI); consumer confidence index (CCI), etc., from OECD
- **Historical Meteorological Data:**
 - monthly land temperature data from the Berkeley Earth dataset
 - sea surface temperature (SST) data from the Hadley Centre Sea Ice and Sea Surface Temperature dataset (HadISST)
 - precipitation data from the Global Precipitation Climatology Center (GPCC)
- **Shared Socioeconomic Pathways (SSP) Projection Data:**
 - Climate model data derived from the 6th Climate Model Intercomparison Project (CMIP6)
 - Monthly SST, atmospheric temperature, and precipitation from 1850 – 2099.
 - Four Tier 1 experiments: SSP1-2.6, SSP2-4.5, SSP3-7.0; SSP5-8.5.

Methodology: Climate Projections

- Project the Climate Change: SSP and RCP Framework

	RCPs (Representative Concentration Pathways)	SSPs (Shared Socioeconomic Pathways)
Focus	<ul style="list-style-type: none">• Primarily concerned with greenhouse gas concentration trajectories.• Do not specify the socioeconomic conditions that lead to these trajectories.	<ul style="list-style-type: none">• Focused on the socioeconomic factors that might affect greenhouse gas emissions and adaptation to climate change.• Outline different futures based on demographic, economic, and technological developments.
Purpose	<ul style="list-style-type: none">• Developed for the Intergovernmental Panel on Climate Change (IPCC) assessments.	<ul style="list-style-type: none">• SSPs were developed to complement RCPs by providing detailed narratives.• They help researchers understand the implications of different mitigation and adaptation strategies.
Scenarios	<p>Main: RCP2.6, RCP4.5, RCP6, and RCP8.5</p> <ul style="list-style-type: none">• The numbers refer to the radiative forcing that each scenario predicts by 2100.	<p>Main: SSP1, SSP2, SSP3, SSP4, SSP5</p>

Representative Concentration Pathway



Shared socioeconomic pathways (SSPs)

SSP1

“Sustainability – Taking the Green Road”

- The world shifts gradually toward a more sustainable path
- The emphasis on economic growth shifts toward an emphasis on human well-being
- Inequality is reduced both across and within countries

SSP2

“Middle of the Road”

- A path in which social, economic, and technological trends do not shift markedly from historical patterns
- Global population growth is moderate and levels off in the second half of the century
- Income inequality persists or improve slowly

SSP3

“Regional Rivalry – A Rocky Road”

- Countries increasingly focus on domestic or regional issues
- Investment in education and technological development decline
- Slow economic development, inequalities persist or worsen, and strong environment degradation in some

SSP4

“Inequality – A Road Divided”

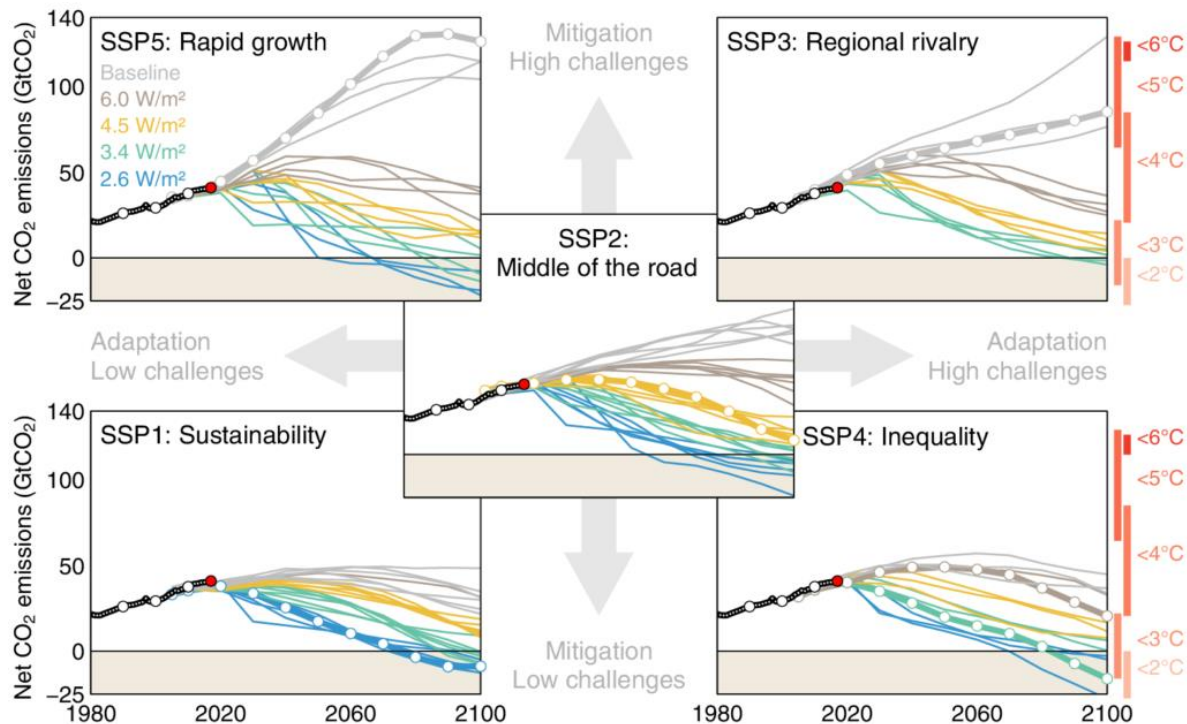
- Increasing inequalities and stratification across and within countries
- Technology development is high in only high-tech economy and sectors
- Energy sector diversifies, with investment in both carbon-intensive and low-carbon energy sources

SSP5

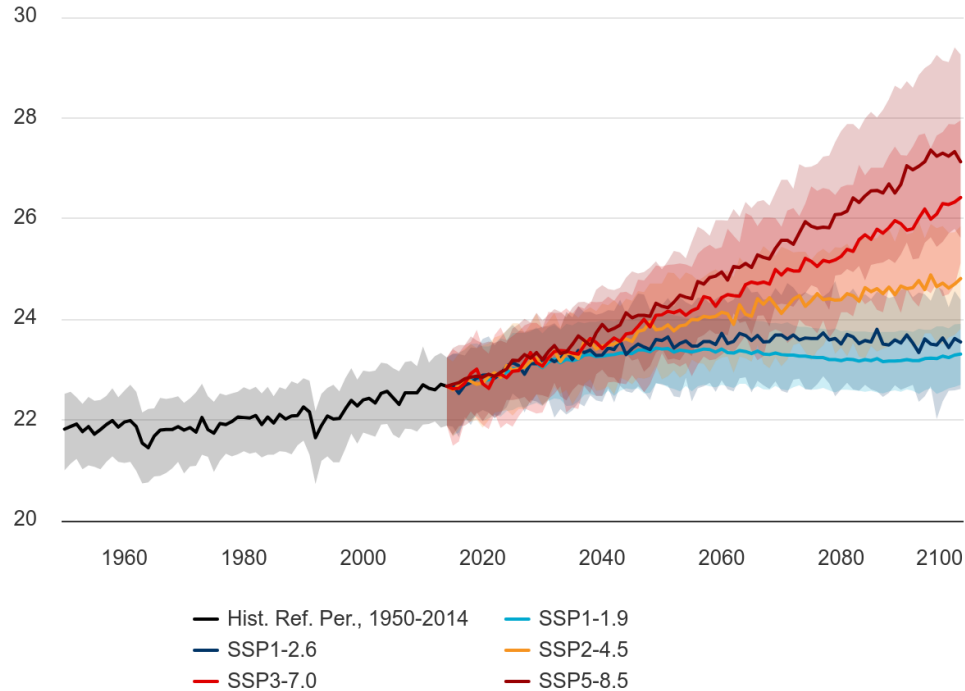
“Fossil-Fueled Development – Taking the Highway”

- Rapid technological progress and development of human capital
- High economic growth and strong globalization
- High carbon intensity and high energy intensity

Shared socioeconomic pathways (SSPs)



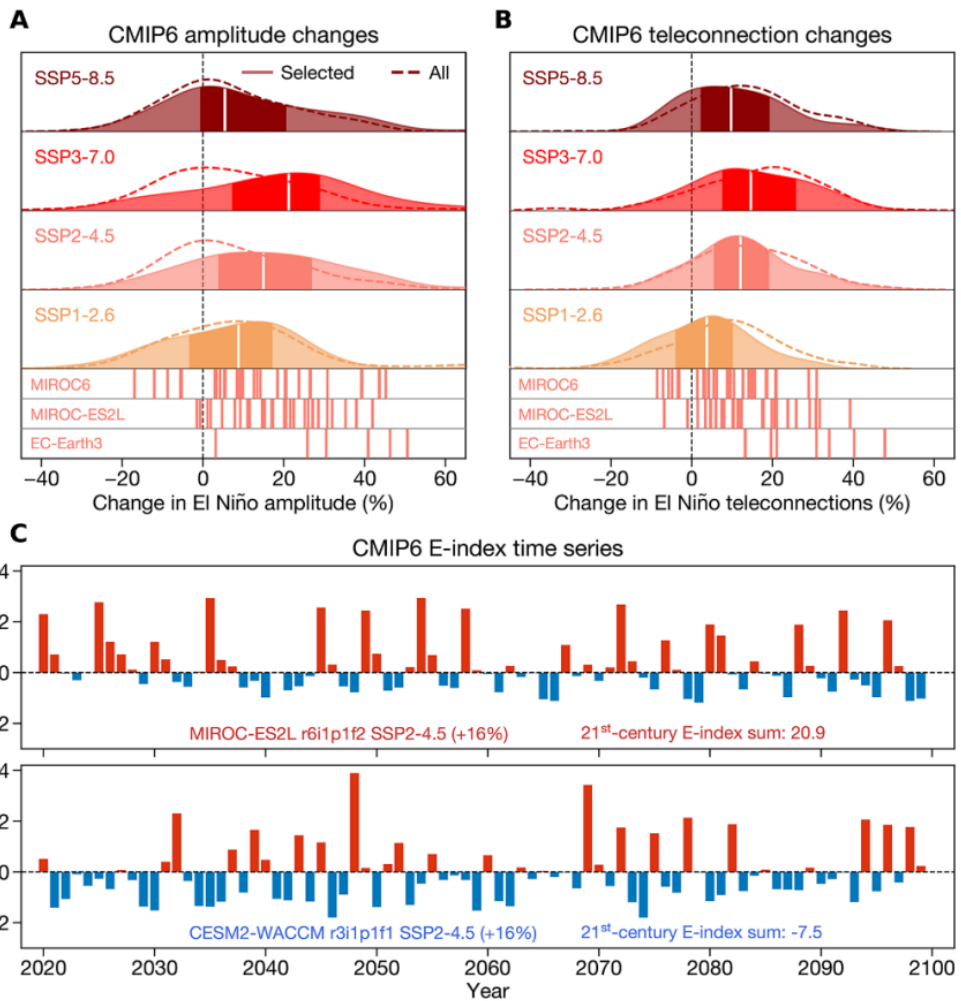
Projected Average Mean Surface Air Temperature Australia; (Ref. Period: 1995-2014), Multi-Model Ensemble



Thermal Risk Projection for Australia by 2099

Source: World Bank

Climate Model Projections of ENSO



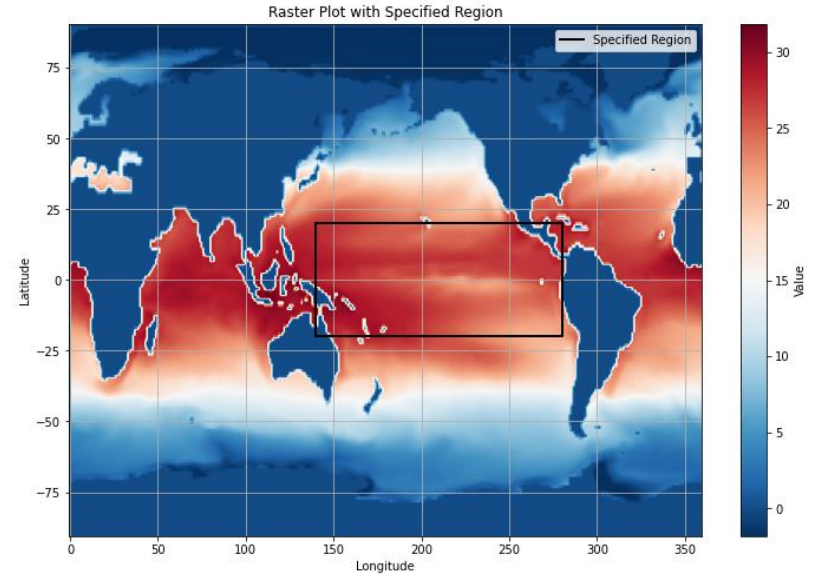
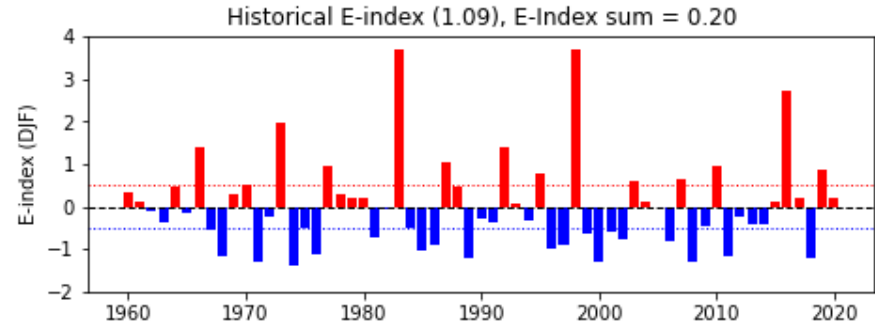
Source: Callahan and Mankin (2023) Fig 3

Methodology: ENSO indices

- E-index & C-index to quantify ENSO's effect:
 - The E-index and C-index are derived from the first two principal components (PCs) applied to Pacific SSTs over the region 20° S to 20° N and 140° E to 80° W:

$$E = \frac{PC_1 - PC_2}{\sqrt{2}} ; C = \frac{PC_1 + PC_2}{\sqrt{2}}$$

- We also calculated the Niño3.4 index, which spans spanning from 5° S to 5° N and 170° E to 120° W as a robustness check.
 - Many other ENSO indices:
<https://www.weather.gov/fwd/indices>



Econometric model

$$MI_{ixt} = \sum_{l=0}^L (\beta_{0l} + \beta_{1l}\tau_i^P + \beta_{2l}\tau_i^T) E_{t-l} + Controls_{it} + u_{ix} + \epsilon_{ixt}$$

- Mortality improvement: $MI_{ixt} = \log(m_{ixt}) - \log(m_{ix(t-1)})$,
- E_t : E-index of time t .
- τ_i^P and τ_i^T are the precipitation and temperature teleconnection for country i , respectively.
 - Allows the effect of ENSO to vary between countries based on the extent to which each country's temperature and precipitation are coupled with ENSO
- u_{ix} : country-age fixed effect to address hidden heterogeneity.

ENSO effect

- The accumulated effect of ENSO in the year t following a shock

$$\Theta_{iL} = \sum_{l=0}^L (\beta_{0l} + \beta_{1l}\tau_i^P + \beta_{2l}\tau_i^T)$$

- Life Expectancy Loss - “*Counterfactual*” E-index and mortality:

- $m_{ixt}^{CF} = m_{ix(t-1)}^{CF} \cdot \exp\{MI_{ixt}^{CF}\} \quad (t \geq t_0)$

- $MI_{ixt}^{CF} = MI_{ixt} - \Delta_{ixt}$

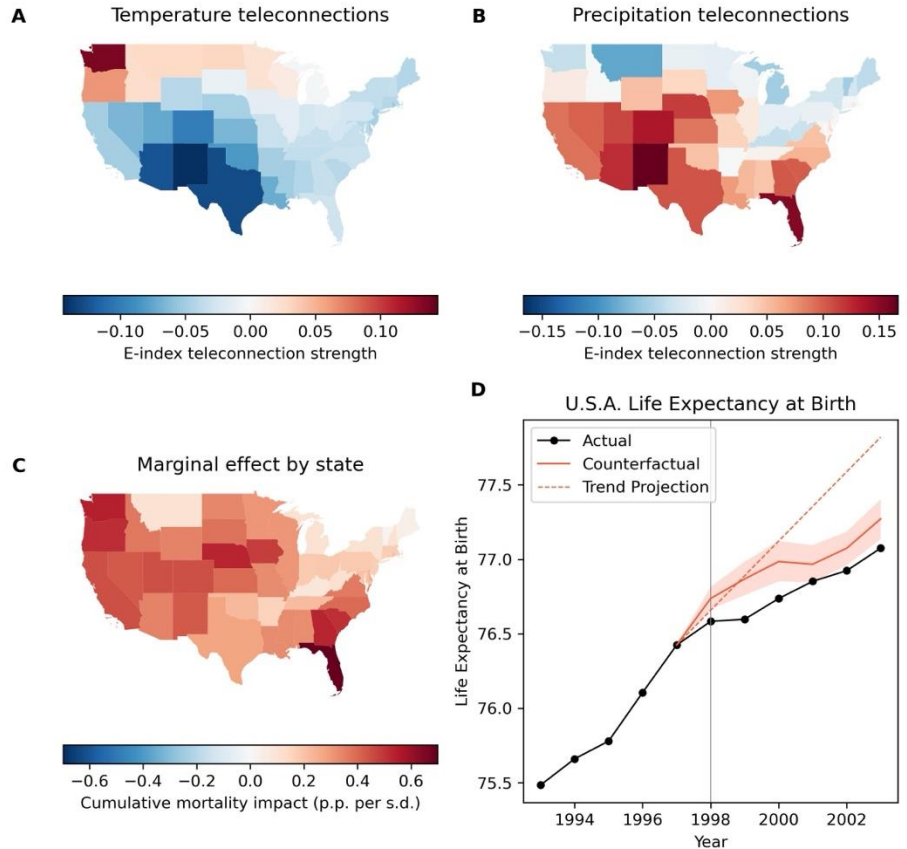
- Δ_{ixt} : change in MI due to El Niño

$$\Delta_{ix(t+l)} = (\beta_{0l} + \beta_{1l}\tau_i^P + \beta_{2l}\tau_i^T) \cdot (E_t - E_t^{CF})$$

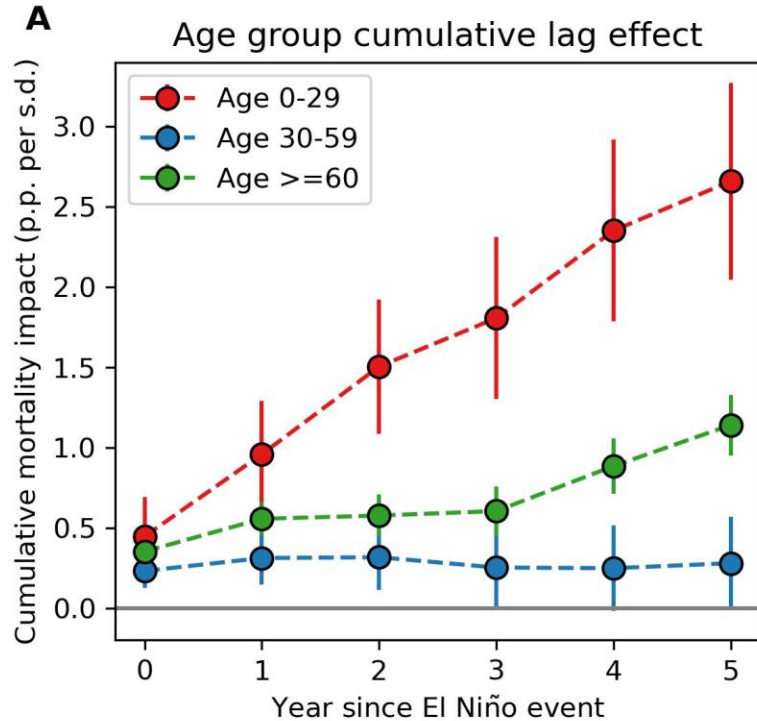
- E_t^{CF} : counterfactual E-index, wherein the corresponding El Niño event is set to zero.
 - We focus on 1982-83 & 1997-98 events.
 - 2016-17 even is also significant, but its enduring effect overlaps with COVID, creating noise.

ENSO Effect

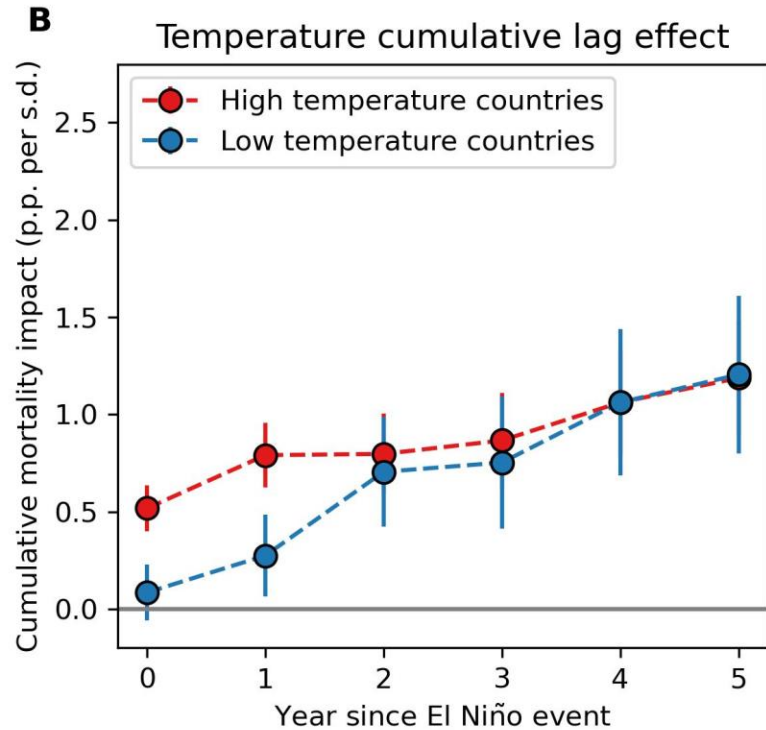
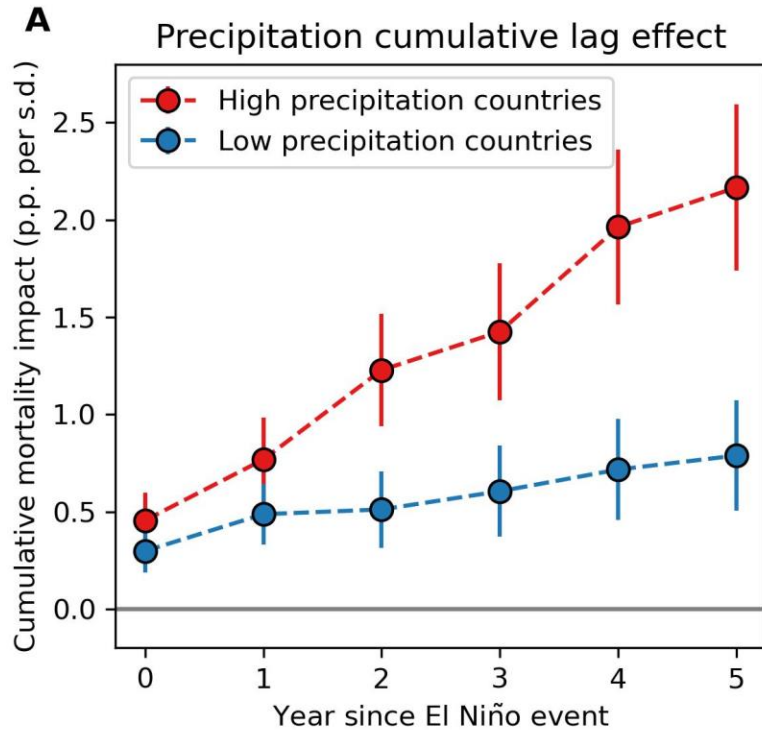
- (A) - (B) State-level temperature and precipitation ENSO teleconnections.
- (C) Cumulative five-lag effect of El Nino on mortality for each state.
- (D) Life Expectancy at Birth in the US Surrounding the 1997–98 El Nino Event.
 - Actual life expectancy (black line)
 - Average counterfactual life expectancy (red line)



Lag Effect of El Nino Events



Impact Channels of El Niño Events



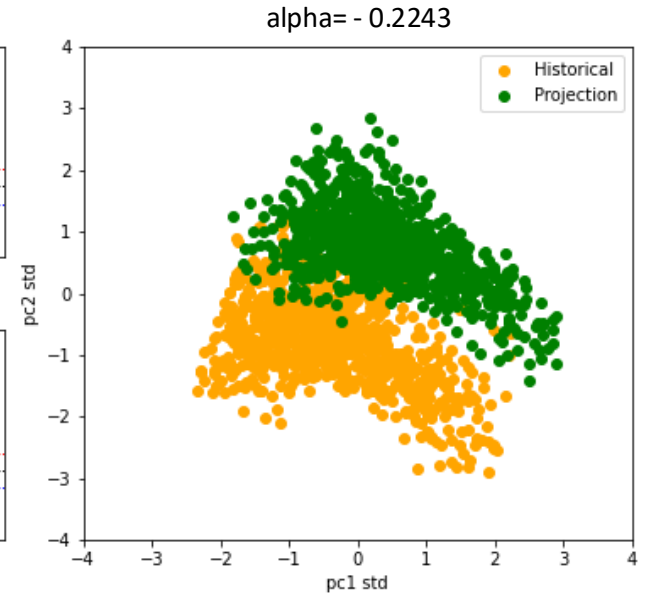
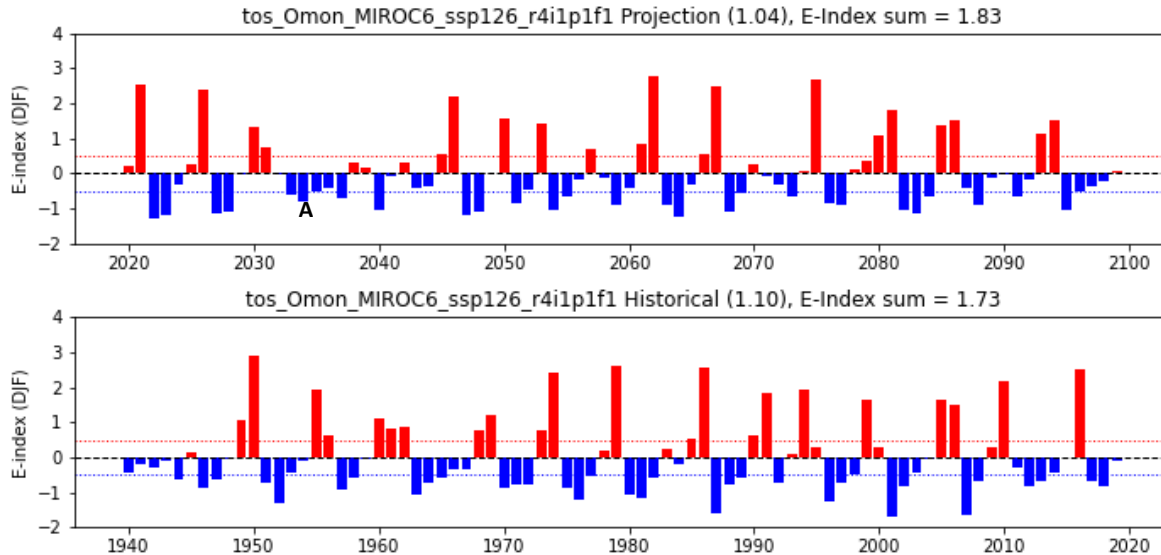
CMIP6 Projects

Coupled Model Intercomparison Project (CMIP)

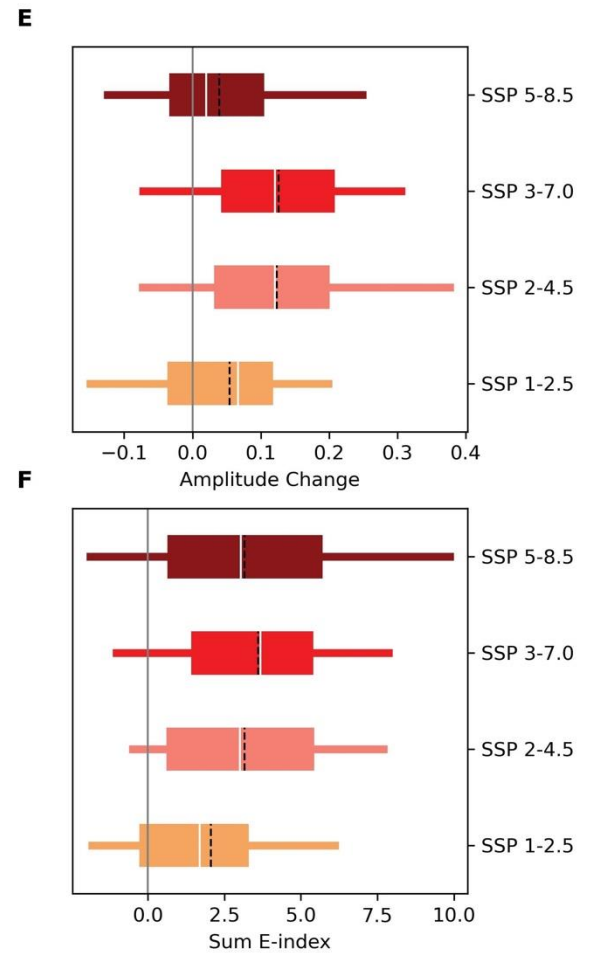
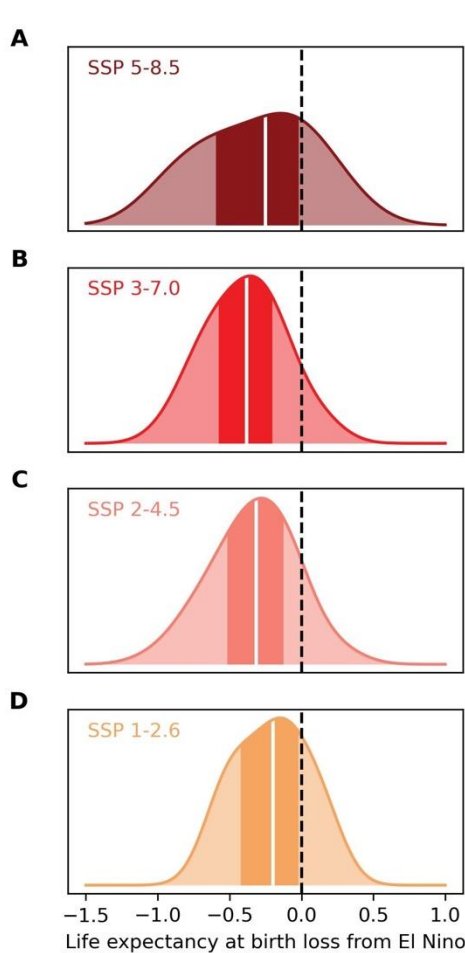
- Climate Model Enhancement: CMIP6 focuses on improving the comparability and understanding of climate models. It aims to facilitate the assessment of the strengths and weaknesses of climate predictions and projections.
 - Broad Participation: It brings together a wide range of climate modeling groups from around the world to perform a standardized set of simulations.
 - IPCC Assessments: The project contributes significantly to the assessment reports of the Intergovernmental Panel on Climate Change (IPCC), offering important insights for the assessment of climate change risks and the formulation of mitigation and adaptation strategies.
- The simulations are publicly accessible at: <https://aims2.llnl.gov/search/cmip6/>

Projecting El Nino's Impact on Life Expectancy for 21st Century

- Coupled Model Intercomparison Project (CMIP)



Projected Life Expectancy Loss from ENSO: for the 21th Century



Conclusion

- We study the effects of El Niño on human mortality improvements
- We identify the persistent effect of El Niño on human life expectancy, and the possible channel is through precipitation.
- Under an emissions scenario aligning with current mitigation pledges, we project **>1-year** reduction in life expectancy among APAC countries.
 - These effects are influenced by stochastic variations in the sequence of ENSO.
- Our study underscores the impact of climate variability on human mortality, independent of warming.
 - Local extreme climate conditions associated with ENSO integrate into a globally persistent demographic effect.
 - There are economic benefits of addressing climate variability, calling for enhanced climate monitoring, early monitoring system, climate mitigation as well as adaptation.

References

- [1] D. Dickson, M. Hardy, and H. R. Waters, *Chaper 2 and 3*. Cambridge University Press, 2020.
- [2] W. Cai, G. Wang, B. Dewitte, L. Wu, A. Santoso, K. Takahashi, Y. Yang, A. Carréric, and M. J. McPhaden, “Increased variability of eastern pacific el niño under greenhouse warming,” *Nature*, vol. 564, no. 7735, p. 201–206, 2018.
- [3] C. W. Callahan and J. S. Mankin, “Persistent effect of el niño on global economic growth,” *Science*, vol. 380, no. 6649, p. 1064–1069, 2023.
- [4] Y. Liu, W. Cai, X. Lin, Z. Li, and Y. Zhang, “Nonlinear el niño impacts on the global economy under climate change,” *Nature Communications*, vol. 14, no. 1, 2023.

Climate Transformation Program



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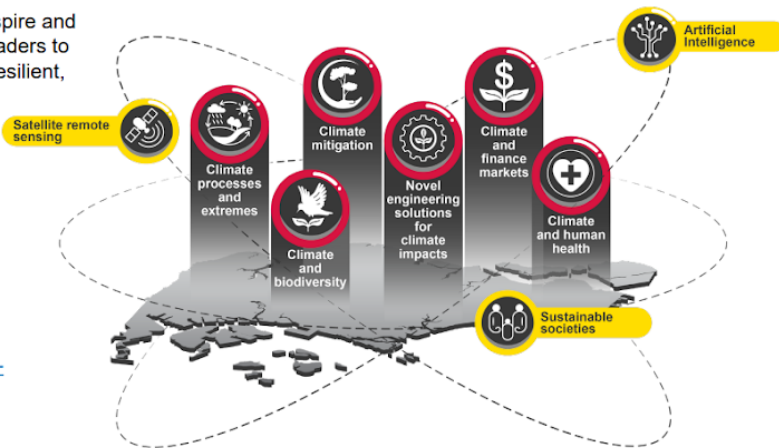
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Q&A