Physical Impacts of Global Climate Change: Insights, Adaptation, and Future Directions

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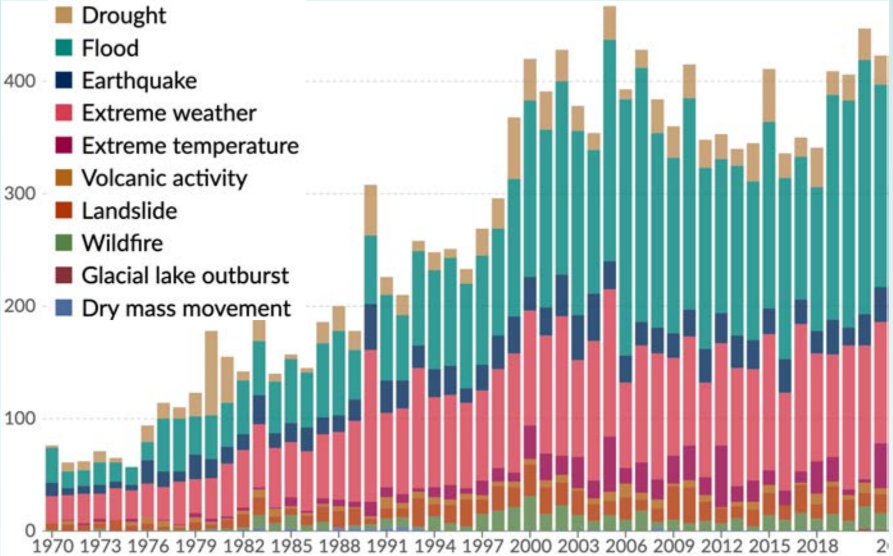
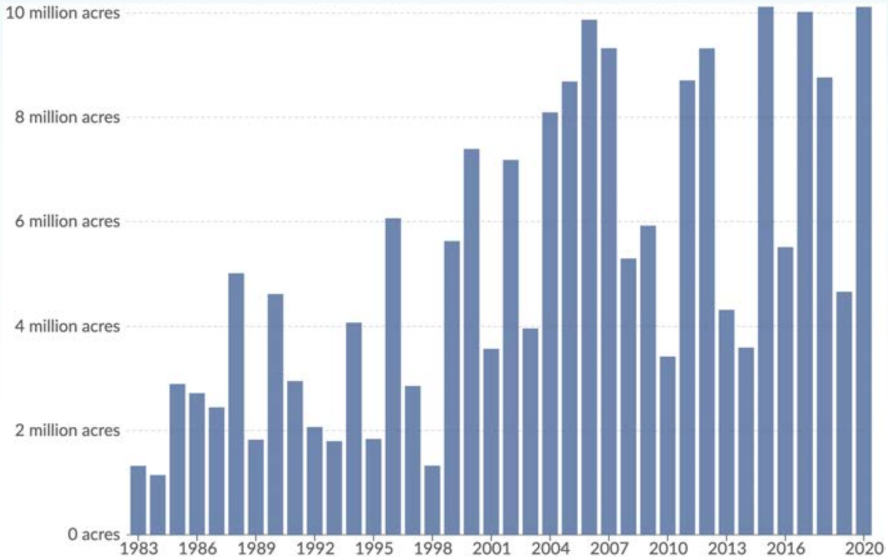
Climate Change Impact: A Complex Issue

- Climate change is not just an increase in temperature, also includes much more.
  - ✓ Seal level rise (SLR)
  - ✓ Extreme weather & compound events
  - ✓ Water, Energy, Infrastructure
  - ✓ Agriculture, Ecosystems
  - ✓ Human health
- Impacts on different sectors are interrelated.
- Impacts are uneven across the world.
- Some alarming changes (NOAA)
  - ✓ SLR has accelerated from 1.7mm/yr in 20th century to 3.2 mm/yr since 1993
  - ✓ Average thickness of glaciers has decreased more than 60 feet since 1980
  - ✓ Arctic sea ice area has shrunk by 40% since 1979.

Global reported natural disasters by type (1970-2022)

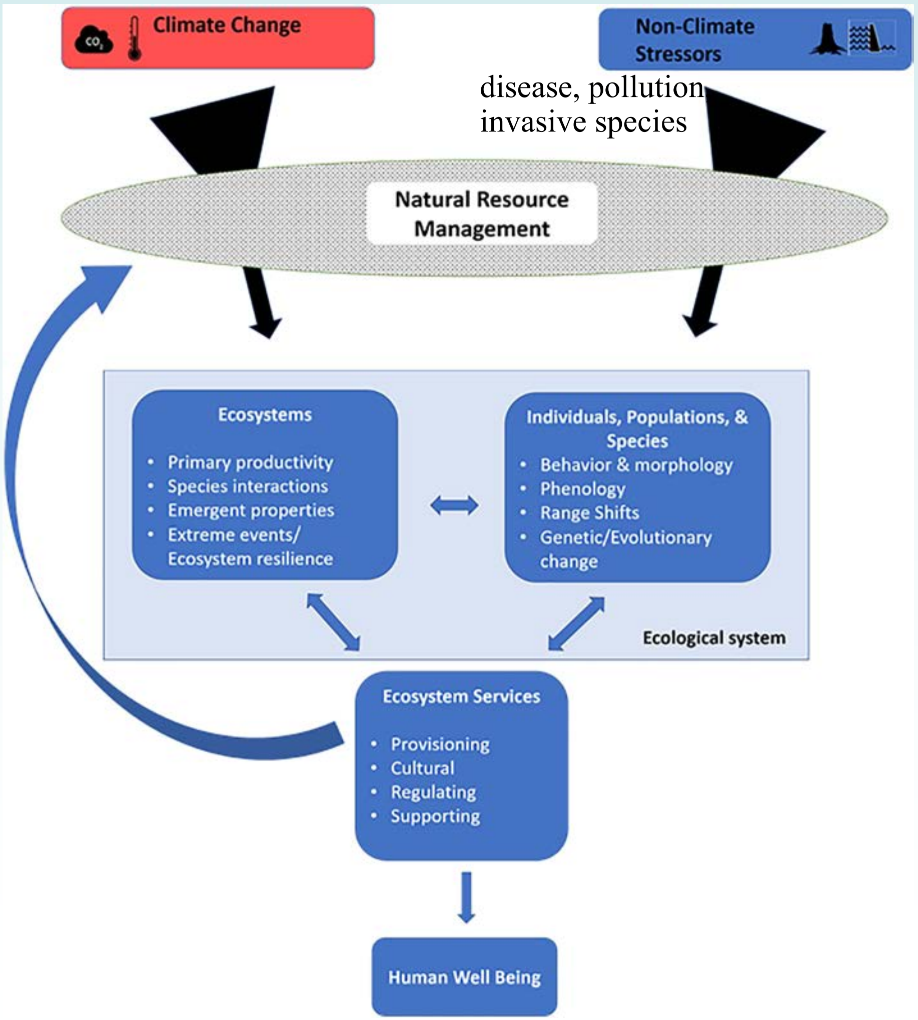


Wildfire acres burned in the US (1983-2020)



Biodiversity, Ecosystems, and Natural Resource Management

Climate change and non-climate stressors interact and affect ecological systems at multiple scales

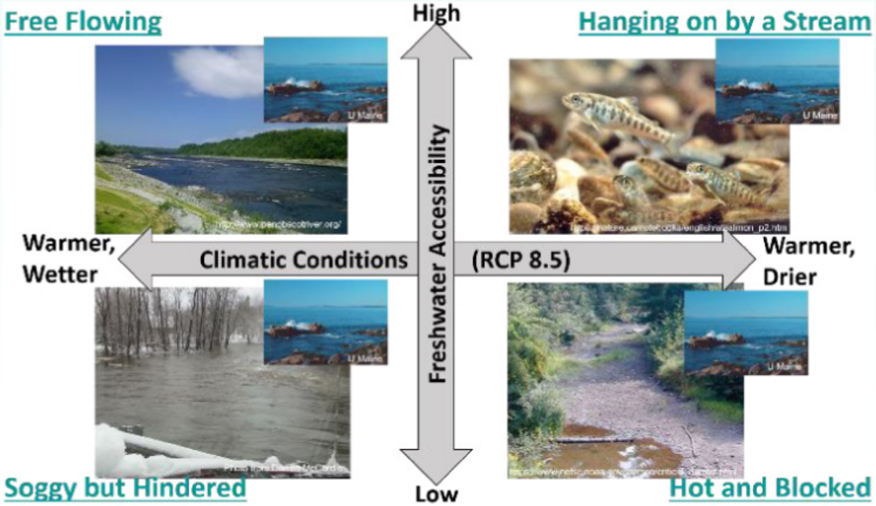


(Borggaard et al. 2019)

Sierra Nevada Forests

2012-2017 drought across California → stress to trees and bark beetle outbreaks → mortality of 129 million trees (ponderosa pine) → incense cedar increases → large wildfires increase → drastically changed ecosystem

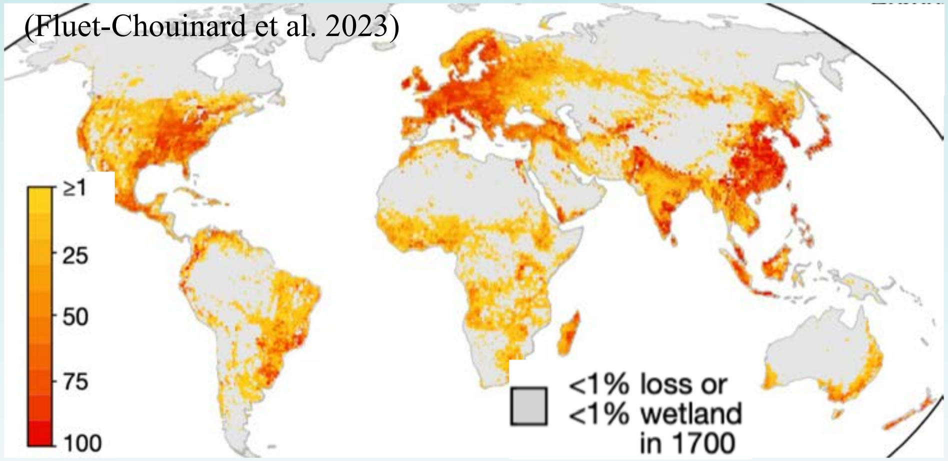
Climate Change Impacts on Atlantic Salmon



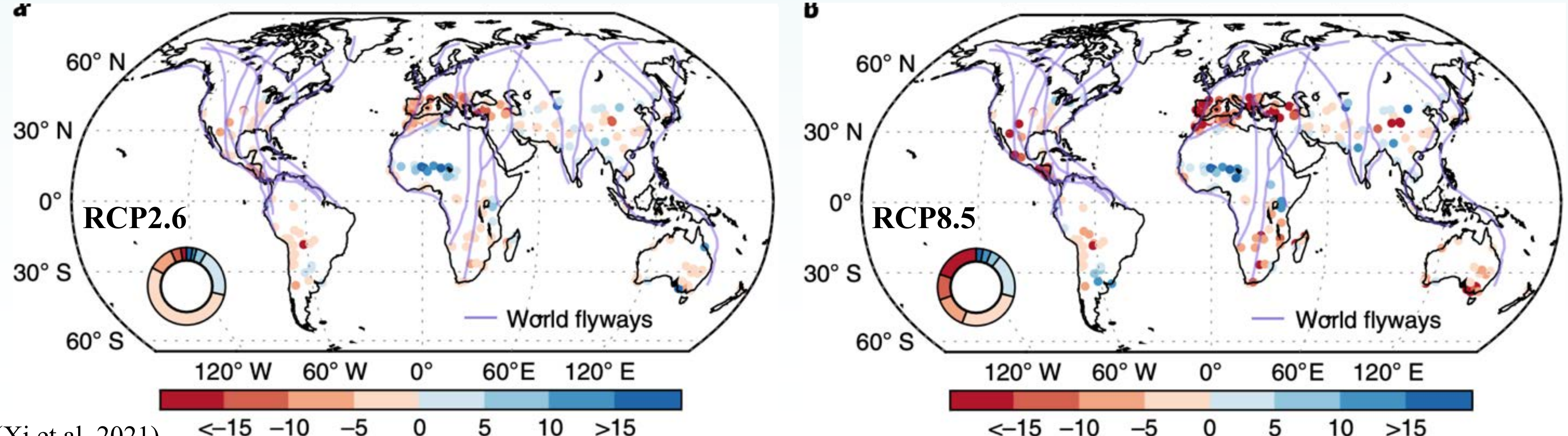
Wetlands: A Complex Social-Ecological System

- 5 ~ 8% of land surface and 20 ~ 30% of carbon pool.
- Provides many ecosystem services (flood control, water purification, biodiversity, food supply, carbon sequestration).
- Important in global carbon cycles, but also most vulnerable to climate change.

Wetland lost in 2020 (% of wetland area in 1700)

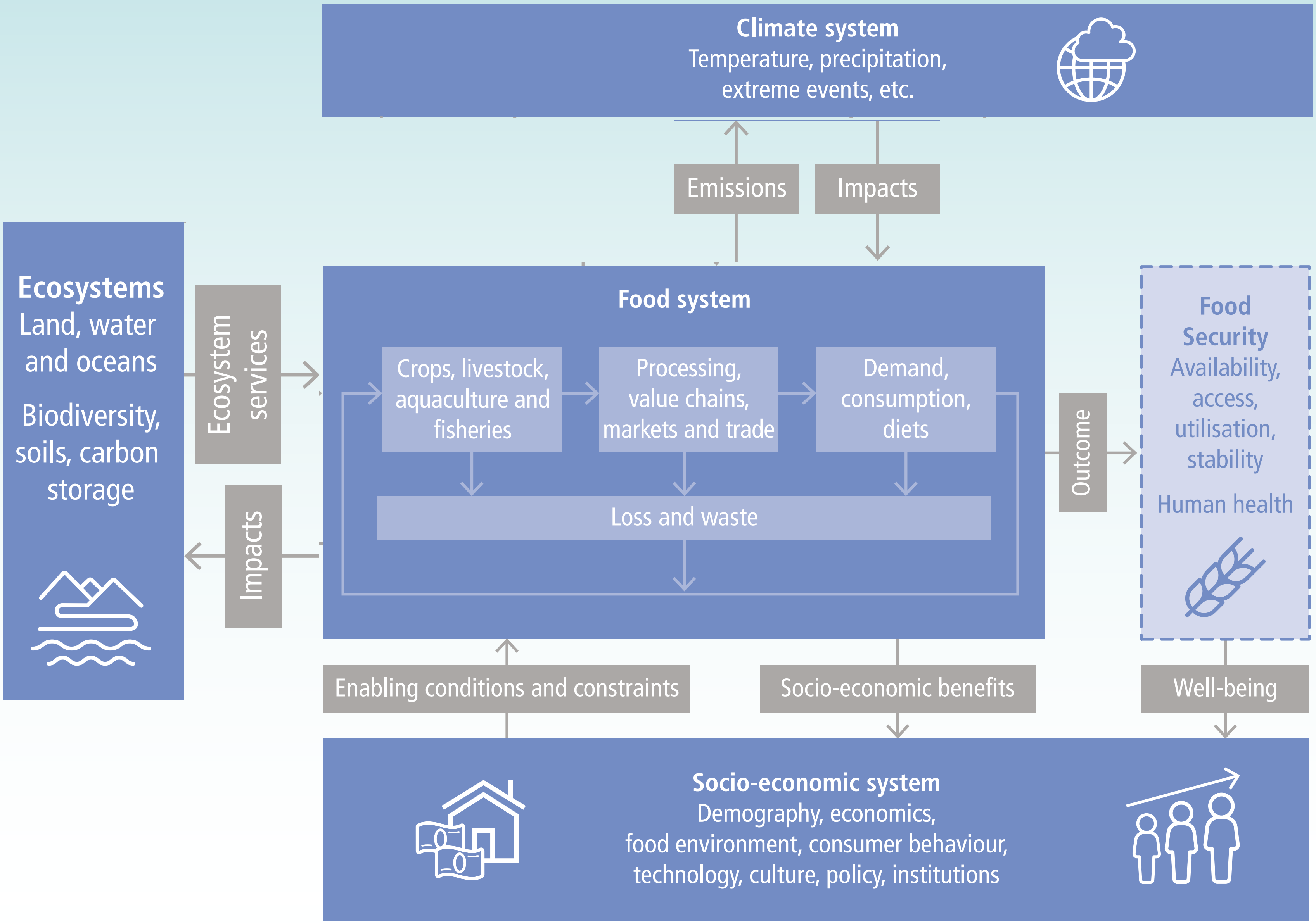


Change in wetland area (%) south of 45°N in winter (December-February) and waterbird migration



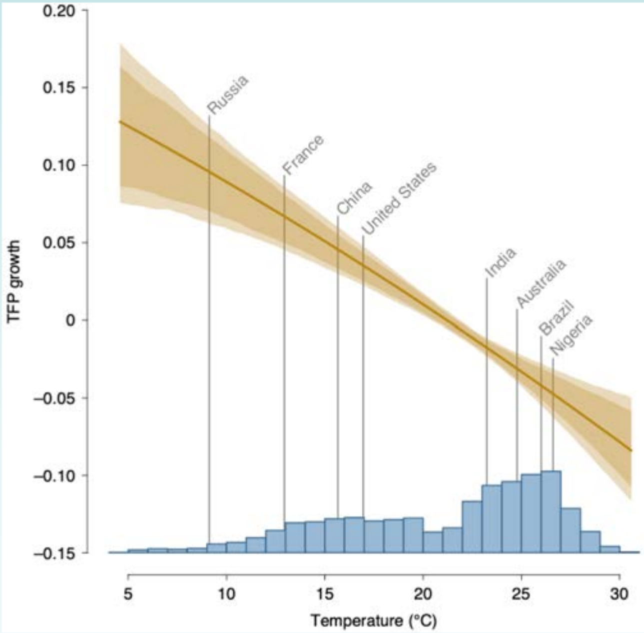
(Xi et al. 2021)

Food System

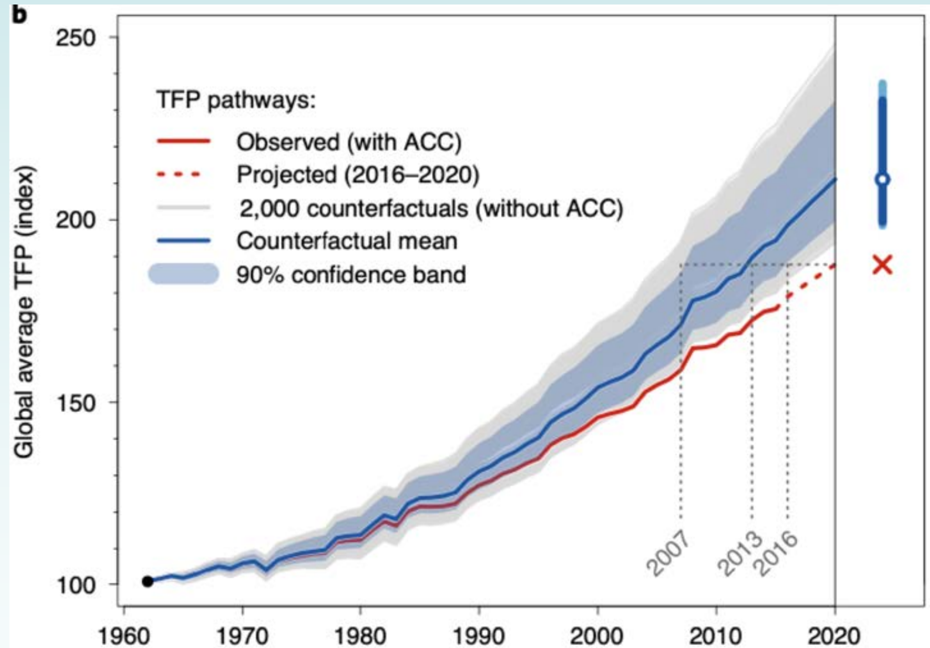


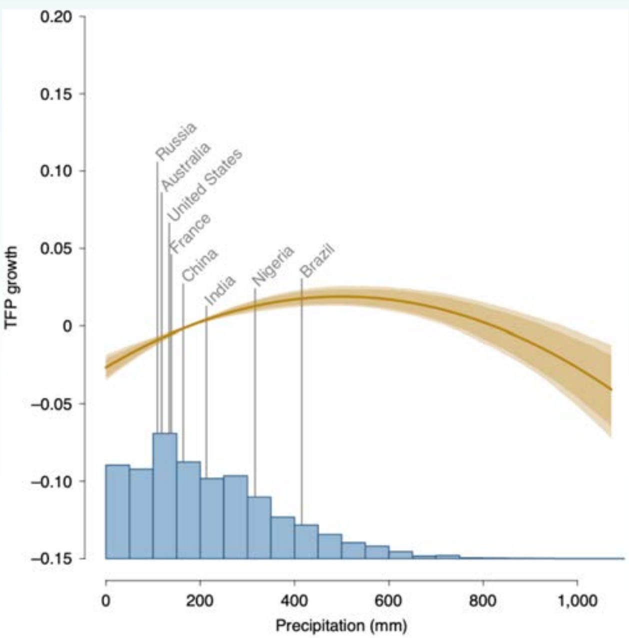
(Mbow et al. 2019)

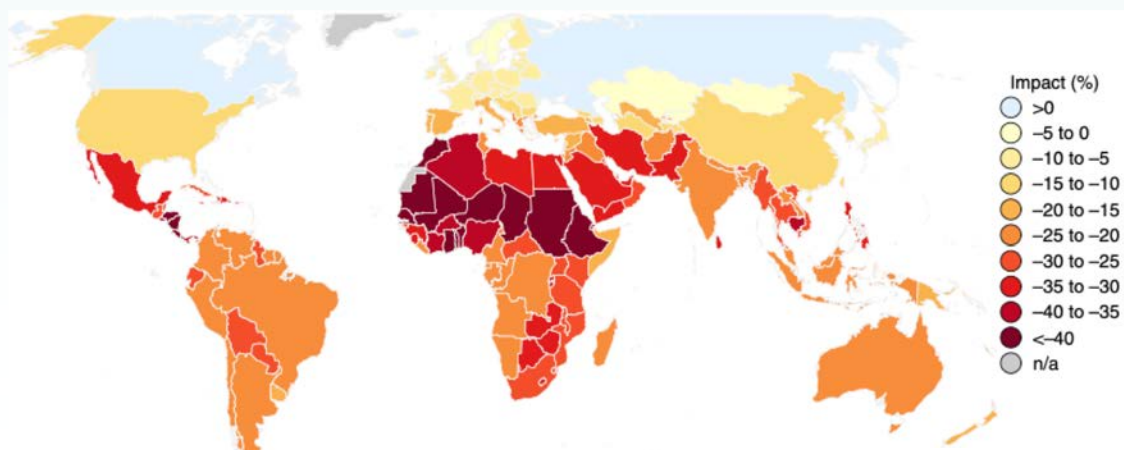
Total Factor Productivity (TFP)



TFP (a measure of productive efficiency)
= aggregated output / aggregated inputs (labor, capital)



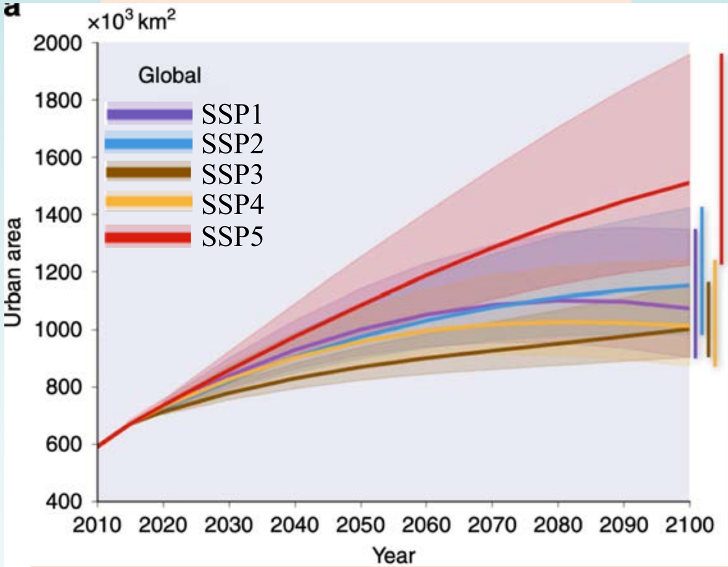




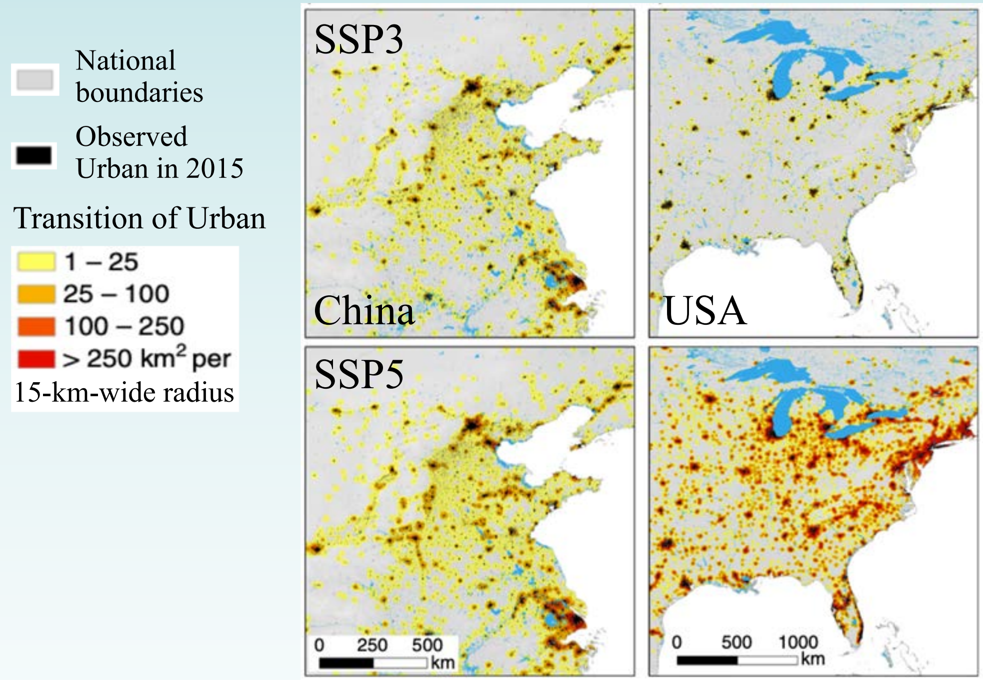
Ortiz-Bobea et al. 2021

Urban Land Expansion and Food Production

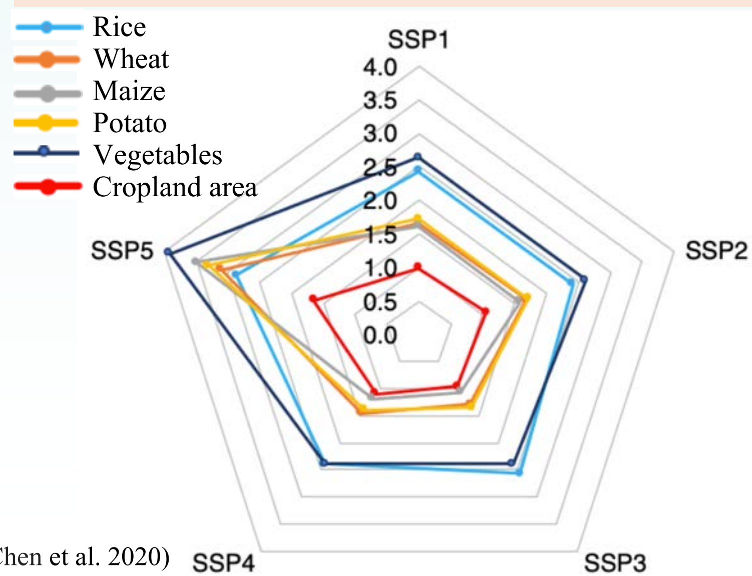
Global Urban Land Demand



Urban Land Maps in 2100



Cropland and food production loss (%) caused by urban expansion by 2100



Global food production loss caused by urban expansion (10^6 ton)

	SSP1	SSP2	SSP3	SSP4	SSP5
Rice	15.19	15.09	16.04	14.99	17.88
Wheat	10.31	10.35	7.99	8.98	19.19
Maize	11.53	11.21	7.56	8.41	24.84
Potatoes	5.46	5.47	4.29	4.42	10.50
Vegetables	19.99	19.84	18.17	18.06	29.67

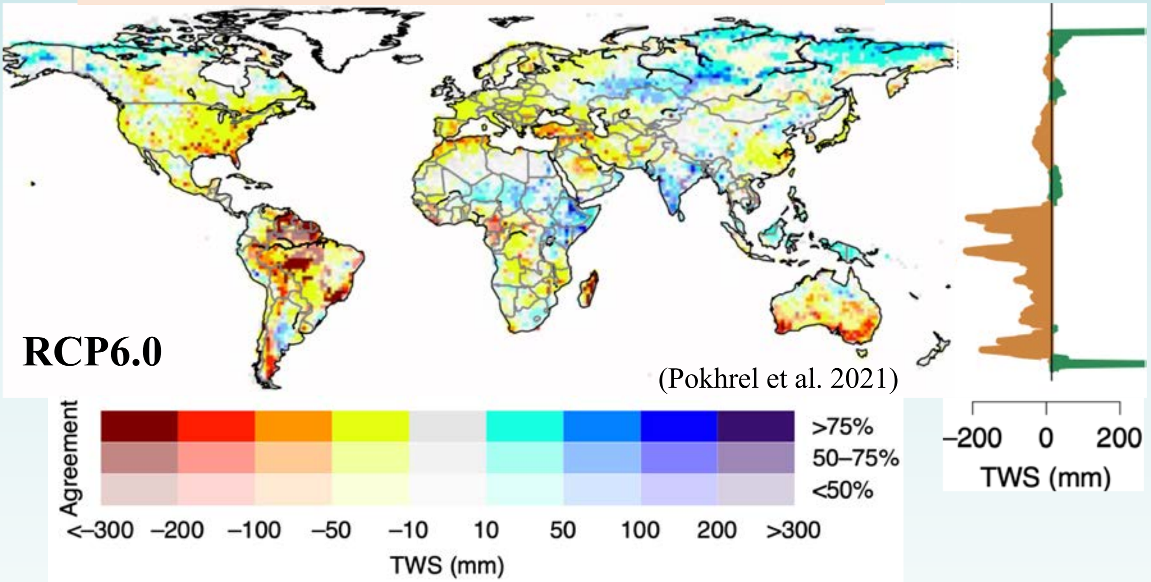
Population affected by food production loss (million)

	SSP1	SSP2	SSP3	SSP4	SSP5
Rice	281.77	279.86	297.51	278.03	331.62
Wheat	157.50	158.25	122.12	137.22	293.35
Maize	644.70	626.72	422.86	470.19	1388.70
Potatoes	159.91	160.09	125.48	129.36	307.31
Vegetables	183.55	182.18	166.79	165.79	272.44

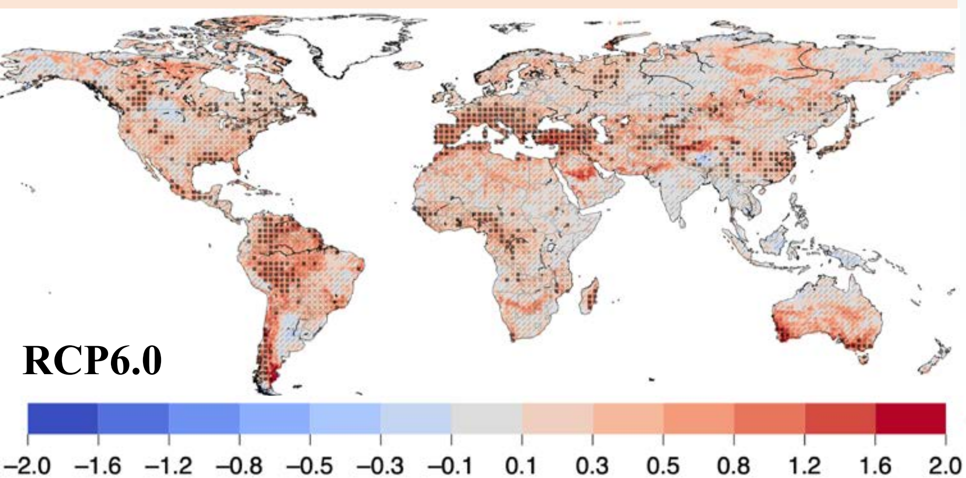
(Chen et al. 2020)

Water Resources

Changes in Terrestrial Water Storage (TWS) for 2070-2099 relative to 1976-2005

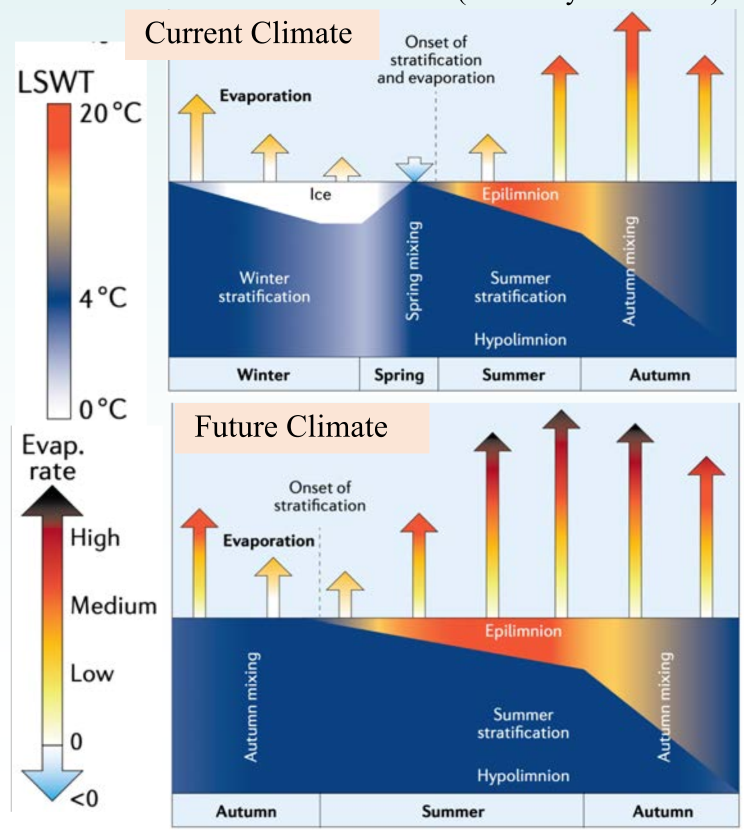


Trend (days/year) in the frequency of extreme-to-exceptional droughts (TWS drought severity index ≤ -1.6 for 2006-2099



- Global lakes are experiencing less ice cover and shorter ice duration
- Lake surface water temperatures (LSWT) have increased worldwide at a global average rage of 0.34˚ C/decade
- Global annual mean lake evaporation rates increase 16% by 2100
- Less frequent mixing of lakes

(Woolway et al. 2020)

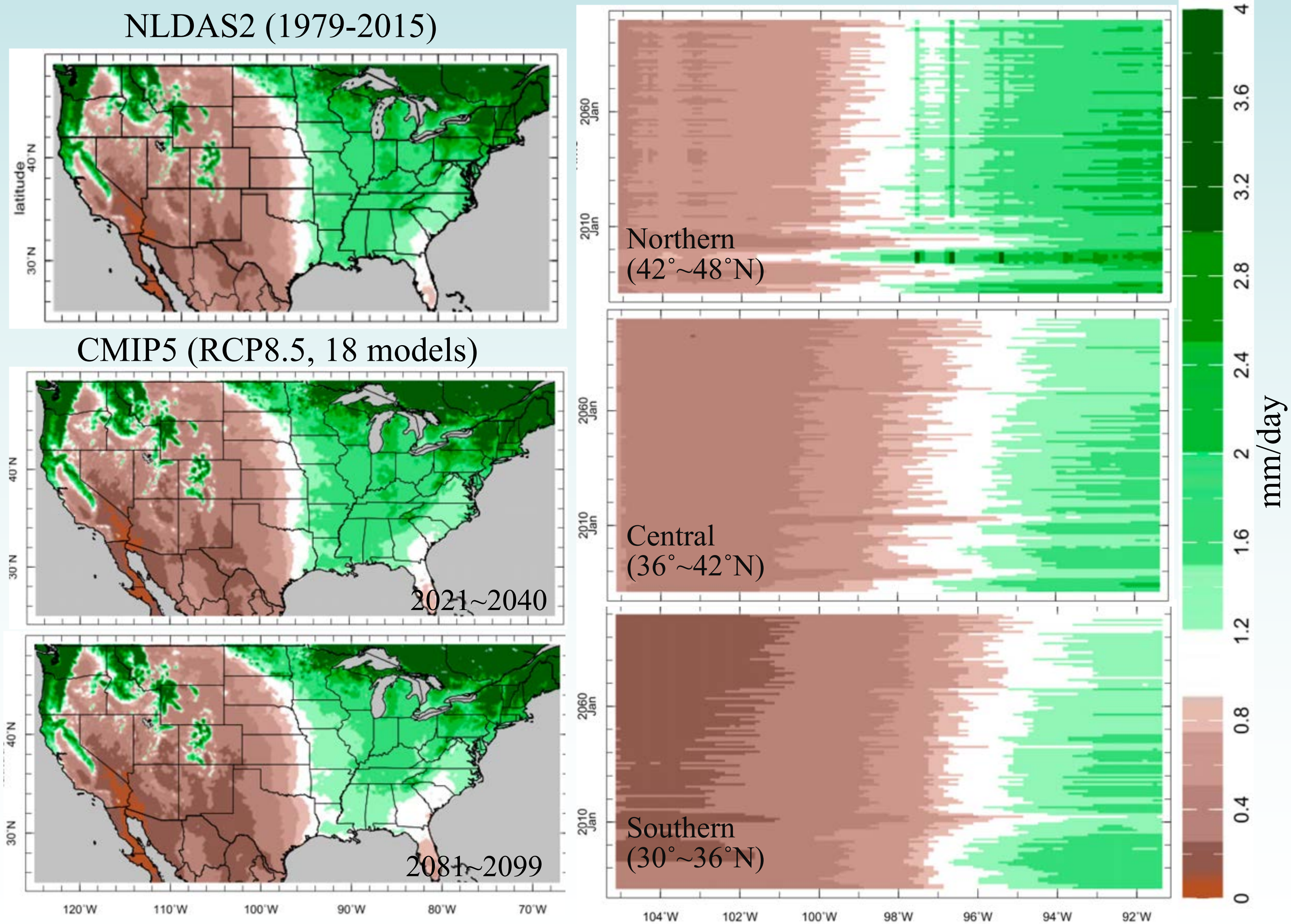


The 100th Meridian: Arid-Humid Divide

Arid Index = P/PET

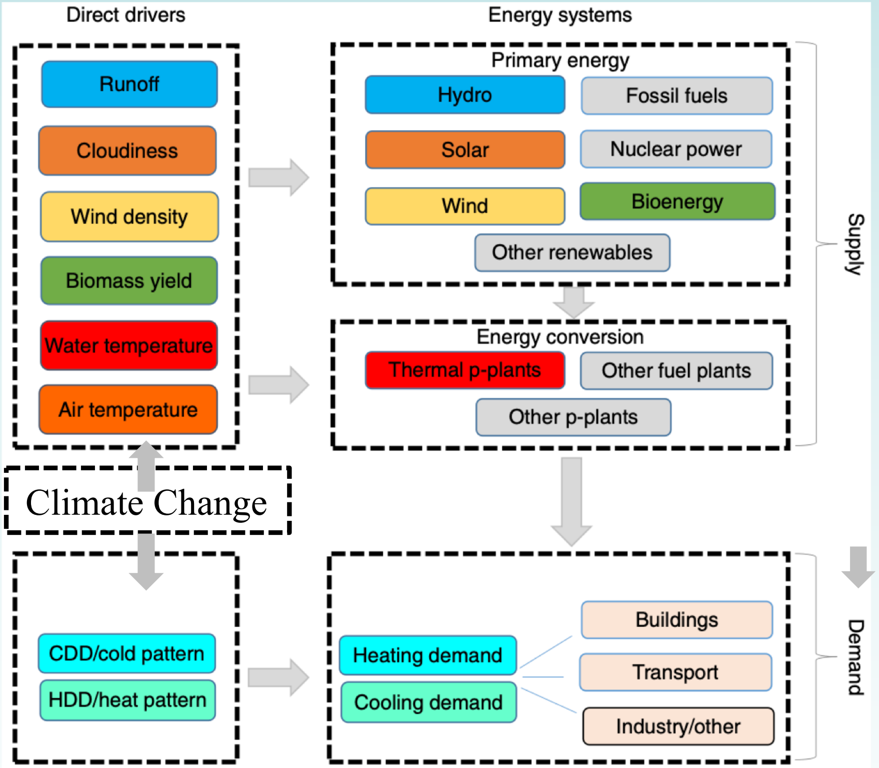
- Vegetation
- Land hydrology
- Crops
- Farm economy

(Serger et al. 2018)

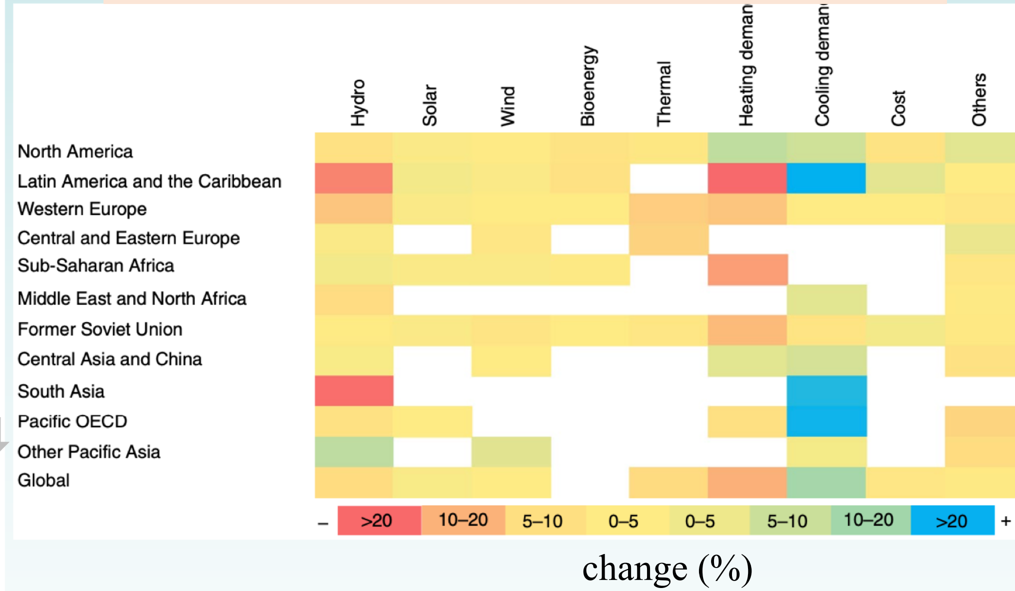


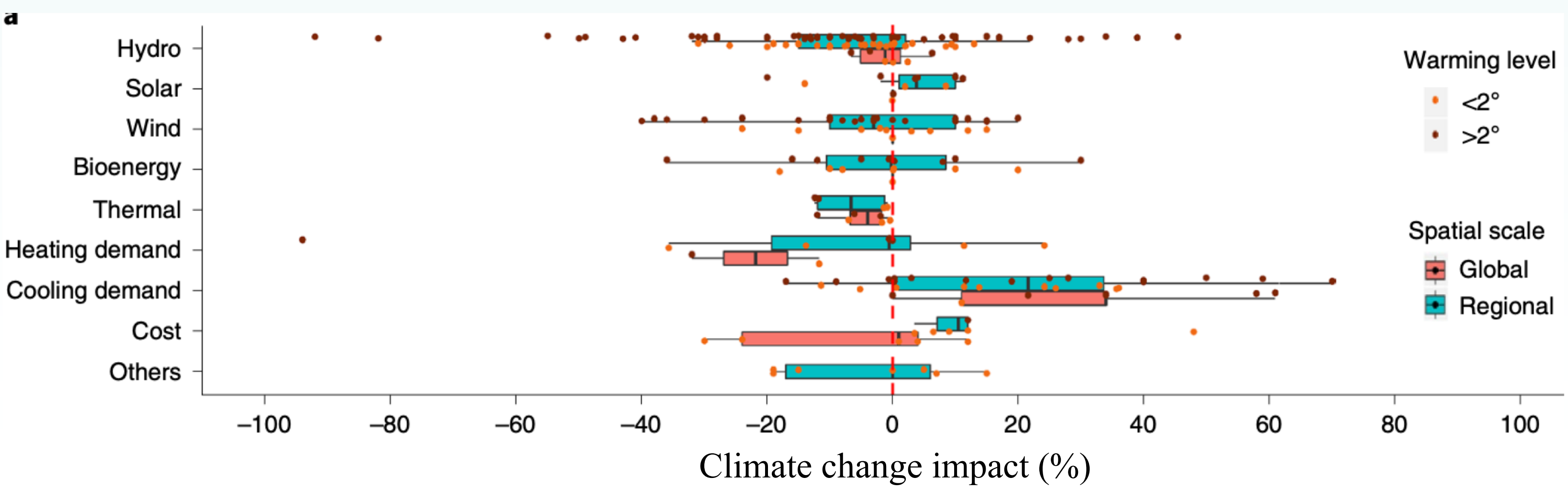
- Aridity increases, the 100th meridian moves east, aridity gradient becomes more muted
- Aridity's eastward shift is evident in the southern and central plains and less so in the north.

Energy Systems



Climate change impacts on energy system per region averaged across > 200 reviewed studies



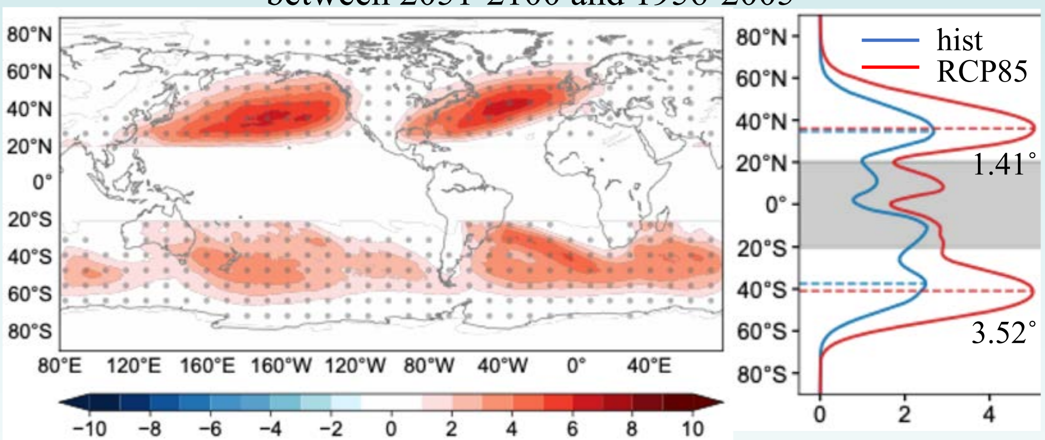


(Yalew et al. 2020)

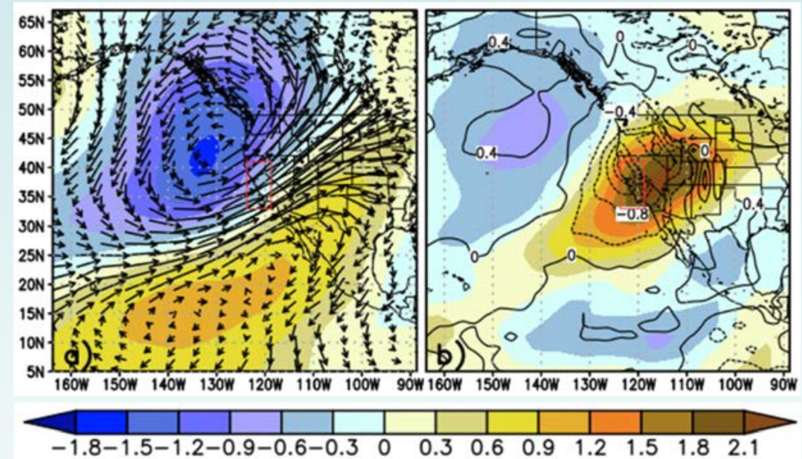
Extreme Atmospheric Rivers (EAR)

AR: a long and narrow corridor of concentrated water vapor transported in the atmosphere

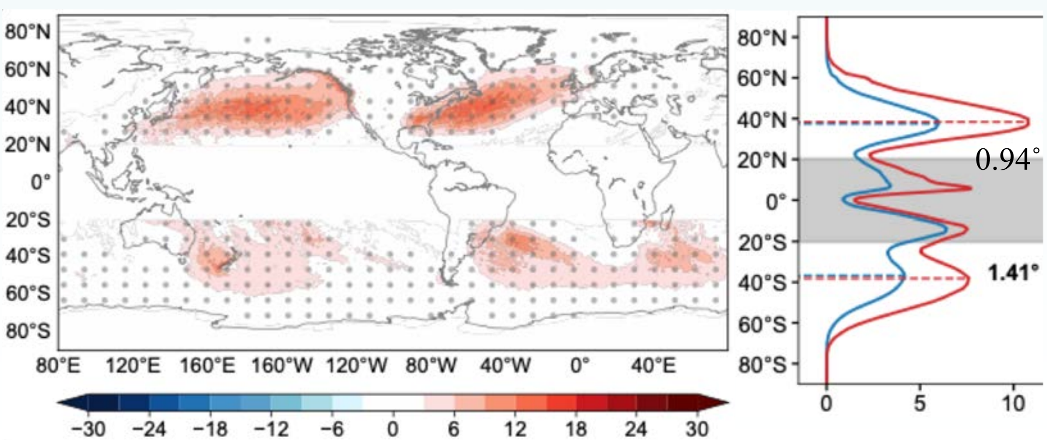
Difference in EAR occurrence frequency (%) between 2051-2100 and 1956-2005

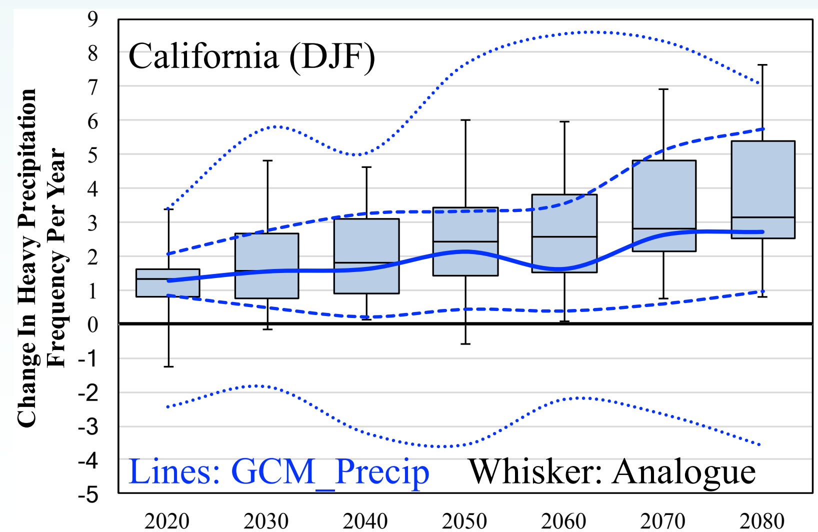


Large-scale Meteorological Patterns (LSMP, Analogue)



Difference in precipitation (mm/day) between 2051-2100 and 1956-2005



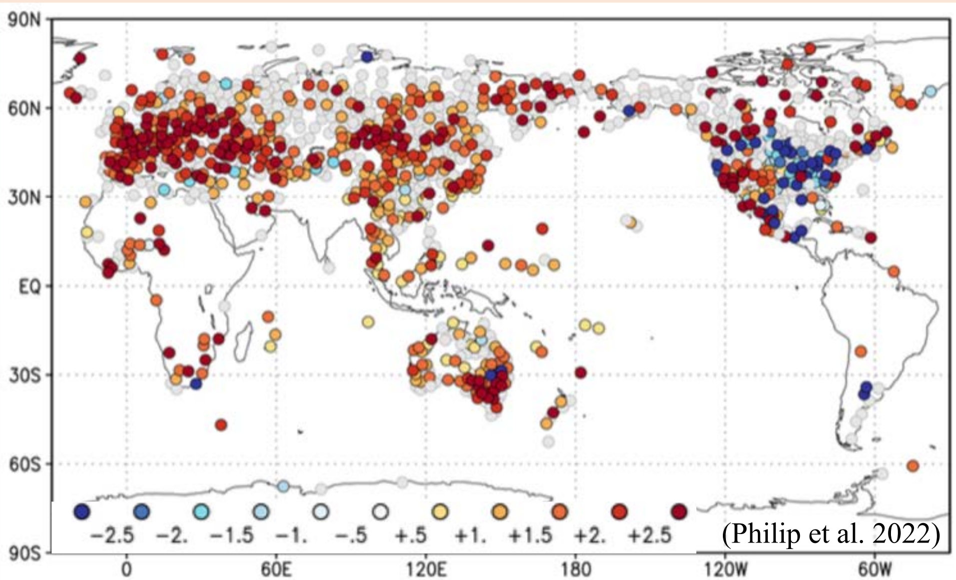


(Wang et al. 2023)

(Gao et al. 2018)

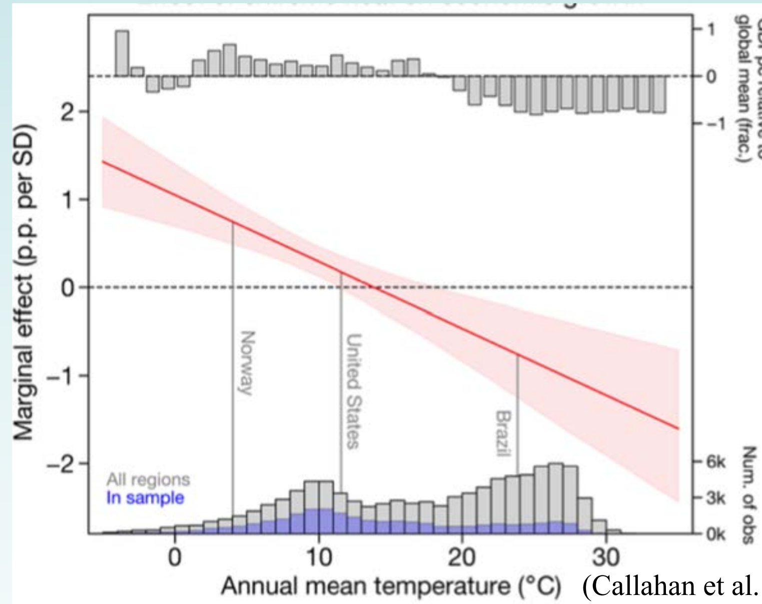
Extreme Heat

Trends in the highest daily maximum temperature of the year (regression on global mean temperature) in the GHCN-D station data

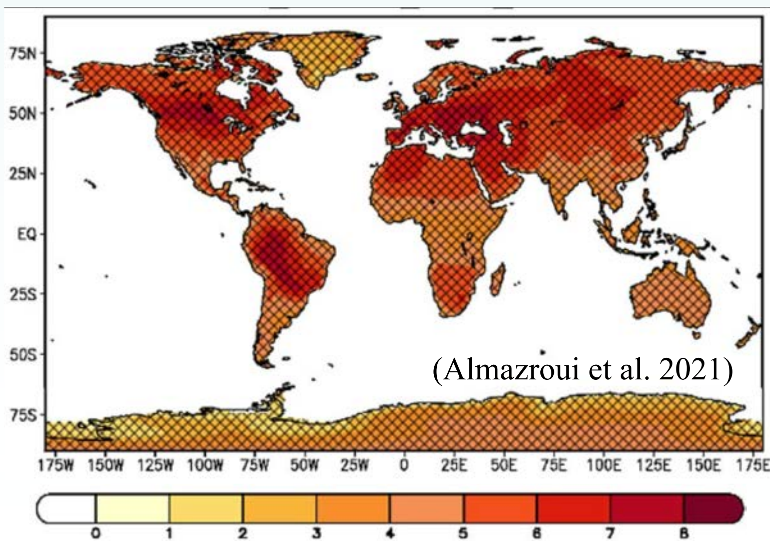


(Philip et al. 2022)

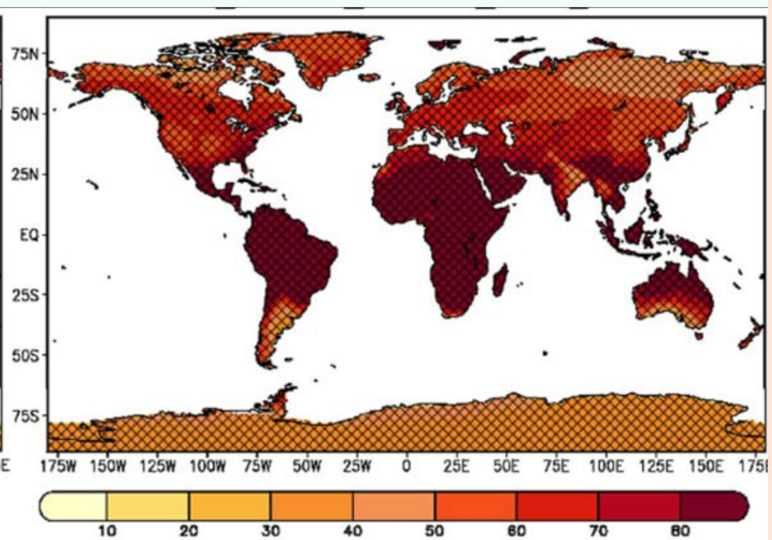
Effect pf extreme heat on economic growth



(Callahan et al. 2023)



(Almazroui et al. 2021)



21 CMIP6 model ensemble-mean changes in annual hottest day temperature (left) and extreme heat wave days frequency (right) between 2070-2099 and 1985-2014 under SSP5-8.5 Scenario.

Adaptation Responses

Types of Adaptation Responses

- Behavioral/cultural
  - change food consumption practices; adopt drought-tolerant plant/animal species
- Technological/infrastructural
  - desalination; rainwater harvesting; boreholes and tube wells for extracting water
- Natural-based
  - protect landscapes to limit deforestation; restore ecosystems; improve land management practices
- Institutional
  - creating policies, programmes, and regulations; establishing formal and informal organizations
- Integrated
  - installation of urban green roofs for cooling; government-supported planting of drought-resistant seeds among subsistence farmers

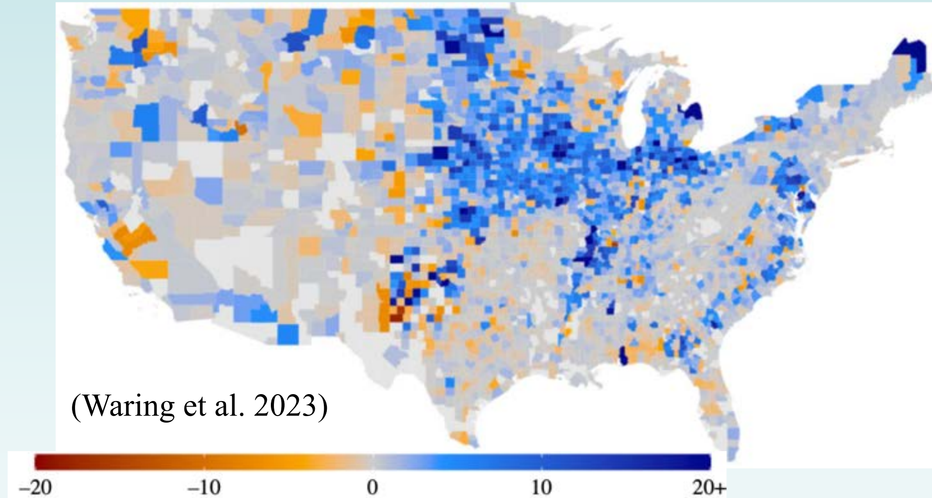
Restoring meadows in the Sierra Nevada

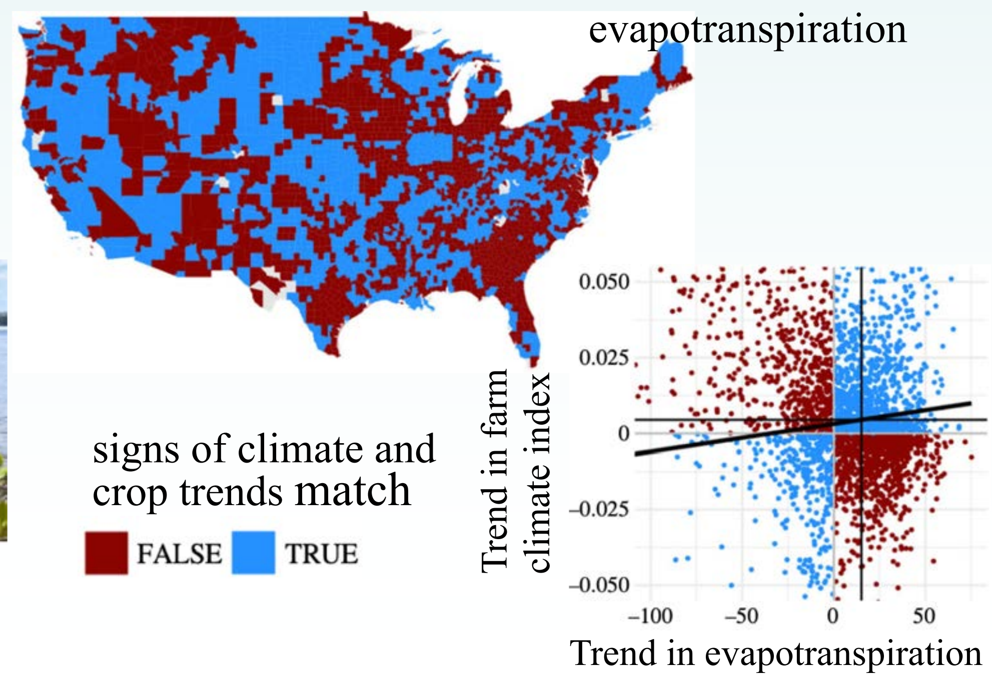
Federal, state, and NGO partners restored four meadows with high ecological value in 2015

Nature-based Infrastructure

Living shoreline as coastal resilience structures for withstanding hurricane

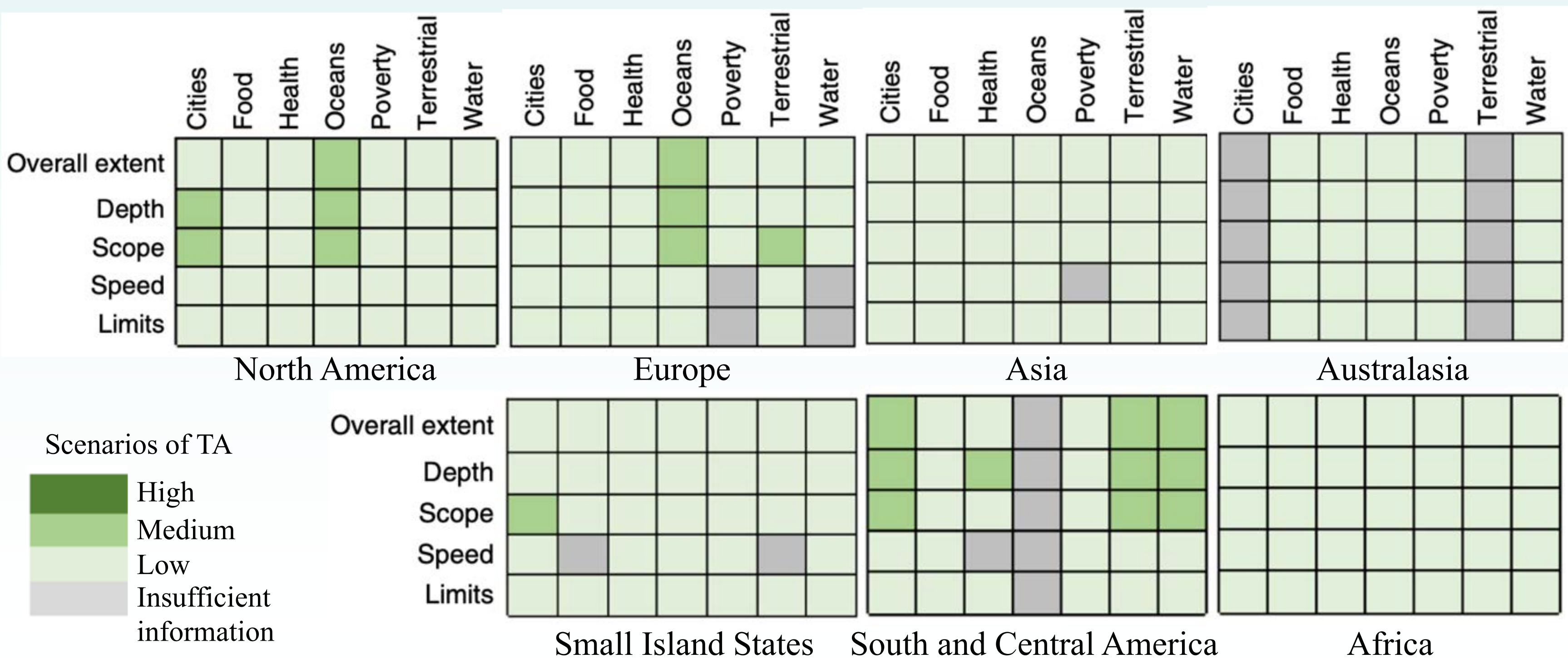
Change in cover crops from 2012-2017 (10^3 acres)





Transformational Adaptation (TA)

Dimensions of TA	Scenarios of TA	
	Low	High
Overall	Sporadic and limited with small adjustments	Widespread and full implementation
Depth	Expansion of existing practices	Entirely new practices with deep structural reform
Scope	Localized and fragmented, lack of coordination across sectors	Widespread and substantial with most possible sectors and levels of governance
Speed	Implemented slowly	Rapid change
Limits	Don't challenge soft limits	Exceed many soft limits and challenge hard limits



Knowledge Gaps and Future Directions

Scientific Perspectives

- A new generation of high-resolution climate models that can explicitly represent relevant fine-scale processes and provide more detailed and precise projections of future climate and severe weather events, particularly at regional and local levels, to support robust climate mitigation and adaptation
- Exascale computing and data facility of unprecedented power, capacity, and scale to deliver the timely simulation, prediction and data analytics of the Earth system
- A global coordinated effort by a trained and well-resourced scientific workforce
- Advanced knowledge of tipping points and improved methodologies (e.g., IAM) for quantification of the complex risks (e.g., feedbacks and interactions between risks, uncertainty, unidentified risks, etc.)
- Interdisciplinary interactions and collaboration within and between natural and social science communities for sharing knowledge and expertise

Mitigation & Adaptation Perspectives

- Identify gaps in adaptation research and practice that address equality, justice, and power dynamics (towards developing more equitable adaptation practices).
- Leverage emerging new technology and infrastructure
- Strengthen governance
- Facilitate public participation and citizen engagement
- Global coordination, cooperation and commitment across localities, sectors of society, and scales of governance to ensure global sustenance