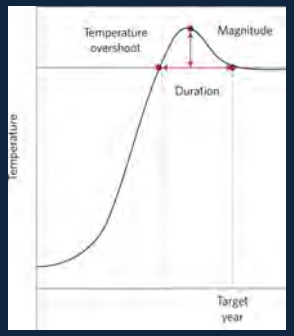
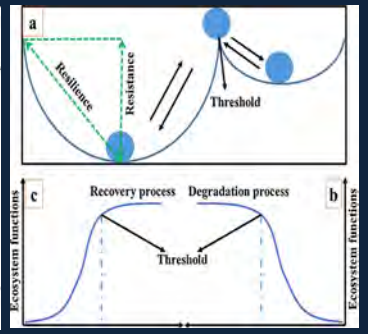
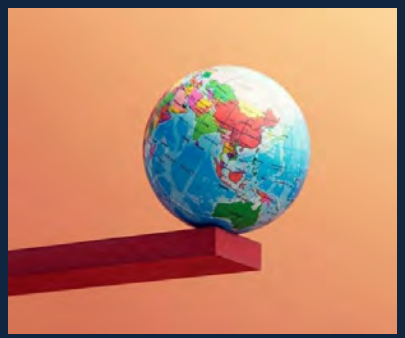
Human-Forced Climate-Change Trends: Probing the Gamut of Overshoots, Thresholds, Tipping Points, Extremes and Unprecedented Events

C. Adam Schlosser, Popat Salunke, Andrei Sokolov, Sandeep Chinta, Kevin Lin Yang, Jeff Scott, Xiang Gao, and IGSM team







XLVI MIT Global Change Forum, "Climate Change Trends" Session
March 27, 2024

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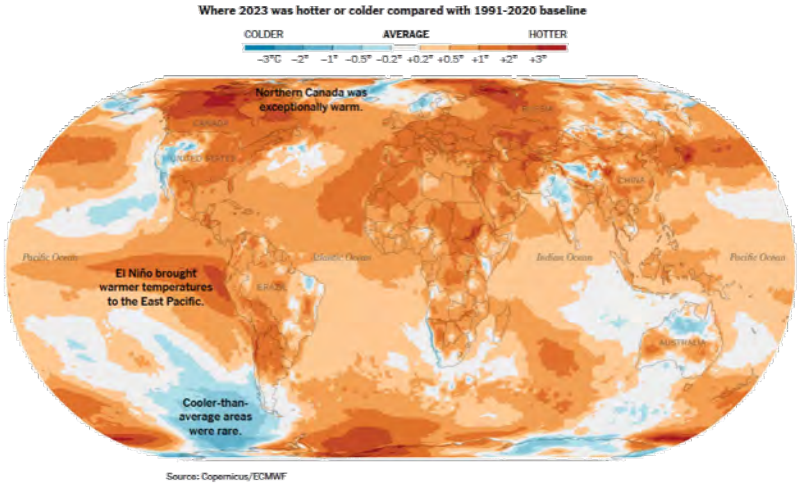
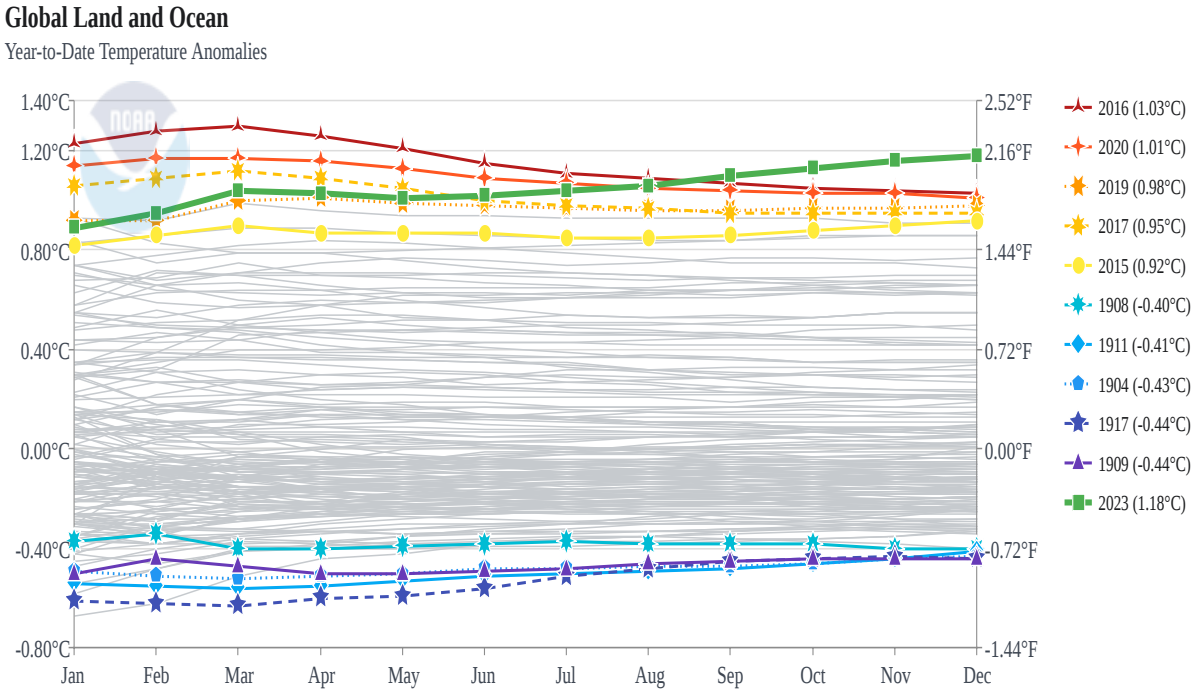
HARD TO MISS THE HEAT BEING "ON"

2023 – WARMEST YEAR (BY FAR) ON RECORD (1880-2023) – THERE WERE MANY MORE WARMER TEMPERATURE THAN COLDER TEMPERATURE REGIONS

Contributing factors

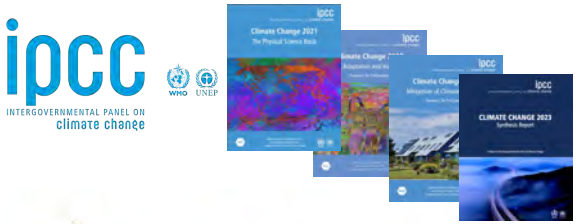
- Suboceanic volcanic eruption injected large amounts of water vapor into atmosphere.
- Reduced sulfur emissions from ocean cargo vessels.
- El Nino emerges in the tropical Pacific Ocean – injecting heat into atmosphere (but late in the year).
- Continued increase in radiatively active trace gas concentrations in the atmosphere.

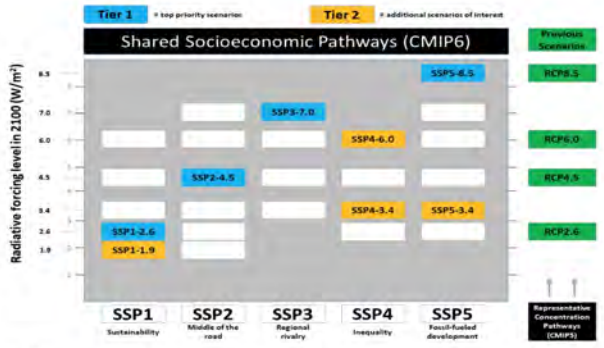




Ref: NOAA-NCDC, LAND & OCEAN TEMPERATURE FOR JAN-DEC 2023 (https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/mapping/)

Looking Into the Future: International and "In-House" Assessments



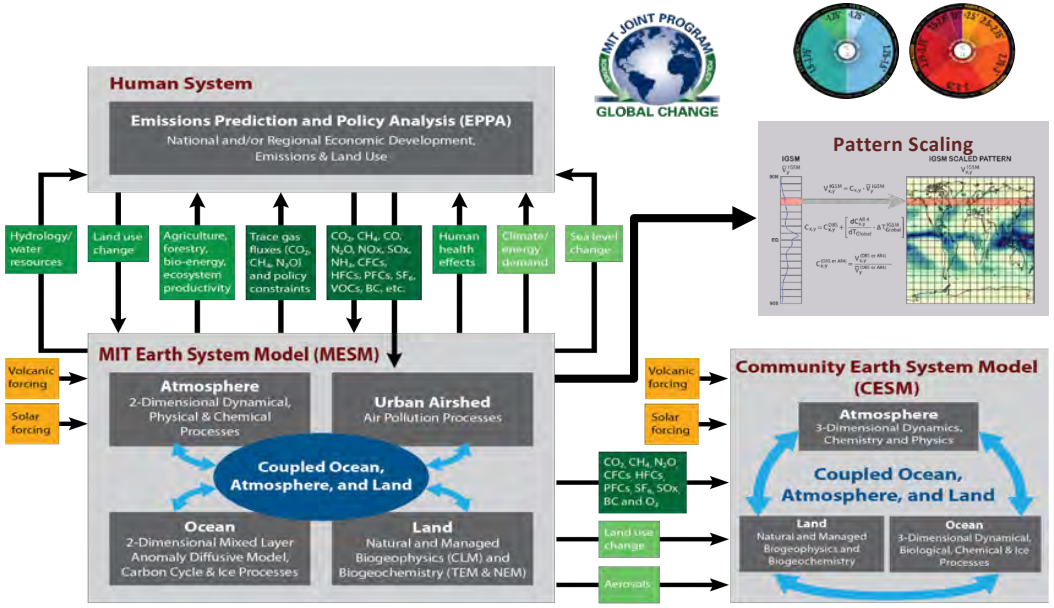


Current Trends (CT) assumes implementation of current policy settings.

The CT scenario is most closely aligned with the RCP6.0 CMIP6/IPCC scenario, but it has lower radiative forcing at 2100 (~5.5 W/m^2 median) .

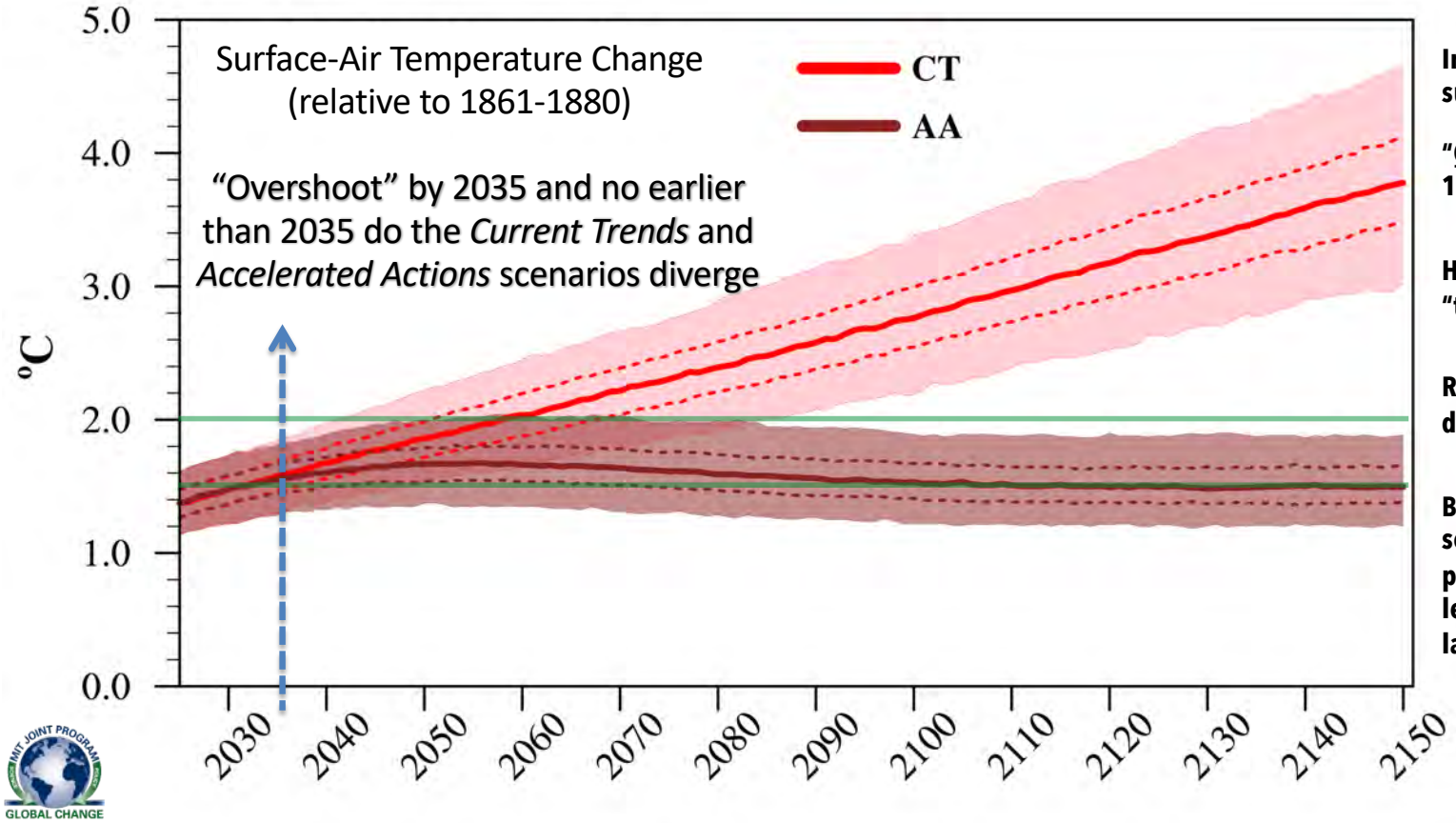
Accelerated Actions (AA), a1.5°C stabilization pathway, countries impose more aggressive emissions targets that represent illustrative actions for increased mitigation.

The AA scenario is most closely aligned with the RCP2.6 CMIP6/IPCC scenario. The AA scenario has slightly higher radiative forcing by 2100. (~2.8 W/m^2)



Climate Overshoot – MIT 2023 Outlook and IPCC AR6 align with (IPCC) statement

"…it is almost inevitable that we will temporarily exceed this [1.5˚C] temperature threshold but could return to below it by the end of the century." (April, 2022)



In the context of IPCC goals and the supporting scientific community:

"Climate Overshoot" viewed as crossing the 1.5˚C global climate warming threshold.

However, 1.5˚C (and 2˚C) are not absolute "thresholds" or "tipping points".

Risks increase in line with the extent and duration of the overshoot.

Beyond 1.5°C, the risk of severe impacts to some ecosystems and locations – particularly in places where people are least responsible for the problem – become larger than the world is "willing to accept".

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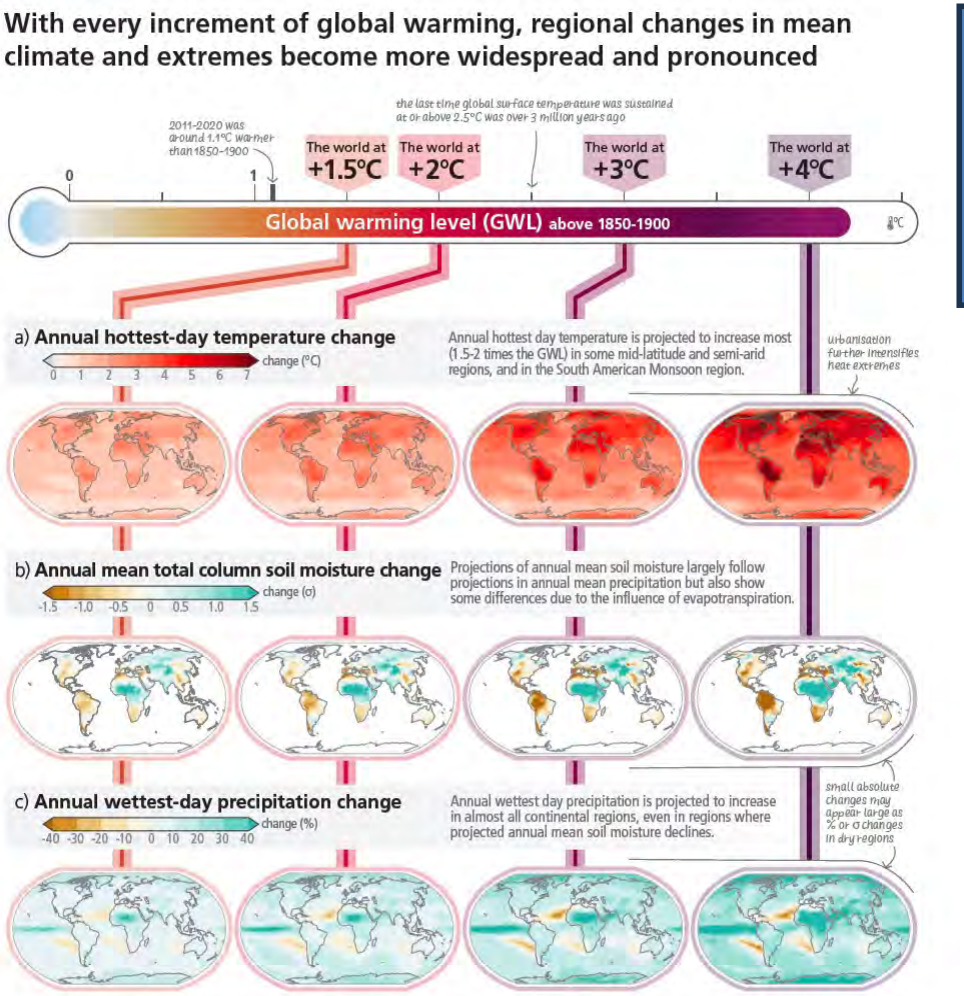
Summary for Policymakers



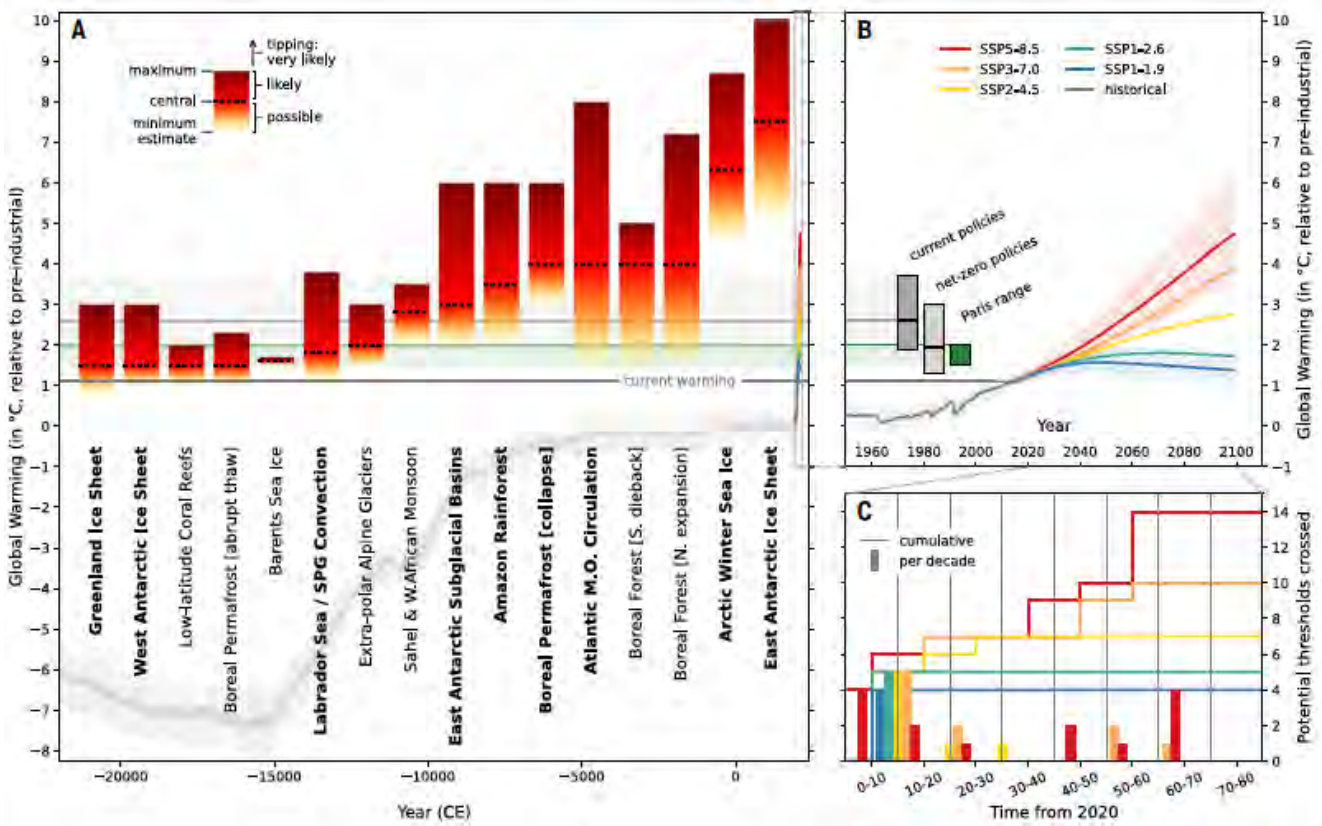
IPCC, 2023: Summary for Policymakers. In: *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

Climate Overshoot and Thresholds

"Every extra tenth of a degree and every extra decade of overshoot matters."

- **Ecological threshold:** Point at which there is an abrupt change in an ecosystem quality, property or phenomenon, or where small changes in an environmental driver produce large responses in the ecosystem (Groffman et al., 2006)
- **Environmental threshold** is a point at which the environment or ecosystem cannot recover. Once an ecosystem passes a threshold, it cannot return to its original state.
- **Climate threshold** is a critical limit where a climate system responds drastically when exposed to an external forcing, resulting in the system changing into a different stable state.

Prolonged Overshoot and/or Exceeding a Warming Threshold Elements of the Earth-Systems Trend Toward "Tipping Points"

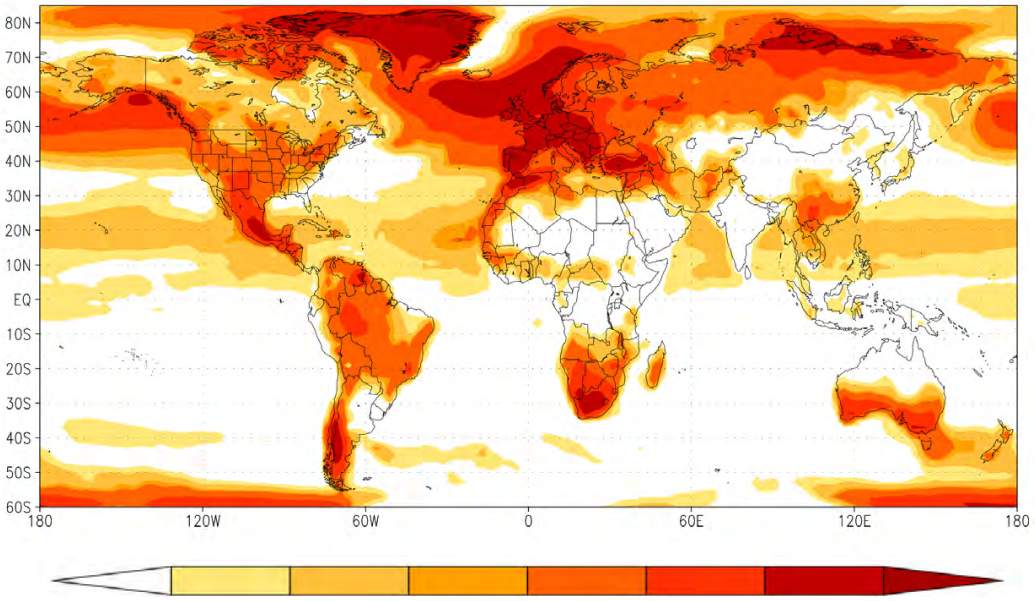


From Armstrong McKay et al., 2022

- **Tipping points** have been defined as "a critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system"
- **"Tipping element"** used to describe large-scale components of the Earth system that may pass a tipping point (Lenton et al., 2008) or large parts of the climate system become self-perpetuating beyond a warming threshold (McKay et al., 2022).
- However – prominent members of the scientific community are of the position that these concepts are "greatly overused and misused"
- Others argue that the idea of a single occasion in which humans cross a barrier from "climate change can be fixed" to "climate change is unfixable" is inaccurate.

Evolving Patterns of "Unprecedented" Temperature Outbreaks

Extreme Temperature Trend Index



Maximum and Mean Temperature Trends Likely at Same Pace

Maximum Temperature Trend Likely to Outpace Mean Temperature Trend

- Relative degree and consensus that trend in daily maximum temperature outpaces the mean temperature change in response to human-forced climate warming.
- Based on climate-response patterns from the Coupled Model Intercomparison Project Phase 6 (CMIP6).
- Darkest shades of red indicate regions where the relative increase of daily temperature maximum is more likely to outpace the rate of mean warming.
- **Regions in hotspots are more likely experience "unprecedented" extreme-temperature events as human-forced climate warming intensifies.**

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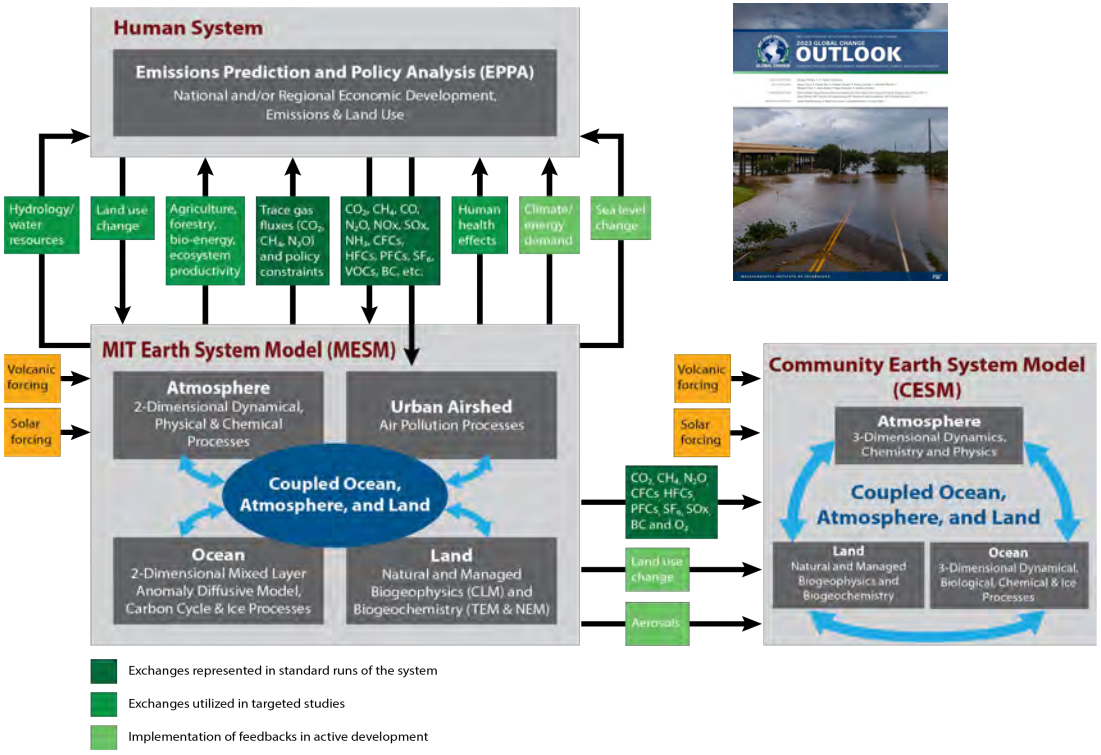
Tracking "Extremes" in 2023 MIT Joint Program Global Change Outlook Scenarios

Short ID	Indicator name	Definitions	Units
PRECTTOT	Total Precipitation	Total Precipitation	mm/day
CDD	Consecutive dry days	Maximum number of consecutive days with RR lt 1mm/day	days
CWD	Consecutive Wet days	Maximum number of consecutive days with RR ge1mm/day	days
SDII	Simple Daily Intensity Index	Total precipitation (RR gt 1mm/day) divided by the number of wet days	mm/day
Rx1day	Maximum 1-day precipitation amount	Maximum 1-day precipitation	mm/day
Rx5day	Maximum 5-day precipitation amount	Maximum consecutive 5-day precipitation	mm/day
R95p	Very Wet days	Total precipitation when RR gt 95th percentile	mm/day
R10mm	Number of heavy precipitation days	Count of days when total precipitation (RR gt 10 mm/day)	days
R20mm	Number of heavy precipitation days	Count of days when total precipitation (RR gt 20 mm/day)	days

Short ID	Indicator name	Definitions	Units
Tmax	Daily maximum temperature	Daily maximum temperature	°C
Tmax5p	Daily maximum temperature 5th Percentile	Percentage values over the all timesteps Tx 5th percentile	%
Tmax95p	Daily maximum temperature 95th Percentile	Percentage values over the all timesteps Tx 95th percentile	%
DTR	Diurnal temperature range	Mean differences between Tmax and Tmin	°C
Yearmax	Yearly Maximum values	Maximum value of daily maximum temperature	°C
SU35	Summer days	Summer days count when Tx > 35°C	days



CESM1 run at "2°" (1.9°x2.5°) and "1°" (0.9°x1.25°) resolutions

- Prescribed GHGs concentrations from CT and AA.
- Consider a suite of diagnostics over three future periods:
  - **Near Term 2021-2040 (NT)**
  - **Mid Term 2041-2060 (MT)**
  - **Far Term 2081-2100 (FT)**

IGSM-CESM1: 2˚ Resolution Current Trends Scenario

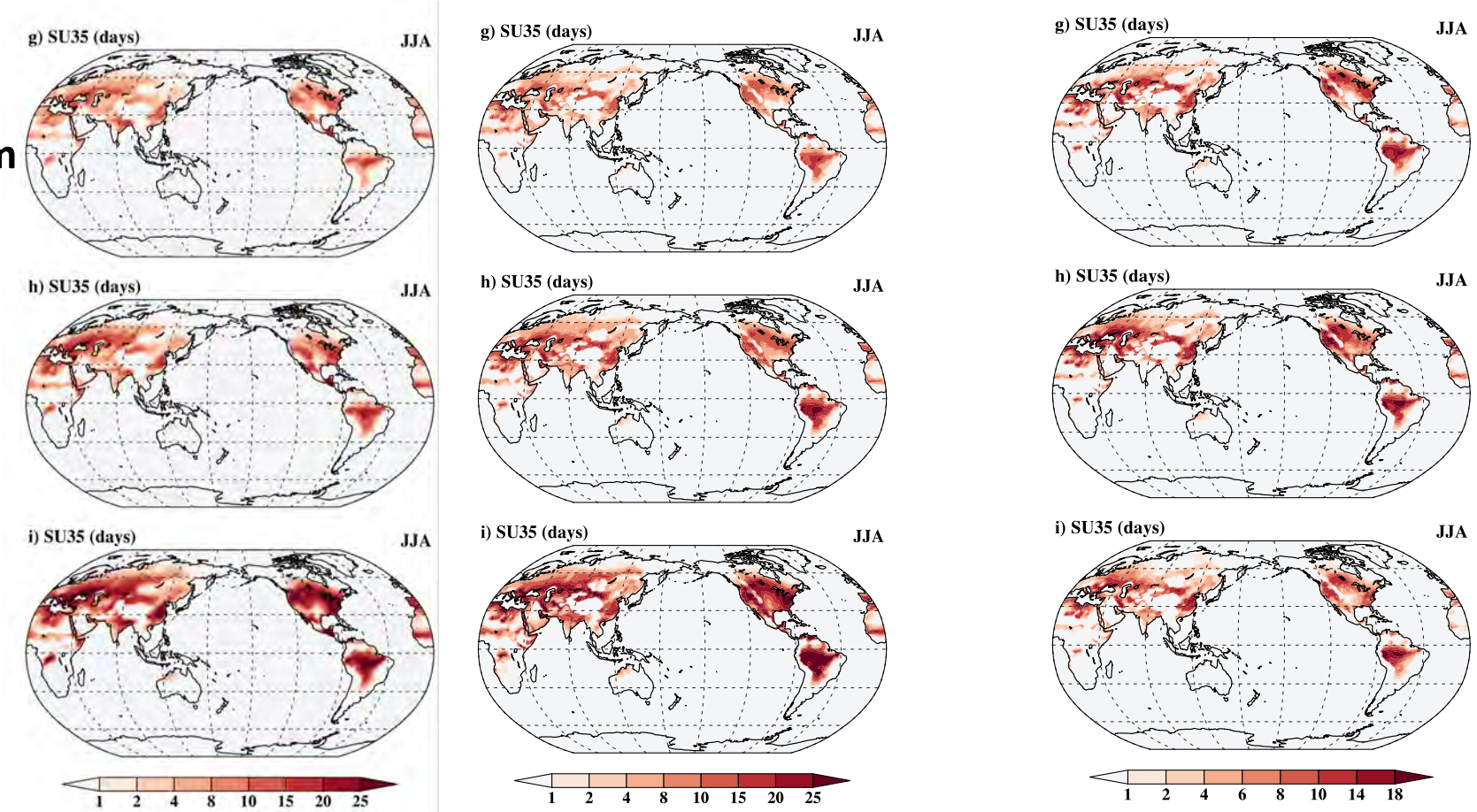
IGSM-CESM1: 1˚ Resolution Current Trends Scenario

IGSM-CESM1 At 1˚ Resolution Accelerated Actions

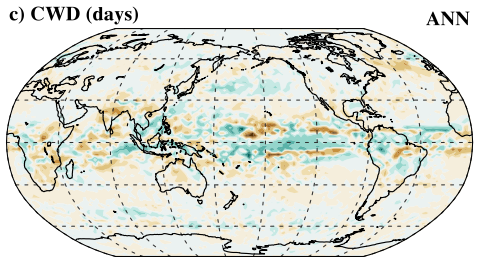
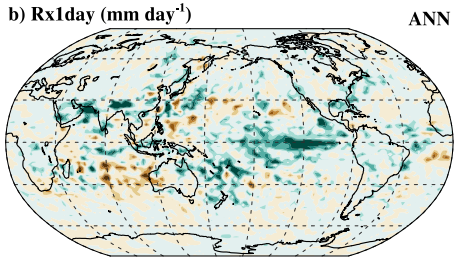
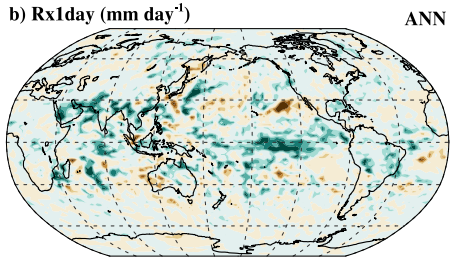
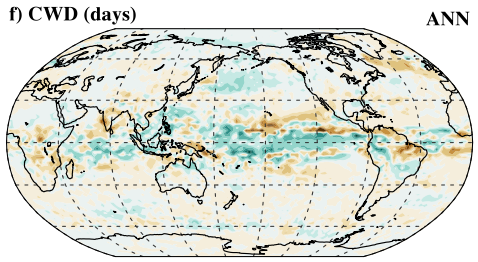
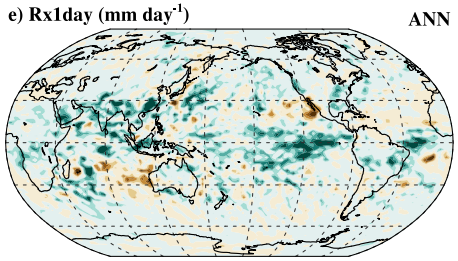
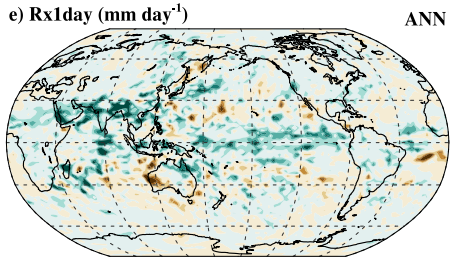
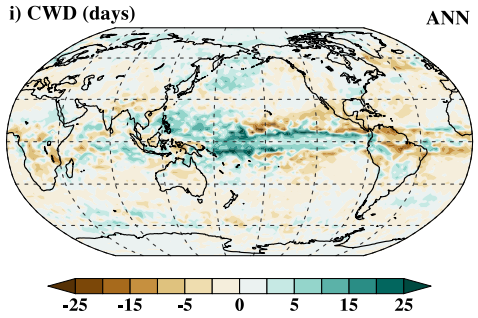
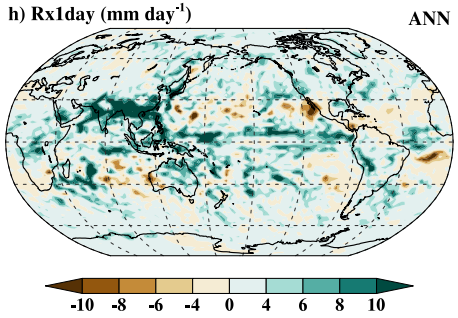
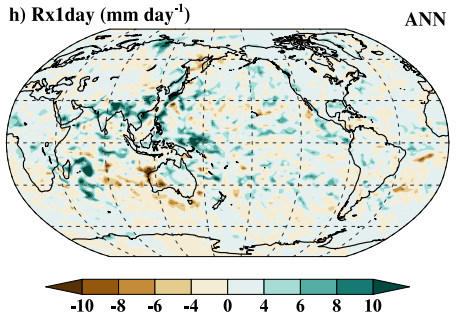
Near Term

Mid Term

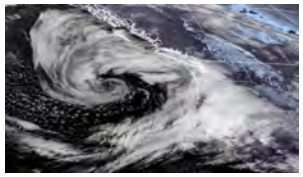
Far Term



- Overall patterns are resolution agnostic; yet intensify hotspots.
- In NH, only high latitude and/or altitude immune to change.
- At far term period, Mid-latitude regions upwards of additional month.
- Winter "heat waves" are also on the rise.

	IGSM-CESM1: 2˚ Resolution Current Trends Scenario	IGSM-CESM1: 2˚ Resolution Current Trends Scenario	IGSM-CESM1: 2˚ Resolution Accelerated Actions
Near Term			
Mid Term			
Far Term			

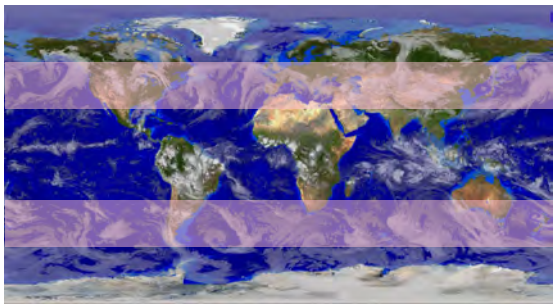
- Fewer wet days over Amazon, Central America, and southern Africa.
- By far term, Southeast Asia sees widespread daily intensification.
- Other regional increases over western U.S., central Africa, Australia.
- Impact of mitigation "noticeable" only until far term.



The Fate of Extreme Extratropical Cyclones (ETCs)

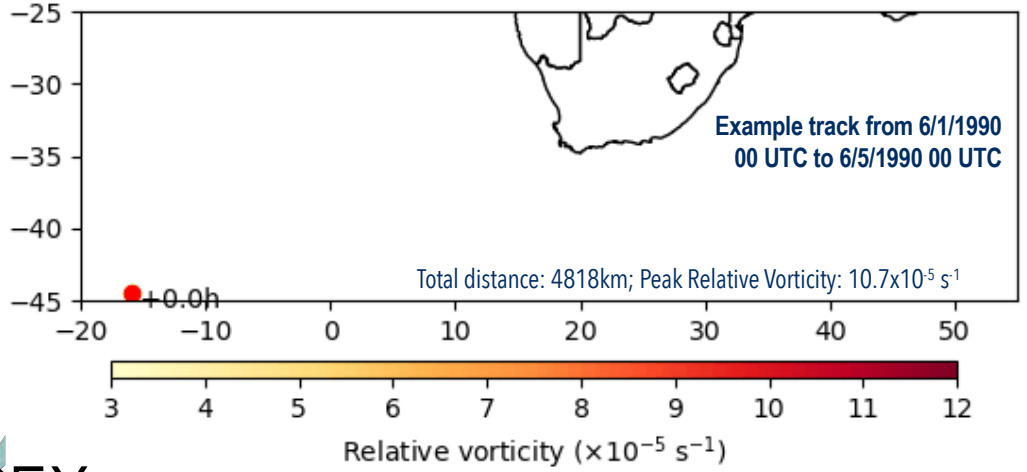
MIT CLIMATE GRAND CHALLENGES

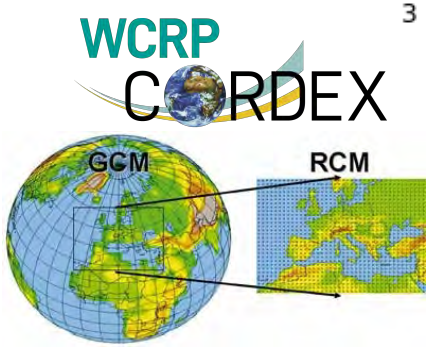
- Extratropical cyclones (ETCs) are low pressure systems that primarily draw energy from the equator-to-pole atmospheric temperature gradients.
- Form between 30° and 60° latitudes in both the northern and southern hemispheres.
- Typically involve a frontal system and associated with phenomena such as heavy precipitation bands, widespread strong winds, and temperature swings.
- Some tropical cyclones transform into ETCs.
- ETCs can also evolve into "cut-off lows", which are slower moving and can cause more extensive, prolonged damage.



Extreme ETC Analysis for South Africa Region

- 3 General Circulation Models (GCMs) drive 3 Regional Climate Models (RCMs)
- Historical: 1986-2005; Future RCP8.5: 2080-2099
- Region restricted to Latitudes [-45, -25] and Longitudes [-20, 55]





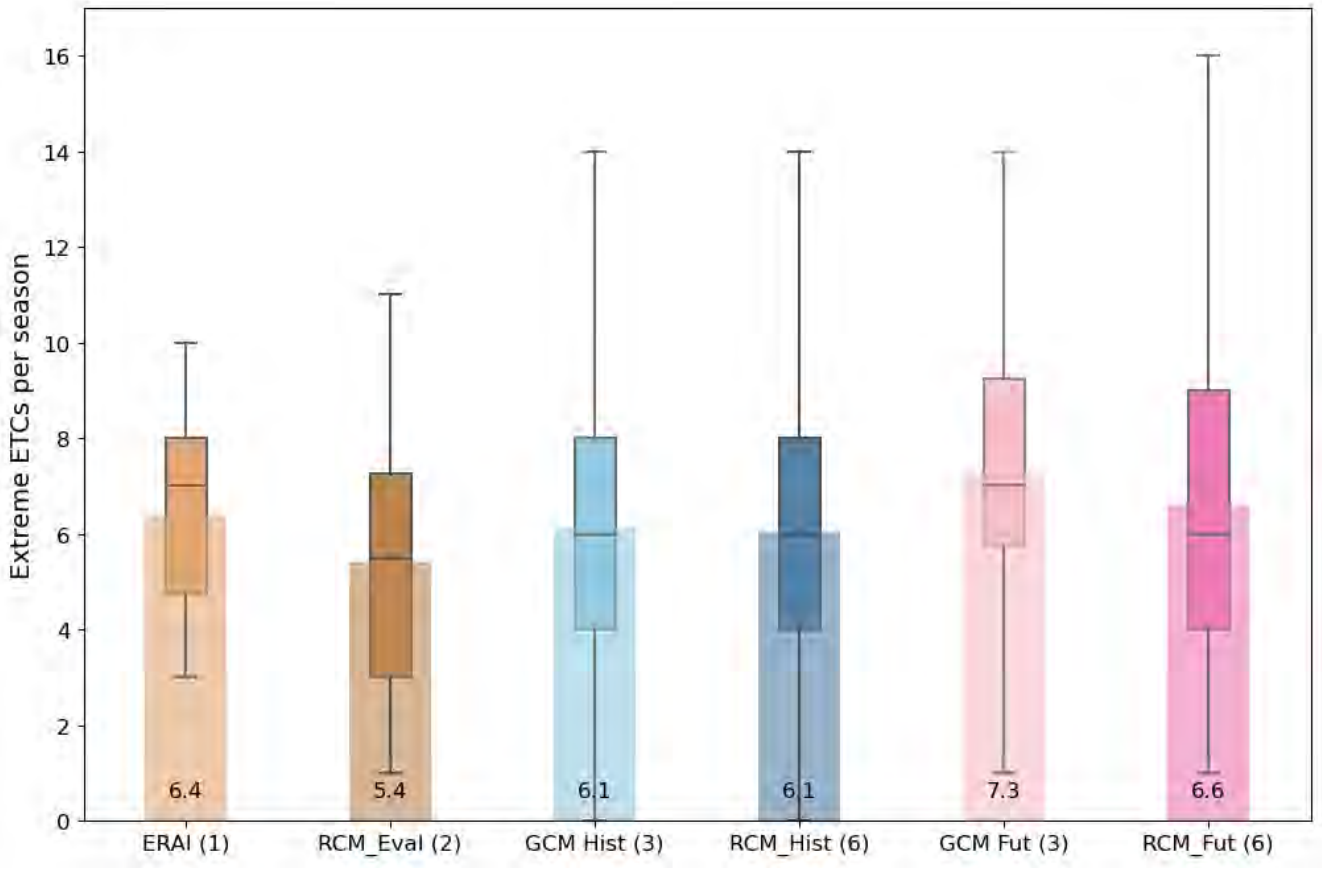
Several Characteristics Logged along track:

- Frequency (Number of ETCs)
- Intensity (Peak Relative Vorticity)
- Average Track Distance and Duration
- Accumulated Rainfall during ETC

Current and Future Extreme ETCs per season

All ETC tracks for Year 2000 from a selected RCM

Number of historical extreme ETCs classified as exceeding 90th percentile values (based on center sea-level pressure and spin).



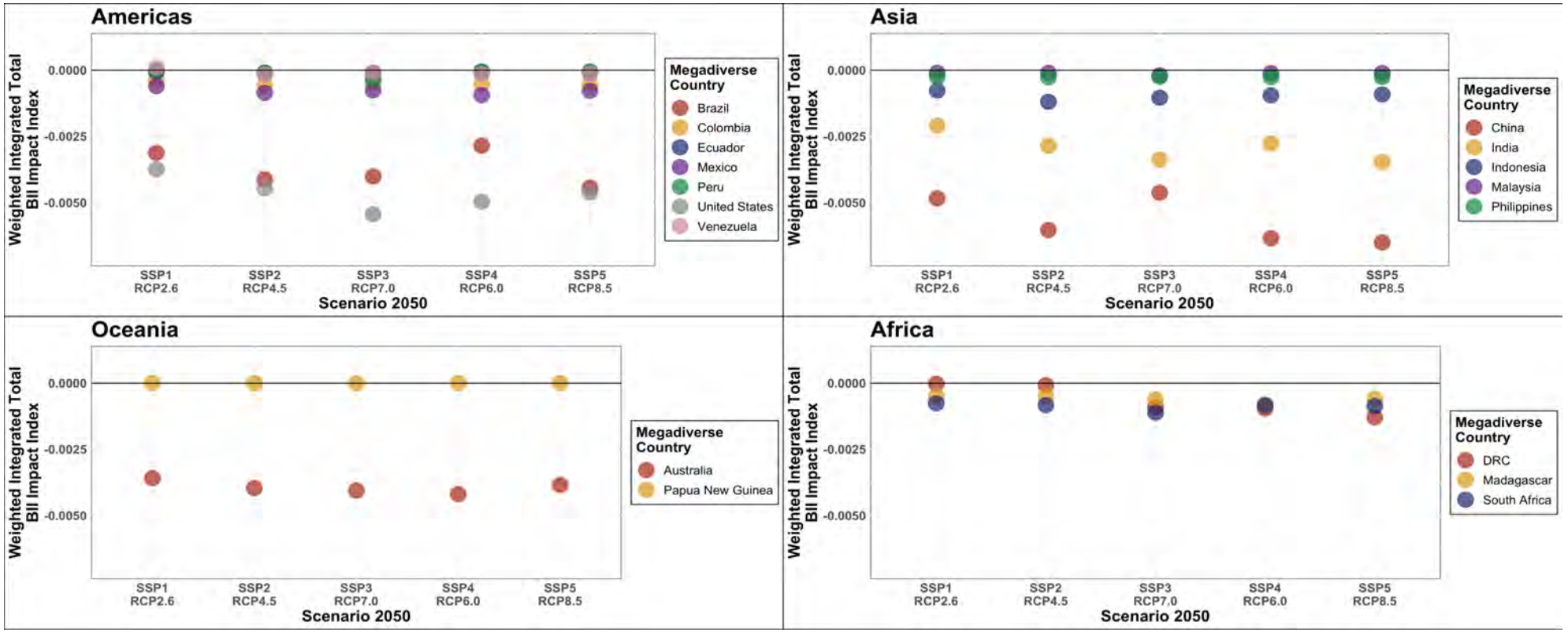
UNDER CLIMATE WARMING

- GCMs and RCMs increase the lowest expectation of an "extreme" ETC to occur.
- In the mean and median expectation – small increases in the number of extremes.
- For RCMs - climate warming brings increase in the maximum expected # of "extreme" ETCs each year.

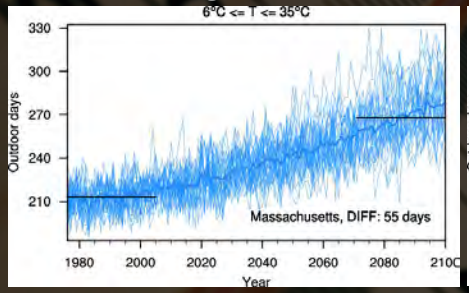
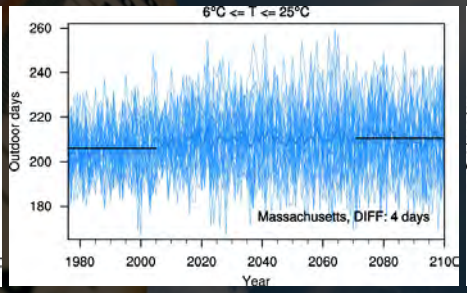
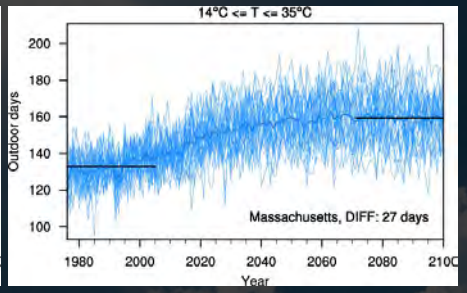
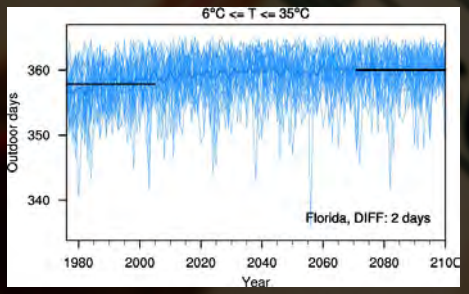
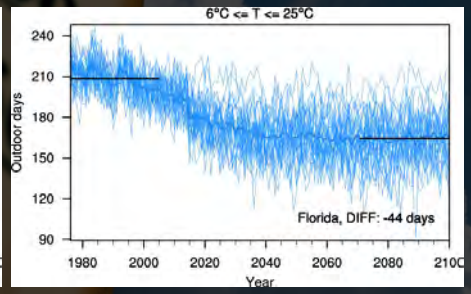
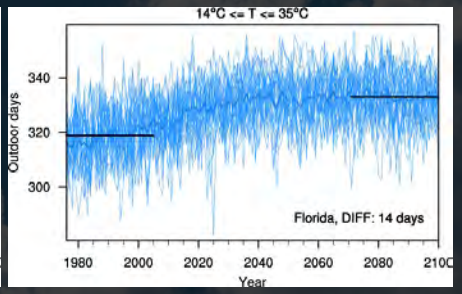
Not all Trends Bend Away from Thresholds Similarly or Equally – Enter Biodiversity

The IPCC Socio-economic pathways and climate-targets ***do not steer "megadiverse" regions and countries away from dangerous biodiversity thresholds.***

Global cooperative efforts toward land conservation, restoration, sustainable agriculture intensification, reduction in (food) use and waste, and improved diets must all be part of an integrated global strategy to improve biodiversity.



Personal perceptions and preferences on Thresholds can bend (and reverse) the trends

	Wide-Range Preference	Low-Tolerance to "Heat"	Low-Tolerance to "Cold"
MASSACHUSETTS			
FLORIDA			

https://eltahir.mit.edu/globaloutdoordays/

- Trends in "outdoor days" from high climate warming (RCP8.5)
- Adjustable Min/Max temperature Tolerances (i.e., personal thresholds)
- Impact of High/low settings on resultant trends
- Other affecting factors?

Closing Remarks

- The global warming "overshoot"- unavoidable yet not terminal.
- Tipping Points: Makers and Users beware and take care.
- Thresholds: Not absolute and not all-telling
- Extremes – Many measures to chose from – each tell a unique story and impact. Most aren't good!
- Climate-related trends point to changes in multi-faceted risks.
- Not all trends bend equally.
- Communication and open data-visualization – more than ever.
- Yet - personal perceptions and preferences are powerful.

Thank you

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