Through Drought and Flood: the past, present and future of Climate Migration

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Climate migration: a potential *social tipping-point* for modern societies

- Migration from low-income countries has doubled in the last 30 years, a flow increasingly associated with climate degradation in nations heavily dependent on agriculture. This process is often confounded with weak institutions, violence and strife.
- Countries at the receiving end have also been affected. With an increasingly negative perception among the general population, migration has contributed to social and political polarization, itself associated with the recent deterioration of the geopolitical landscape.
- But the scale of migration thus far will likely pale in comparison with future pressures. As climate further deteriorates, the map of uninhabitable ecosystems will continue to expand, many of which house some of the largest concentrations of people today.
- Regions that will suffer the most are often those already degraded,[1] suggesting observed trends may soon become highly non-linear. Thus, mass migration --the main adaptation mechanism of our species to survive climate change in the past-- may well constitute a key *social tipping-point* in our modern, overpopulated societies.

[1] IPCC, AR6.

This paper: advance the study of the climate-migration relation to project future scenarios

- **Question**: What will be the migratory pressures in the coming decades as climate further deteriorates?
- **Key Challenge**: Data
  - Comprehensive datasets on migration go back only a few decades.
  - Since the relationship between environmental change and migration is highly non-linear, and the current 1.2° increase still moderate, the magnitude of the non-linearity remains poorly understood.
- **Our Approach**:
  - Study the past: Recorded history includes multiple episodes that can help us understand the effects of environmental degradation on migration and its effects on societies.
  - Extend studies about the "present": We revisit the empirical literature on climate migration, extending previous studies in several dimension --most importantly, interacting its impact with income levels of different climatic zones (closest reference: Missirian and Schlenker, *Science* 2017).
  - Project future migration: We use our empirical model to project migration under moderate (SSP2) and high (SSP5) temperature increase IPCC scenarios. We also offer a preliminary discussion on the implications of more disruptive T° changes associated with the triggering of *tipping-points* –the collapse of Atlantic Meridional Ocean Circulation (AMOC) (quantitative estimation pending).

Preview of the Results

- **The past:**
  - The history of human migration is strongly related to climate change. The four selected episodes suggest that severe climate disruption leads to significant outward migration.
  - Furthermore, migration has highly disruptive consequences on societies at the receiving end, constituting one of the main elements precipitating violence, regime change and, in some cases, societal collapse.
- **The present:**
  - The relationship between climate change and migration over the last 30 years is highly significant and non-linear –an inverted U-shape around a "climate optimum." The non-linearity is stronger in poorer countries.
  - Indeed, despite tropical climatic zones having experienced the smallest increase in T° thus far, they exhibit the largest increase in outward migration due to their higher initial T° and lower GDP per capita (limits adaptation).
- **The future:**
  - We find moderate effects on migration increase under moderate climate scenarios, but more significant (**doubling**) of current cumulative migration from tropical zones in more extreme scenarios.
  - We conjecture our results constitute a **lower bound** of the possible effects, given:
    - The inherent non-linearity of ecosystem resilience to chronic climate change and the increased frequency extreme events –a ubiquitous feature of nature not yet triggered by the so-far moderate T° increases.
    - With worsening climate, incomes in the most affected regions will fall, enhancing the non-linear relationship due to limited adaptation and income divergence w.r.t. developed countries.

Outline

- **The Past: Narrative of four historical events**
  - The end of the Bronze Age (circa 1200 BCE).
  - The collapse of the Eastern Mediterranean (circa 1000 ACE).
  - The Bhola cyclone, the Indo-Pakistani war, and the creation of Bangladesh (1971).
  - The Rwandan genocide, and conflict in the Congo basin (1994-2001).

- **The Present: Quantitative analysis**
  - Data and empirical approach
  - Main results

- **The Future: Projecting climate migration**
  - Climate migration under IPCC Shared Socio-Economic Pathways (RCP 4.5 and 8.5)
  - Work in progress: migration under tipping points --AMOC Collapse

- **Discussion and policy implications**

The Past: the end of the Bronze age

- The bronze age marks the transformation of dispersed neolithic villages into "the state" (and eventually, regional empires) characterized by high population concentration (4,000/3,000 BCE, to circa 1,200 BCE).[1]
- The period witnessed technological improvements (irrigation systems, bronze tools, wheels and wagons) and increases in social complexity: marked social differentiation and inequality, writing, and hierarchies for administrating vast agricultural resources.[2]
- The late Bronze age also saw a growing trade network between "the club of the great powers": Egypt, Hatti, Mitanni, and (Kassite) Babylon. Minor players included rising Assyria, Arzawa, and many city-states of Mycenean Greece.[3]
- Geographically, the region sits between two mayor climatic regimes, dominated by N. Atlantic winter precipitation towards the NW, and the Monsoon summer rain system towards the SE.
- Importantly, shifts in the range of Earth´s wind circulation cells can significantly affect T°s and precipitations throughout the region, at times for many years and even decades. These shifts correlate with cycles of solar radiation intensity (also a factor in the 2nd case study), the most important being the 2,400-year *Hallstat* cycle. [4]

[1] Scott, J. (2017). "Against the Grain". [2] Tainter, J. (1990). "The Collapse of Complex Societies". [3] Bryce, T. (2005). "The Kingdom of the Hittites".

[4] Brooke, J. (2014). "Climate Change and the Course of Global History".

The Past: the end of the Bronze age –widespread societal collapse

- Around 1,200 BCE, during a *Hallstat* radiation minimum, a multi-decade drought appears to have hit states in the N/NE of the region. This is documented by Egyptian and Hittite trade contracts showing significant increases in grain deliveries from Egypt to Hatti and its many vassal states.[1]
- The drought appears to have hit Mycenae the hardest, triggering mass migration into Anatolia, the Levant, and Egypt in successive waves of population displacements ("Sea Peoples", between 1,200-1,170 BCE).[2]
- This movement resulted in the looting, burning and abandonment of cities in Greece; the destruction of Hattusa and dissolution of Hittite empire and Babylon; destruction and loss of Egypt´s territories in the Levant.
- The aftermath: a 400-year "dark age".[3]

[1] Bryce, T. (2005). "The Kingdom of the Hittites". [2] Carpenter, R. (1966). "Discontinuity in Greek Civilization". [3] Tainter, J. (1990). "The Collapse of Complex Societies"

The Past: summary and lessons for the future

Summary

1. These selected episodes illustrate the tight relationship between climate change and mass migration, particularly for severe and/or long-lasting events (multi-year/decade).
2. Climate migration is usually accompanied by violence and strife, and socio-economic impacts range from regime change to societal collapse. Significantly, it often affects receiving countries at least as much than at the origin:

> *"The domino effect was felt by countries outside the region of the cold spell no less –and very often much more— than it was by countries in which cold spells and droughts were the most severe" (Ellenblum, 2012).*[1]

But is history informative for the future? Keep in mind that in all these episodes:

1. Climate disruptions were mild compared to scenarios above 2°C warming.
2. Disruptions were local, while the current climate disturbance is global, driven by changes in atmosphere´s composition (rather than solar radiation cycles and Bond ice rafting events -- Brooke (2014)).
3. Climate eventually normalized after a few years (a few decades is at the long-end of the range). Our current climate crisis will only get worse after 2100, in scenarios with insufficient CO2 reduction in the next few decades.

History is an imperfect mirror, but this is a cause of concern, not reassurance.

[1] Ellenblum, R. (2012). "The Collapse of the Eastern Mediterranean: Climate Change and the Decline of the East, 950-1072"

The Present: Data Sources

- **Migration:**
  - Census data - Department of Economic and Social Affairs and Population Division at the UN (UNDESA).
  - We construct the emigration stock in a 5-years frequency for 154 countries over the period 1990-2020.
- **Agriculture and Weather:**
  - Agricultural data: the Crop and Livestock Production and Utilization data and the Land & Water section from the FAO's Data Collection to identify the maize growing season for each country.
  - Temperature: the Climate Change Knowledge Portal (World Bank) provides historical series at the country-level.
- **Economic data:**
  - World Development Indicators (World Bank) for country's total population and the GDP per capita (PPP) in 2017 USD.
- **Classification of climatic zones:**
  - Each country is classified according to their dominant area into: temperate, arid, cold, and tropical climates – (Peel et al., 2007, for more detail).

The Present: Current Migration from Different Climactic Zones

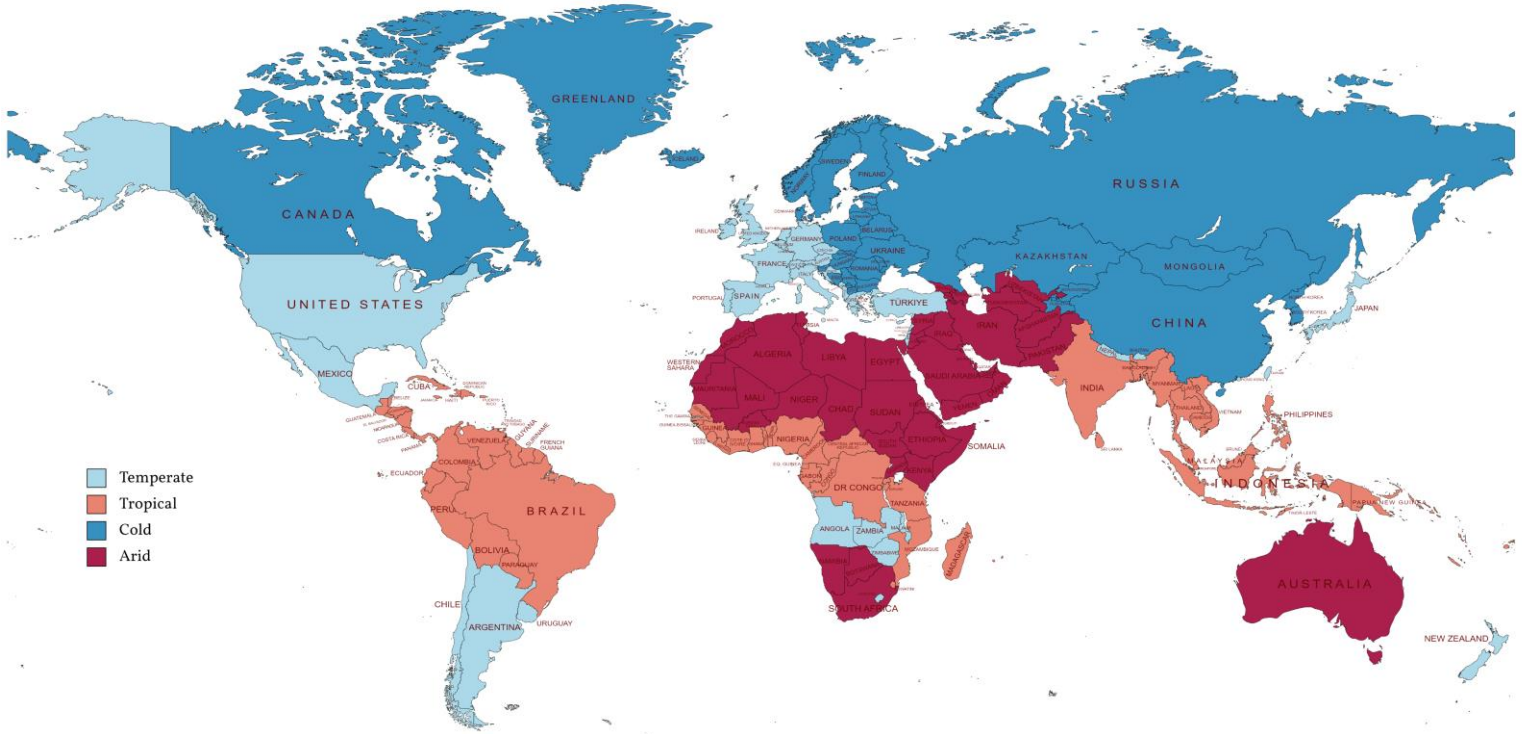


Figure 1: *Climate classification by country, according to the main covering area – see Peel et al. (2007) for more detail. The figure shows the more general classification: tropical, temperate, cold, and arid.*

Table 1: *Emigration stock in millions and average temperature for the growing season of maize by climate classification.*

	Arid		Cold		Temperate		Tropical		Global	
Year	Emigration stock (millions)	Temperature (maize season)	Emigration stock (millions)	Temperature (maize season)	Emigration stock (millions)	Temperature (maize season)	Emigration stock (millions)	Temperature (maize season)	Emigration stock (millions)	Temperature (maize season)
1990	26.4	19.6°C	38.3	15.1°C	32.1	18.2°C	**36.0**	**24.0°C**	**132.9**	**20.4°C**
2000	24.2	20.0°C	40.8	15.4°C	40.3	18.5°C	45.5	24.2°C	150.8	20.7°C
2010	31.4	20.4°C	46.7	16.0°C	46.5	18.8°C	66.2	24.3°C	190.8	21.0°C
2020	36.5	20.6°C	53.7	16.3°C	31.2	19.1°C	**84.9**	**24.6°C**	**226.4**	**21.3°C**

Empirical Approach

Reduced-form model

$$E_{it} = (\beta_1 + \beta_2 y_{it})T_{it} + (\beta_3 + \beta_4 y_{it})T_{it}^2 + \beta_5 y_{it} + \theta Pop_{it} + \alpha_i + \gamma_t + \epsilon_{it} \quad (1)$$

- Variables:
  - E_{it}: ratio between emigration stock from country i in year t with respect to 1990
  - T_{it}: mean temperature of the maize growth season of country i over previous 5 years
  - y_{it}: log of the GDP per capita of country i in year t
  - Pop_{it}: ratio between the population of country i in year t with respect to its population in 1990
  - α_i, γ_t: country and time fixed-effects

- Level of GDP per capita captures income and other drivers of migration.
- Interaction terms of GDP per capita: capture whether sensitivity of migration to temperature shifts is associated with institutions and state capacity to manage environmental stressors.

Main Results

	(1) Only Temperature	(2) Temperature and Rain	(3) Baseline	(4) Baseline with Rain
Population norm. to 1990	-0.117 (0.13)	-0.139 (0.14)	0.009 (0.07)	0.034 (0.07)
5-year average temperature	-1.626** (0.58)	-1.662** (0.59)	**-5.084**** (1.83)	-5.092** (1.91)
5-year average temperature^2	0.039** (0.01)	0.039** (0.01)	**0.137**** (0.05)	0.135** (0.05)
5-year average total precipitation		-0.005 (0.00)		-0.021 (0.01)
5-year average total precipitation^2		0.000 (0.00)		0.000* (0.00)
Log GDP pc (PPP, USD 2017)			**-3.929*** (1.59)	-4.091* (1.65)
Temperature and GDP (linear interaction)			**0.435*** (0.17)	0.426* (0.18)
Temperature and GDP (quadratic interaction)			**-0.012**** (0.00)	-0.012* (0.00)
Precipitation and GDP (linear interaction)				0.002* (0.00)
Precipitation and GDP (quadratic interaction)				0.000* (0.00)
Inflection Temp. (°C)	20.7	21.1	24.5	24.5
N countries	154	154	147	147
N years	7	7	7	7

*Standard errors in parantheses. * p < 0.1,** p < 0.01,*** p < 0.001*
Weather variables are estimated for the growing season of maize.

Main Results: Quadratic Response Function

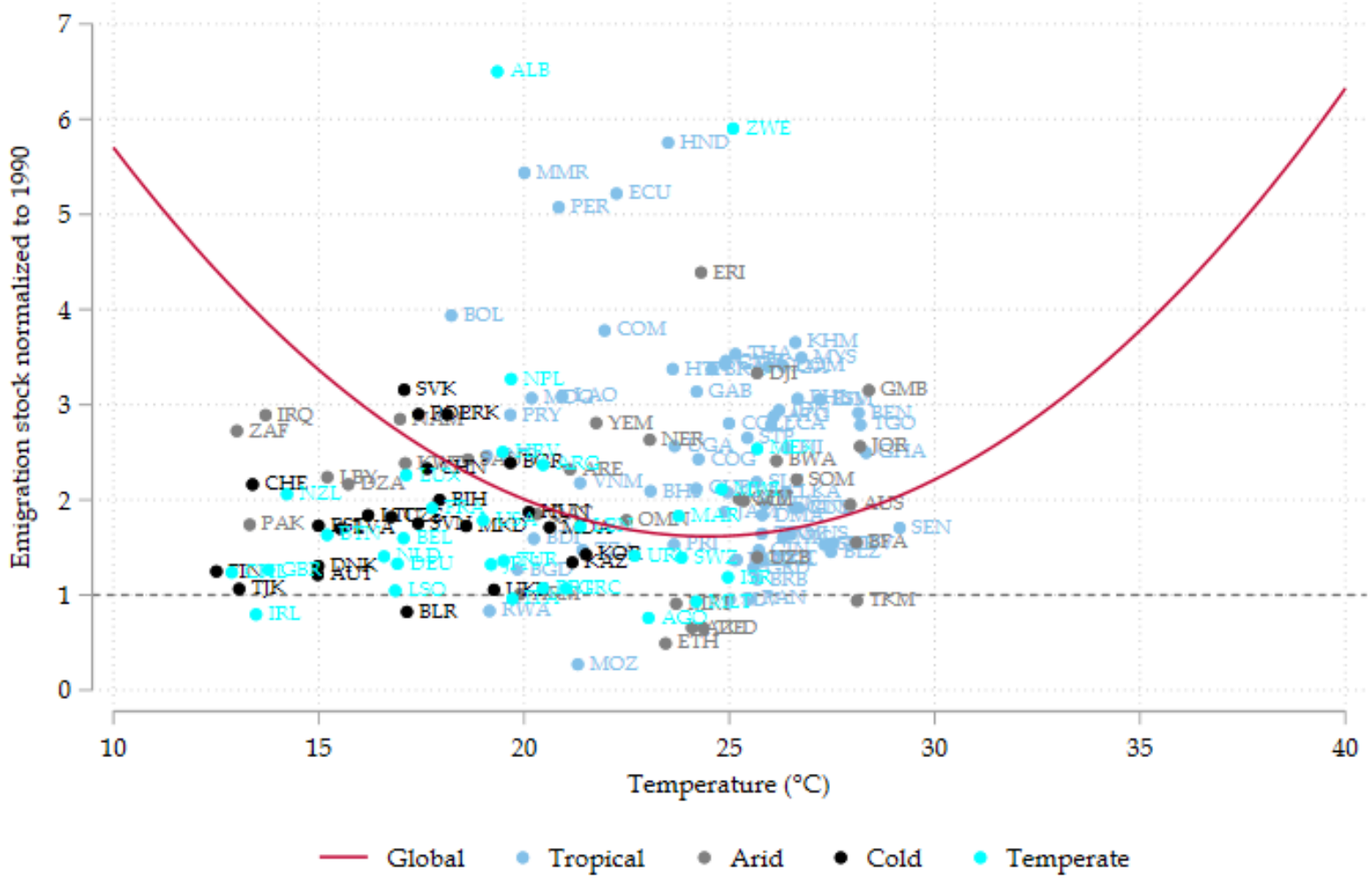


Figure 2: *Relationship between the average temperature for the growing season of maize and the ratio between the emigration stock in 2020 and 1990. The scatter plot shows the relationship for our sample of countries in 2020, by their climate classification.*

<u>Countries distribution:</u>

- Global Inflection point is at 24.5° Celsius.
- Tropical and arid climate countries are mostly located in the right part of the quadratic response function, while cold and temperate countries line towards the left.

Heterogeneity of Impacts: Role of GDP per capita and Climate

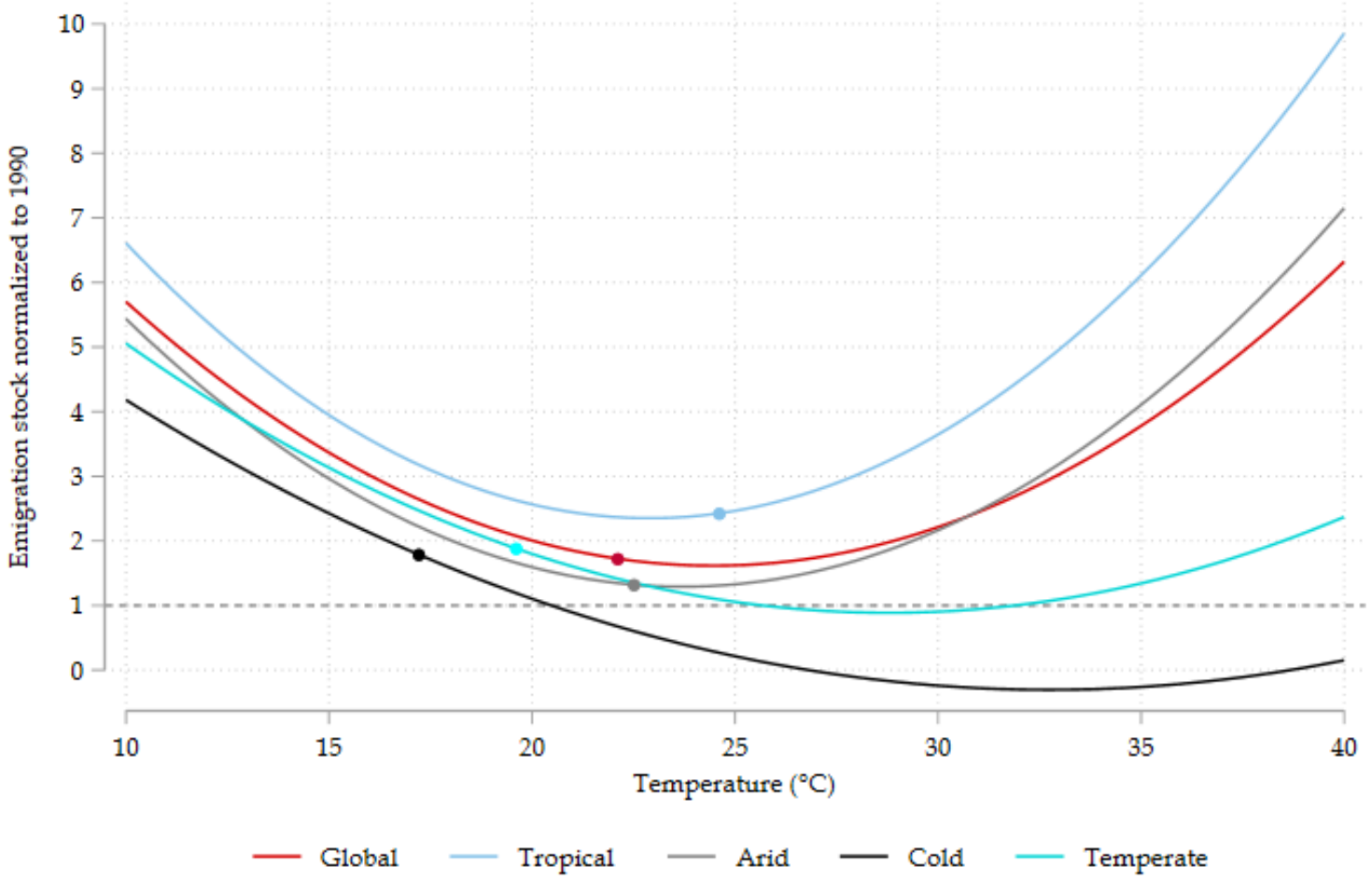


Figure 3. *Relationship between the average temperature for the growing season of maize and the ratio between the emigration stock in 2020 and 1990, by climate classification. The lines show the estimated function of this relationship by our baseline specification for different climates. The dots represent the average temperature in 2020 for each climate.*

<u>GDP per capita</u>

- GDP per capita diminishes the quadratic positive relationship between temperature increases and emigration.
- This probably reflects that temperate and cold countries with higher GDP per capita are more resilient (adaptation capacity) to temperature increases than tropical and arid countries.

<u>Type of climate</u>

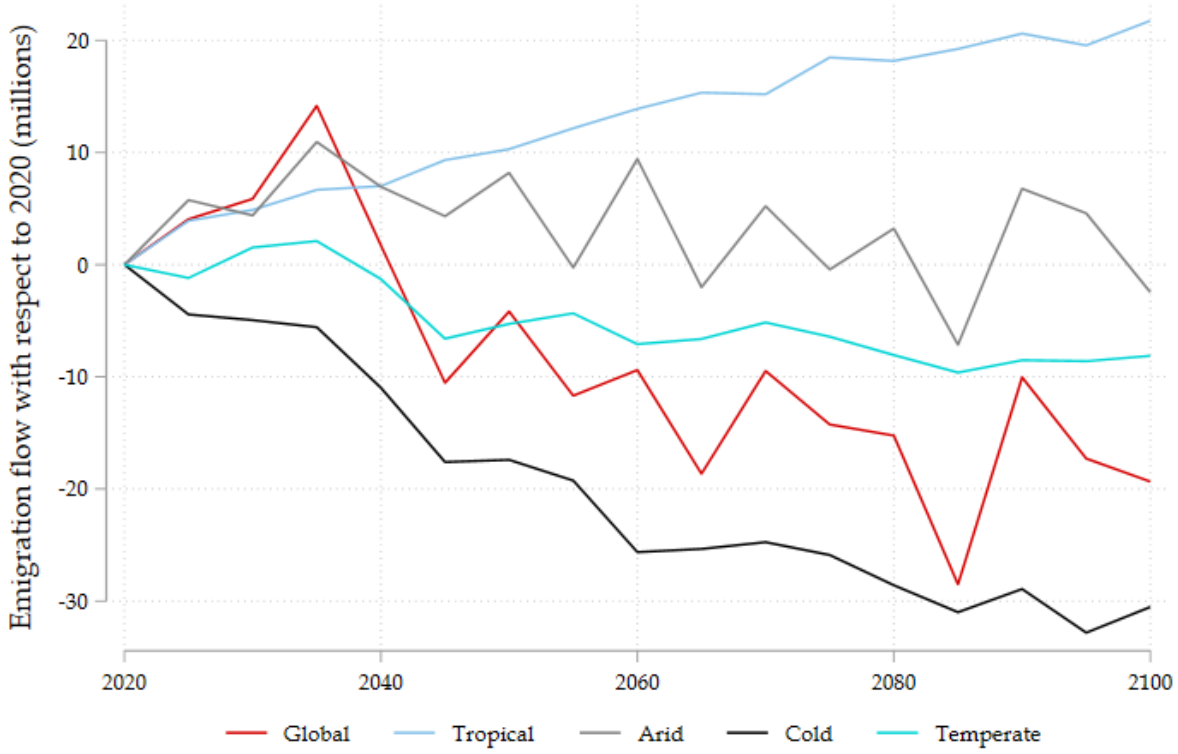
- Different levels by country fixed-effects.
- Heterogeneous current average temperatures implies different positions of the quadratic response function.
- **Tropical countries** are the most exposed to higher T°s, given their position in the non-linear relationship.

The Future: IPCC SSP Scenarios

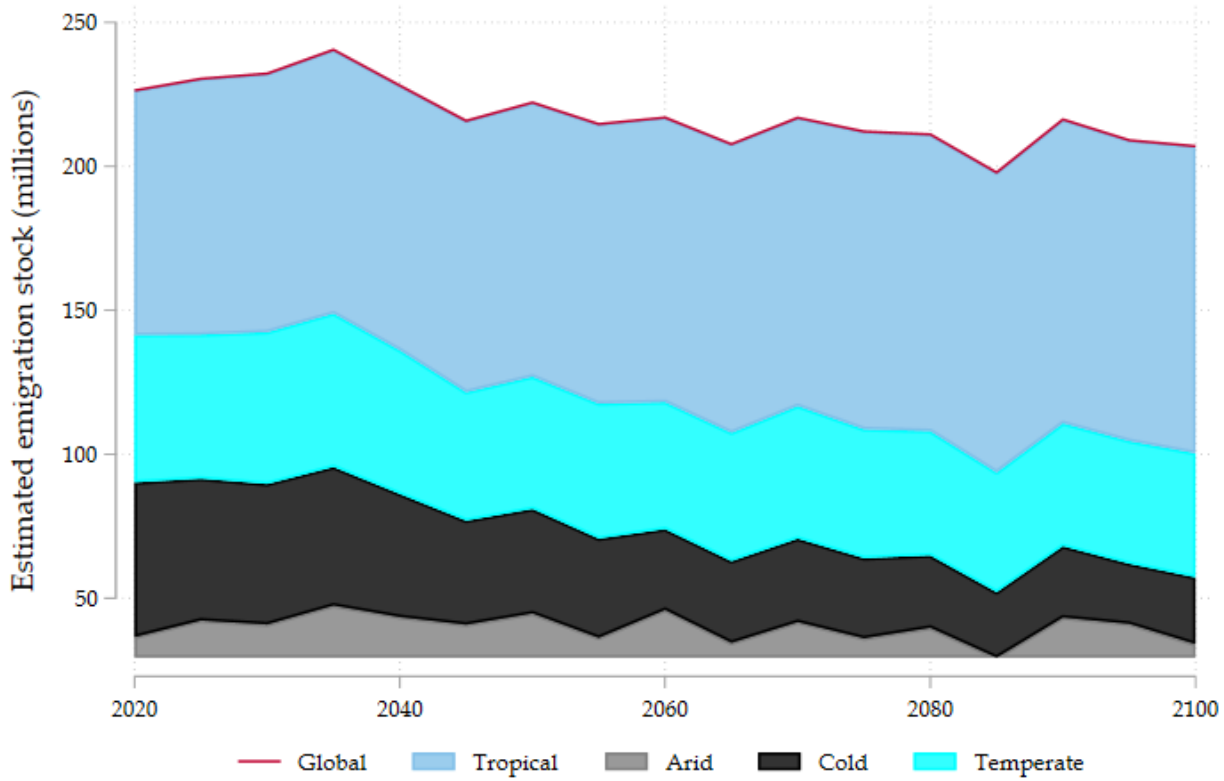
Scenario	Description	Warming Range by 2100
SSP1-2.6	Scenario that supports increasing sustainability with global emissions cut severely but reach net zero after 2050.	1.3°C - 2.4°C
SSP2-4.5	Presents a 'middle of the road' scenario in which emissions remain around current levels before starting to fall around mid-century but do not reach net zero by 2100.	2.1°C - 3.5°C
SSP3-7.0	Presents a pathway in which countries are increasingly competitive, and emissions continue to climb, roughly doubling from current levels by 2100.	2.8°C - 4.6°C
SSP5-8.5	Presents a future based on an intensified exploitation of fossil fuel resources where global markets are increasingly integrated, leading to innovations and technological progress.	3.3°C - 5.7°C

Table 3: *Description of the scenarios used for projections.*

The future: SSP2 – 4.5 scenario--> migration from tropical countries increases moderately (25%)



(a) *Projected emigration growth by type of climate*

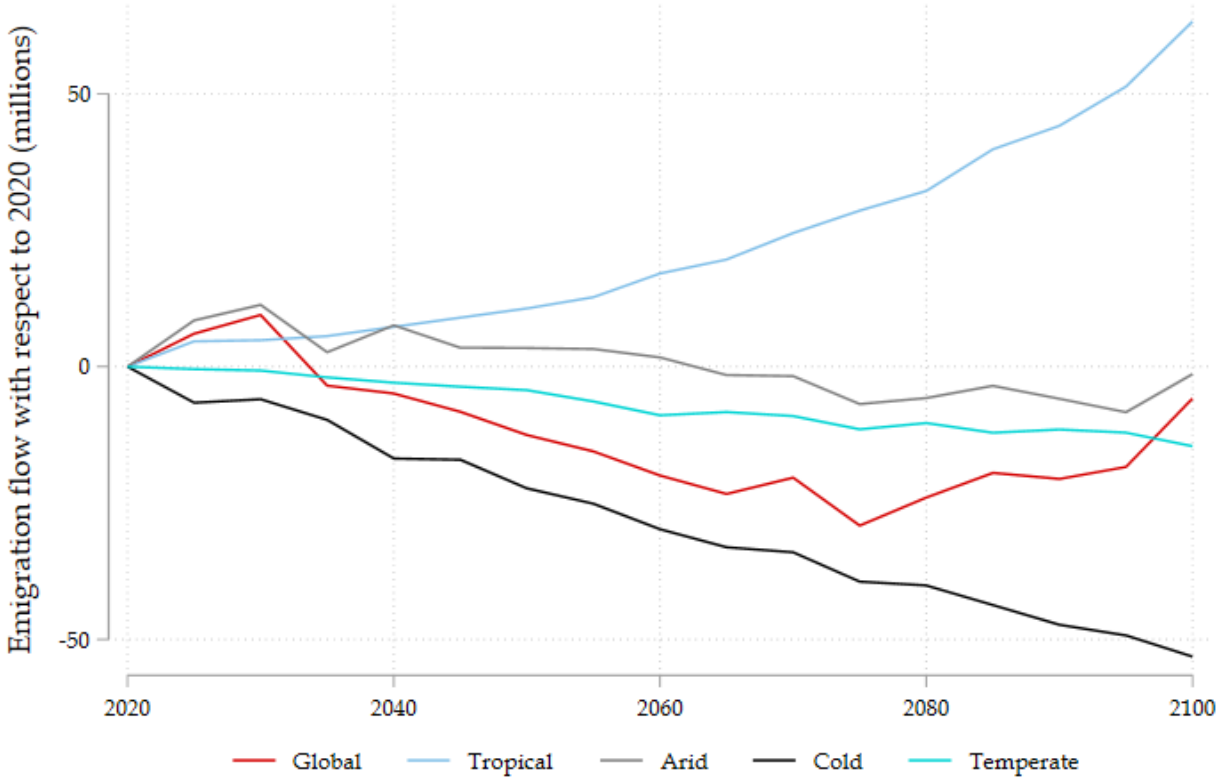


(b) *Projected emigration stock by type of climate*

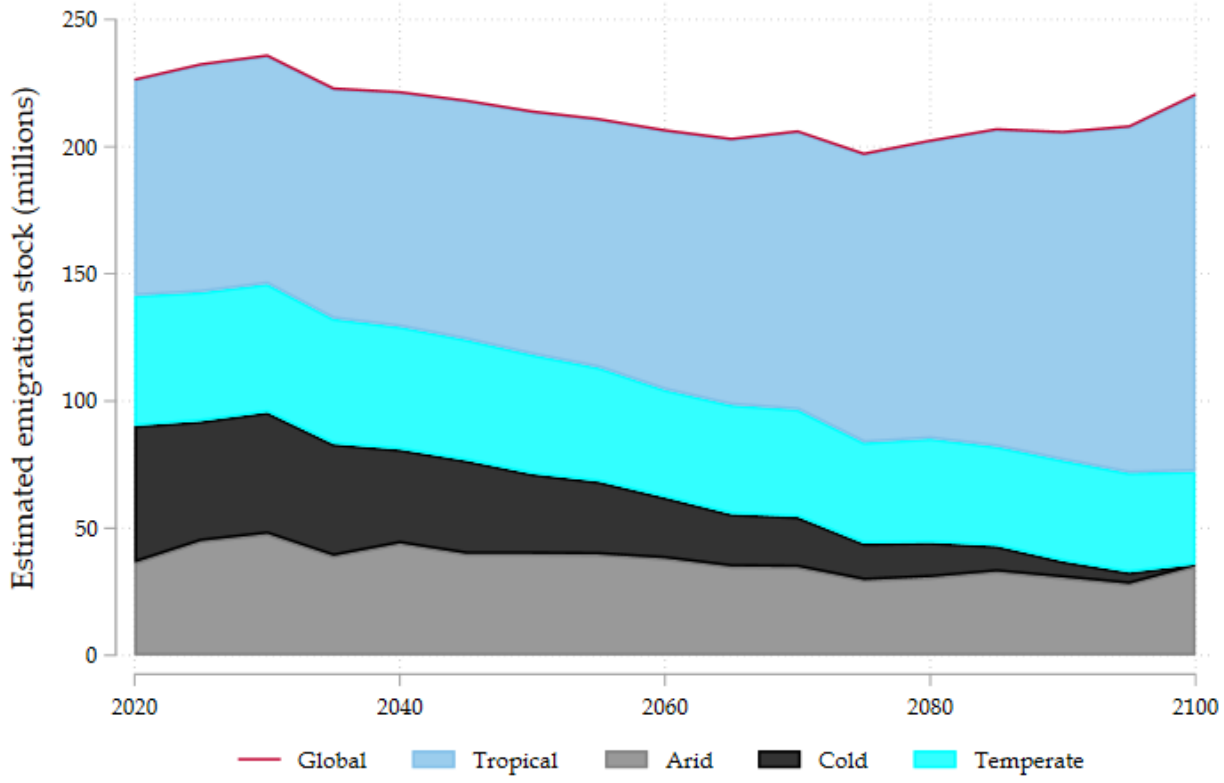
Figure 4: *Projections based on the SSP2-4.5 scenario*

Year	Global	Arid	Cold	Temperate	Tropical
2020	21.4°C	21.0°C	16.5°C	19.3°C	24.7°C
2100	24.3°C	23.5°C	19.3°C	22.4°C	27.5°C

The future: SSP5 – 8.5 scenario --> migration from tropical countries would roughly double



(a) *Projected emigration growth by type of climate*



(b) *Projected emigration stock by type of climate*

Figure 5: *Projections based on the SSP5-8.5 scenario*

Year	Global	Arid	Cold	Temperate	Tropical
2020	21.4°C	21.0°C	16.5°C	19.3°C	24.7°C
2100	27.5°C	26.3°C	23.8°C	25.7°C	30.4°C

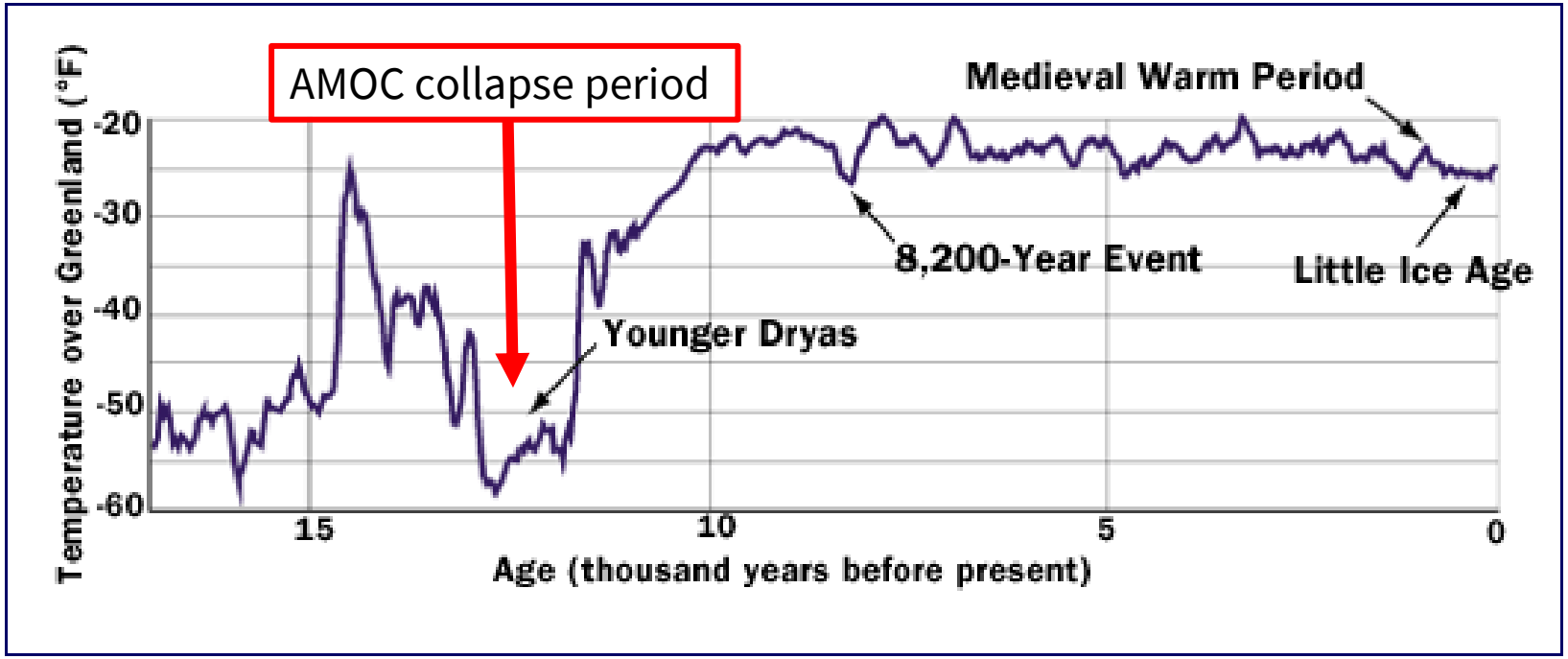
The future: Tipping points –Migration under AMOC collapse

- The NA ocean thermohaline circulation (AMOC) plays a key role in mitigating T° differences between the NA and the equator. Its functioning relies on increased water salinity as it moves northward. Recent work suggests AMOC has slowed more than previously thought, and significantly moves forward the time range when it could collapse (2050, as opposed to after 2100).[1]
- What would be the impact of this tipping point? The NA region would reduce its T° significantly, with the heat remaining "trapped" at the equatorial belt. This would increase migration in tropical countries, but significantly, also in developed countries in the NA –divergent T°s move both regions towards opposite tails of the quadratic response function –although where would all these people migrate remains unclear!
- **Work in progress**: use T° change projections under AMOC collapse scenario to estimate migration from different regions.

[1] Ditlevsen and Ditlevsen (2023). "Warning of a forthcoming collapse of the Atlantic meridional overturning circulation". Nature Communications.

The future: How big a deal is this *tipping point*?

- The last glacial maximum occurred about 20,000 years ago. The earth started to warm up after that (with significant T° volatility, at least in the NA). Archaeological records show incipient domestication of plant species (agriculture).
- Warming caused a "natural accident" about 11,000 BCE: melted water contained within a huge lake (Agassiz) was suddenly poured over the NA, decreasing water salinity and halting the AMOC. This sent the NA into ice-age T°s for 1,000 years, significantly reducing human population, which returned to hunter-gatherer strategy.
- Indeed, the Holocene starts when the AMOC reignites, and T° rises in NA.[1]



[1] Brooke, J. (2014). "Climate Change and the Course of Global History".

Concluding Remarks

- Climate migration could represent a *social tipping point* if it leads to within country conflict and polarization, and between country conflict and further deterioration of international cooperation – both already happening-- which is a prerequisite for international climate and environmental agreements to get traction and speed up the environmental transition.
- Past episodes suggest that climate induced migration is not “a nuisance” that slightly amplifies GDP or welfare losses, but rather “the main thing” (at the very least, a significant contributor) in precipitating socio-economic dislocation/collapse.
- Estimates with data since 1990 suggests migration from poor nations will further increase, although data scarcity in the "non-linear" region probably leads to an underestimation of the effects.
- We highlight two immediate policy implications from the analysis
    1. High priority should be given at identifying and financing the key investment in adaptation to mitigate emigration from most affected zones, particularly poor countries (IPCC, AR5, AR6).
    2. Still, migration pressures will increase in coming decades, as the alternative for many populations is death. The most we can aim for is an “orderly” migration process --for which current international agreements look woefully unprepared.

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The Past: four historical events

- The end of the Bronze Age (circa 1200 BCE)
  - Over a few decades, numerous cities in the Eastern Mediterranean were destroyed in fiery conflagrations attributed to waves of invasions or migration from the so-called Sea Peoples (Sanders et al. 1985).
  - Evidence shows that climate events might have caused these large and disruptive migrations.
- Climate events and the Eastern Mediterranean collapse (circa 1000 ACE)
  - Around the close of the first millennium, nine episodes of drought – totaling twenty-six years – hit the valley of Egypt over a period lasting more than a century, representing a tenfold increase in the frequency of droughts compared to the previous six centuries.
  - At the same time, a cold weather anomaly hit the steppes, dislocating the seasonal migration pattern of the pastoralist Turkic tribes, and without Egypt acting as a buffer of grain supply due to droughts, famines spread across the whole region including Mesopotamia and Syria (Ellenblum, 2012).
  - **The economic effects of the climate shocks experienced from Egypt to Mesopotamia and Iran were significant**: GDP per capita in Egypt in 1000 ACE was 18% below 730 ACE, and by 1120 ACE was still 10% below the level three centuries before. In Iraq, income per capita in 1120 ACE was 17% below the level observed 120 years before, while in Turkey, it had fallen 3% over the same period (Bolt & Van Zanden, 2020). These magnitudes are even more dramatic if one assesses the gap between workers' incomes and the subsistence level of wages.

The Past: four historical events

- The Bhola cyclone, the Indo-Pakistani war of 1971, and the creation of Bangladesh
  - The 1970 one of the deadliest monsoon seasons (reaching wind speeds of nearly 200 km/h) affected an already politically and ethnically tense area. The whole area was devastated mostly due to tidal waves that ravaged towns and crops and killing hundreds of thousands of people.
  - The slow and inefficient response of the Government resulted in a brutal political backlash giving more influence to the Pakistan People's Party (PPP) and the Awami League. The political conflict reached a tipping point in March 1971 when the government decided to crack down on Eastern Pakistani independent and nationalist movements.
  - The resulting civil-war conditions created acute internal strife, as the East Pakistani military split along ethnic lines, pushing millions of refugees across the border to India, joining an already large diaspora from the previous year's exodus from the immediate dislocations created by the cyclone, which caused the involvement of India in the civil war, and culminating in the defeat of the East Pakistan military in late 1971.
- Environmental degradation, the Rwandan genocide, and conflict in the Congo basin (1994-2001)
  - In Rwanda, one of Africa's most densely populated countries in Africa, 96% of the population lived in the countryside, where 90% of the labor force was employed in agriculture. Unsustainable practices led to falling soil fertility, while degradation of watersheds and forest erosion resulted from overcultivation. This dwindling resource base resulted in increased stress between ethnic groups.
  - As the exploitation of available land was reaching its natural limits, aggregate agricultural production fell 20% in per-capita terms between 1980 and 1990. A severe drought affected Rwanda in particular, as rainfall totals fell 30%, which together with a collapse in international prices for crops locally produced led to a civil war as the Rwandan Patriotic Front (RPF), predominantly made up of post-independence displaced Tutsi and their descendants, invaded Rwanda from their bases in Uganda, intending to topple the government.
  - The tension escalated and blew up into full-scale conflict and genocide less than a year later with Habyarimana's assassination. As the extremist Hutu government was falling under the pressure of the RPF, its cadres fled, alongside close to two million Rwandans of Hutu ethnicity.
  - The cost of the war in the DRC (formerly Zaire) was very high. Many of the thousands of Hutu refugees who escaped eventually returned to Rwanda. However, the UNHCR reckons that two hundred thousand refugees disappeared, likely perishing during the war.