Climate Change and Political Upheaval in Imperial Rome

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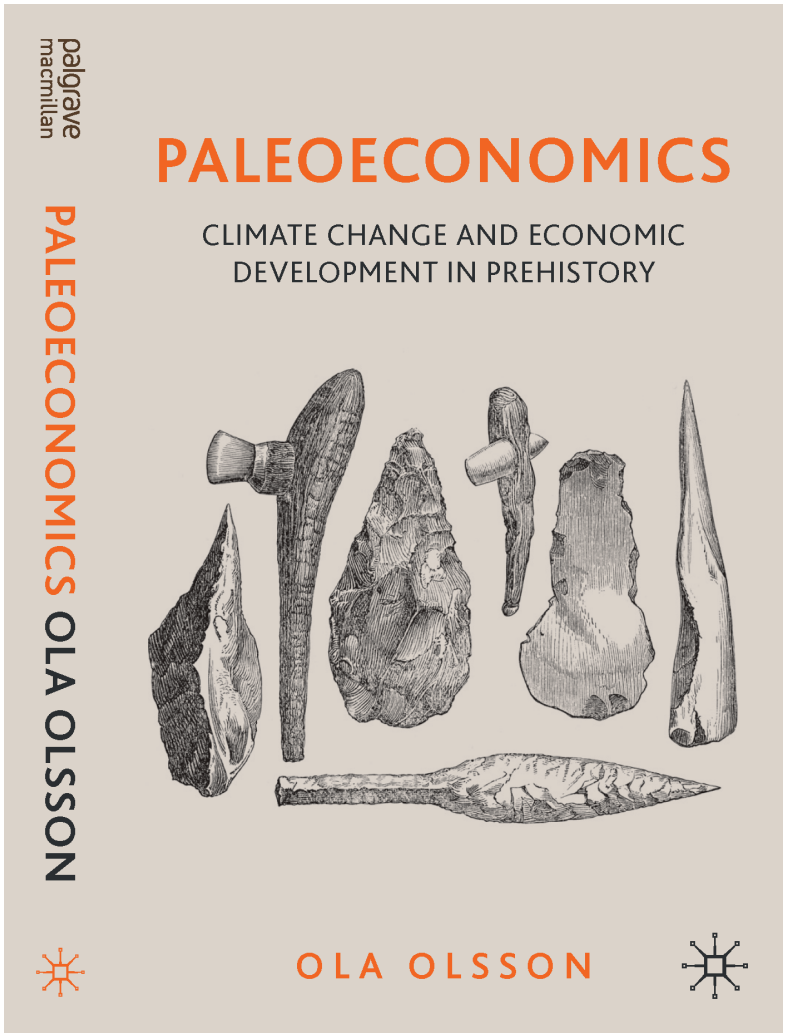
Research question

- General question: How have short-run weather shocks and long-run climate change affected political stability and socioeconomic developments in history? Are insights from such studies important for predicting likely impact of future climate warming on human resilience and adaptation?
- Numerous qualitative studies in archaeology and history, fewer quantitative studies using time series regression designs.
- In this study:
  - A time series analysis of the relationship between climatic variations and political upheaval based on new data on Italian temperature and precipitation and Roman lead emissions, in combination with own data on political stability in Imperial Rome (27 BCE - 476 CE).
  - The role of a climate shock in the east and lead emissions in the west for explaining the collapse of Western Roman Empire in 476 CE.

Previous literature I: Climate change and social dynamics



- Economics: Miguel et al (JPE, 2004); Hsiang et al (Science, 2013); Dell et al, "Temperature shocks and economic growth" (AEJ Macro, 2012); Waldinger, LIA in Europe (JPE, 2022); Anderson et al, "Jewish persecutions" (EJ, 2017)
- Science: Paleoclimatic archives and visual correlations with historical sociopolitical development (e.g. Kennett et al on Maya collapse (Science, 2012)
- Own recent work: *Climate Pulse Model* of prehistory in Olsson (*Paleoeconomics*, 2024); Nile floods in ancient Egypt (Mayoral and Olsson, JOEG, 2025; Rainfall and Maya monument construction (Rubio-Ramos et al, 2026)

Previous literature II: Political upheaval and societal dynamics in Imperial Rome

- Heather (2005) *The Fall of the Roman Empire*: The collapse of the Western Roman Empire (WRE) after 450 CE was unexpected and a consequence of a series of random events starting with the movement of the Huns from 350 CE.
- Harper (2018) *The Fate of Rome: Climate, Disease and the End of an Empire*: The empire was plagued and weakened by previously underestimated pandemics (the Antonine, Cyprian, Justinian Plagues).
- Scheidel (2019) *Escape from Rome: The failure of empire and the road to prosperity*: Roman domination of a naturally scattered Mediterranean geography was a historical anomaly and Europe was better off without an empire.
- De Soto et al (Scientific Data, 2025), Dalgaard et al (JCEC, 2022) and Fluckiger et al (ReStat, 2023) on persistence of Roman roads and transport networks.

Conceptual framework

Like in most of the literature, we assume the following basic causal relationship between climate change/weather variations and socioeconomic outcomes:

- High temperature, high rainfall $\Rightarrow$ High agricultural output, high economic activity $\Rightarrow$ People are well-fed, healthy, busy and content $\Rightarrow$ High political stability.
- Low temperature, low rainfall $\Rightarrow$ Low agricultural output, low economic activity $\Rightarrow$ People are hungry, sick, unoccupied, and discontent $\Rightarrow$ High political instability.
- Maybe extremes in either direction could be problematic (for instance both droughts *and* floods along the Nile as in Mayoral and Olsson, 2025)? Mainly an issue in riverine civilizations, not necessarily in rain-fed agricultural areas.

Key locations in Roman empire for our study

Political instability index for Imperial Rome, 27 BCE - 476 CE

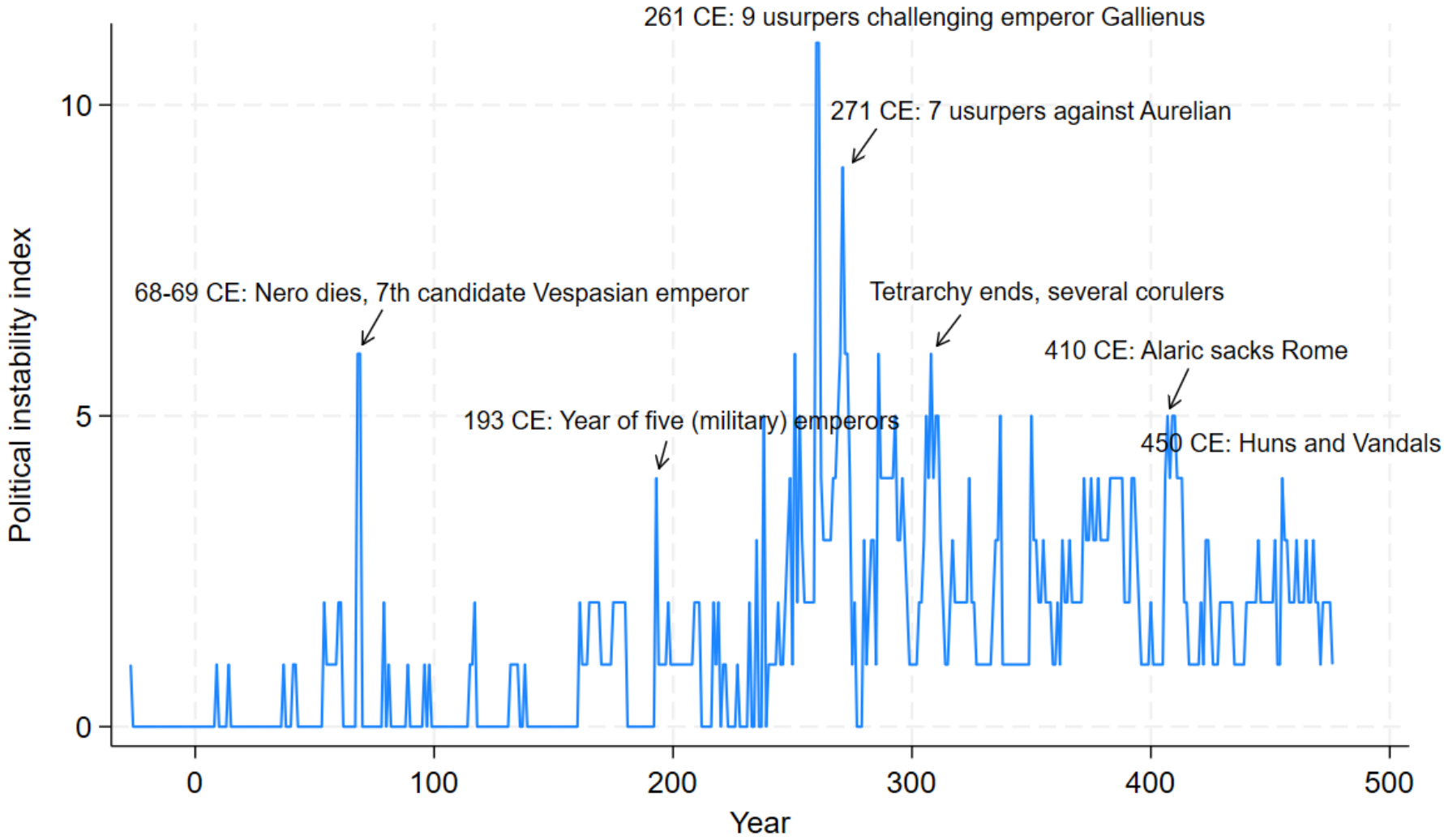
- I construct an annual composite index of political instability for Imperial Rome, 27 BCE - 476 CE, from *World Statesmen* (www.worldstatesmen.org/)
- Six indicators;
  - *change* (number of changes of emperor during year)
  - *coruler* (number of corulers with incumbent emperor)
  - *usurper* (number of usurpers during year)
  - *unrest* (number of barbarian invasions (e.g. Goths in 376 CE), major internal migrations (Vandals from Iberia to North Africa in 429 CE), major rebellions (Jews in 115-117 CE)
  - *defeat* (dummy=1 in case of major Roman military defeats (Teutoburg Forest in 9 CE) or sackings (Rome in 410 CE)
  - *plague* (dummy=1 for year of major plague (Antonine 165-180 CE; Cyprian 251-266 CE)(Source: Harper, 2018)

Coding example: Period around death of Nero in 68 CE

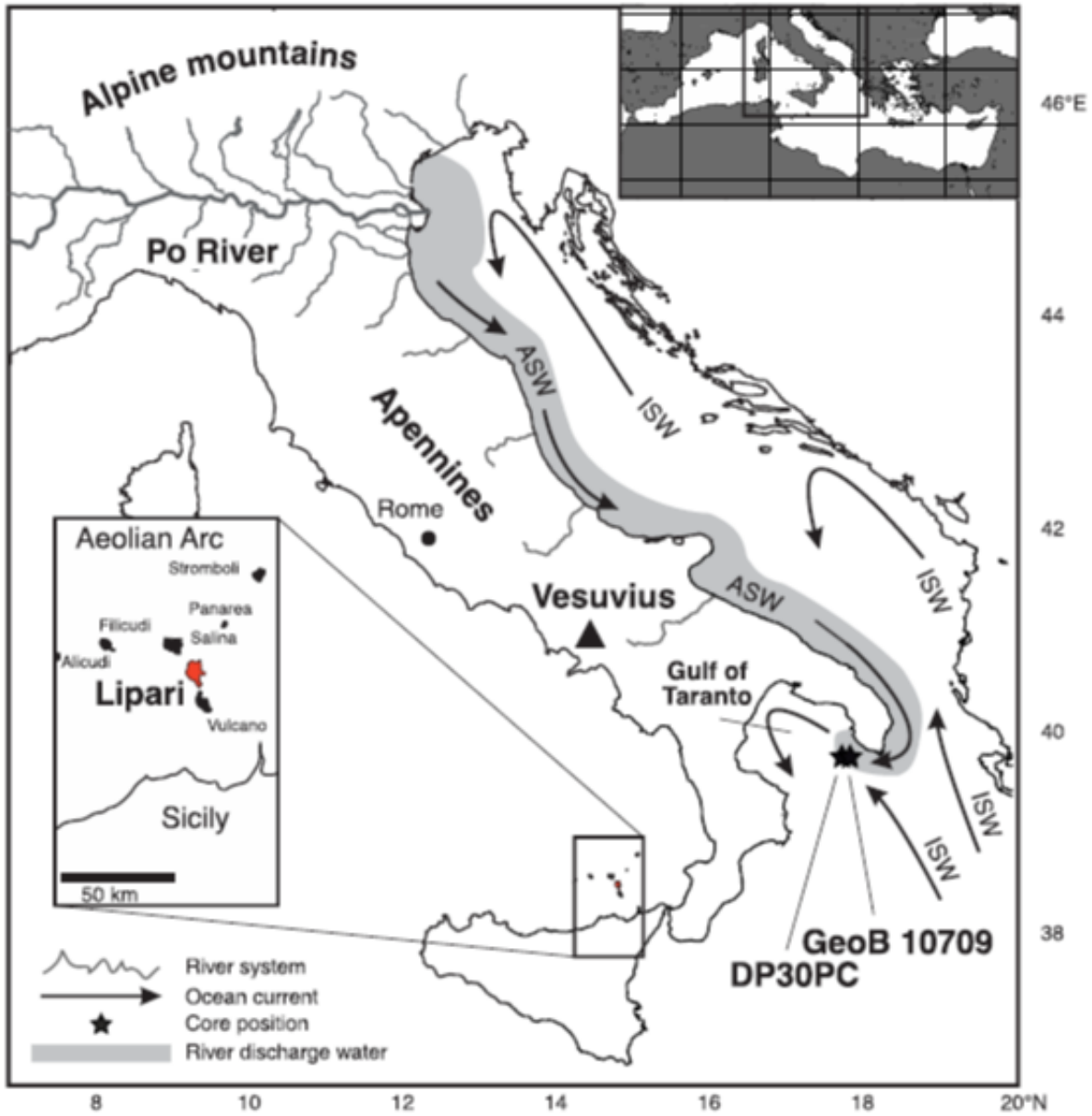
13 Oct 54 - 9 Jun 68	Nero	(b. 37 - d. 68)
	(Nero Claudius Caesar Augustus Germa	nicus)
13 Oct 54 - 2 Mar 59	Julia Agrippina (f) -Regent (de facto)	(b. 15 - d. 59)
Mar 68 - May 68	Gaius Julius Vindex	(b. c.25 - d. 68)
	(in rebellion, in Gallia Lugdunensis	and Gallia Narbonensis)
Mar/Apr 68 - Oct 68	Lucius Clodius Macer	(d. 68)
	(in rebellion, in Africa Proconsular	is)
Jun 68 - Oct 68	Gaius Nymphidius Sabinus (usurper)	(b. c.35 – d. 68)
	(in rebellion, in Rome)	
8 Jun 68 - 15 Jan 69	Galba	(b. 3 BC - d. 69 AD)
	(Servius Sulpicius Galba Caesar Augu	stus)
15 Jan 69 - 16 Apr 69	Otho	(b. 32 - d. 69)
	(Marcus Salvius Otho Caesar Augustus	)
17 Apr 69 - 20 Dec 69	Vitellius	(b. 15 - d. 69)
	(Aulus Vitellius Germanicus)	
21 Dec 69 - 23 Jun 79	Vespasian	(b. 9 - d. 79)
	(Titus Flavius Vespasianus Caesar)	

- Example shows ruler changes (death of Nero in 68 CE; Galba, 68-69; Otho, 69 CE; Vitellius, 69 CE; Vespasian, 69-79 CE)
- Corulers (Julia Agrippina, 54-59 CE)
- Usurpers (Vindex, 68 CE; Macer, 68 CE; Sabinus, 68 CE

Political instability index, 27 BCE - 476 CE

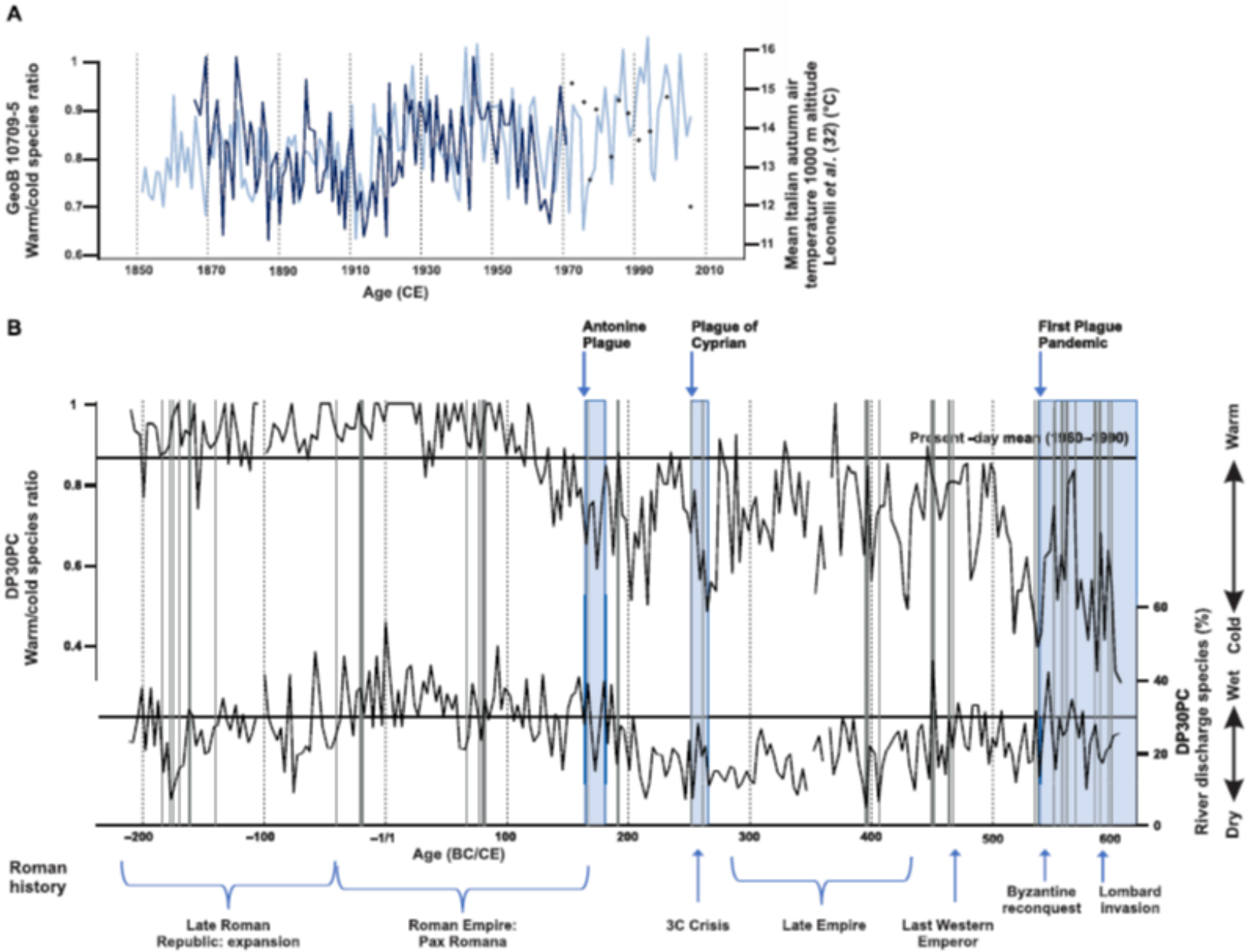


Temperature and precipitation data for Ancient Rome

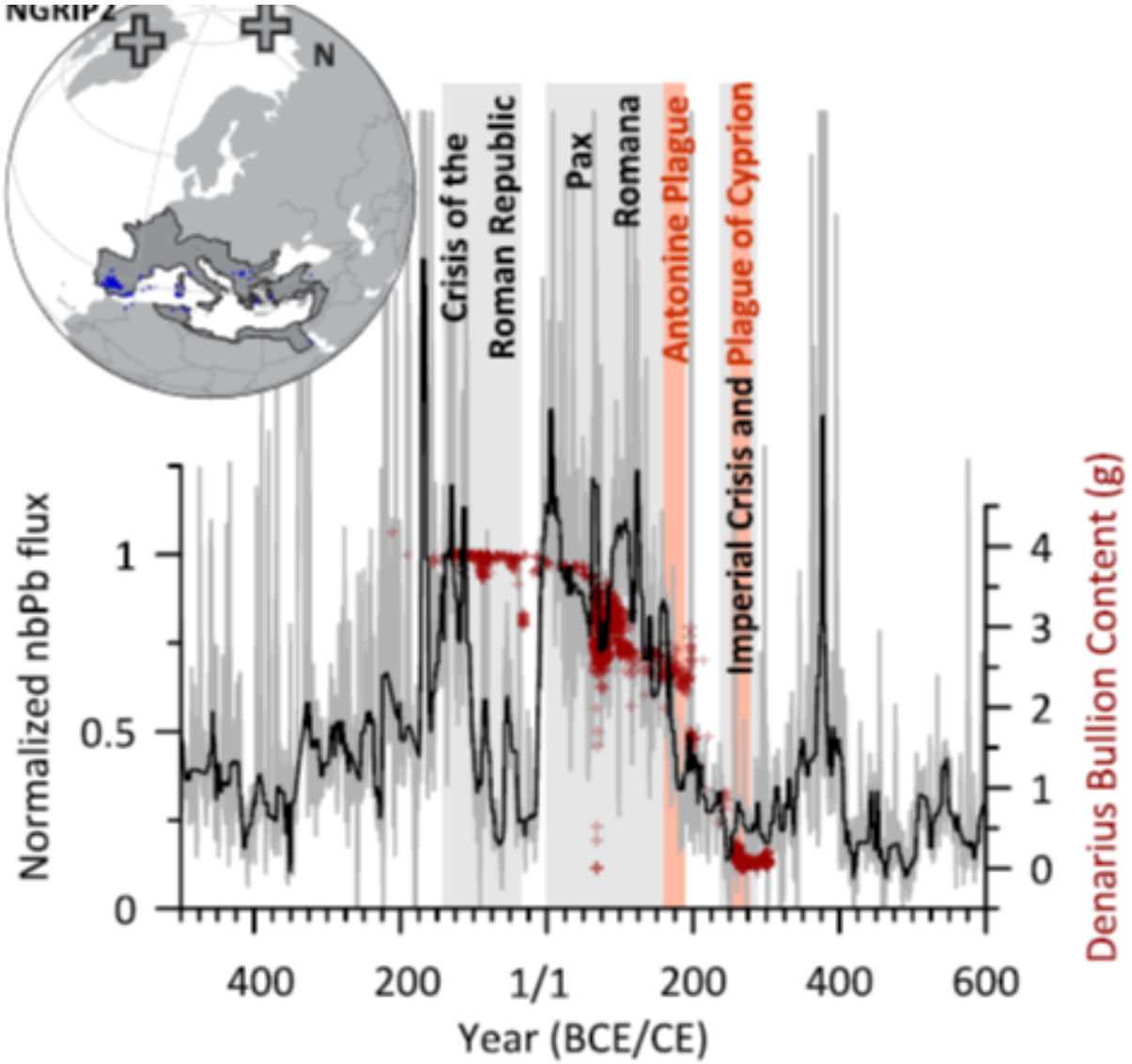


- Data from Zonneveld et al (*Science Advances*, 2024).
- High-resolution (2.9 years) climate record of marine sediment deposits from Roman Climate Optimum to Late Antique Little Ice Age.
- First proxies of temperature and precipitation for Italy during Antiquity.

Temperature and precipitation 200 BCE - 600 CE



Silver mining and lead pollution during Roman period



- Data from McConnell et al (*PNAS*, 2025), extending McConnell et al (*PNAS*, 2018).
- Updated high-resolution Arctic ice core measurements from 3 sites of Roman era lead pollution.
- Nonbackground air pollution from mining and smelting of silver and lead ores (galena) in Hispania (Rio Tinto) and Gaul.

What does lead pollution proxy for?

Unclear how to interpret lead pollution records. Do they proxy...

- Local *mining and smelting activity* in Hispania and Gaul?
- Silver mining for denarius coin production (and hence an indicator of Roman *money supply*)?
- Since coins are used in goods exchange, maybe an indicator of *trade intensity*?
- Production of silver and lead goods and an indicator of *manufacturing activity*?
- A proxy for the level of *airborne lead poisoning* of the western Roman population, linked to infertility, anemia, cardiovascular disease, and cancer among adults, and reduced concentration, cognitive decline, and a lower IQ among exposed children (McConnell et al, 2025).

Empirical strategy

We estimate the following main time series equation:

$$P_t = \sum_{l=1}^{L} \alpha_{t-l} P_{t-l} + \beta_t \left(\sum_{n=0}^{N} R_{t-n}/N \right) + \gamma_t \left(\sum_{n=0}^{N} T_{t-n}/N \right) + \epsilon_{it} \quad (1)$$

- P_t is a proxy for *political instability* (or lead emissions) in year t
- R_t is a proxy for *precipitation* in Italy in year t (averaged over N=5)
- T_t is a proxy for *temperature* in Italy in year t (averaged over N=5)

Main results I

Table: Climate variations and political upheaval

	Dependent variable:				
	Political instability(t)			Change(t)	Usurper(t)
	(1)	(2)	(3)	(4)	(5)
Temperature (5y)	-0.383***		-0.271**	0.001	-0.093
	(0.108)		(0.114)	(0.035)	(0.080)
Rainfall (5y)		-0.028***	-0.018**	-0.003	-0.011**
		(0.007)	(0.007)	(0.003)	(0.005)
Observations	502	502	502	502	502
Dep var lags	2	2	2	2	2
Cumby-Huizinga	0.29	0.07	0.31	0.11	0.31
Estimator	Newey	Newey	Newey	Newey	Newey

Newey-West standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Main results II

Table: Climate variations and lead emissions

	Dependent variable:		
	Log Lead emissions(t)		
	(1)	(2)	(3)
Temperature (5y)	0.144***		0.088**
	(0.033)		(0.036)
Rainfall (5y)		0.014***	0.010***
		(0.003)	(0.003)
Observations	504	504	504
LnLead lags	2	2	2
Cumby-Huizinga	Y	Y	Y
Estimator	Newey	Newey	Newey

Newey-West standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Interpretation

- Levels of temperature and rainfall have a negative impact on general political instability, implying that cold and dry years give rise to political upheaval.
- Temperature and rainfall have no impact on regular ruler changes (which often are normal events).
- Low rainfall (but not low temperature) is associated with more usurpers.
- Both high temperature and rainfall have a positive impact on lead emissions. Supply or demand effect?

The collapse of the WRE in 476 CE

Why did the WRE finally collapse around 476 whereas ERE lived on until 1453?

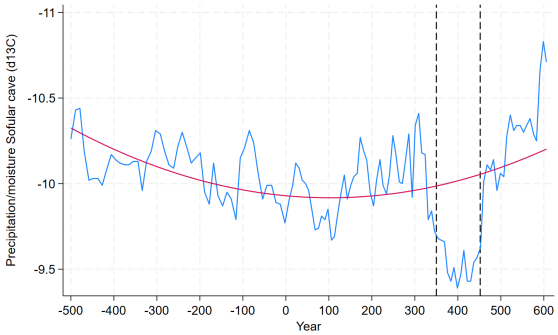
- A certain climatic downturn in Italy but nothing catastrophic.
- Heather argues that the borders of the Roman Empire and the political situation were stable until 376 CE.
- What explains the dynamics and unravelling of WRE 376-476?
- Theories include the softening impact of Christianity (Gibbon), slowdown in expansion and slave capture, pandemics (Harper), the domino effect of Hunnic movement to the west (Heather), natural end to an anomaly (Scheidel).

My hypothesis

On the basis of recent evidence, two factors appear to play key roles:

1. A *dramatic downturn in rainfall in eastern Europe* around 350 CE, presumably not only affecting the ERE but also the steppes north of the Black Sea where Huns and Alans were practicing nomadic pastoralism. $\rightarrow$ Huns started moving west in search of better grazing, causing panic among agricultural Goth populations who fled further and further west. $\rightarrow$ Goth populations cross the Danube in 376 and again in 406 CE.
2. Centuries of *aerial lead pollution* in Hispania and North Africa weakened the population's resistance to barbarian invasions. $\rightarrow$ After entering WRE in 406, Vandals and Suebi easily conquer and settle in Hispania. $\rightarrow$ From 429, Vandals under Geiseric conquer Carthage (Africa Proconsularis), sack Rome in 455 and strangle taxes and grain to WRE, failed large Roman reconquest in 468 CE.

Rain/moisture Sofular cave (Anatolia)



Late Roman Megadrought 350-450 CE coincides with Hunnic threat, barbarian invasions, and the fall of WRE.

Lead exposure in Roman Empire (McConnell et al, 2025)

Hispania and North Africa strongly exposed to airborne lead pollution + Strong pollution around 400 CE $\rightarrow$ Weak resistance to invading Vandals and Suebi

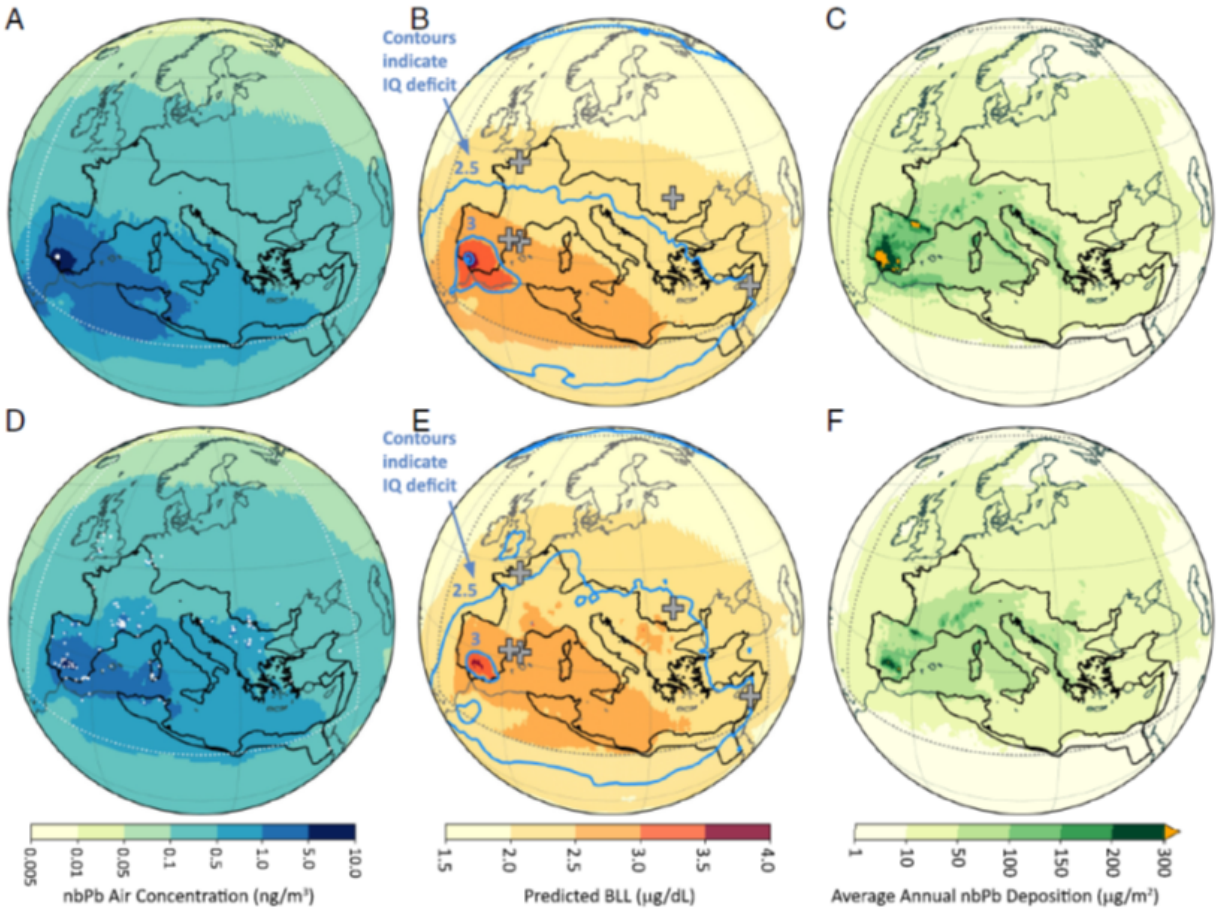


Fig. 2. Simulated annually averaged nonbackground lead (nbPb) concentrations in air, blood lead level (BLL) enhancements in young children with associated cognitive deficits, and average annual nbPb deposition during the Pax Romana. (*A*–*C*) Scenario 1 with emissions only from Rio Tinto (white dot). (*D*–*F*) Scenario 2 with emissions distributed equally among known Roman-era silver and lead mining sites (white dots). Blue contours in *B* and *E* show estimated IQ point changes resulting from enhanced BLLs. Crosses identify tooth enamel study sites. The dotted line shows the high-resolution FLEXPART model domain. The heavy black line delineates the extent of the Roman Empire in 14 CE.

Twin factors causing collapse of the WRE?

Why did the WRE finally collapse around 476 whereas ERE lived on until 1453?

- Twin environmental factors of Late Roman Megadrought and substantial accumulated lead pollution among population in Hispania and North Africa contributed to the double calamities of Huns and Vandals.
- Roman Empire could cope with one major challenge at a time (Carthage, Persia, Goths, etc) but the combined threat of Huns and Vandals became too much for the WRE.
- The collapse of WRE will always attract new attention, this is not the final answer but an additional environmental angle.