From Forest to Farmland and Meadow to Metropolis

How did the environment shape human history, and how did humanity bring about the Anthropocene?

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Acknowledgements

- Kristen Krumhardt, Mirjam Pfeiffer, Carsten Lemmen, Dorian Fuller, Erle Ellis, Gustav Strandberg, Feng He

- European Research Council
- Swiss National Science Foundation
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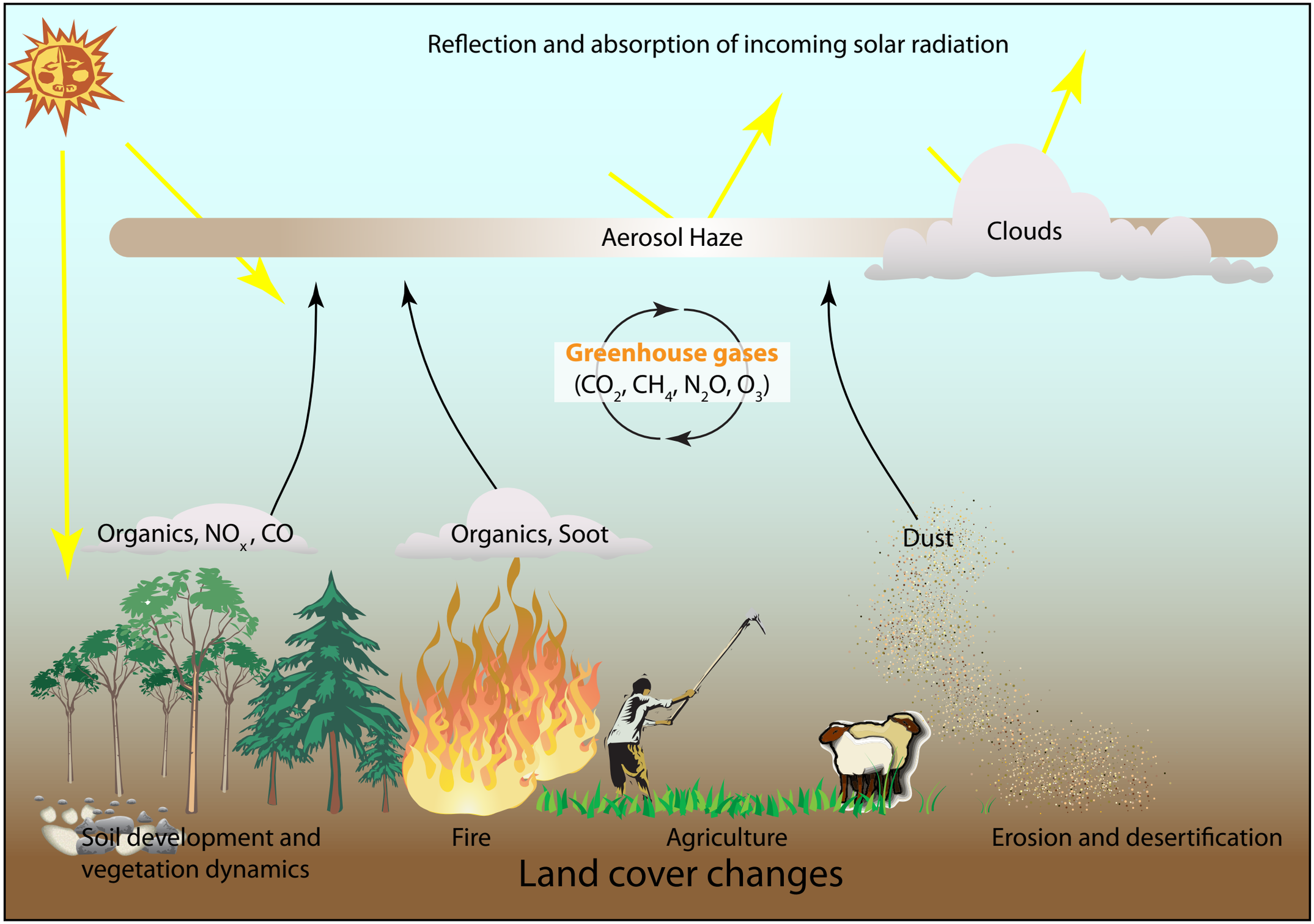
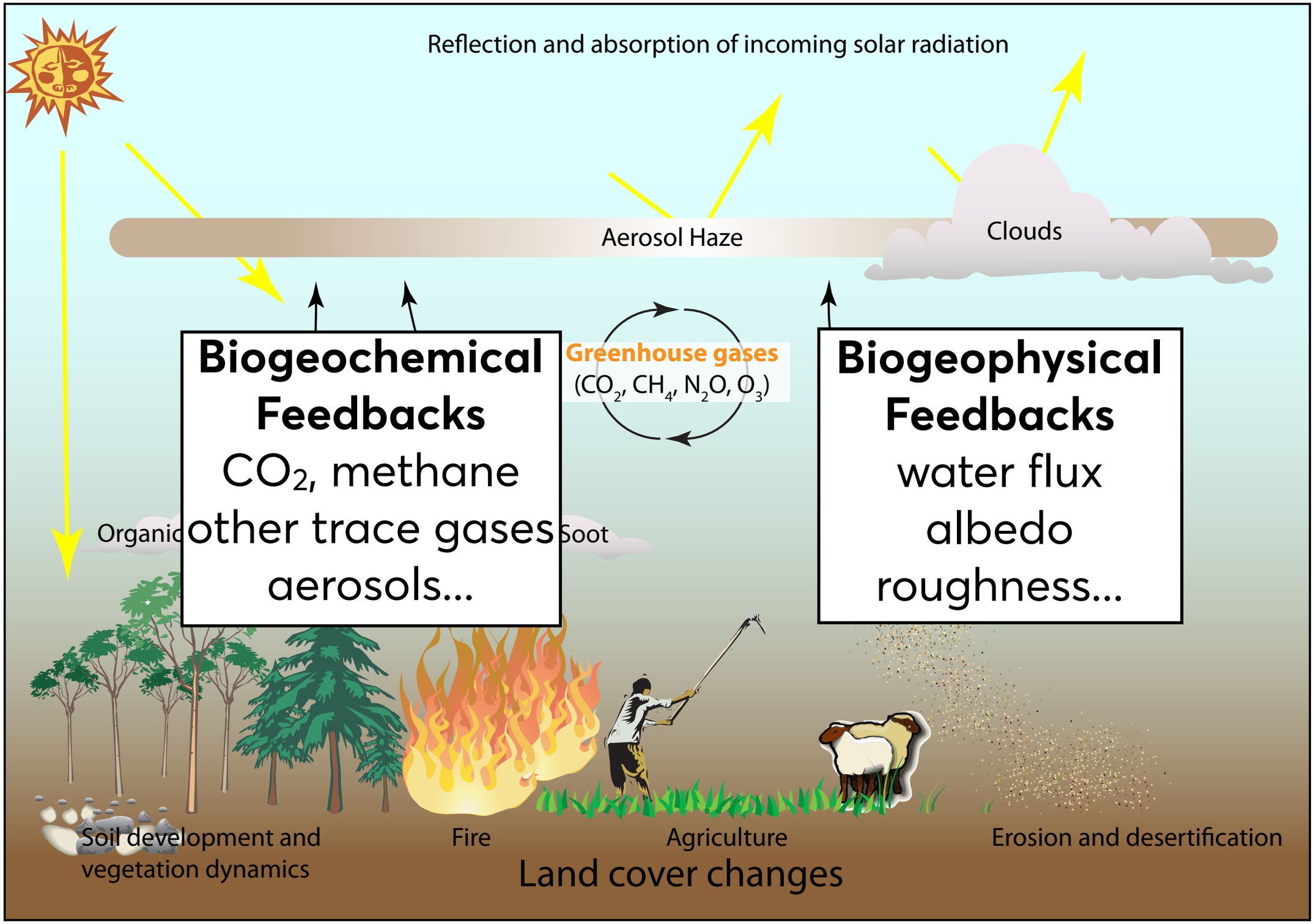
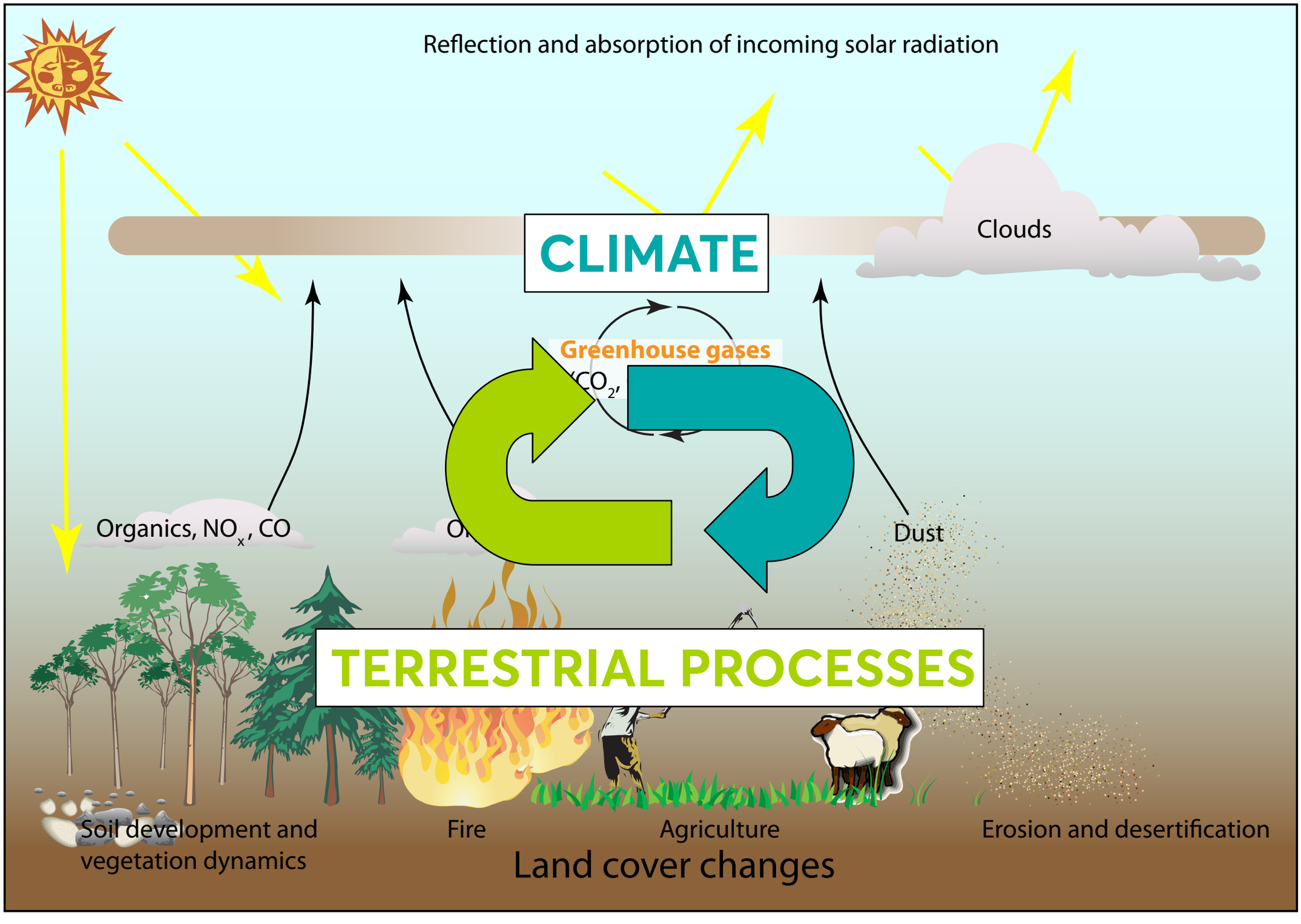
What is the role of land cover in the earth system?



How does land cover change affect climate?

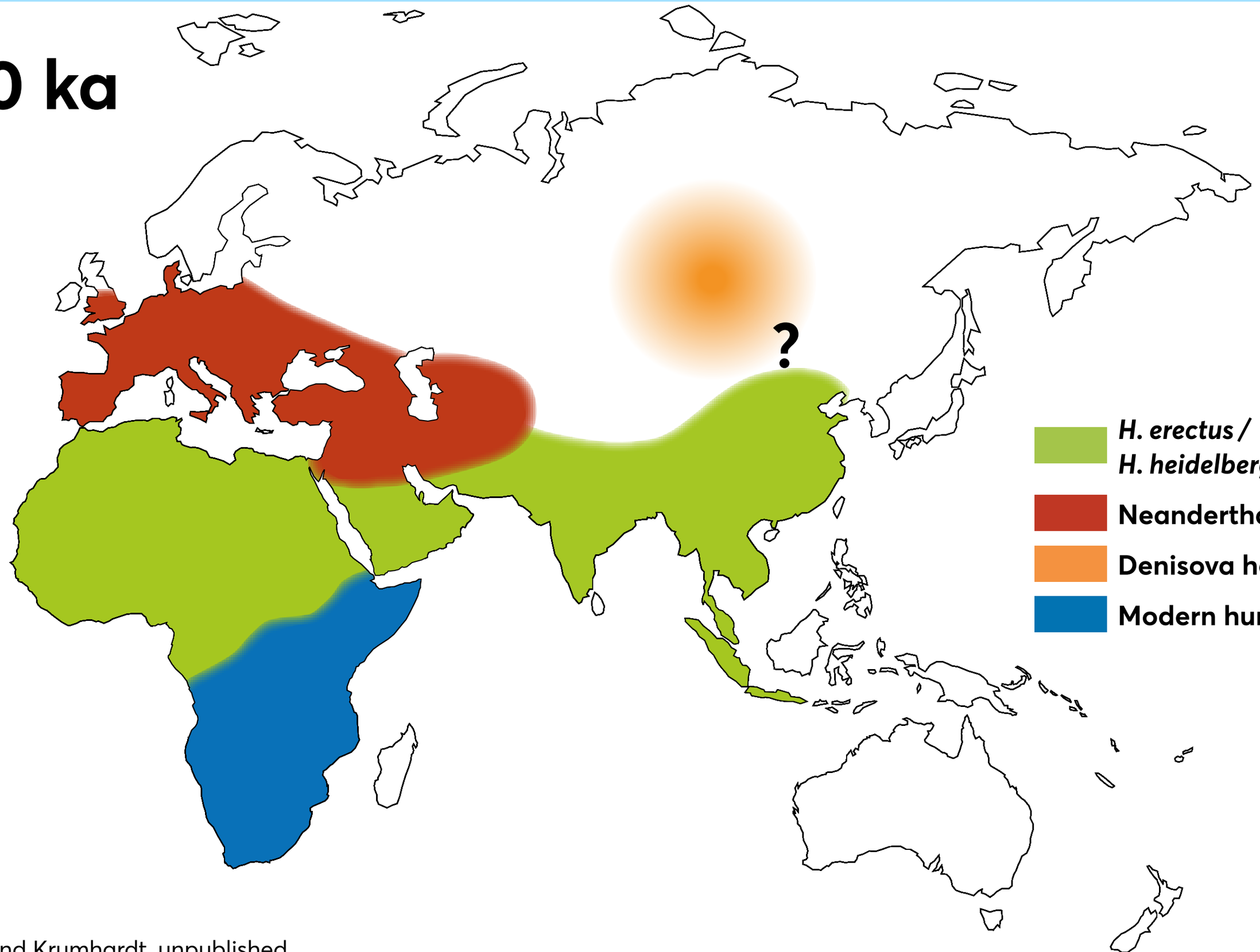


Climate-land cover feedbacks



200,000 years ago, Penultimate interglacial

200 ka



Kaplan and Krumhardt, unpublished

Homo erectus, Africa

150,000 years ago, Penultimate glacial maximum

150 ka

?

H. erectus /
H. heidelbergensis

Neanderthals

Denisova hominin

Modern humans

Kaplan and Krumhardt, unpublished

125,000 years ago, Last Interglacial (Eemian)

125 ka

?

H. erectus /
H. heidelbergensis

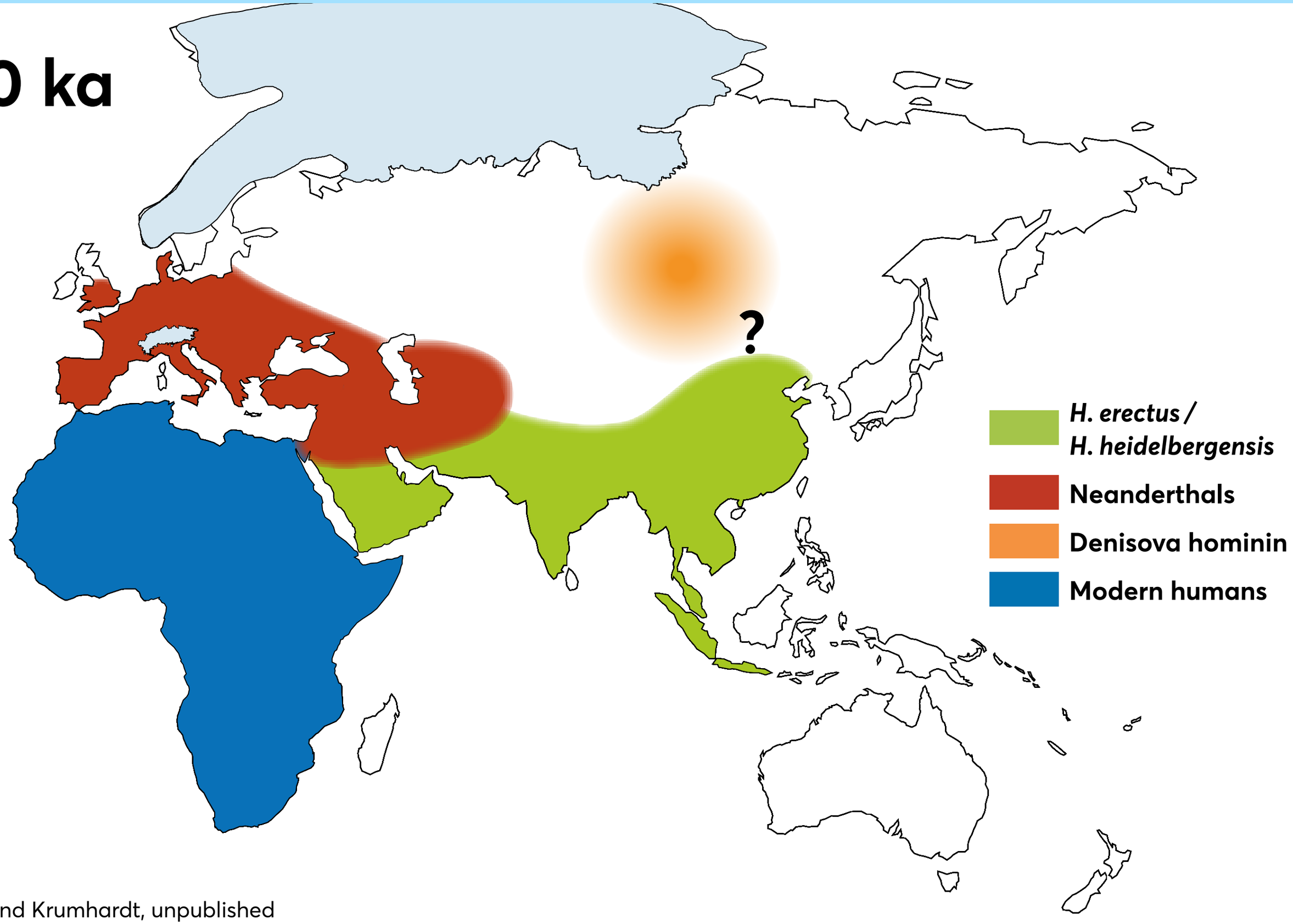
Neanderthals

Denisova hominin

Modern humans

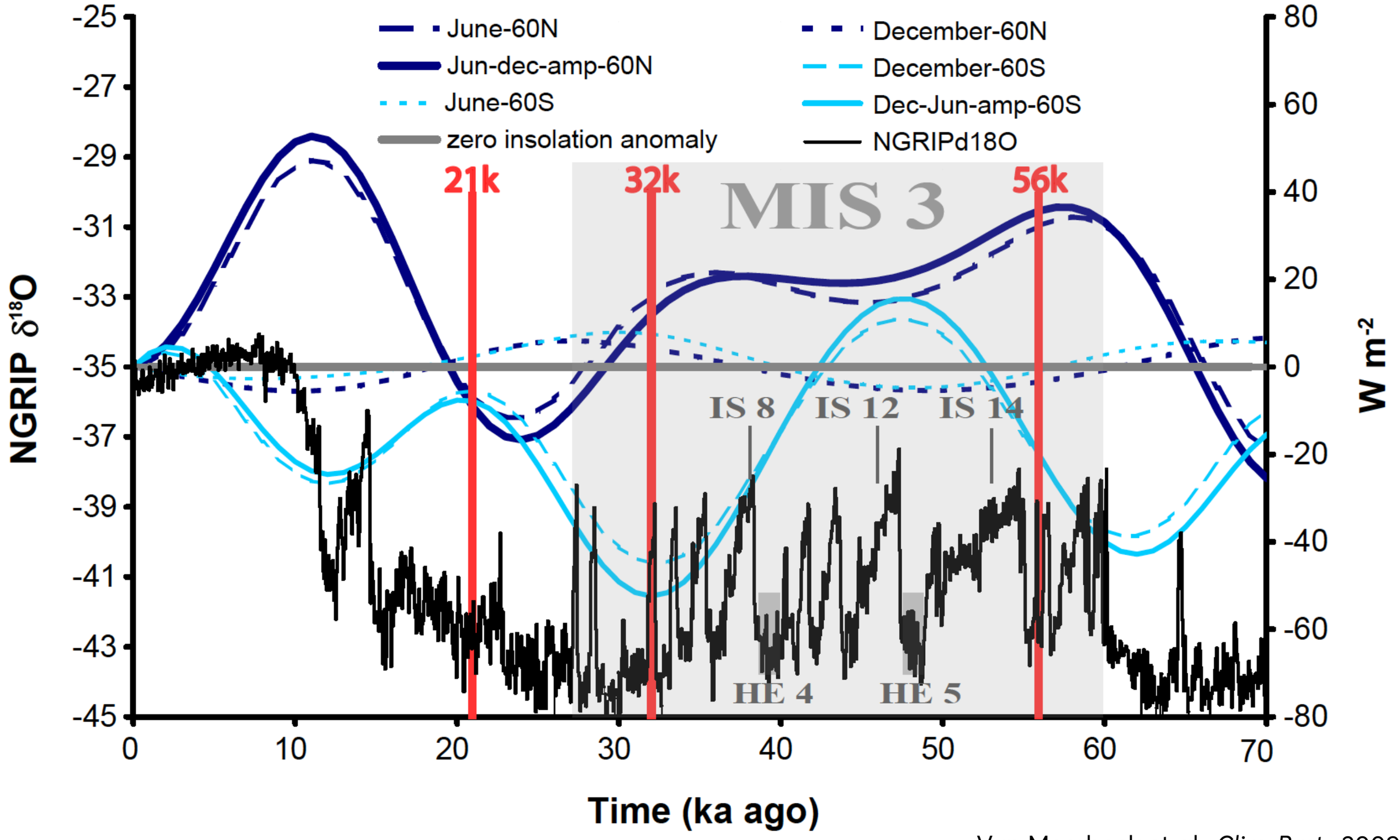
Kaplan and Krumhardt, unpublished

90,000 years ago, early last glacial



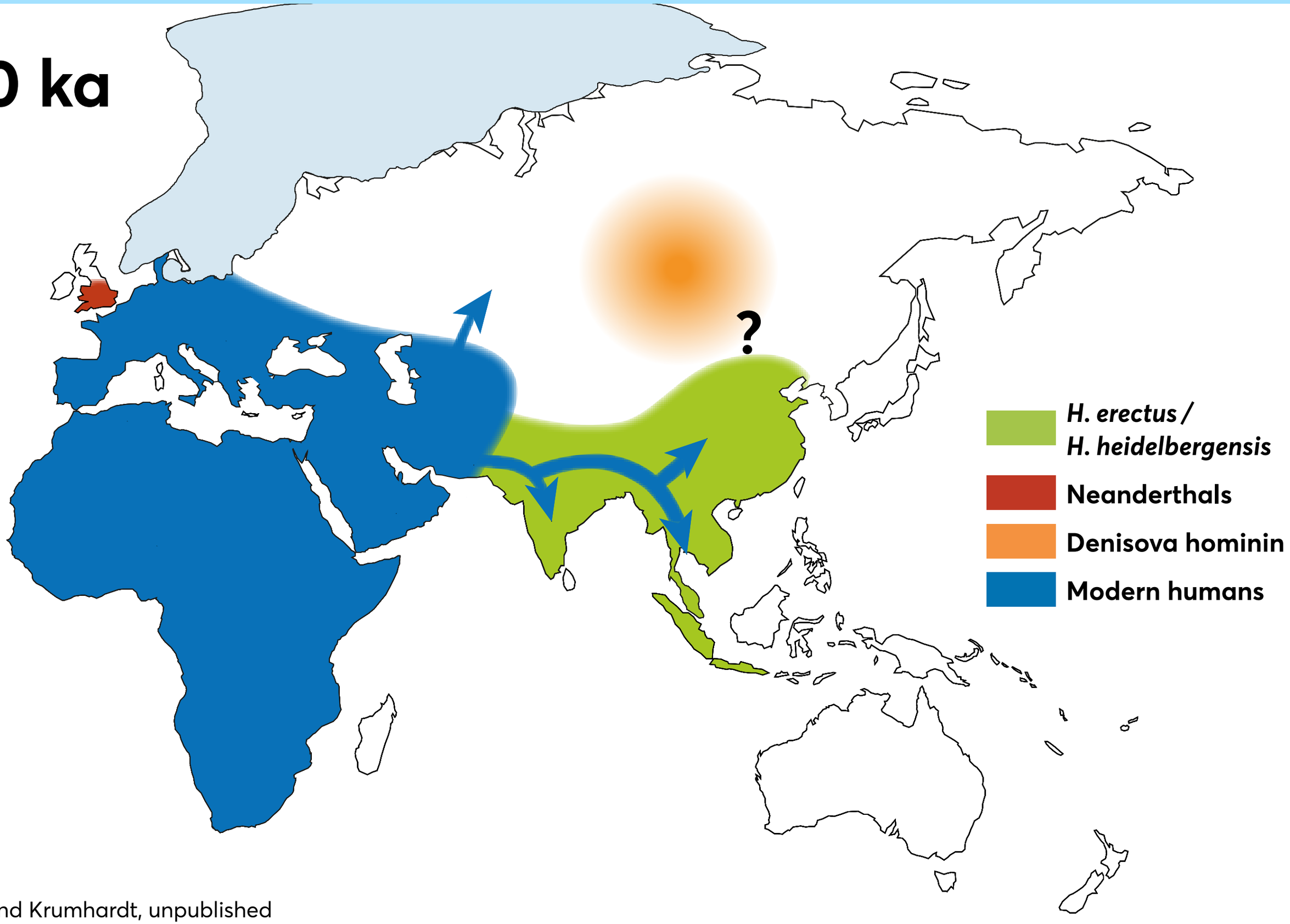
Kaplan and Krumhardt, unpublished

Climate of the last glaciation



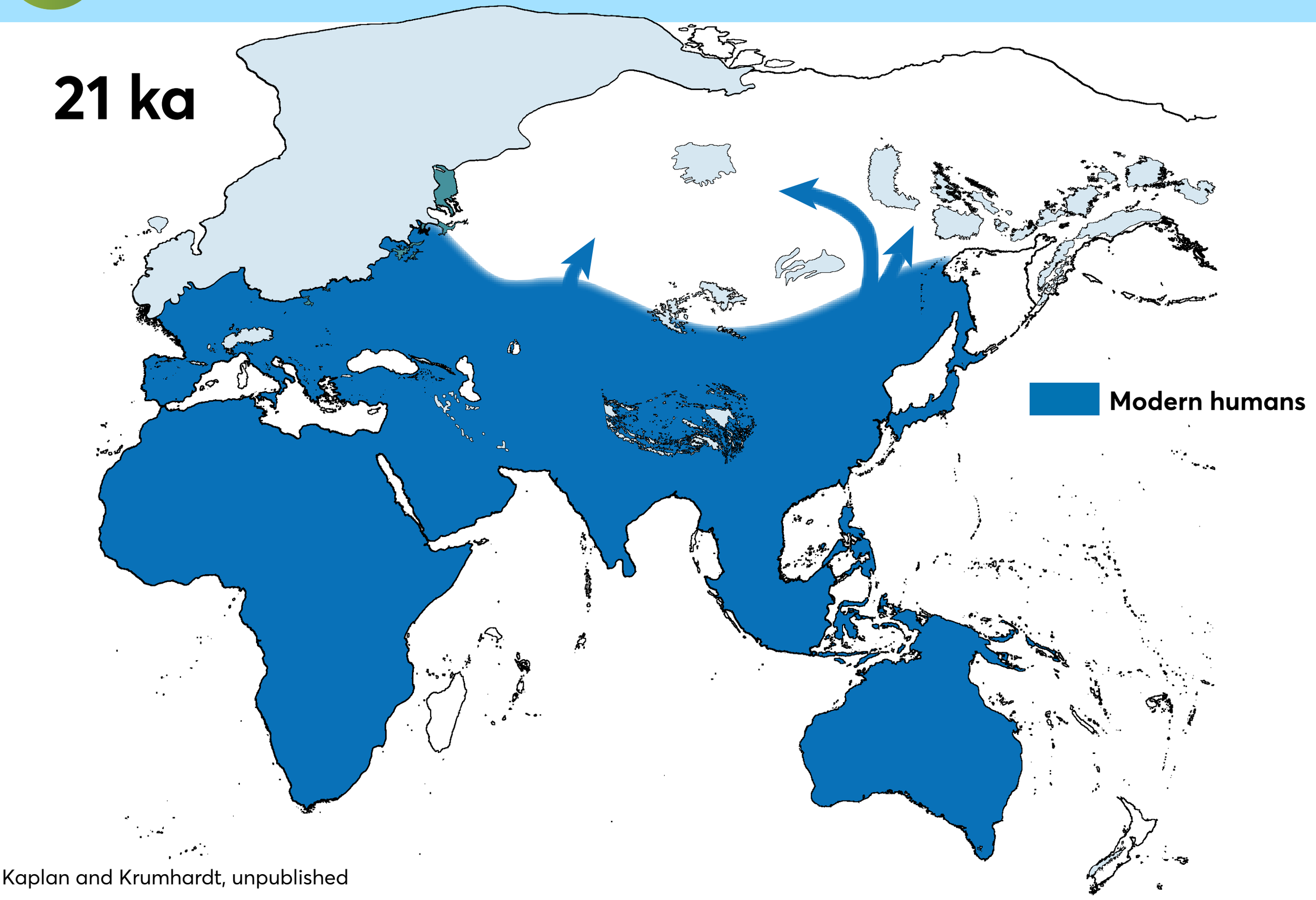
Van Meerbeck et al., *Clim. Past.*, 2009

60,000 years ago, mid last glacial



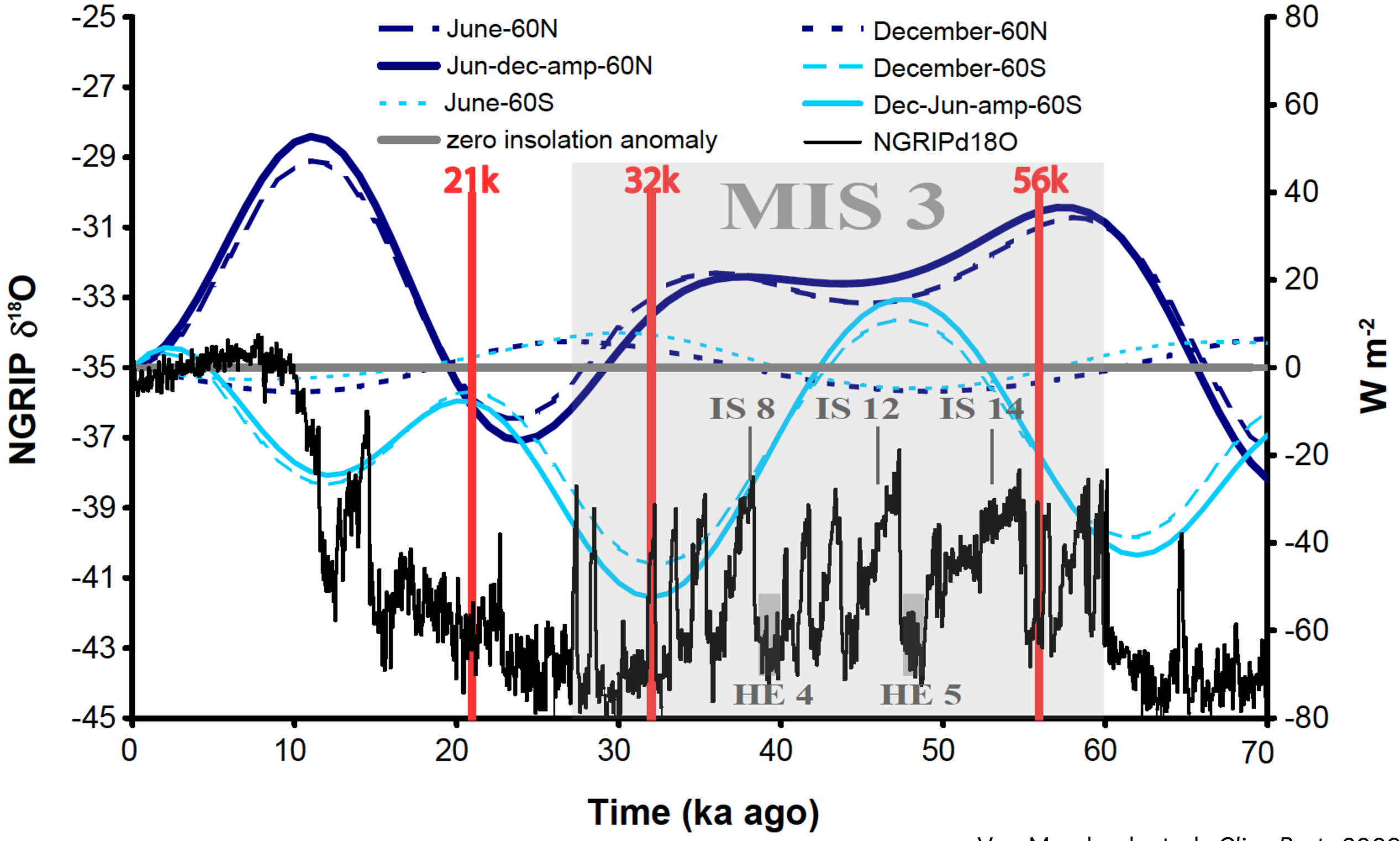
Kaplan and Krumhardt, unpublished

21,000 years ago: Last Glacial Maximum



Kaplan and Krumhardt, unpublished

What was the Last Glacial Maximum?



Van Meerbeck et al., *Clim. Past.*, 2009

What was the Last Glacial Maximum?

- Period of relatively stable, cold (but not coldest) conditions towards the end of the last glacial cycle
- Period with some of the lowest atmospheric CO_2 levels in the last several million years
- Generally distinguished as period with the largest ice extent/ice volume —> lowest sea level
- A focus of research for understanding the climate system at a time very different from today

Land cover in the Earth System

- *We know* the Earth's land surface plays an important role in the climate system
- *We think* we know the land surface changed greatly over the late Quaternary (1m yrs)
- *We might know* that both climate and human activities influence land cover, and are influenced by climate
- *We have very little understanding* of how much of late Pleistocene and Holocene land cover change was caused by climate vs. humans

Land use in the earth system

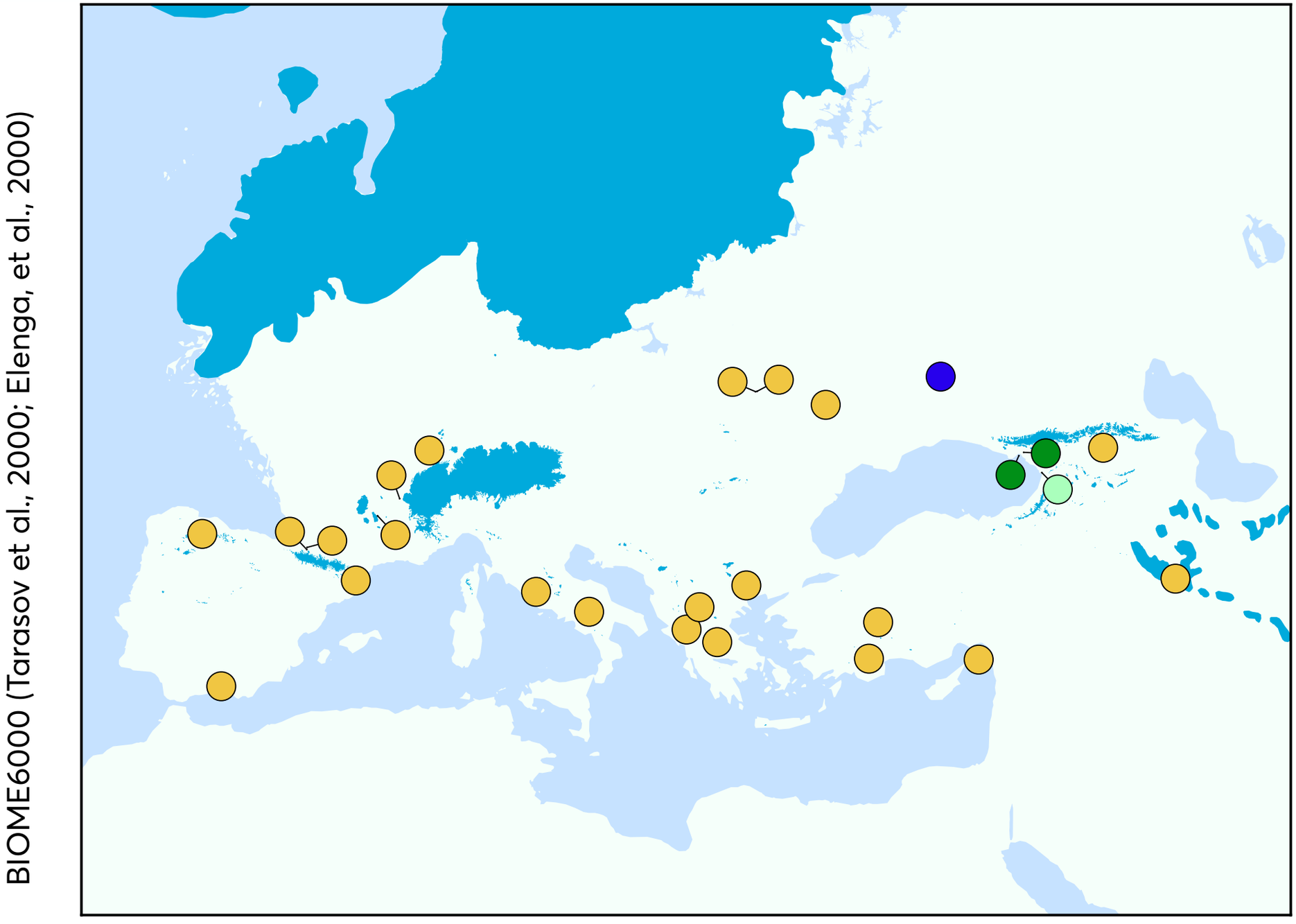
- Anthropogenic, i.e., human-induced, land cover change is a product of the changing relationship between people and their environment over time
- Major developments in human history changed the way we perceived, exploited, and permanently modified our environment
- These land use revolutions led to land cover changes that affect us at present and in the future

Last Glacial Maximum landscapes

Last Glacial Maximum landscapes

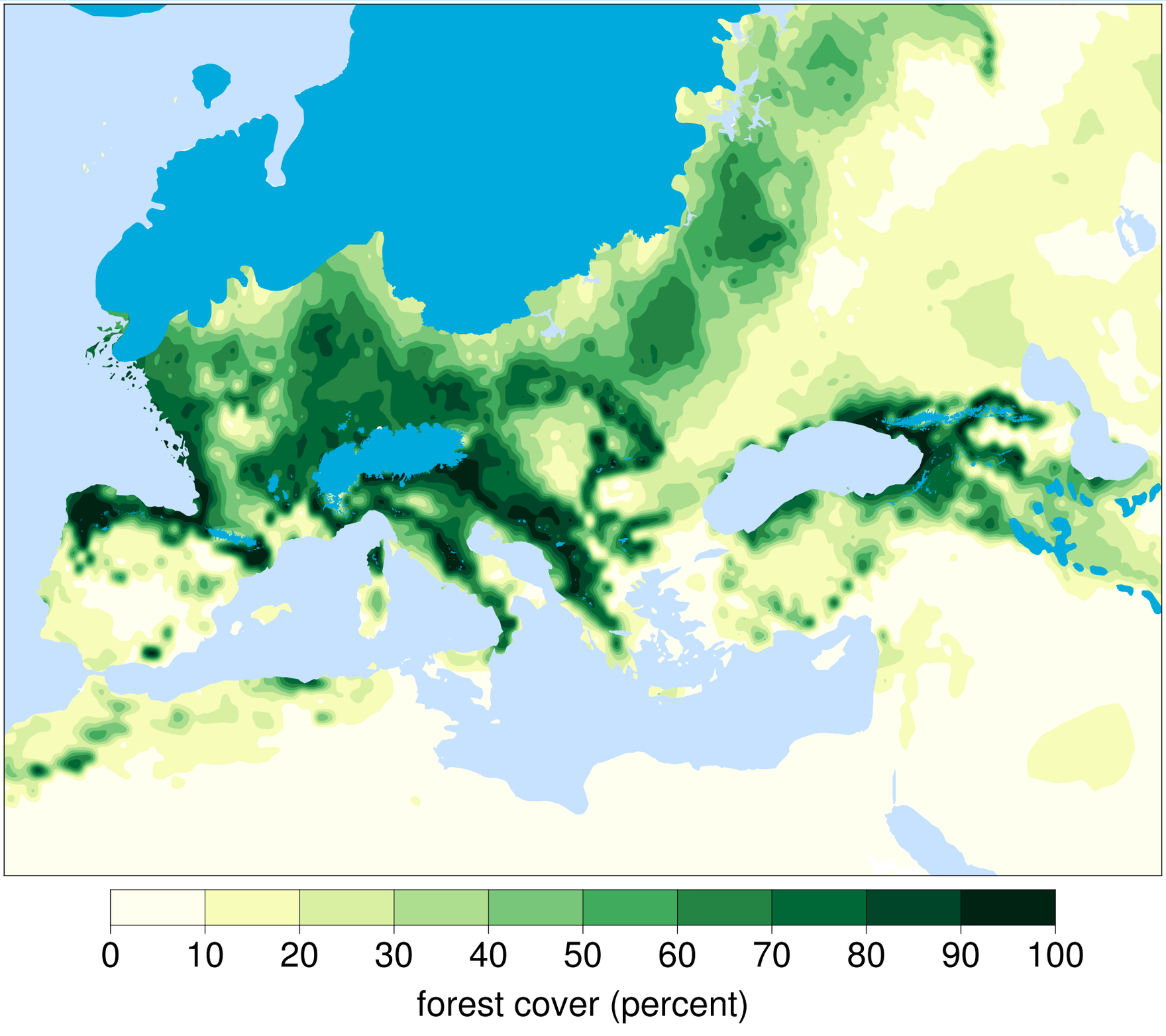
Mauricio Antón

The LGM forested Europe conundrum



Kaplan et al., *PLOS One*, 2016

The LGM forested Europe conundrum



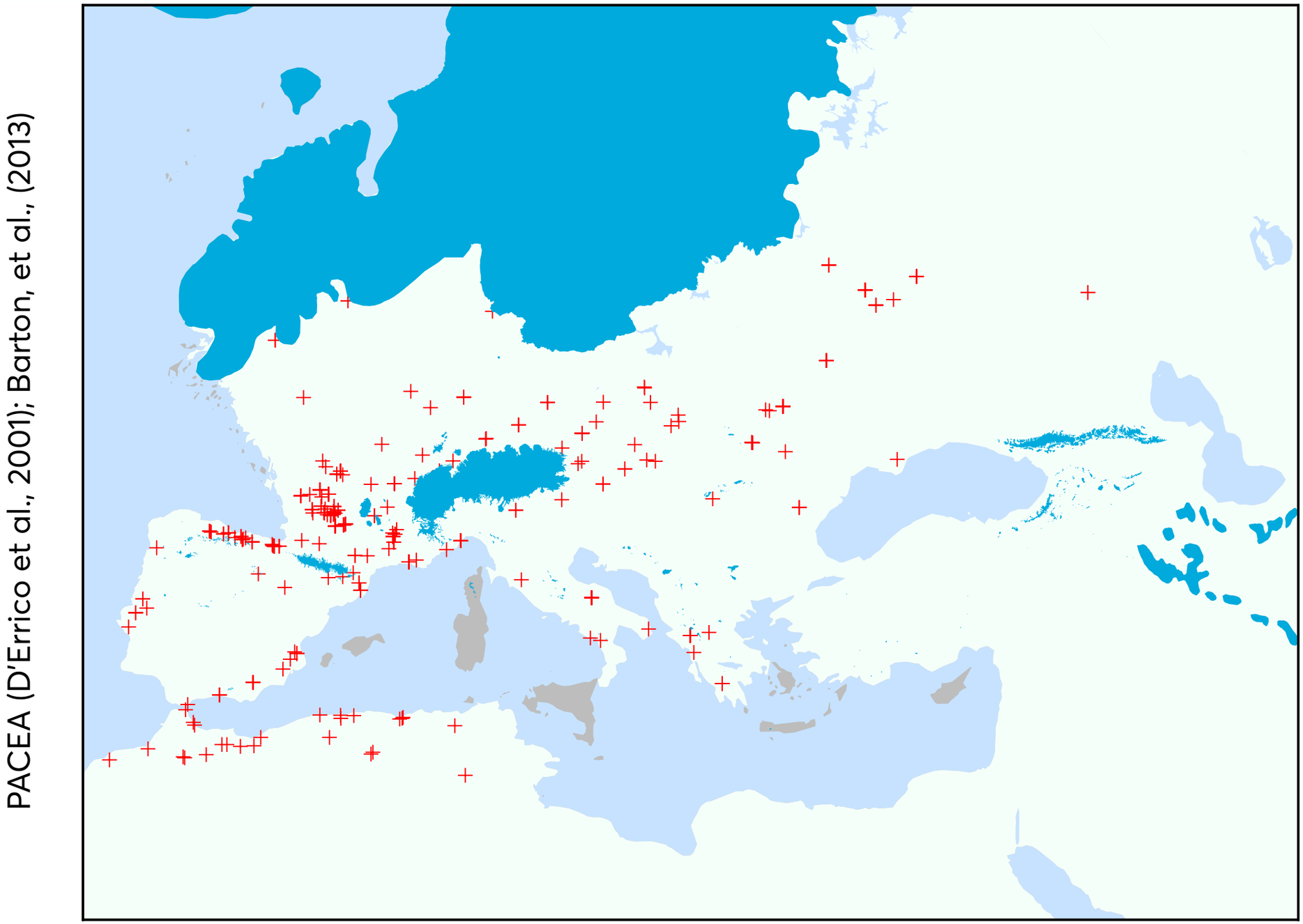
Kaplan et al., *PLOS One*, 2016

The 1st land use revolution: Human use of fire

How Solutrean hunters drove wild horses to their deaths in eastern France

Anonymous artist

Archaeological evidence for human presence



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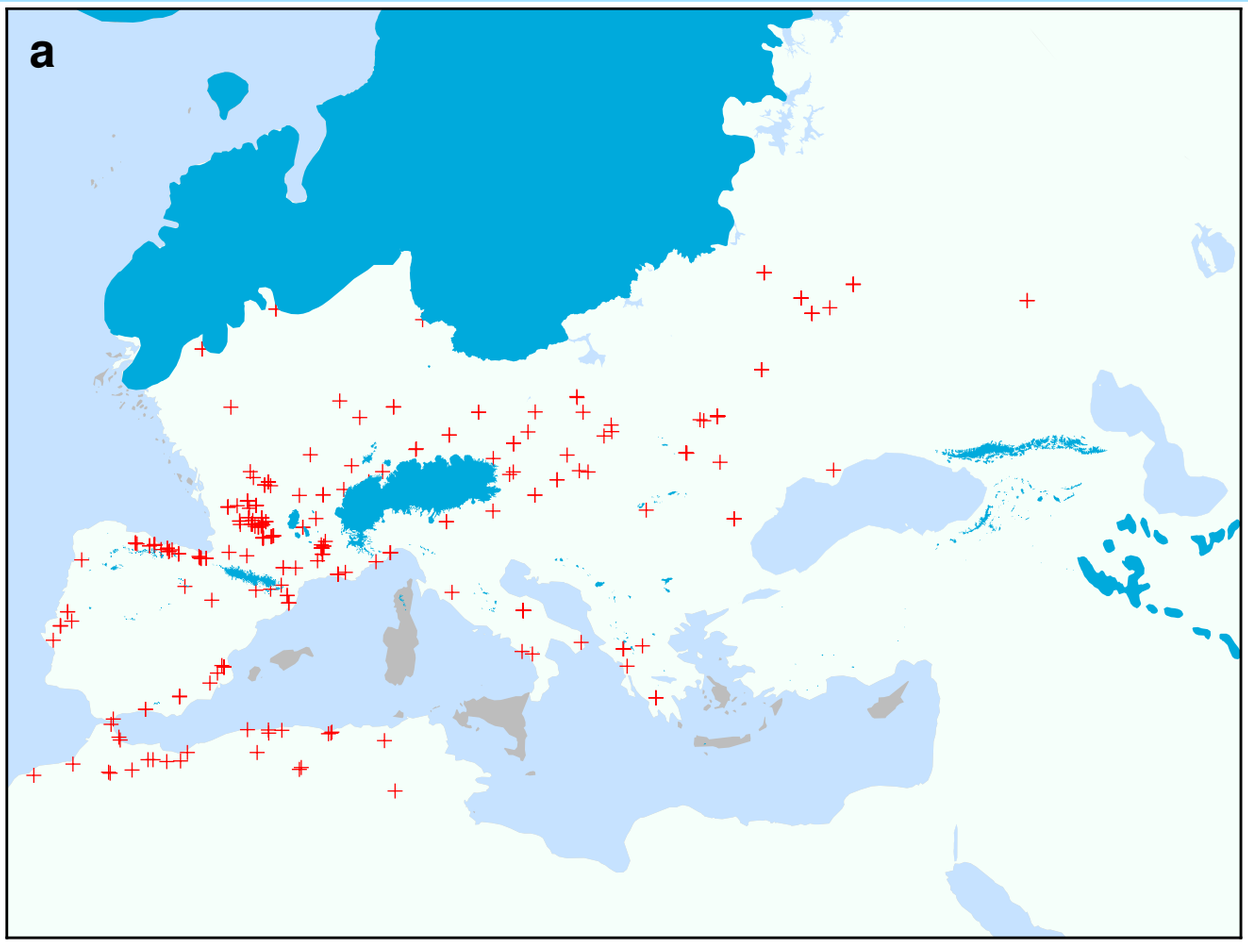
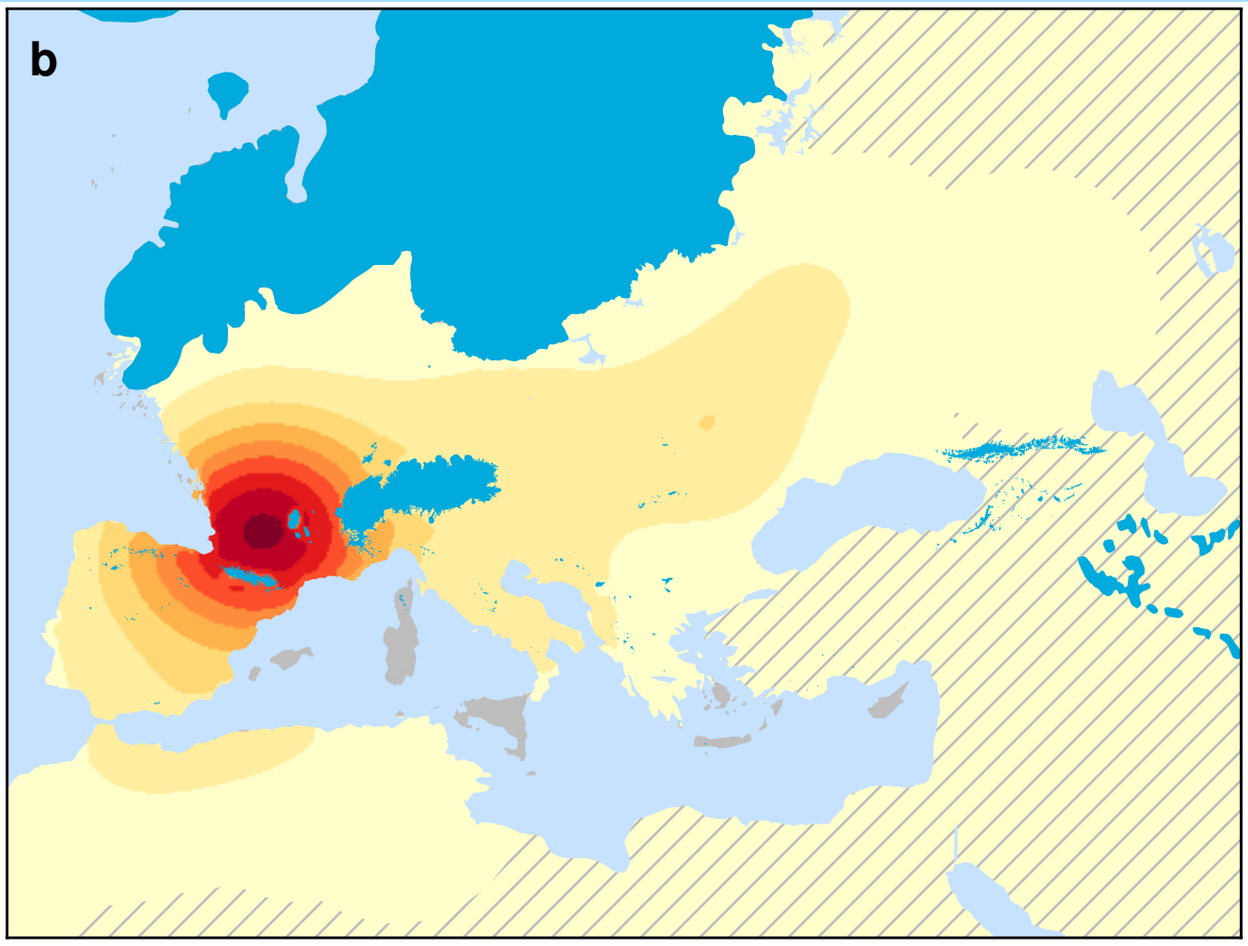




archaeological sites dating to 21,000 ± 1000 BP

water

ice sheets / glaciers

uninhabited

estimated (no data)

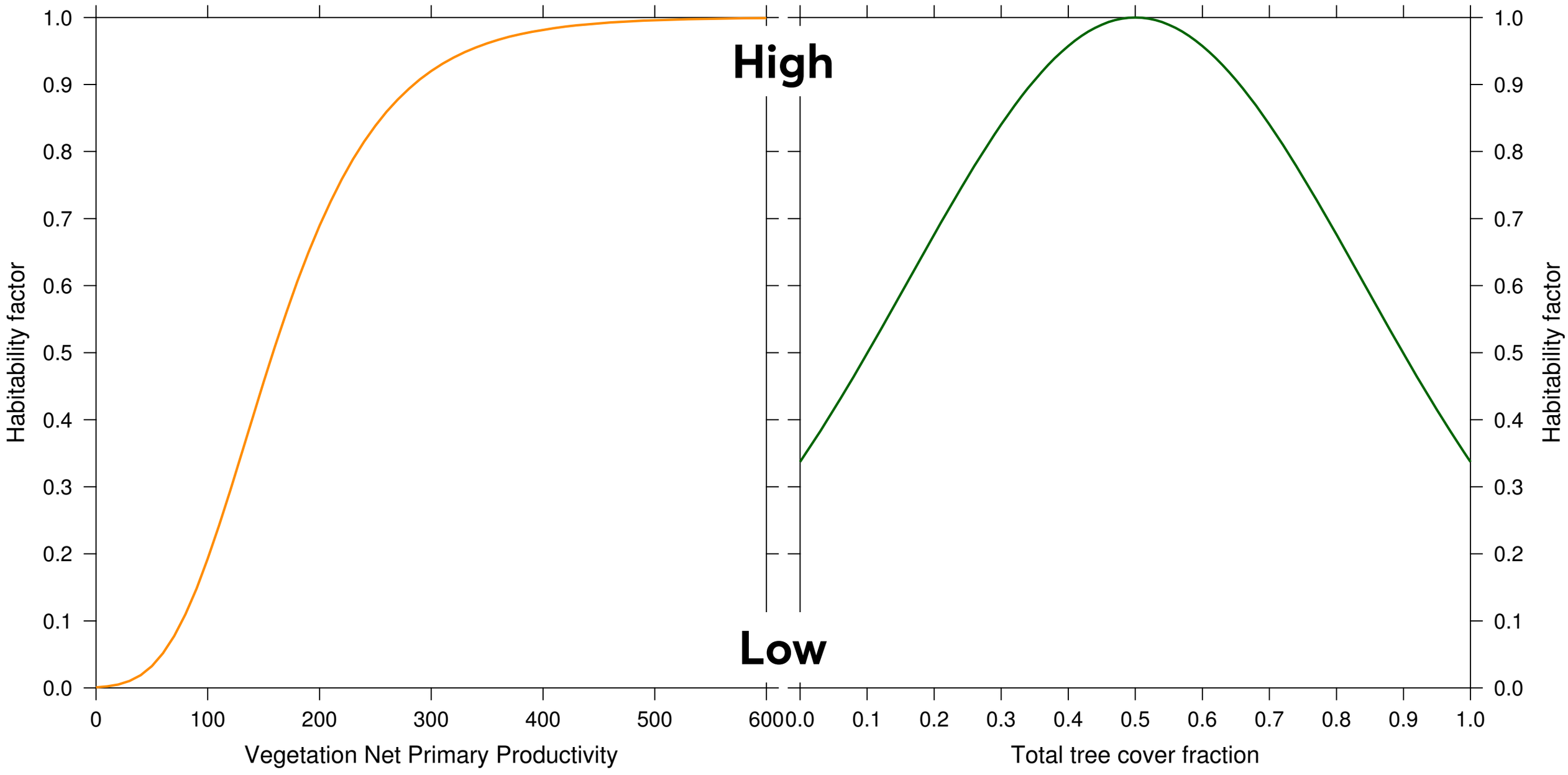
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6

potential density (persons 100 km^{-2})

PACEA (D'Errico et al., 2001); Barton, et al., (2013)

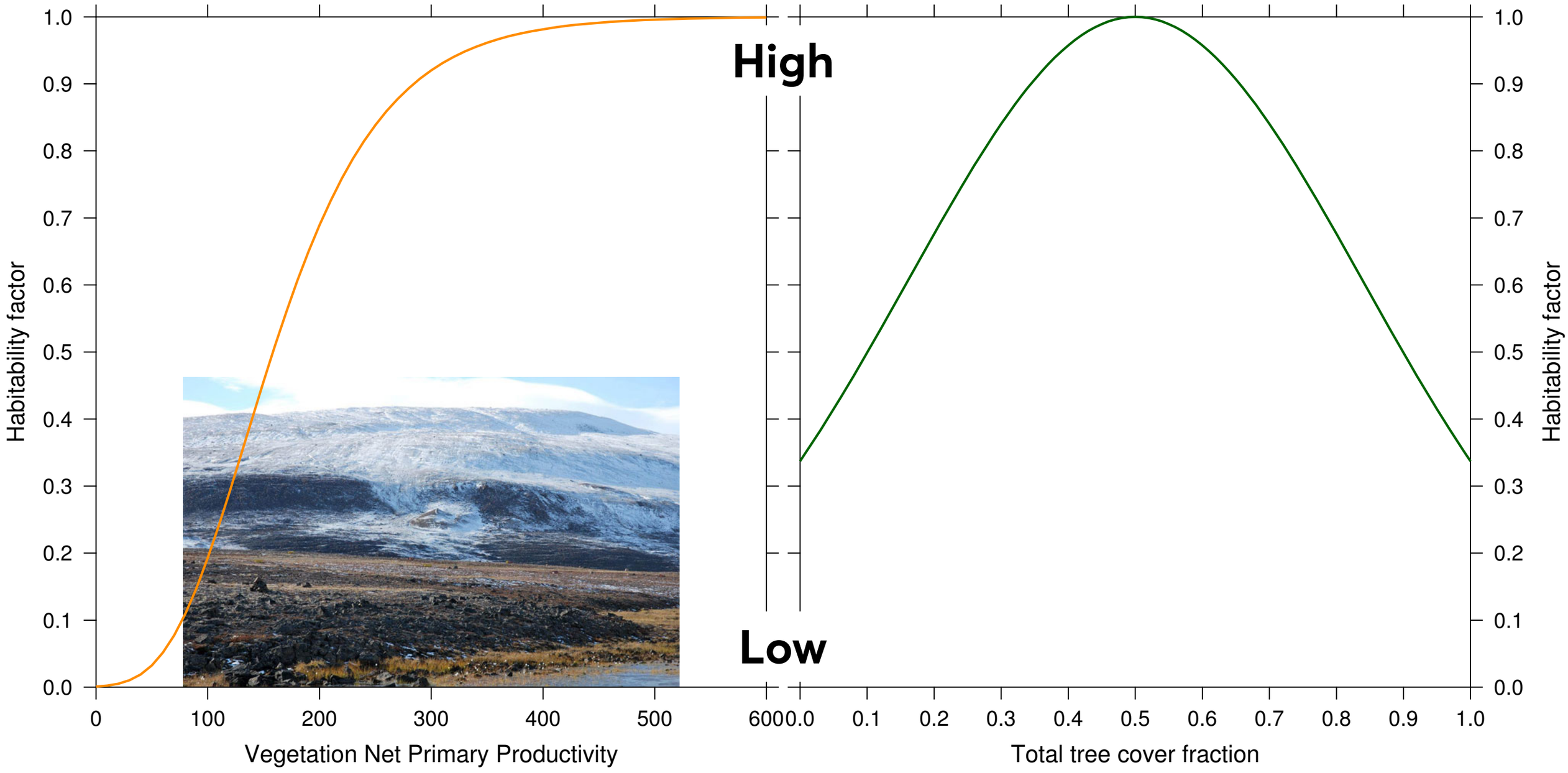
Kaplan et al., *PLOS One*, 2016

Carrying capacity calculation



Kaplan et al., *PLOS One*, 2016; Kaplan et al., *JGR-Atmospheres*, 2003

Carrying capacity calculation



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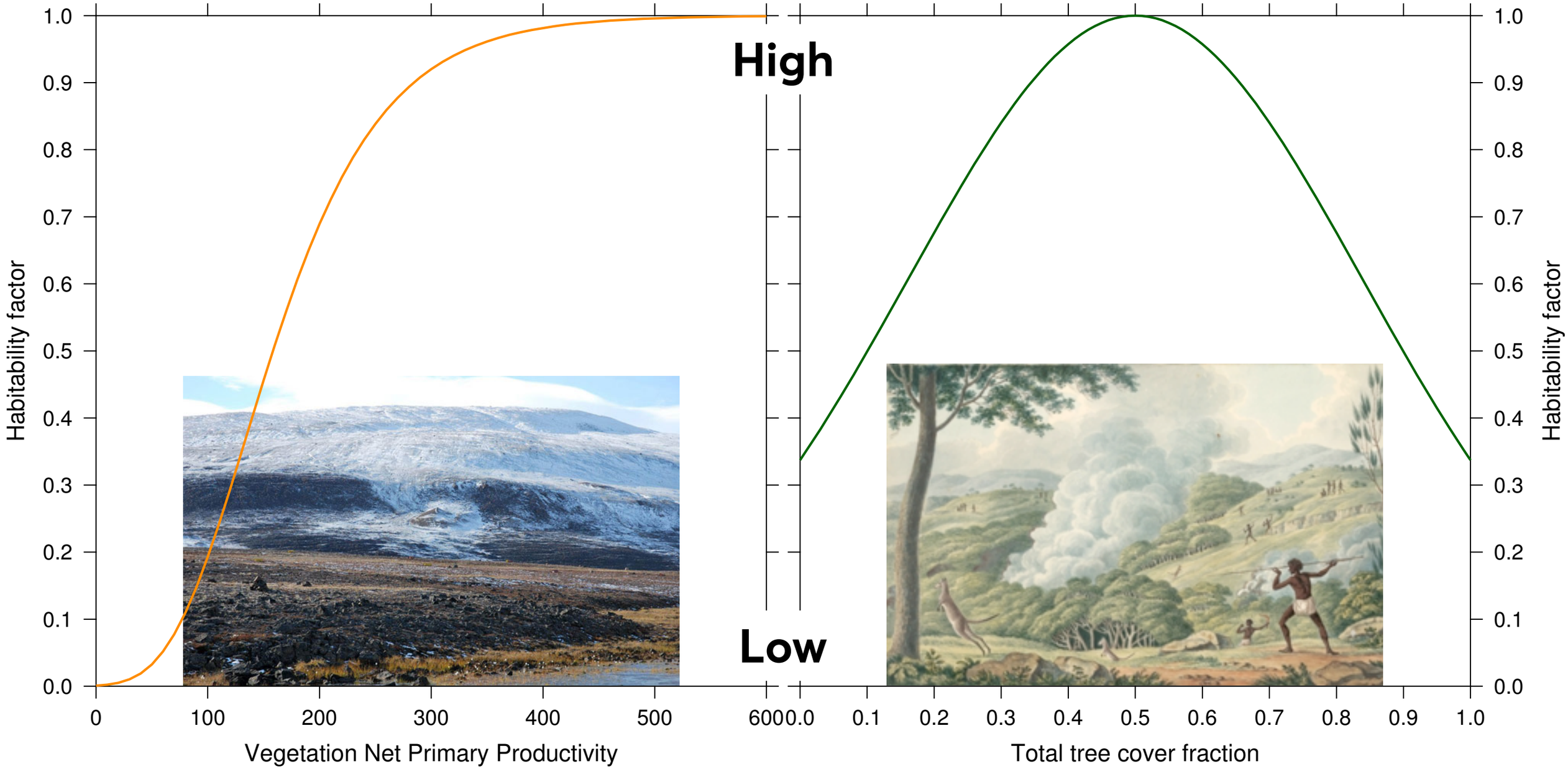
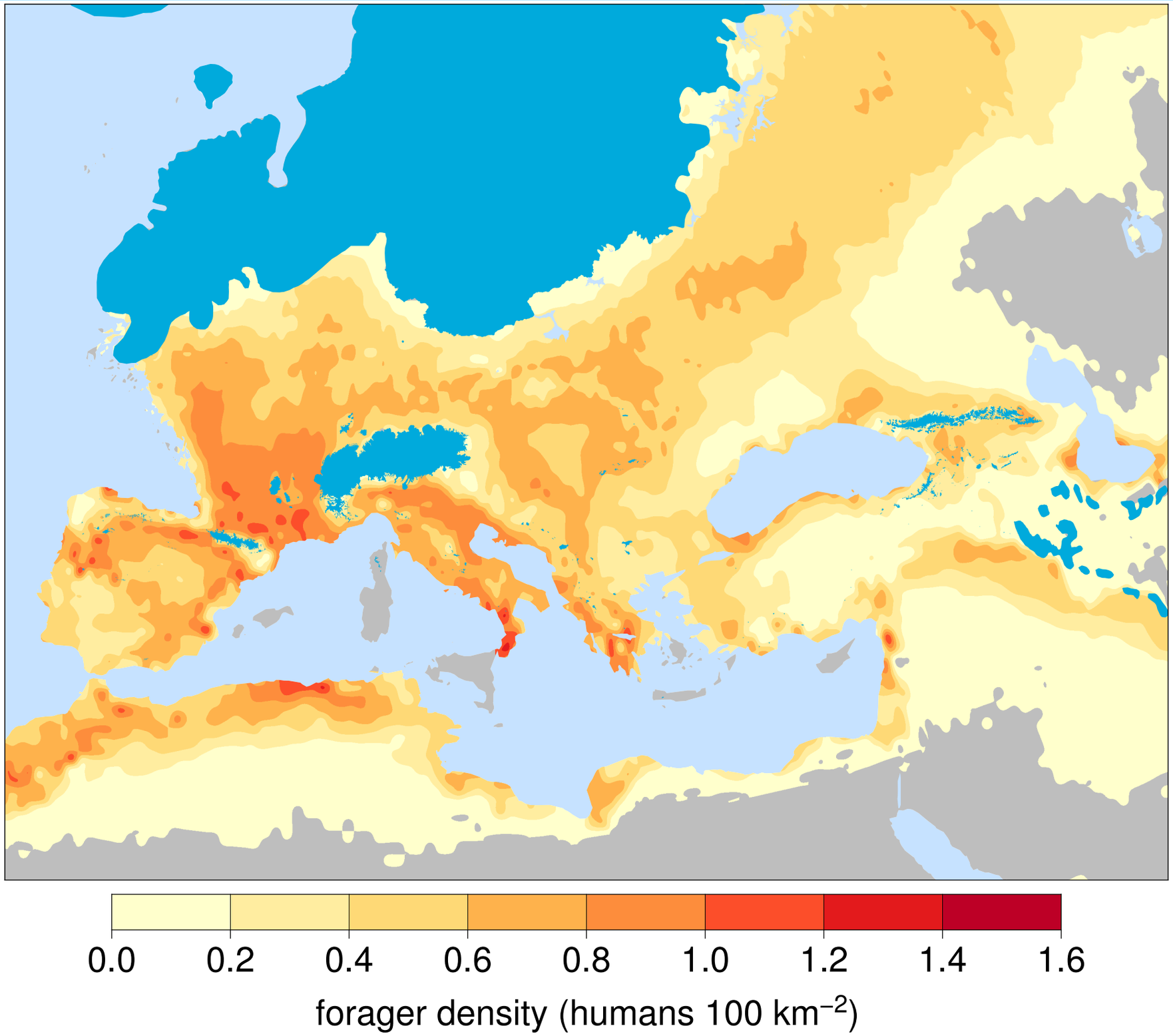


Kaplan et al., *PLOS One*, 2016; Kaplan et al., *JGR-Atmospheres*, 2003

Simulated population density



Kaplan et al., *PLOS One*, 2016

Conceptual setup of fire model

Fuel characteristics and lightning ignitions (daily)

Human ignitions (managed wildfire)

Agricultural burning (annual)

Fire behavior
- Rate of spread
- Fireline intensity
- Average fire size

Fire impact
- Biomass consumed
- Trees killed

Total burned area and trace gas emissions
- CO2
- CH4
- VOCs...

Why would humans burn in the past?

Hunter-gatherers

- semi-open landscapes
- habitat diversity for prey
- ease mobility
- foster growth of desirable species
- *ignition frequency* ***variable****, function of landscape openness*

Faivre et al., 2011). We therefore link the annual amount that foragers will try to burn to the simulated degree of landscape openness, i.e. tree cover, and the effectiveness of fires to open up forest, i.e. the rate of change of vegetation cover over time. The annual burn target for foragers is calculated as

$$t_{\mathrm{ann}} = \max\left(\min\left((1-\mathrm{grass})\max\left(\frac{\mathrm{d}(\mathrm{grass})}{\mathrm{d}t}, 0\right)20, 1\right), 0\right), \qquad (5)$$

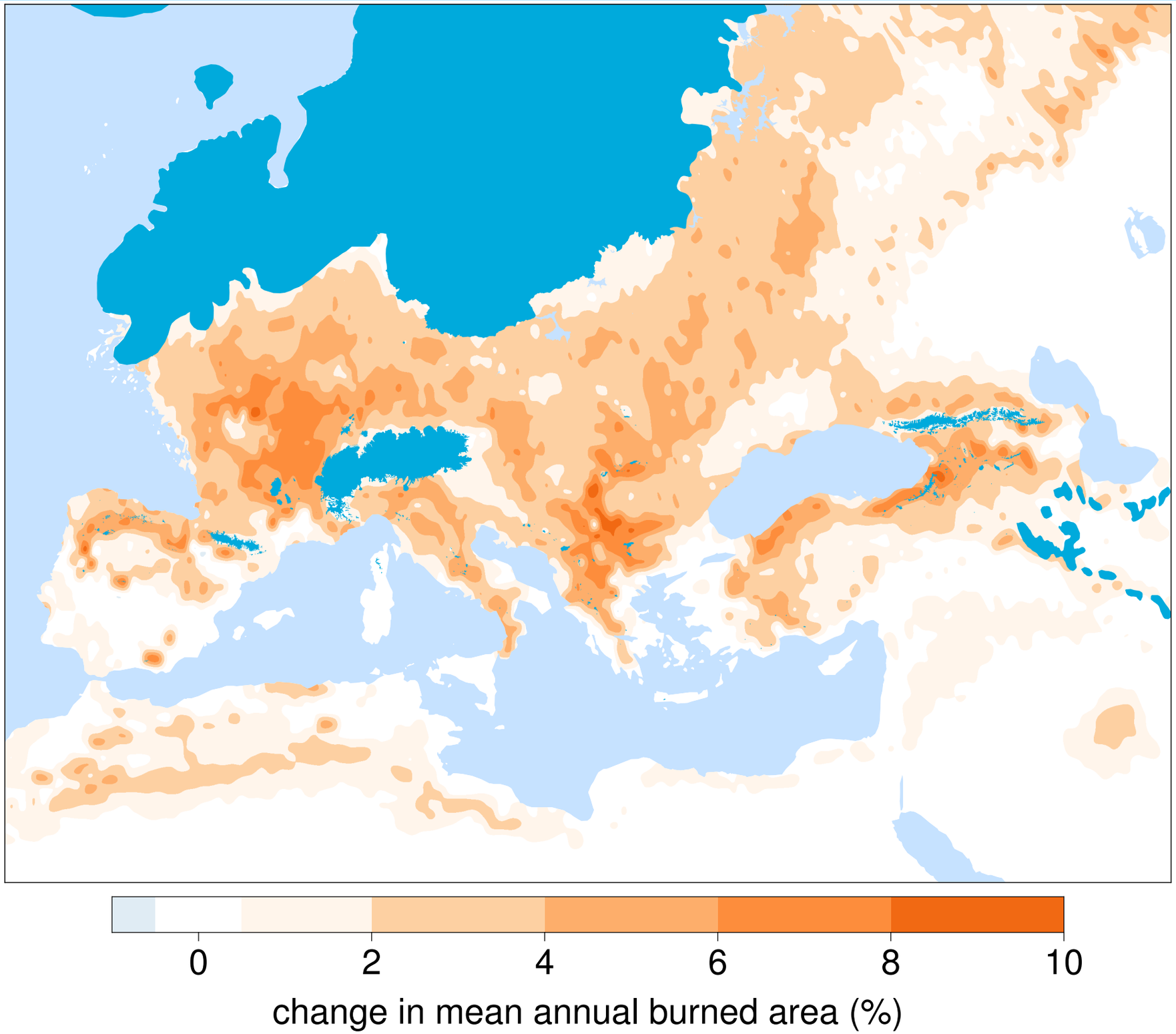
with the change in grass cover being estimated as

$$\frac{\mathrm{d}(\mathrm{grass})}{\mathrm{d}t} = \mathrm{grass}_{(t-1)} - \left(0.9\mathrm{grass}_{(t-1)} + 0.1\mathrm{grass}_{t}\right). \qquad (6)$$

These equations imply that foragers living in an area with high forest cover will initially try to use fire to open the landscape. As the forest cover is reduced, the annual amount of anthropogenic fire will be reduced to maintain an equilibrium level of openness of the landscape. Alternatively, if anthropogenic burning has little effect on forest cover, e.g. in wet environments, humans will "give up" trying to burn their landscape after a short period of time. This quantification of

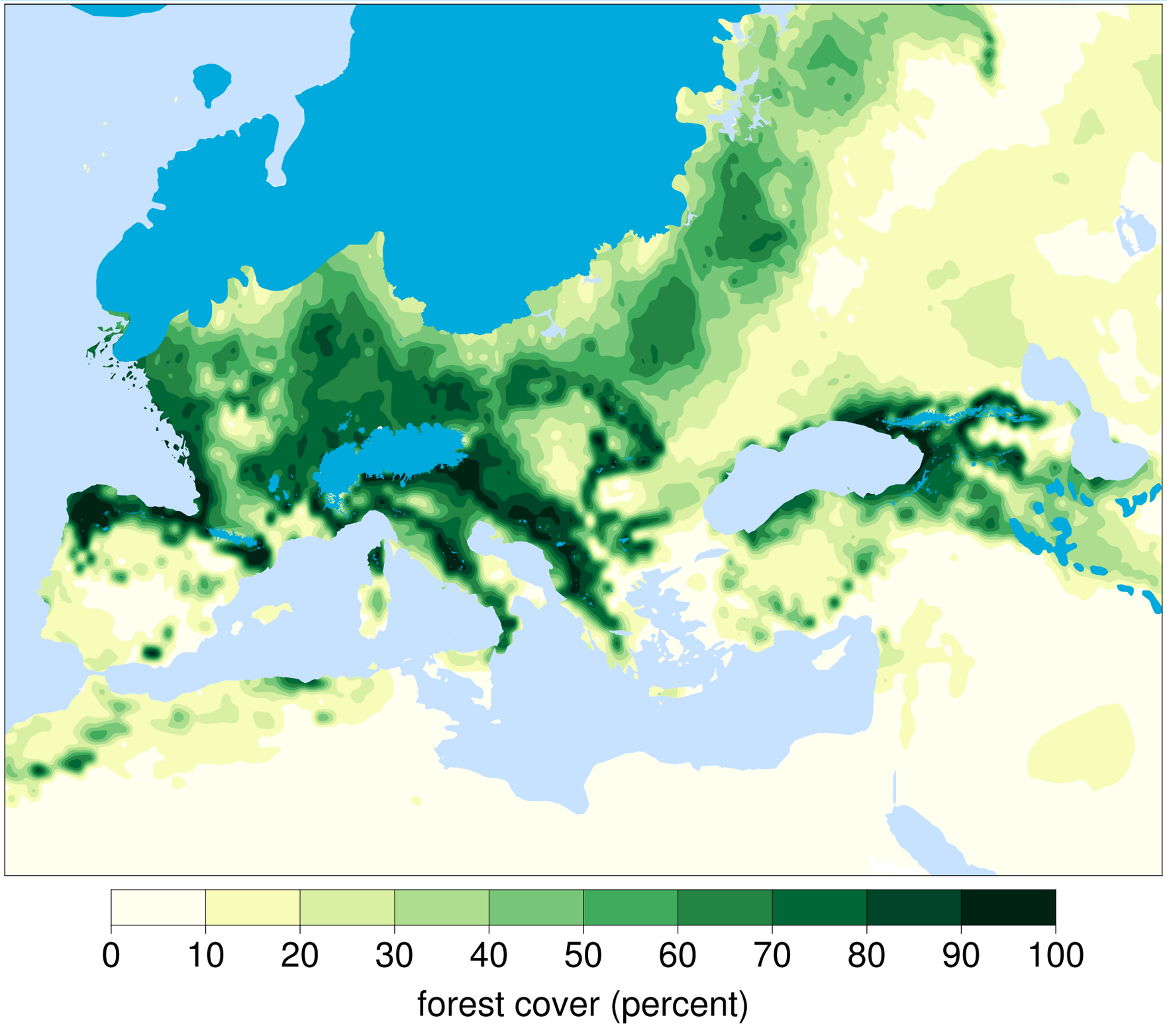
Pfeiffer et al., *Geoscientific Model Devel.*, 2013

Fire caused by humans



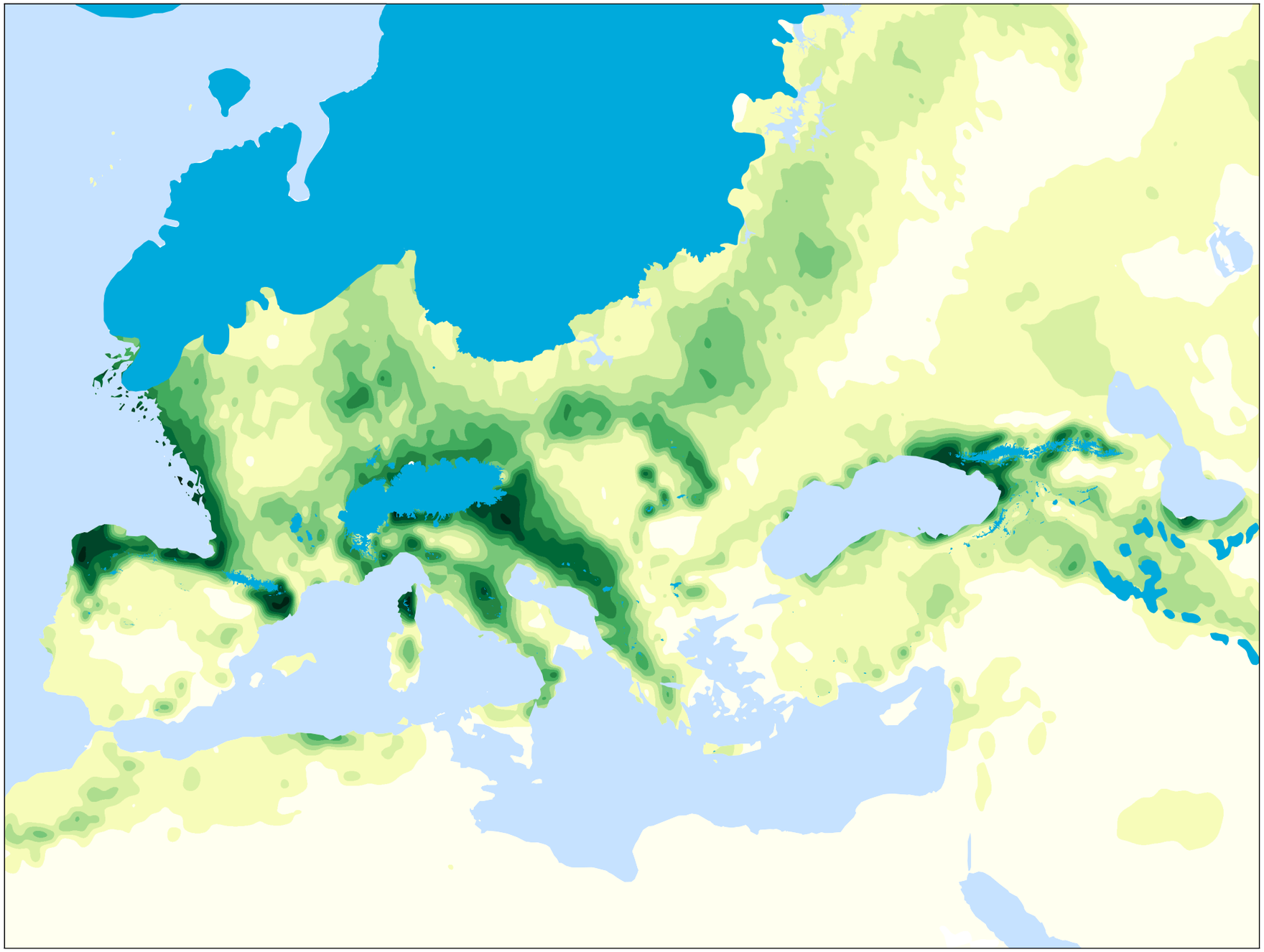
Kaplan et al., *PLOS One*, 2016

Modeled forest cover without humans



Kaplan et al., *PLOS One*, 2016

Forest cover as influenced by human burning



Kaplan et al., *PLOS One*, 2016

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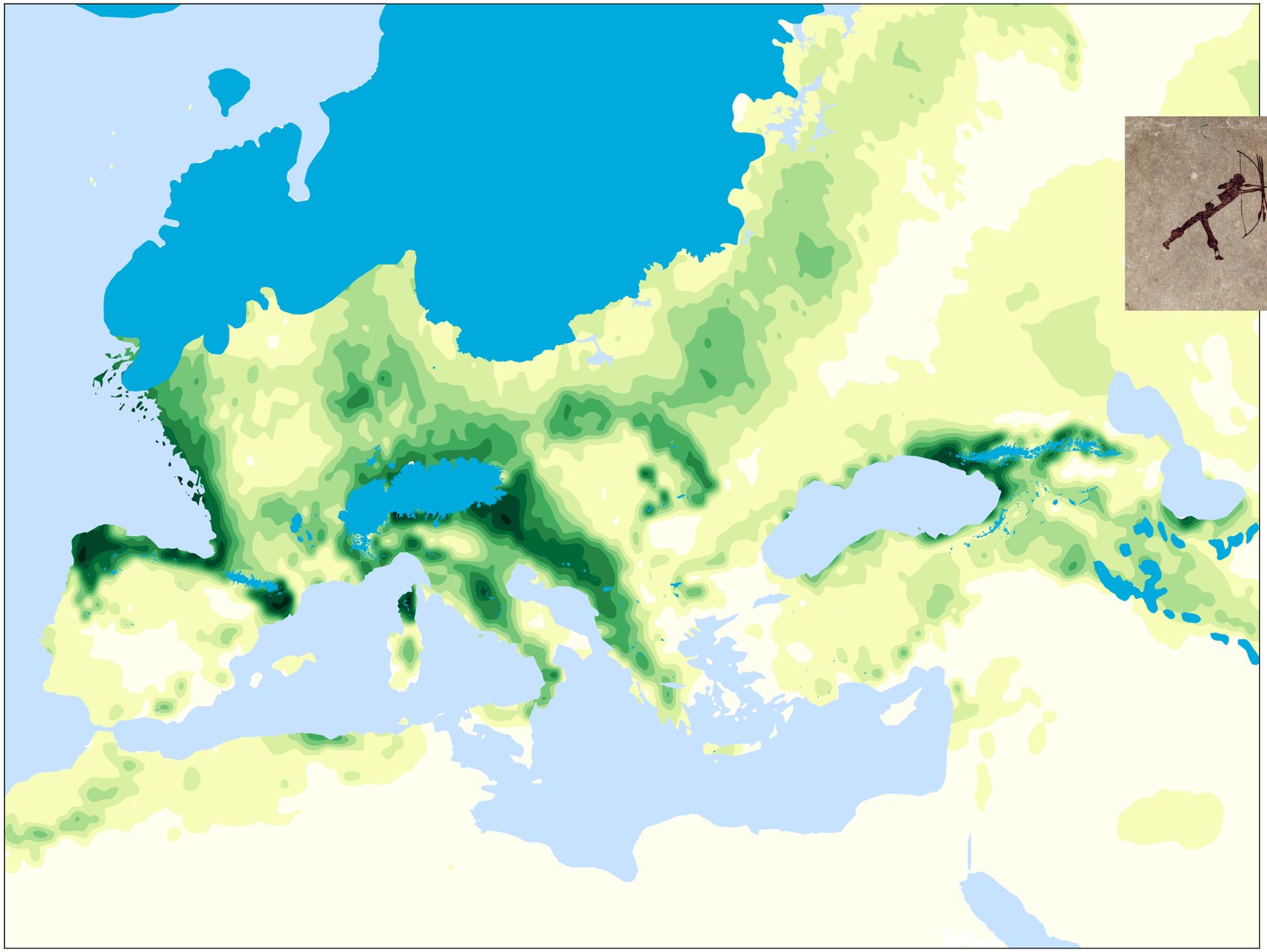

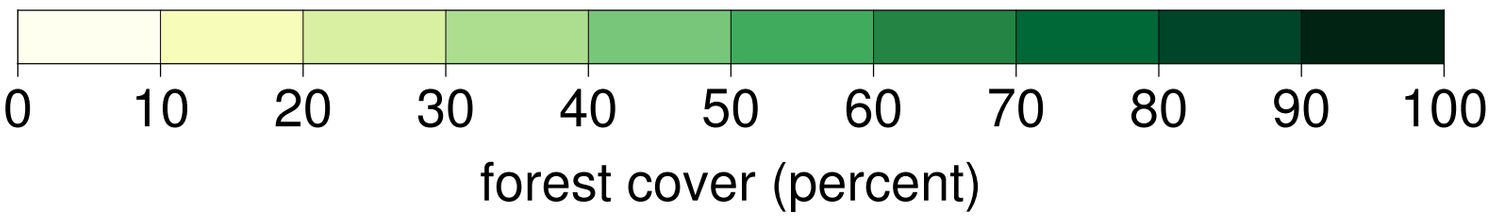

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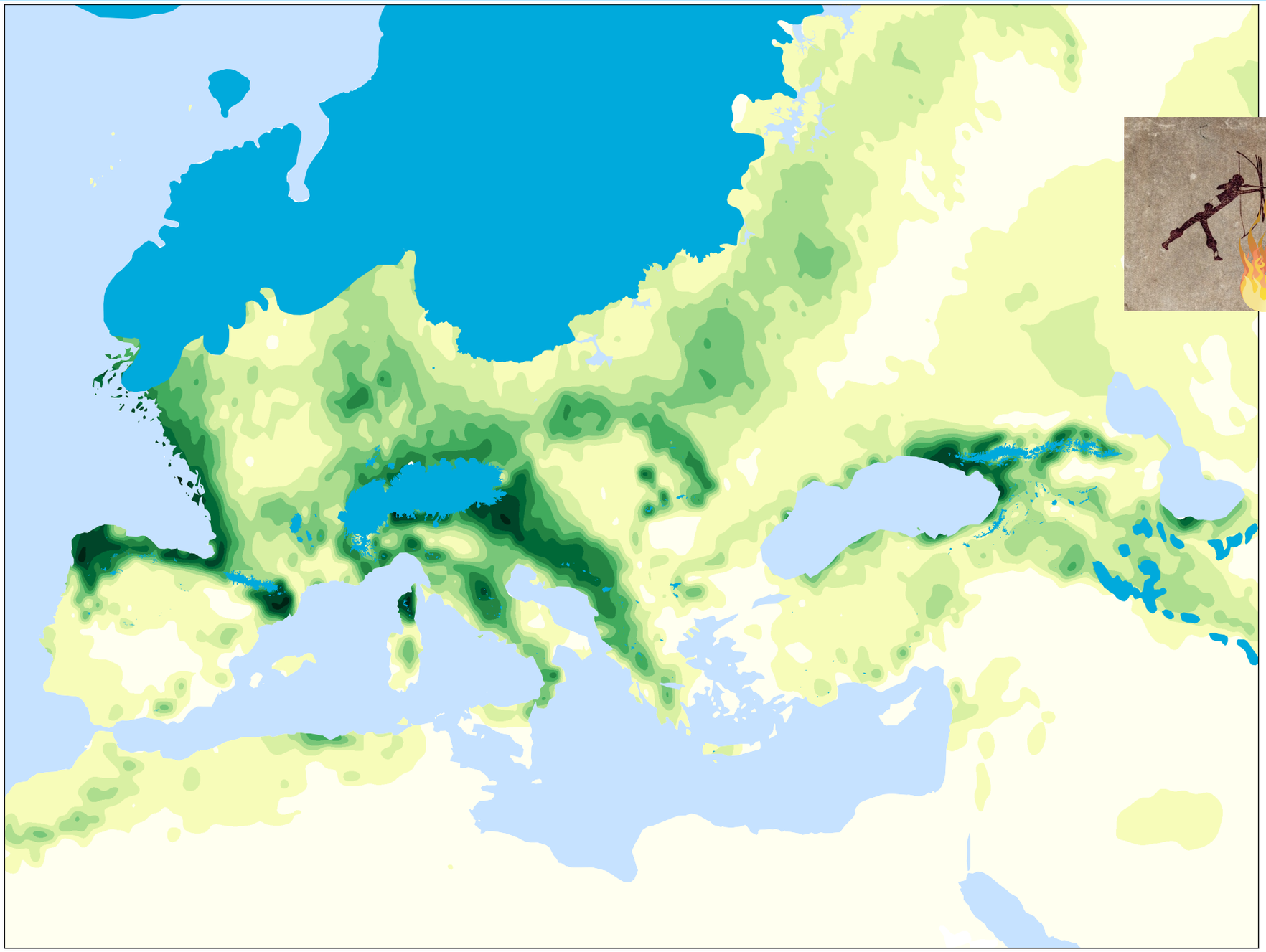
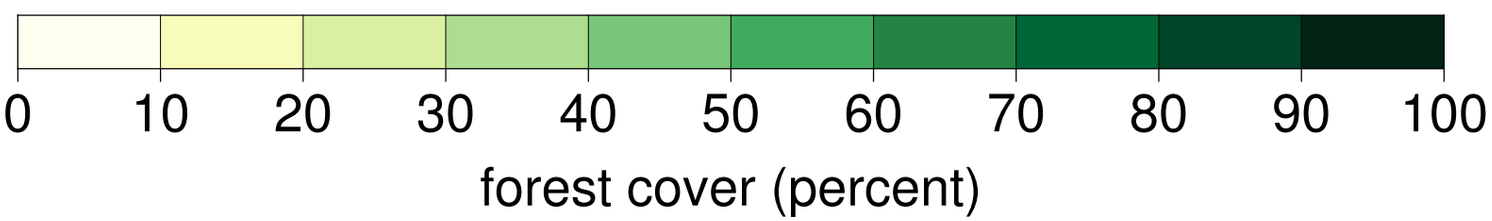
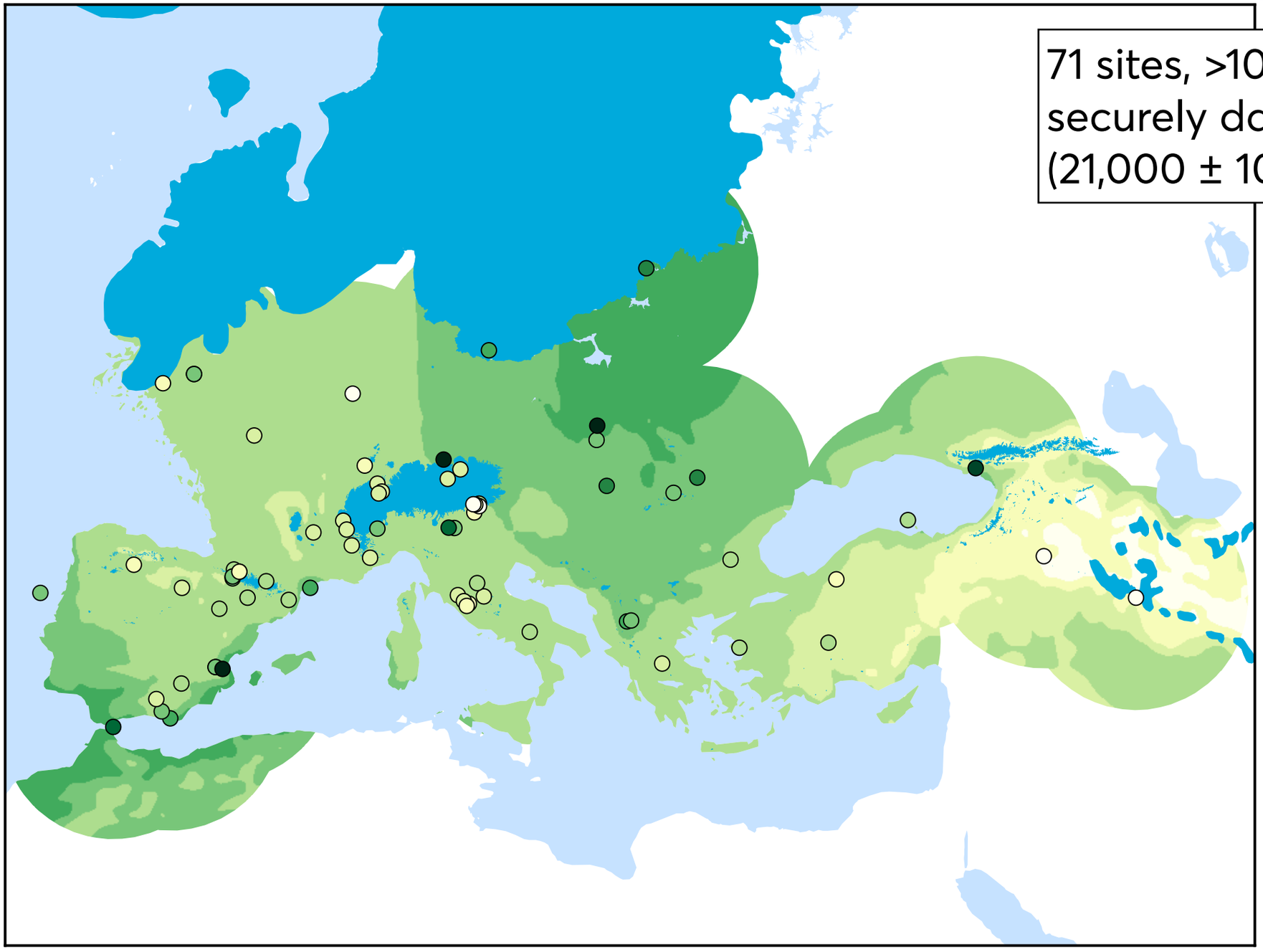




Kaplan et al., *PLOS One*, 2016

The LGM forested Europe conundrum

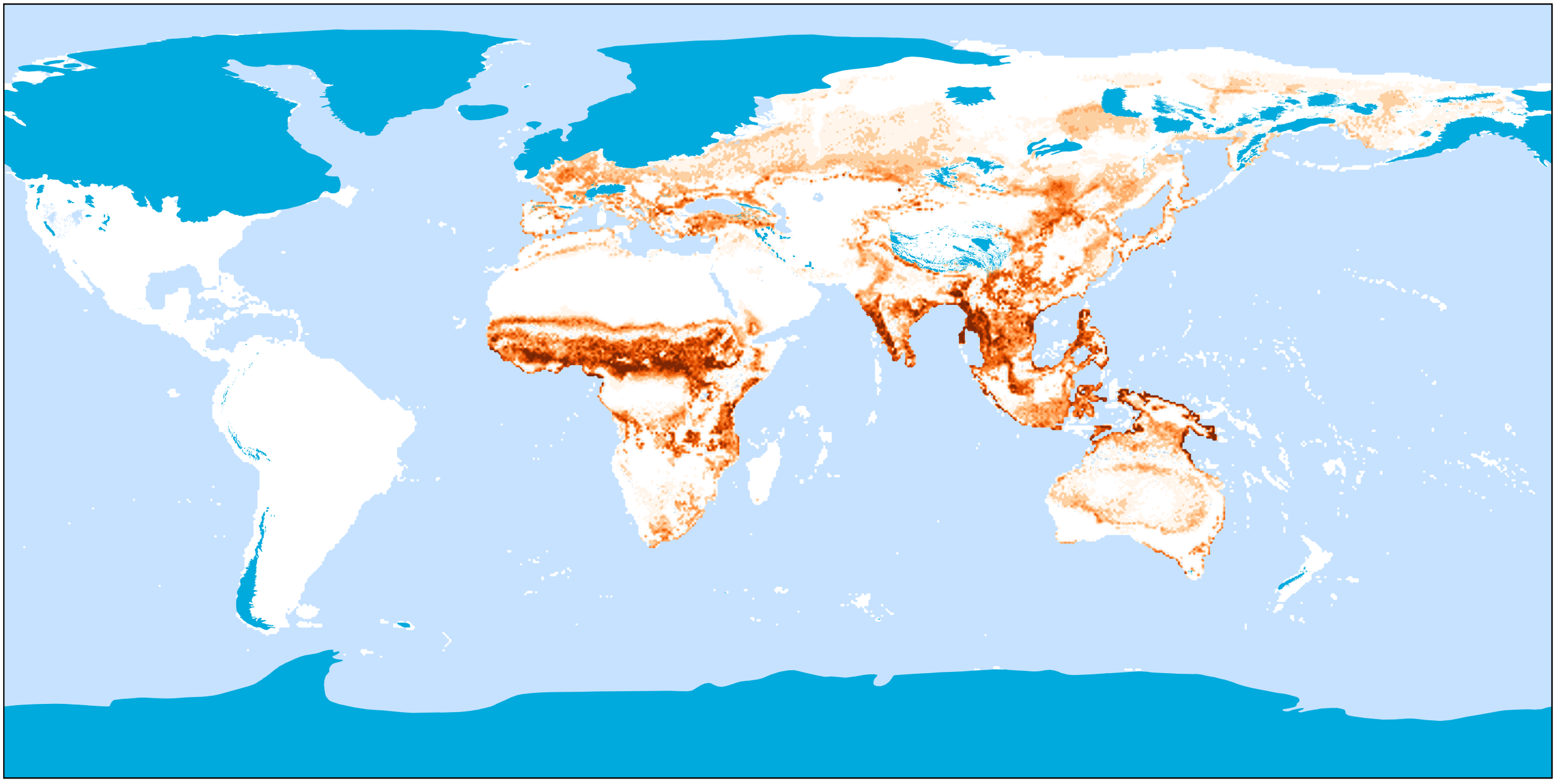


Kaplan et al., *PLOS One*, 2016

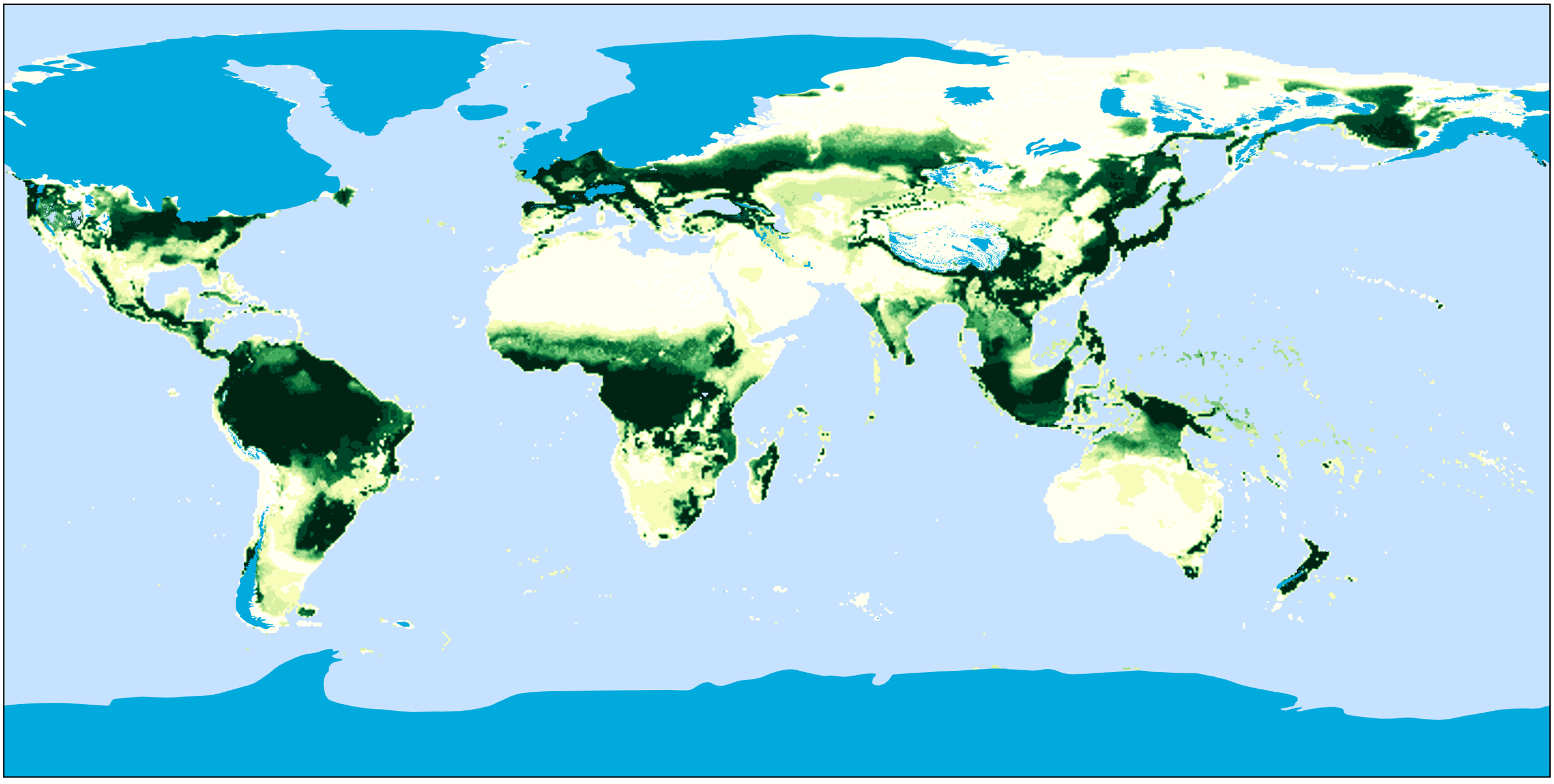
Summary

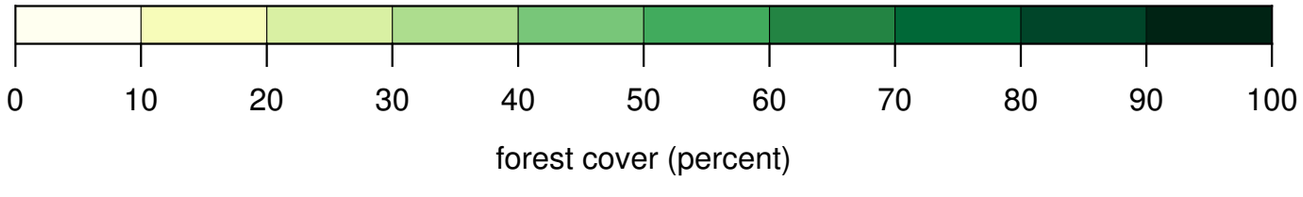
- Climate simulations for LGM Europe show large differences between models. However,
- Much of Europe may have been suitable for human occupation at LGM
- Limited human application of fire, to wooded landscapes already stressed by cold temperatures and low CO_2, would have led to large-scale opening of landscapes
- This process helps reconcile models with independent reconstructions of land cover

Fire caused by people (burned area)

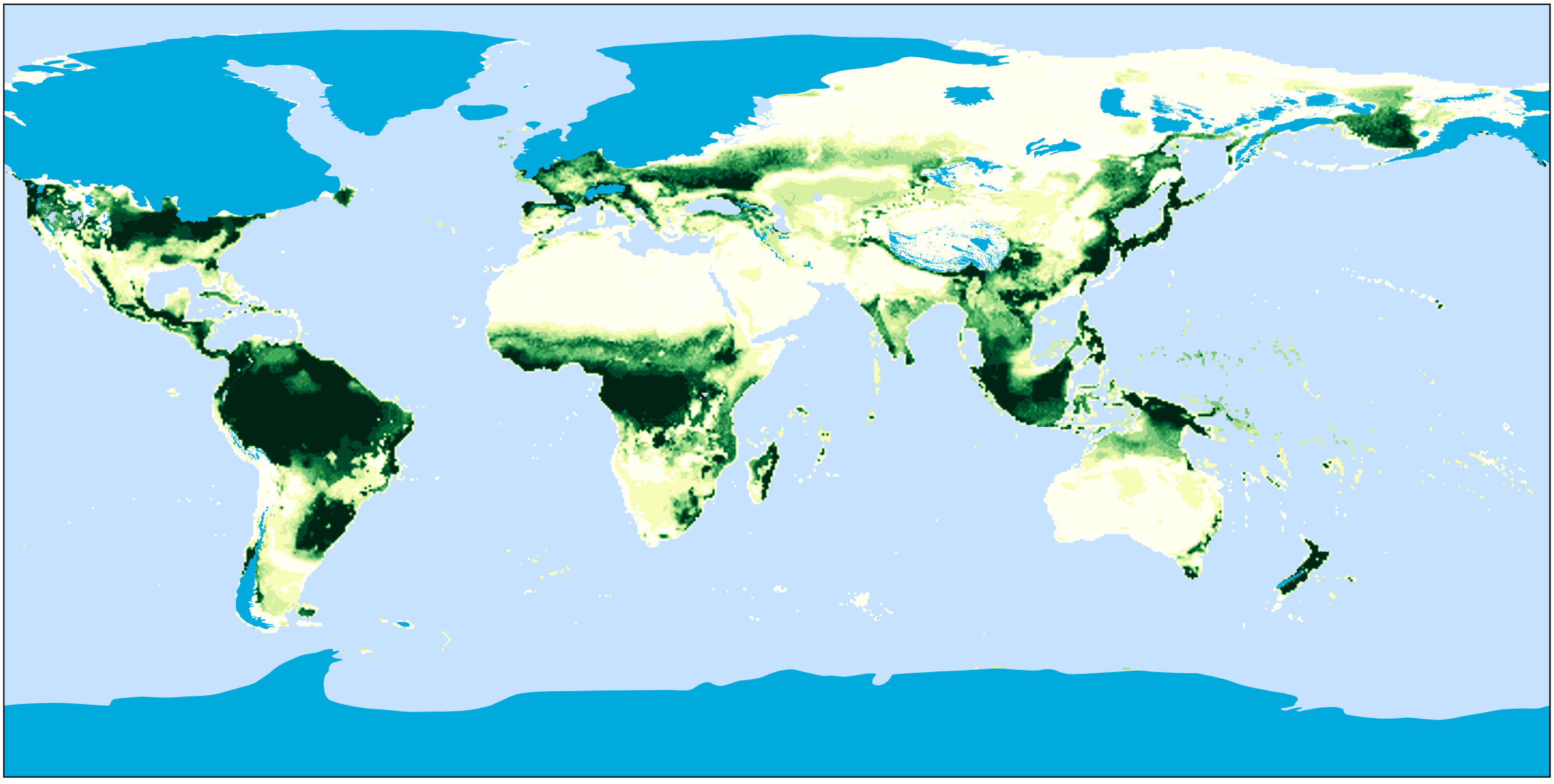


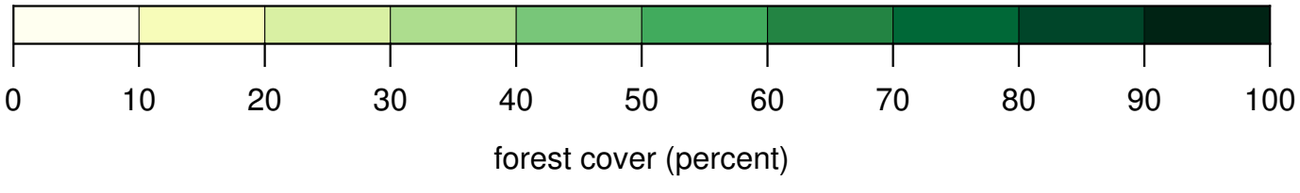
LGM tree cover in the absence of humans





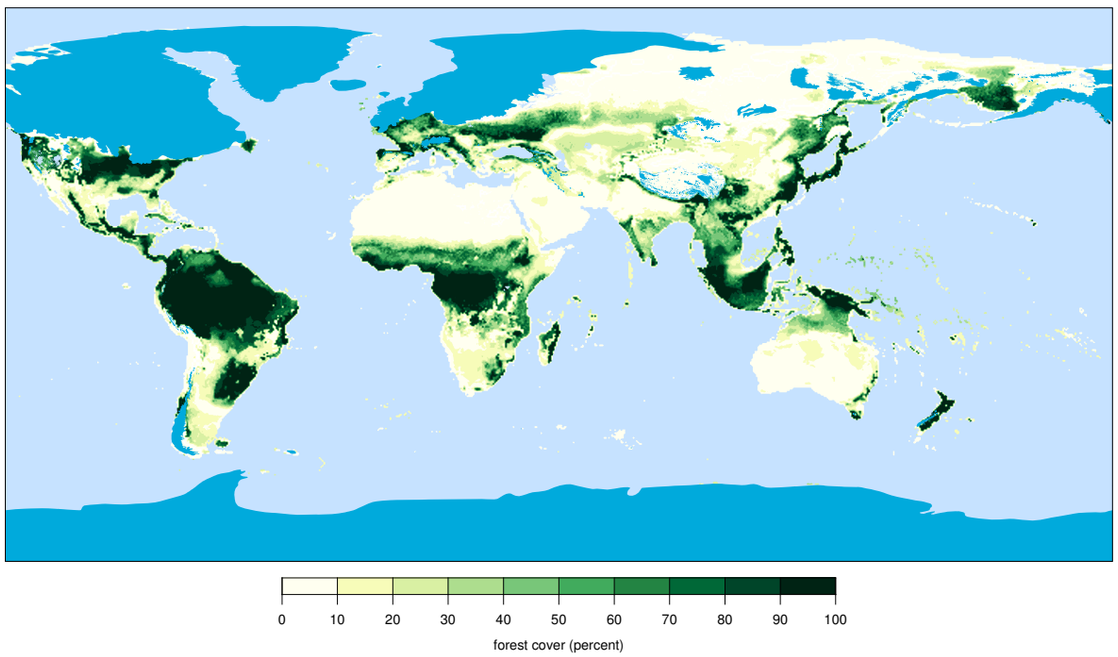
LGM tree cover with anthropogenic fire



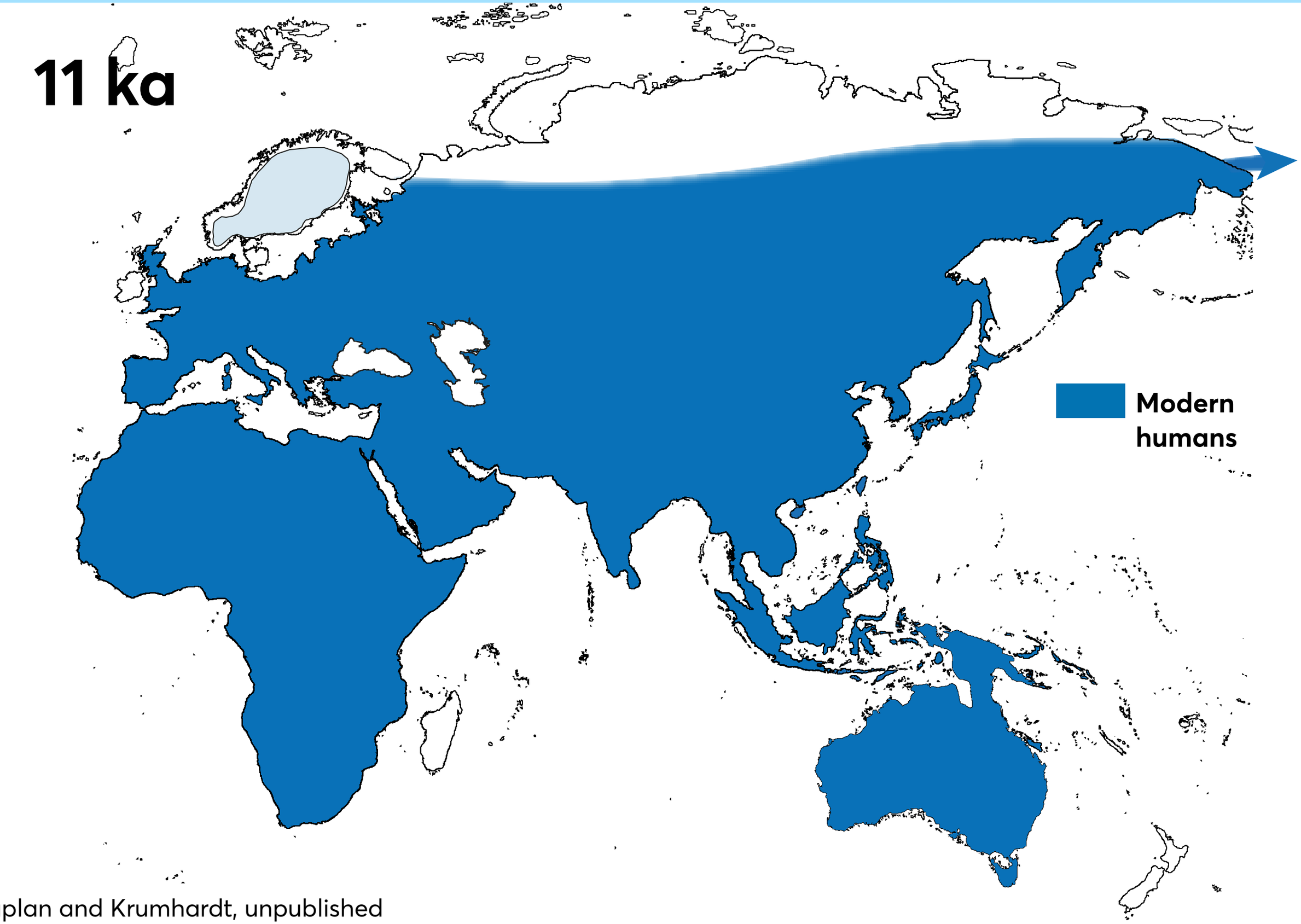


The beginning of the anthropocene?

- Human use of fire could have led to large changes in land cover in temperate/boreal latitudes
- These would feedback to climate, intensifying already cold glacial conditions
- Are these the first large-scale anthropogenic transformations of the earth system?

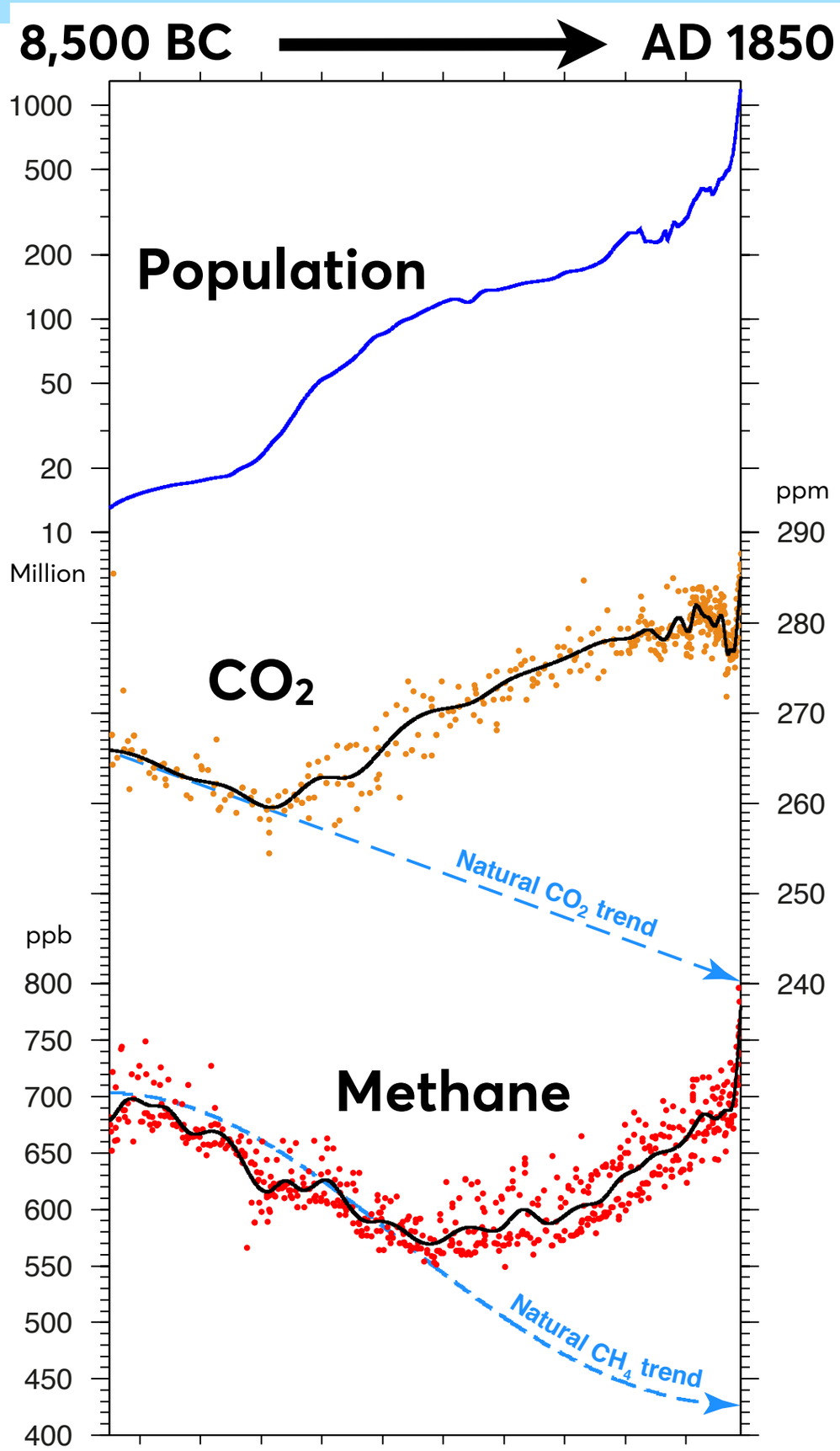


11,000 BP: Beginning of the Holocene



Kaplan and Krumhardt, unpublished

The **enigma** of Holocene CO_2 and methane



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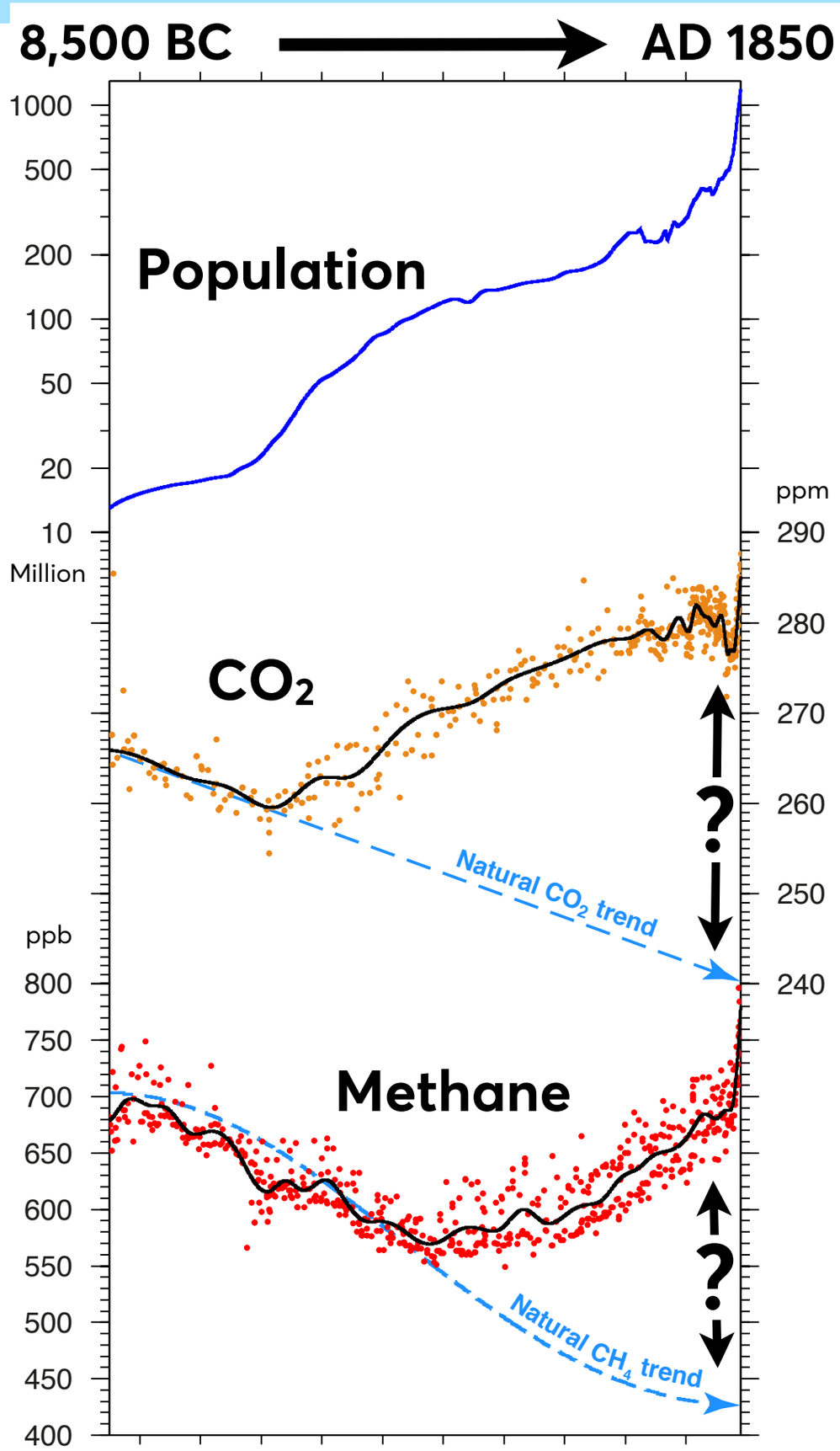

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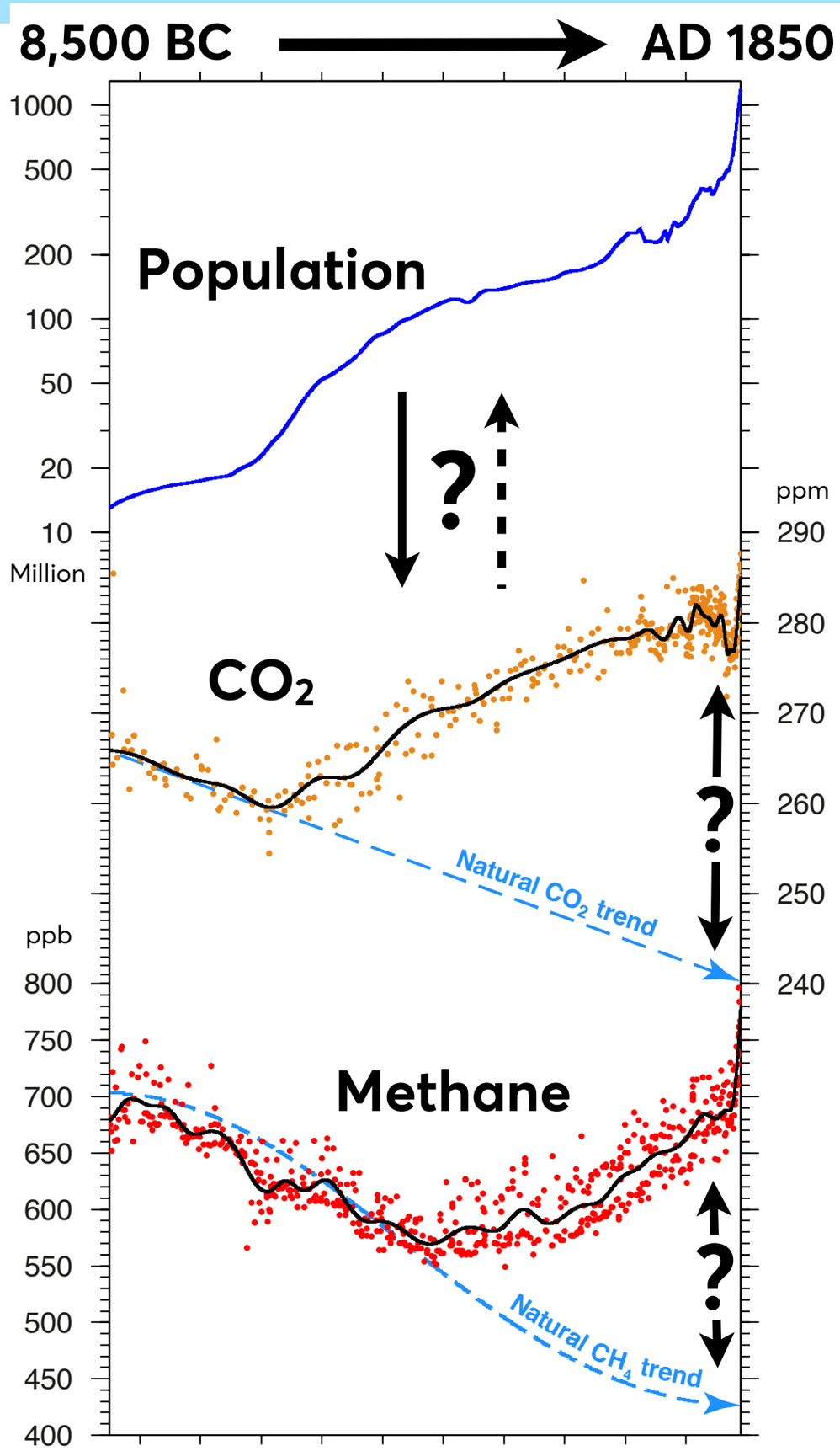
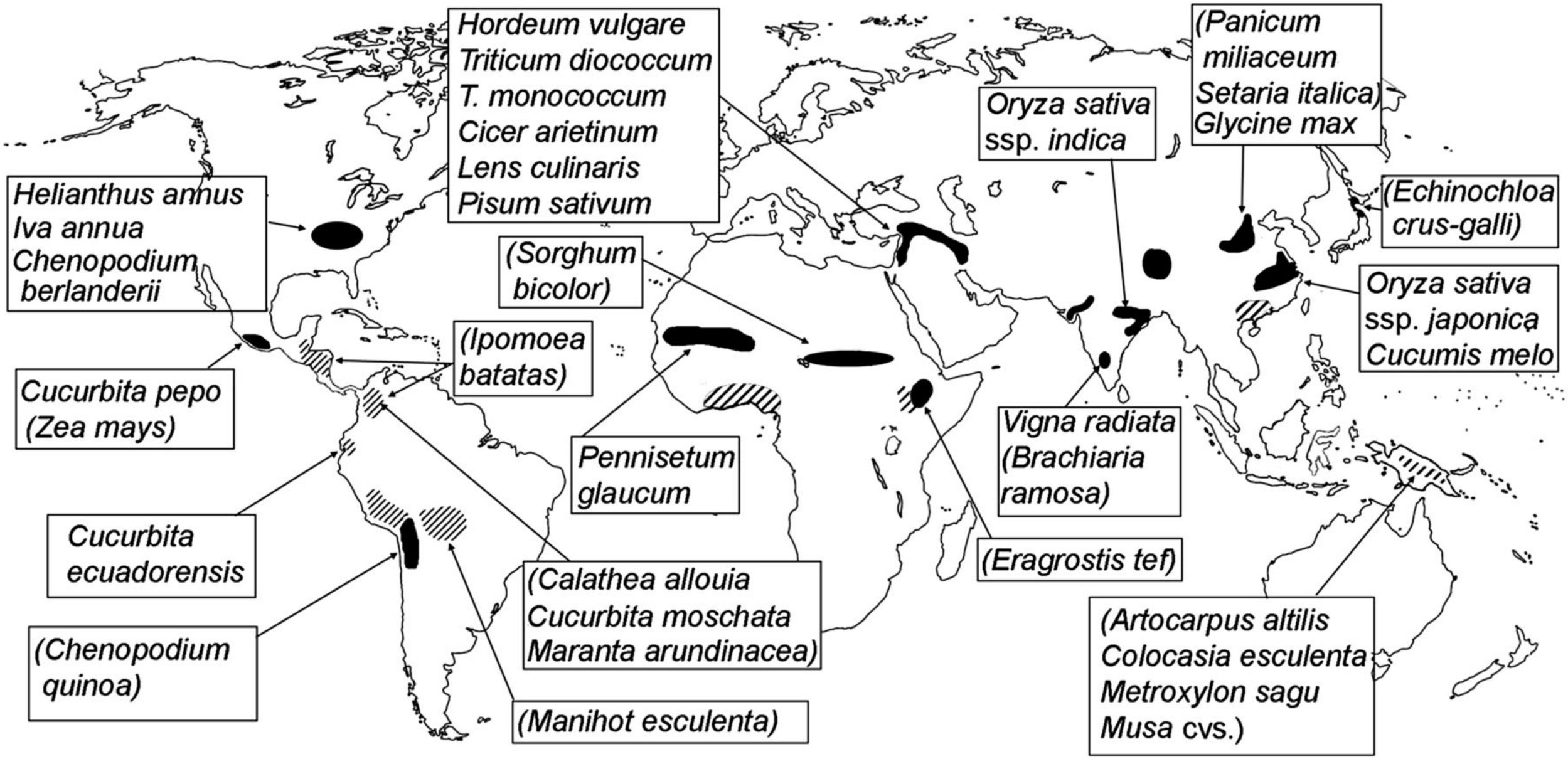


The 2nd land use revolution: Agriculture and pastoralism

Centers of domestication



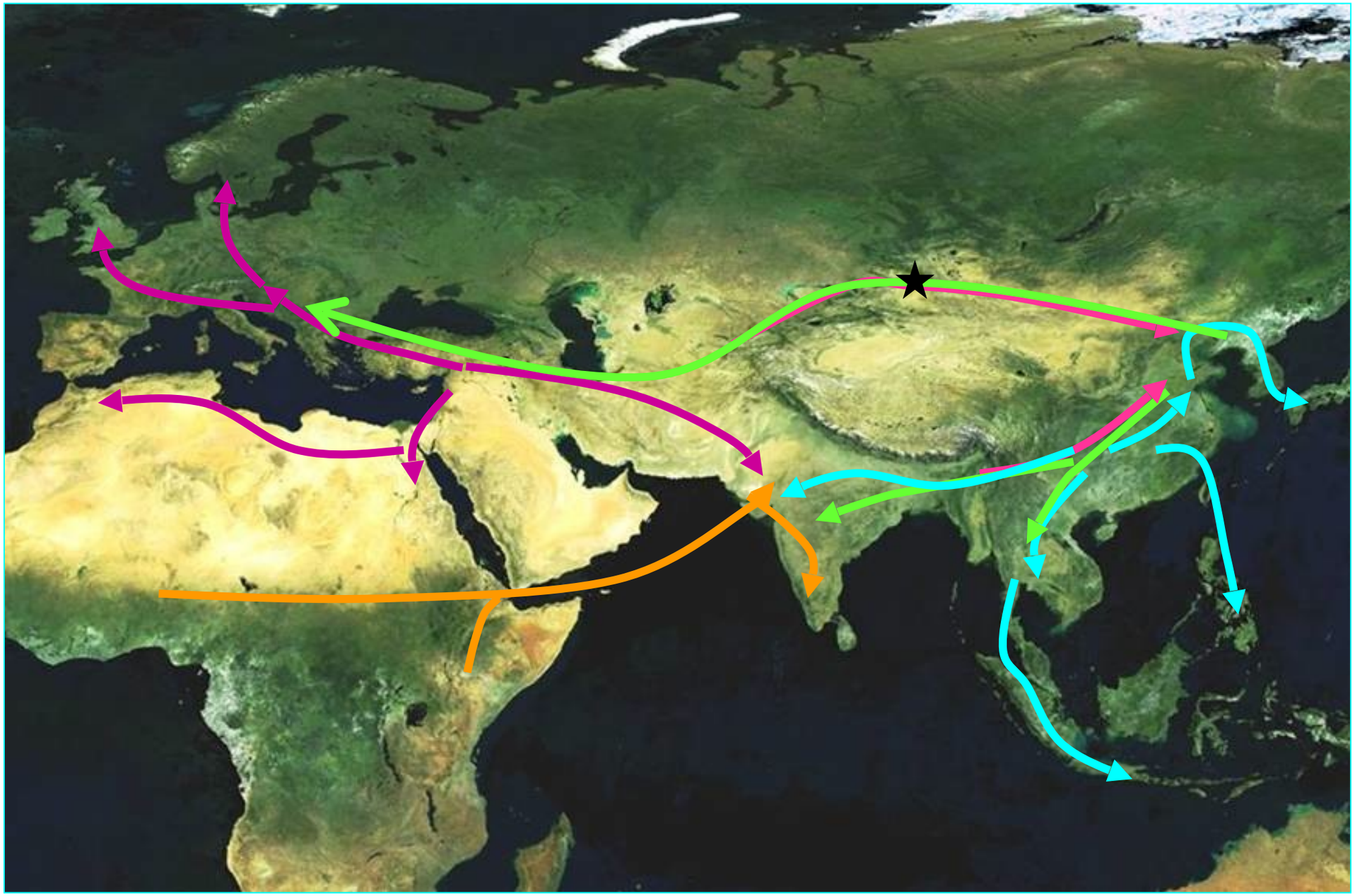
Fuller et al., PNAS, 2014

Spread of agriculture and change in diet

Wheat, barley

Rice

Asian Millets and Buckwheat



African millets and Sorghum

extent of cross-continental cereal exchange by 3,800 BP

Courtesy Martin Jones, Cambridge

The 3rd land use revolution: Metallurgy

Photos courtesy of The British Museum

Base Map: After Haywood, 2011

The 3rd land use revolution: Metallurgy

Photos courtesy of The British Museum

Base Map: After Haywood, 2011

The 3rd land use revolution: Metallurgy

Photos courtesy of The British Museum

Base Map: After Haywood, 2011

The 3rd land use revolution: Metallurgy

Photos courtesy of The British Museum

Base Map: After Haywood, 2011

The 3rd land use revolution: Metallurgy

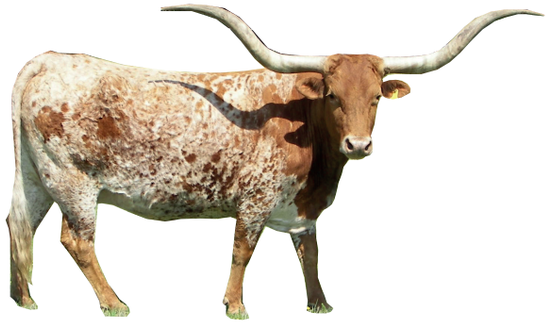
Photos courtesy of The British Museum

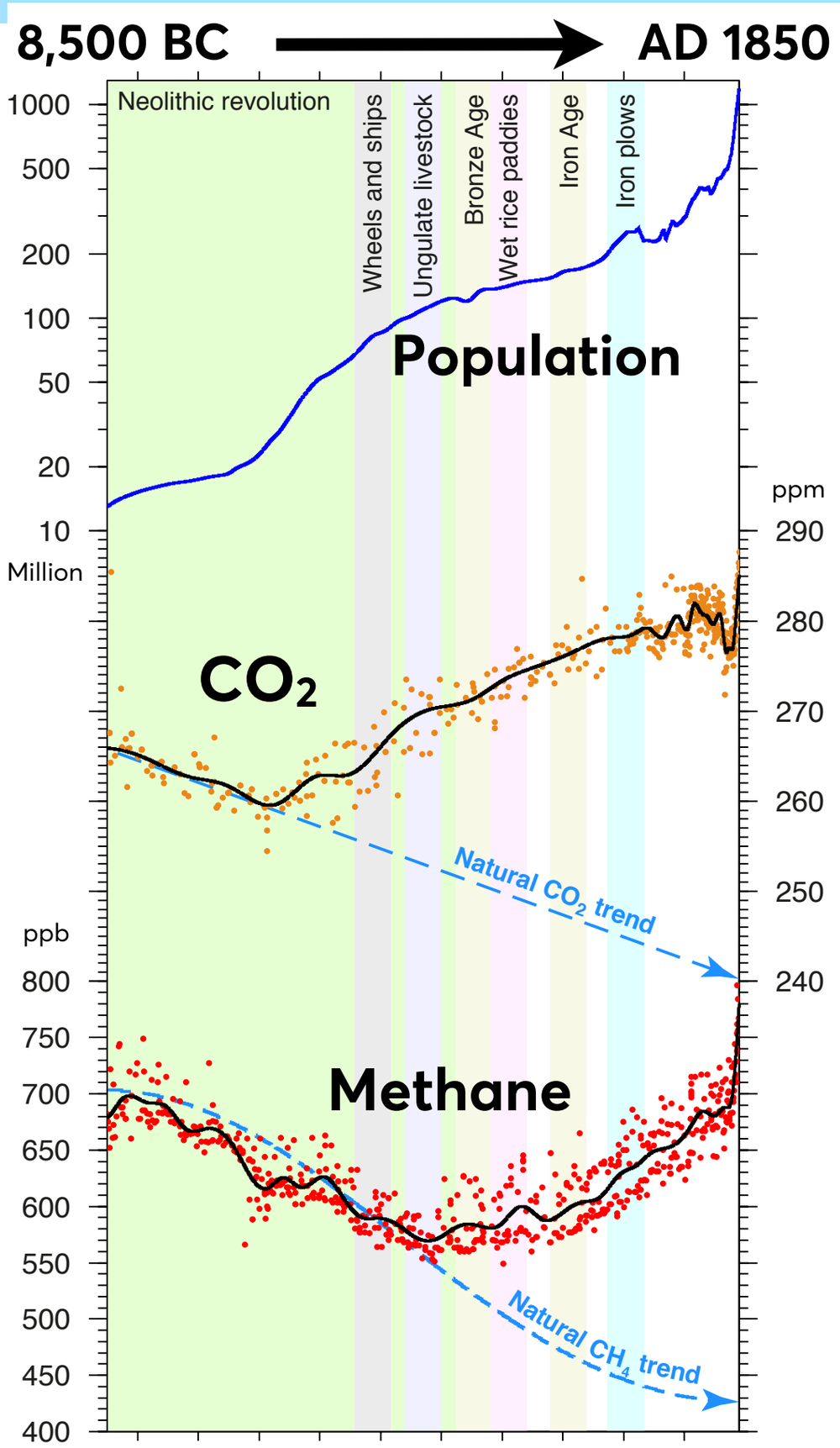
The 4th land use revolution: Trade

- Large-scale trade in bulk commodities started in the empires of antiquity
- This was already a form of "regionalization" and de-localization of economic activity

Monte Testaccio, Rome, ca. AD 140-250. 53 million amphorae

Human activities emit greenhouse gases

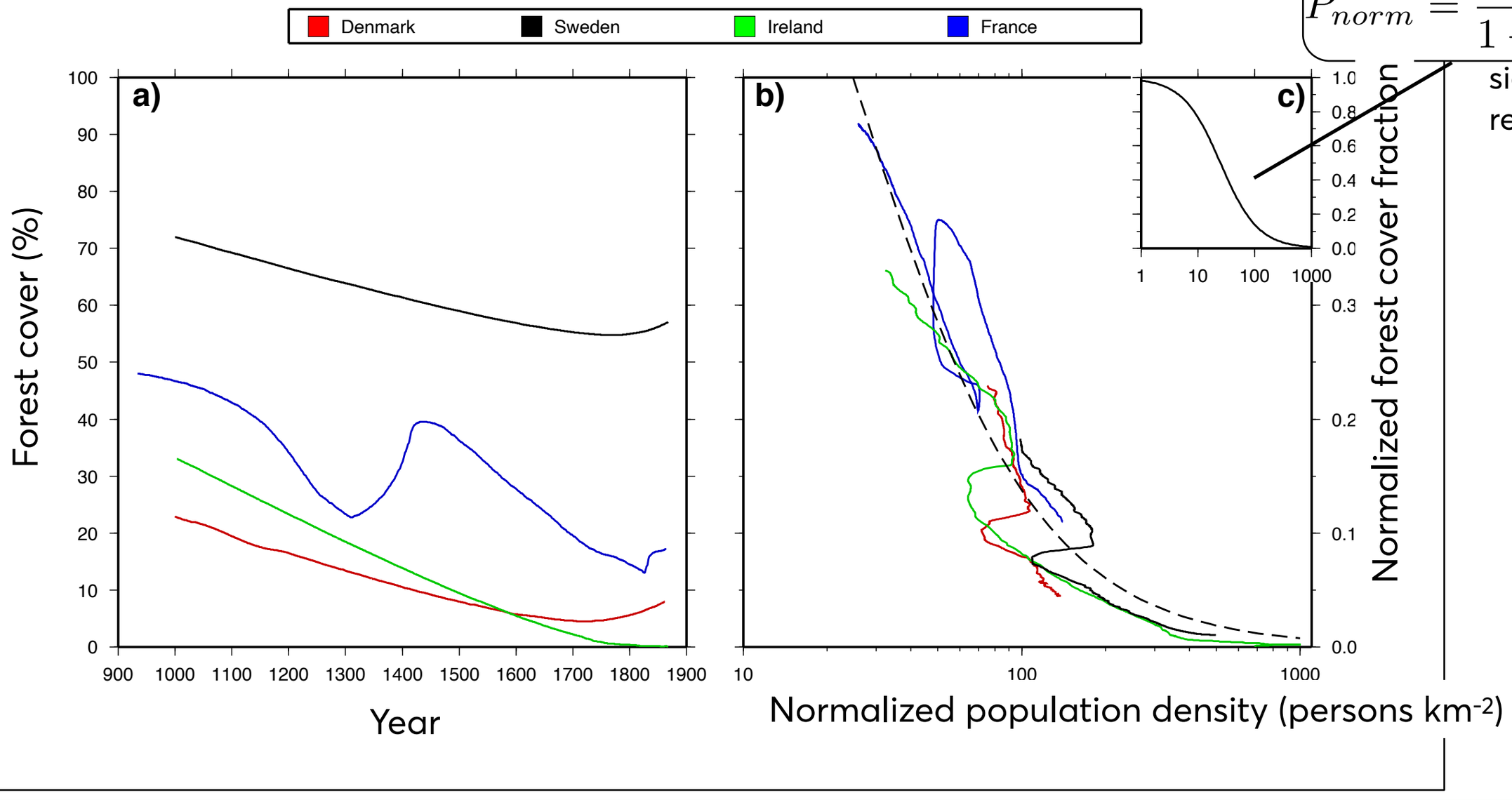




Modeling anthropogenic land cover change

$$P_{norm} = \frac{0.9958}{1 + e^{b(c - FC_{norm})}}$$

sigmoidal relationship

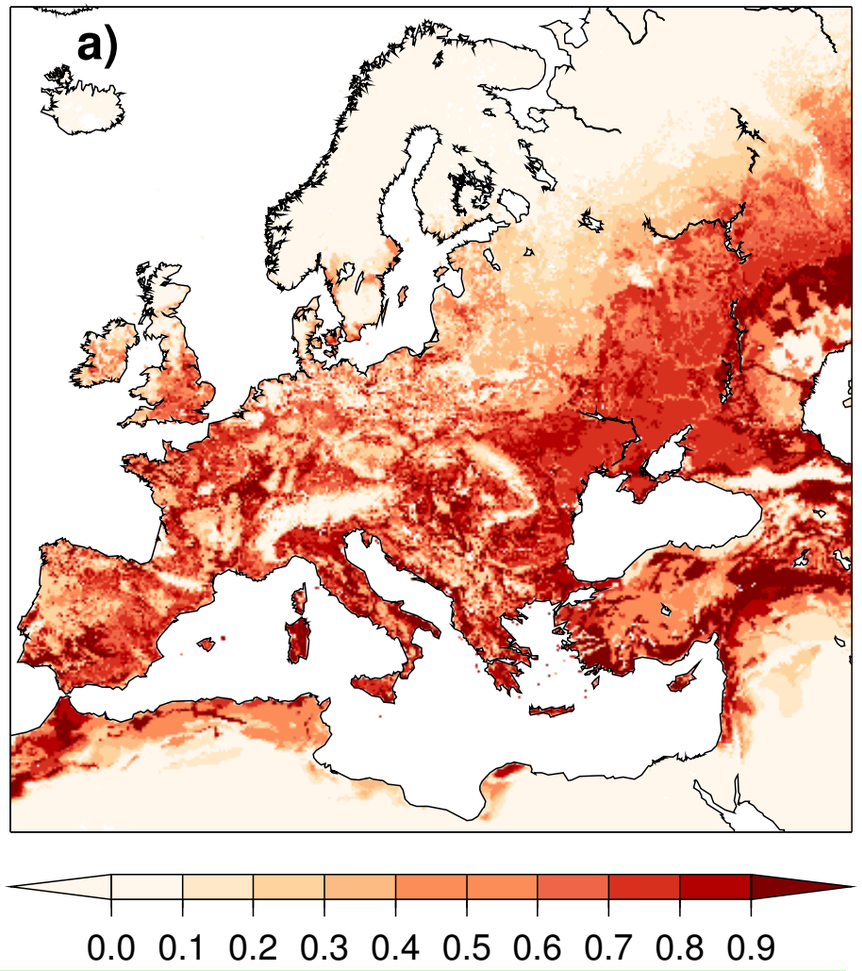


Normalized population density = $\frac{\text{population density on arable land}}{S_{crops}}$

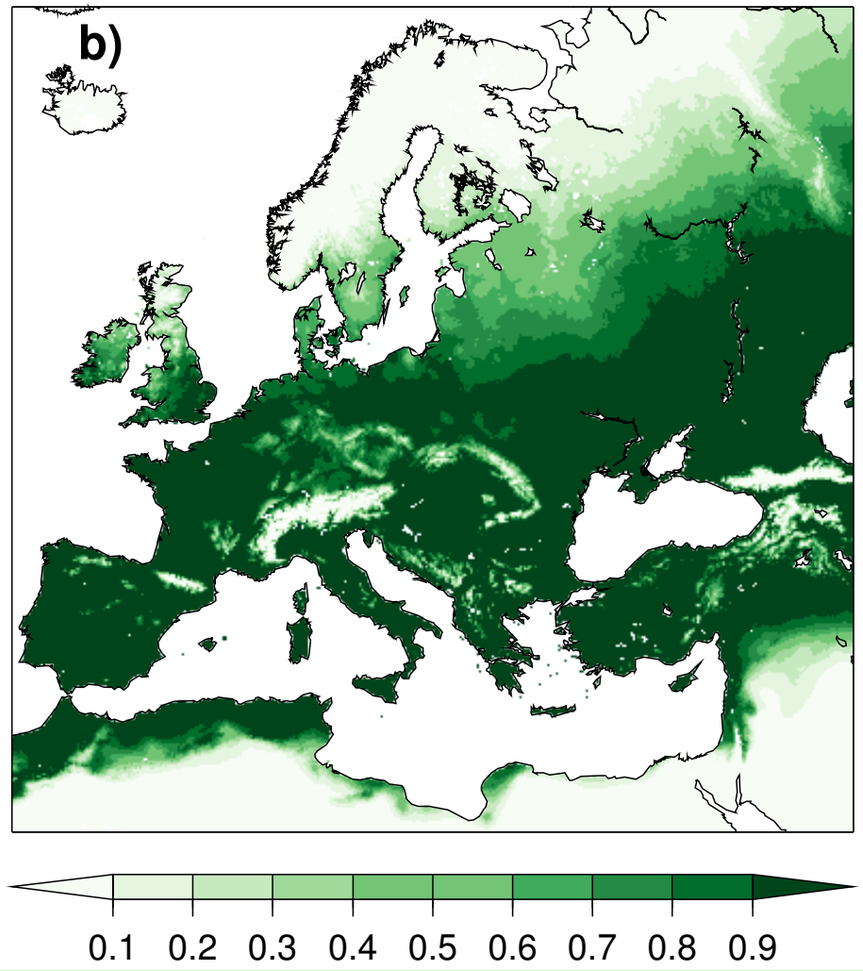
Normalized forest cover = Forest cover *only* on usable land (before forest transitions)

Bradshaw 2004, Mather et al. 1999, Kaplan et al., 2009

What determines the distribution of land use?



Land suitability for cultivation (S_{crops})



Land suitability for pasture (S_{usable})

To account for land under cultivation:

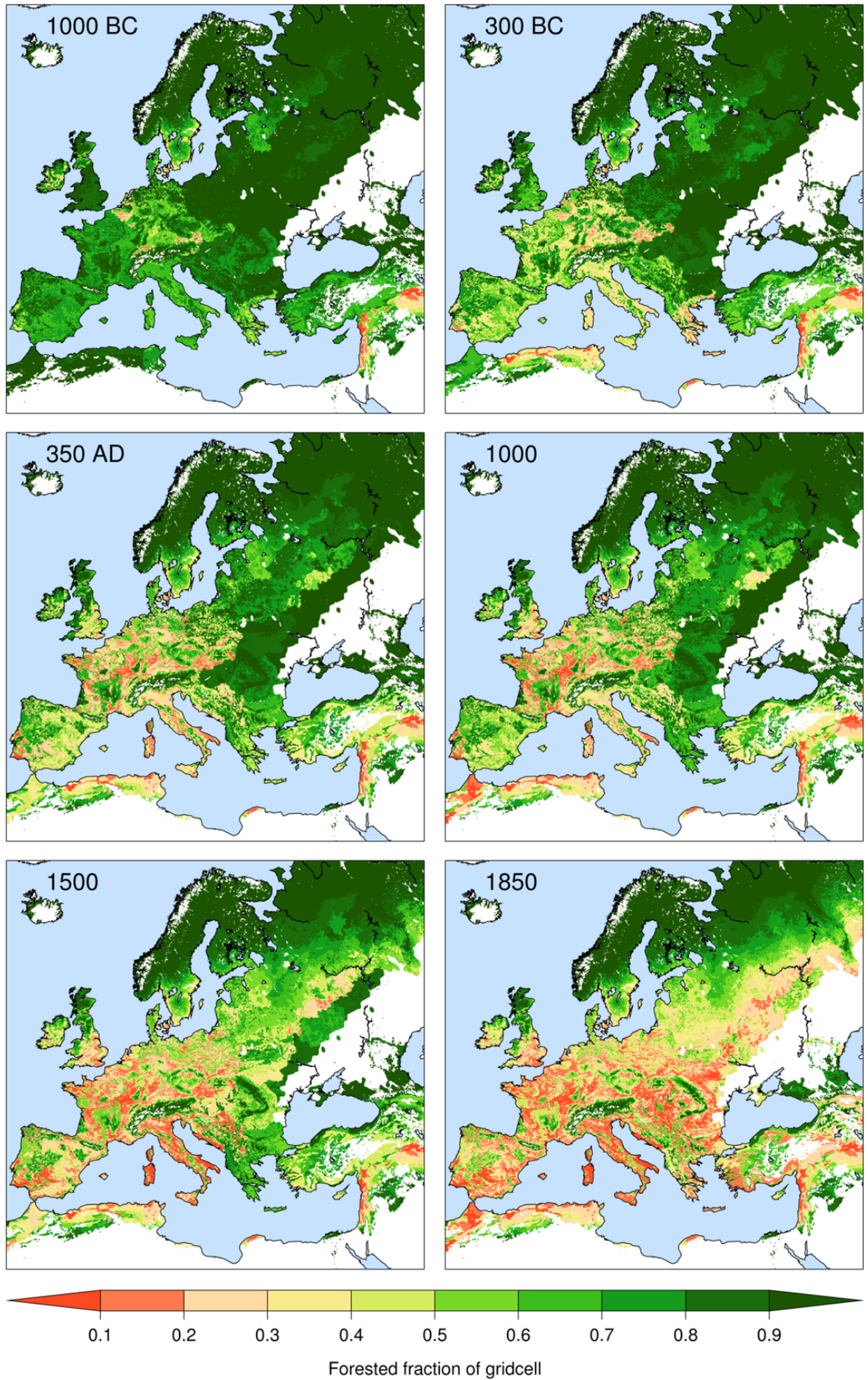
$$S_{crops} = f(\alpha) \times f(GDD) \times f(pH_{soil}) \times f(C_{soil})$$

To account for pasture and other forest uses:

$$S_{usable} = f(\alpha) \times f(GDD)$$

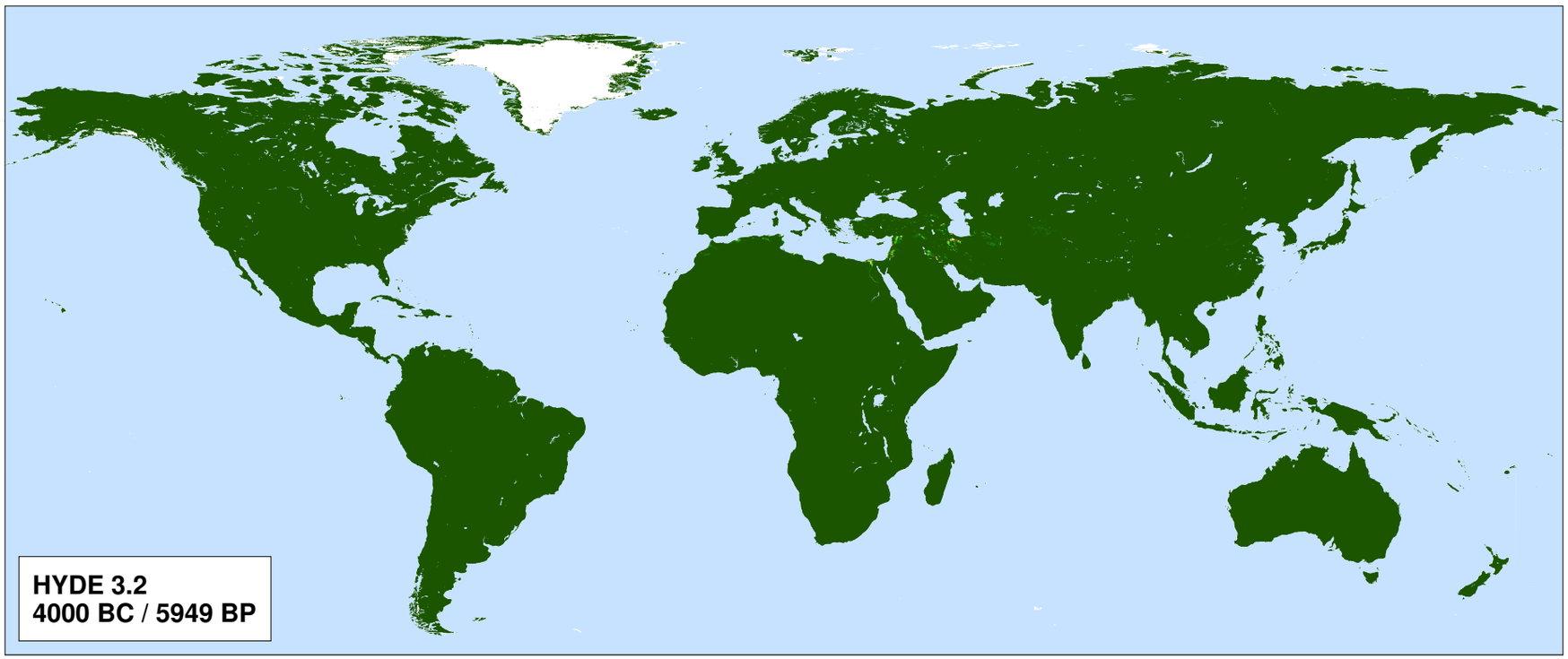
Kaplan et al. (2009)

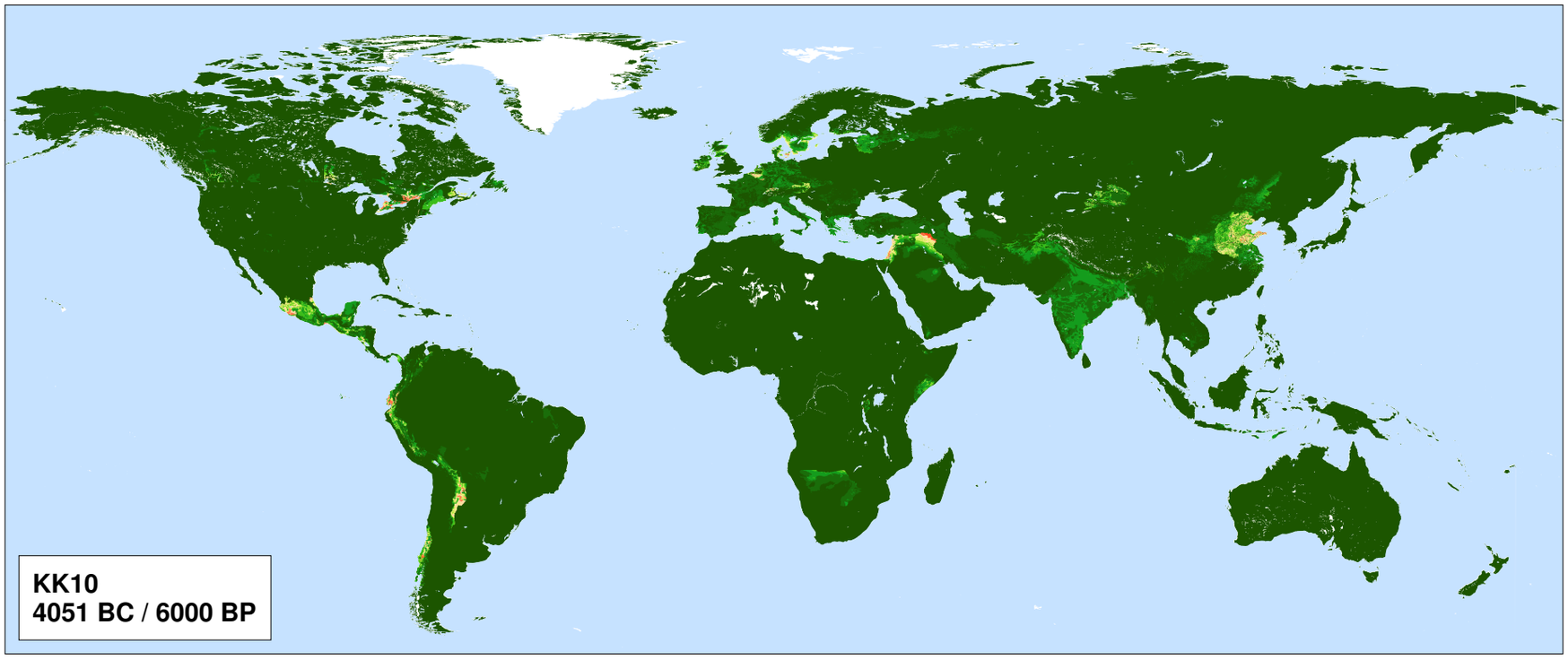
Preindustrial land use in Europe

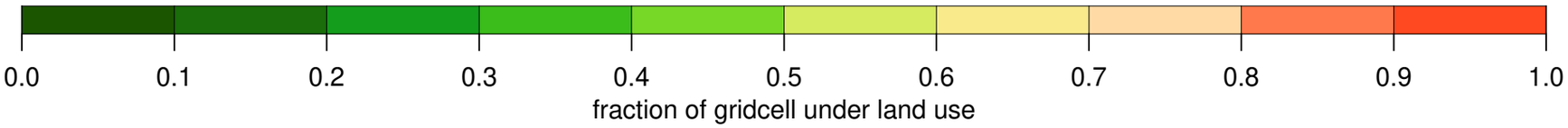


Kaplan et al., 2009

Preindustrial land use in Europe

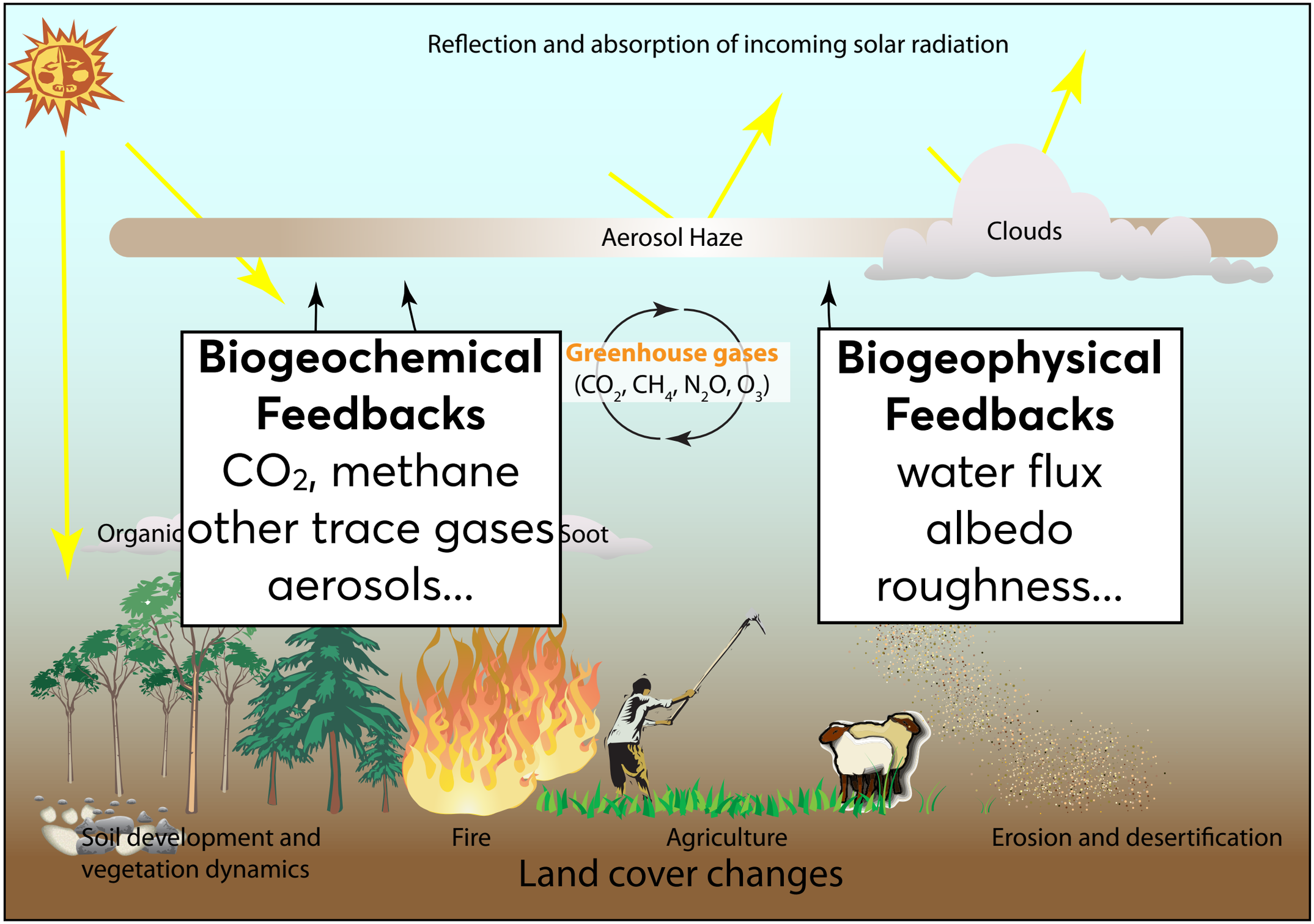






Kaplan et al., 2011

How does land cover change affect climate?



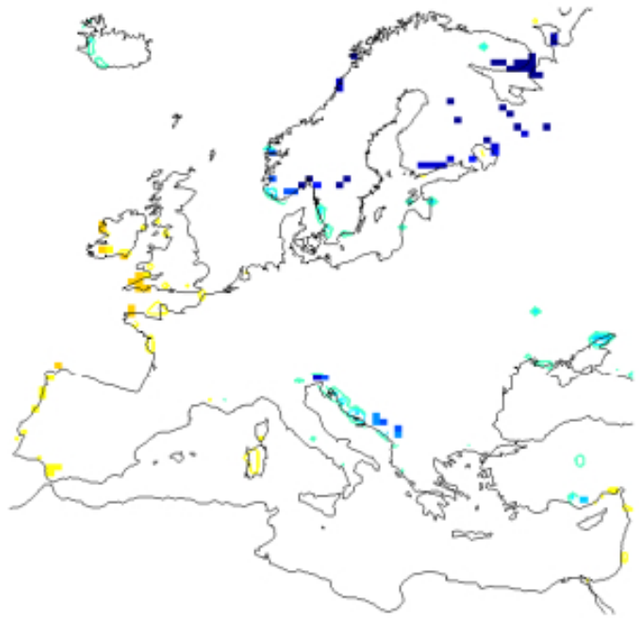
Preindustrial human impact on climate

- Regional studies
  - Focus on biogeophysical feedbacks
  - Used GCMs or RCMs
  - Studied idealized time periods, e.g., afforestation and deforestation during Classical Rome, or Land cover change in Europe over the Holocene
- Global studies
  - Both biogeophysical and biogeochemical feedbacks

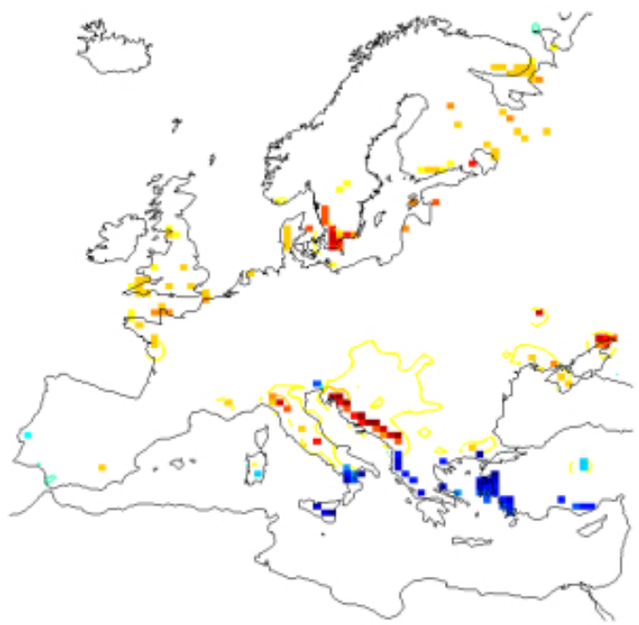
ALCC effect on temperature 6000 BP

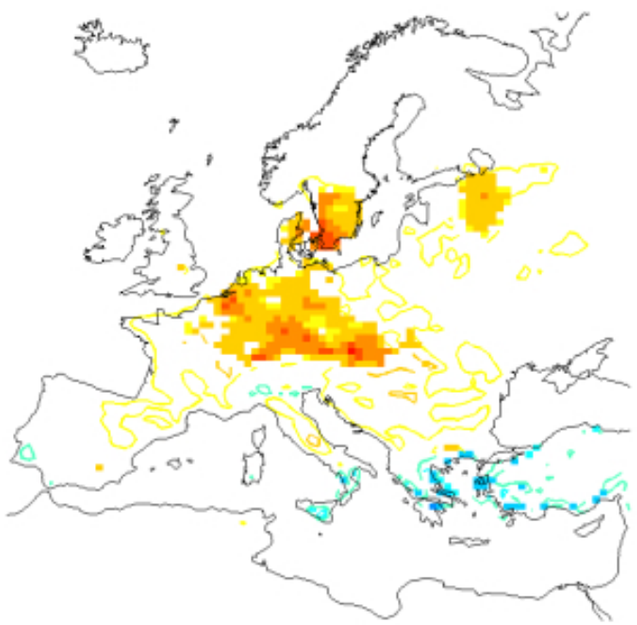
Low land use scenario **High land use scenario**

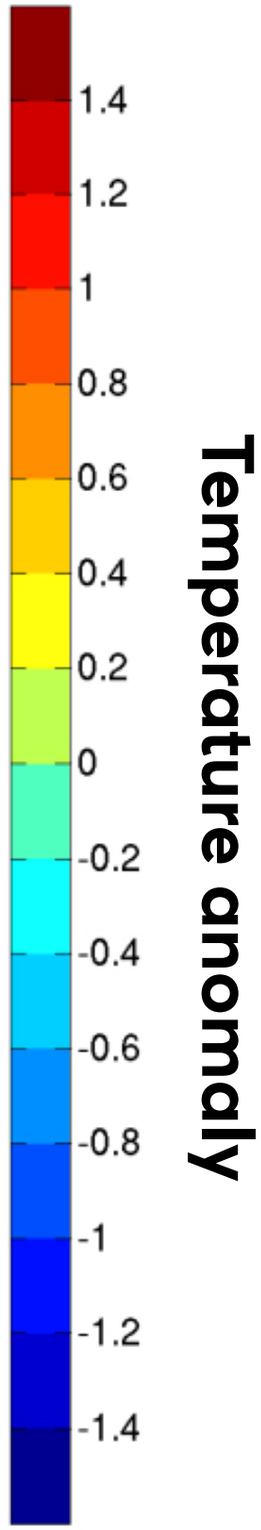
Winter



Summer





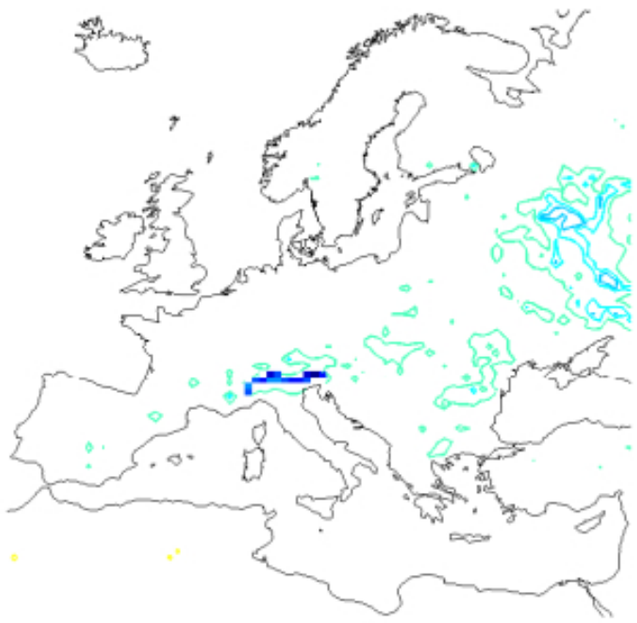


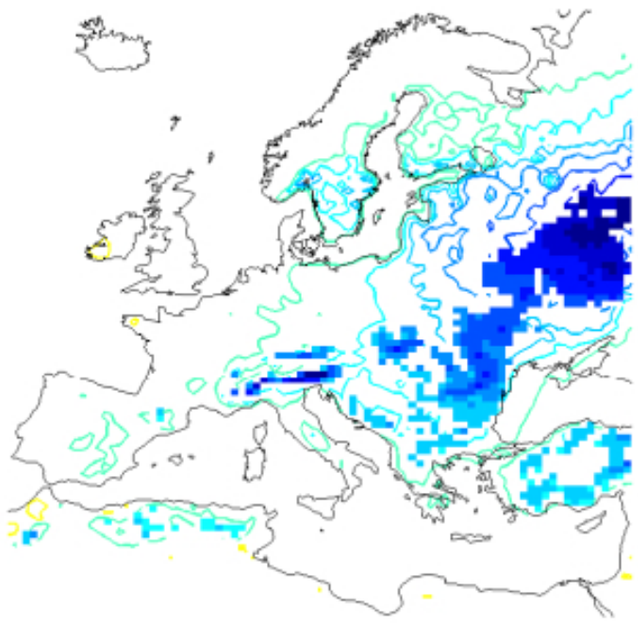
Using KK10 land use and ECHO-G GCM to force RCA3 RCM. Strandberg et al., *Clim. Past*. 2014

ALCC effect on temperature AD 1800

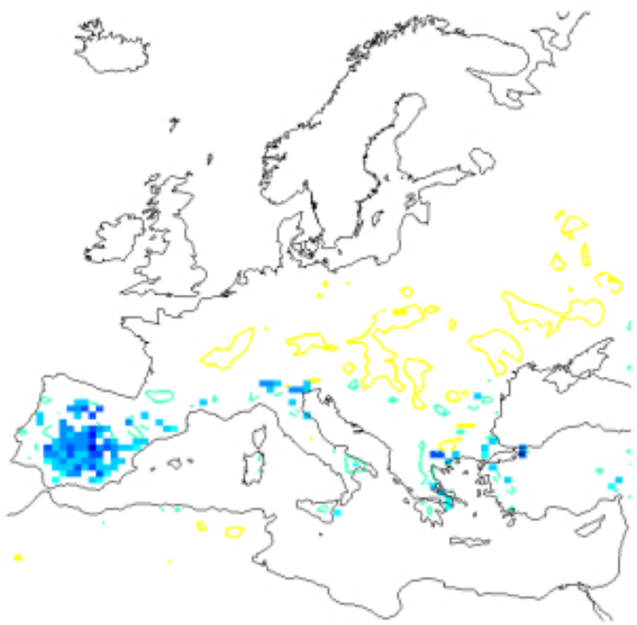
Low land use scenario **High land use scenario**

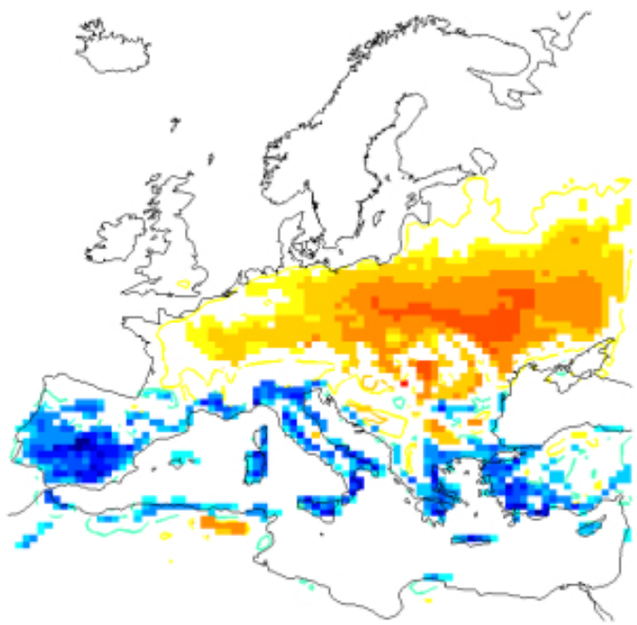
Winter

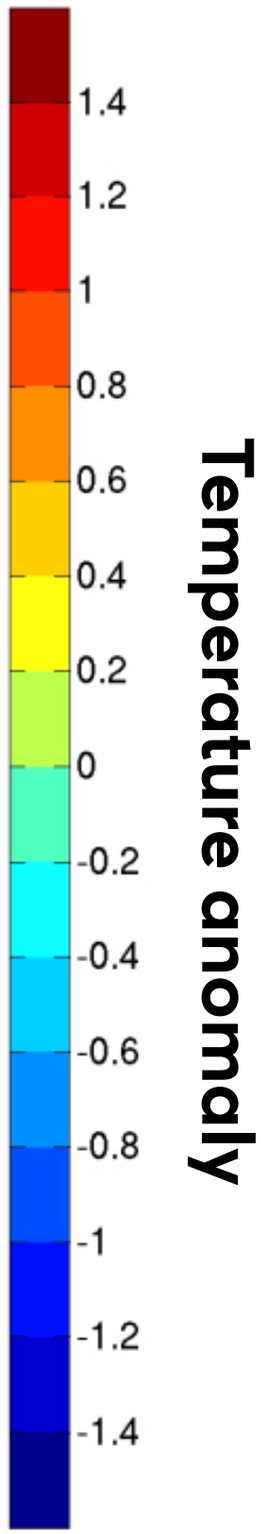




Summer







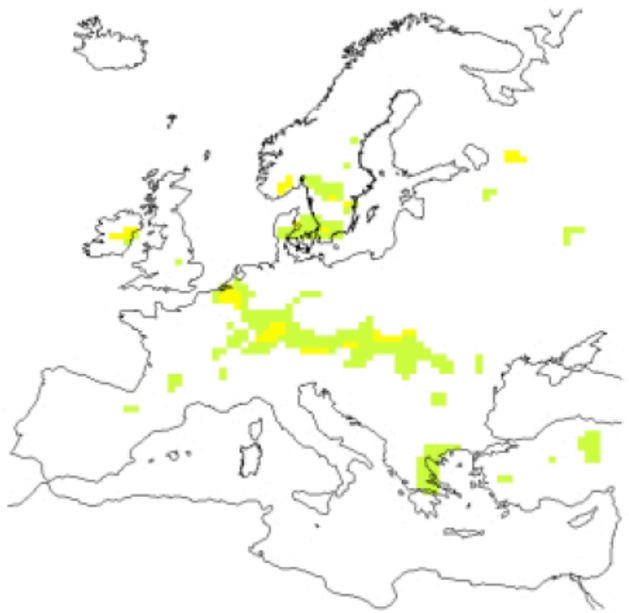
Using KK10 land use and ECHO-G GCM to force RCA3 RCM. Strandberg et al., *Clim. Past*. 2014

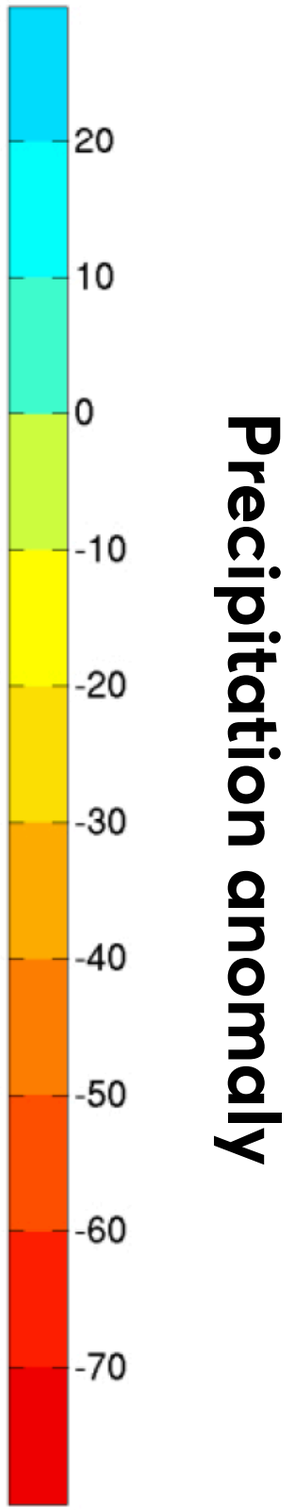
ALCC effect on precipitation 6000 BP

Low land use scenario **High land use scenario**

Winter

Summer





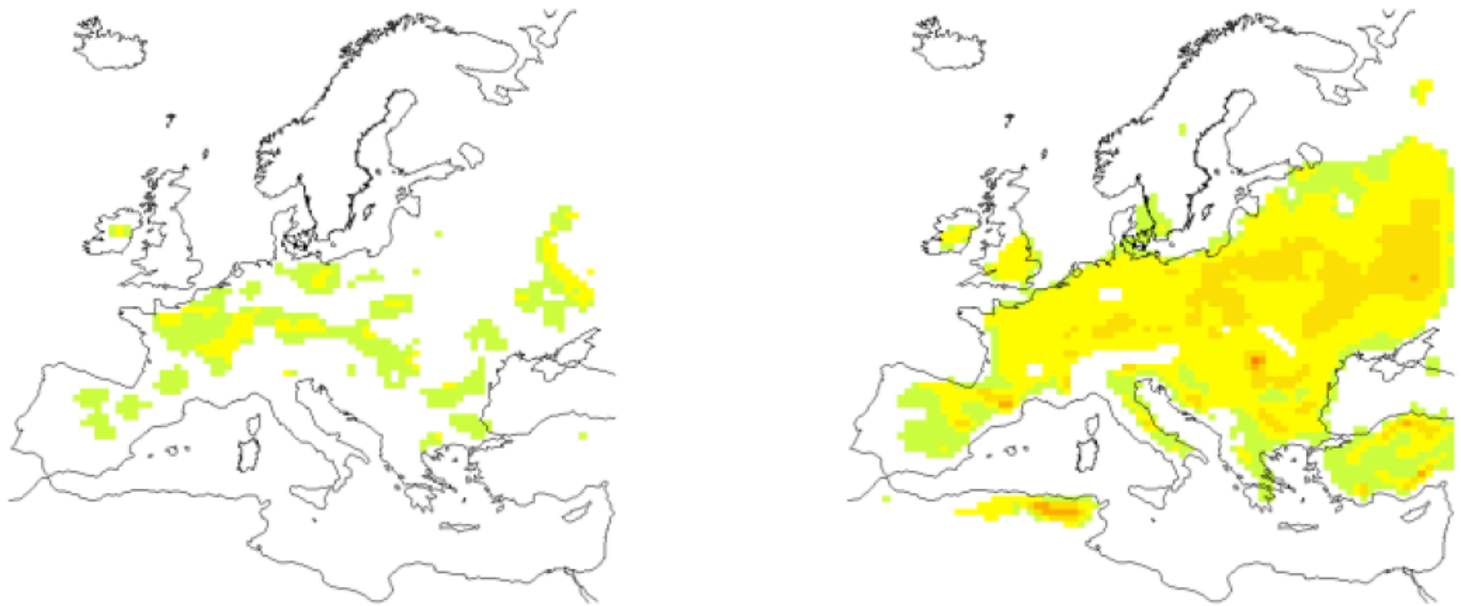
Using KK10 land use and ECHO-G GCM to force RCA3 RCM. Strandberg et al., *Clim. Past*. 2014

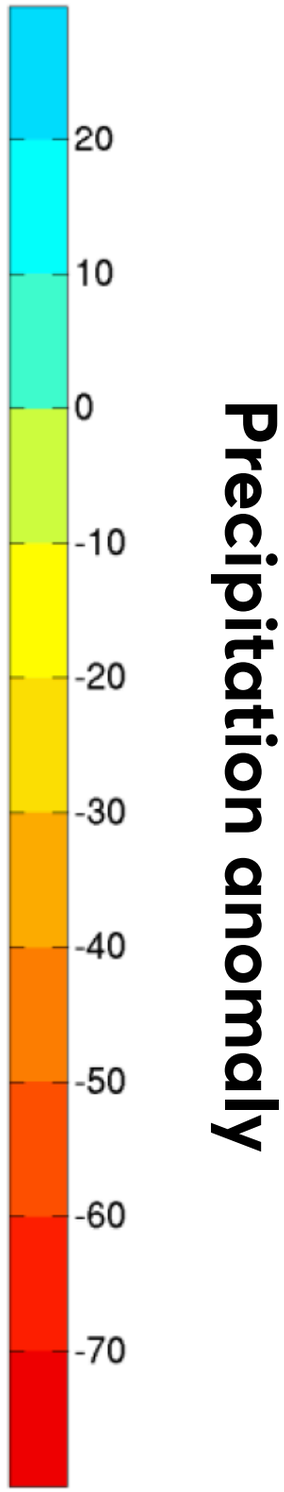
ALCC effect on precipitation AD 1800

Low land use scenario **High land use scenario**

Winter

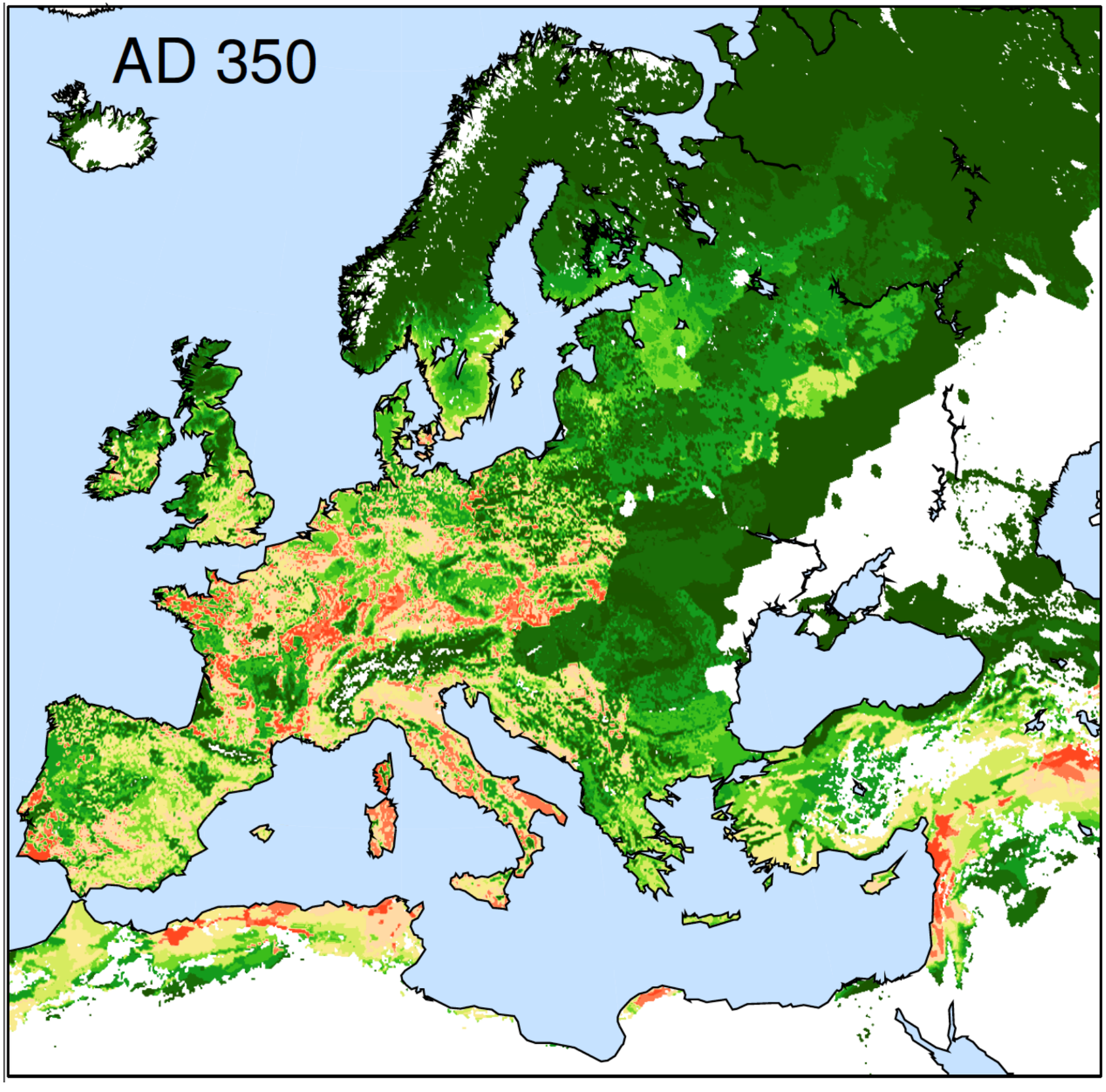
Summer





Using KK10 land use and ECHO-G GCM to force RCA3 RCM. Strandberg et al., *Clim. Past*. 2014

Peak deforestation in classical antiquity



Kaplan et al., 2009

Precipitation changes as a result of deforestation

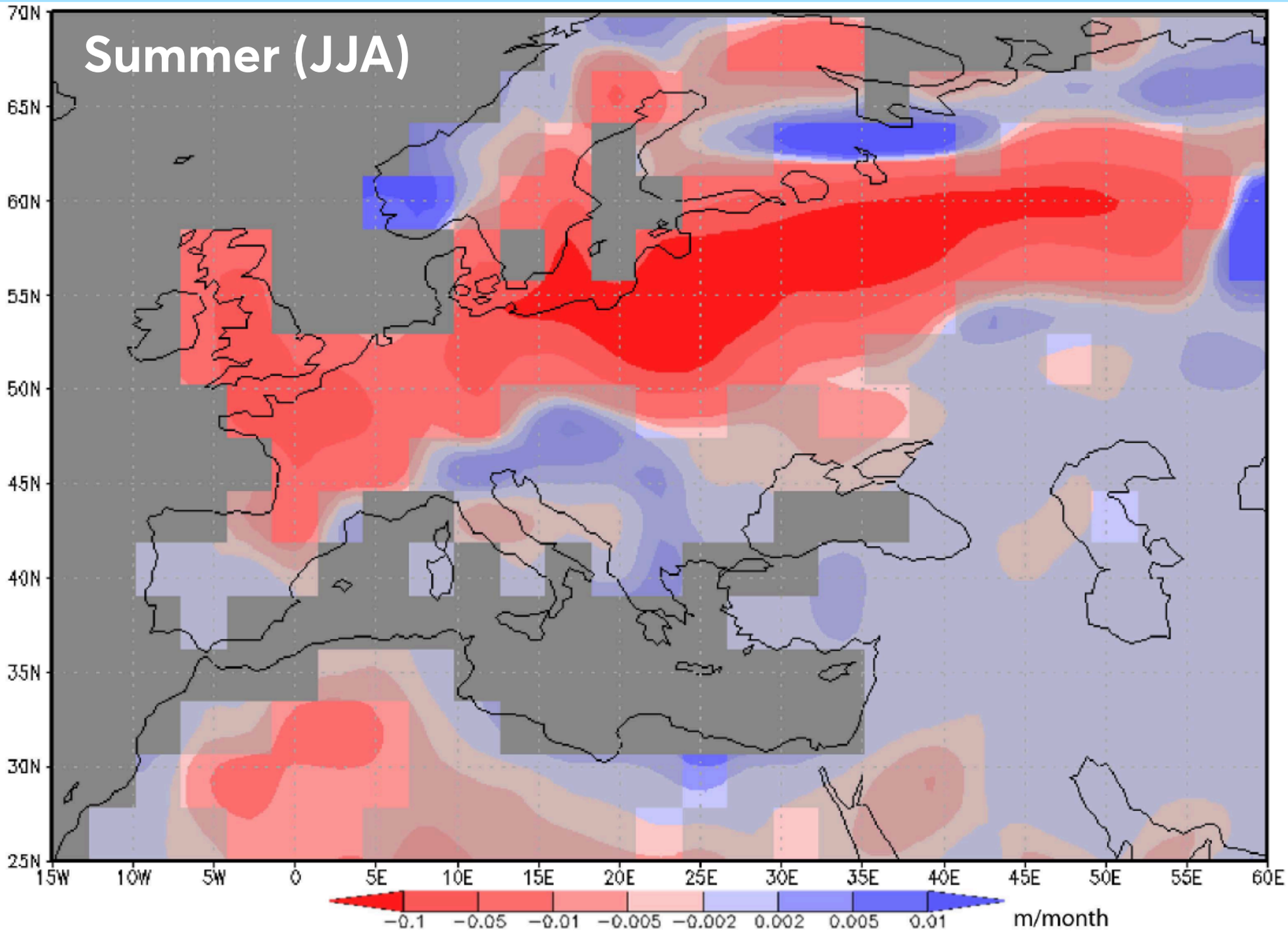
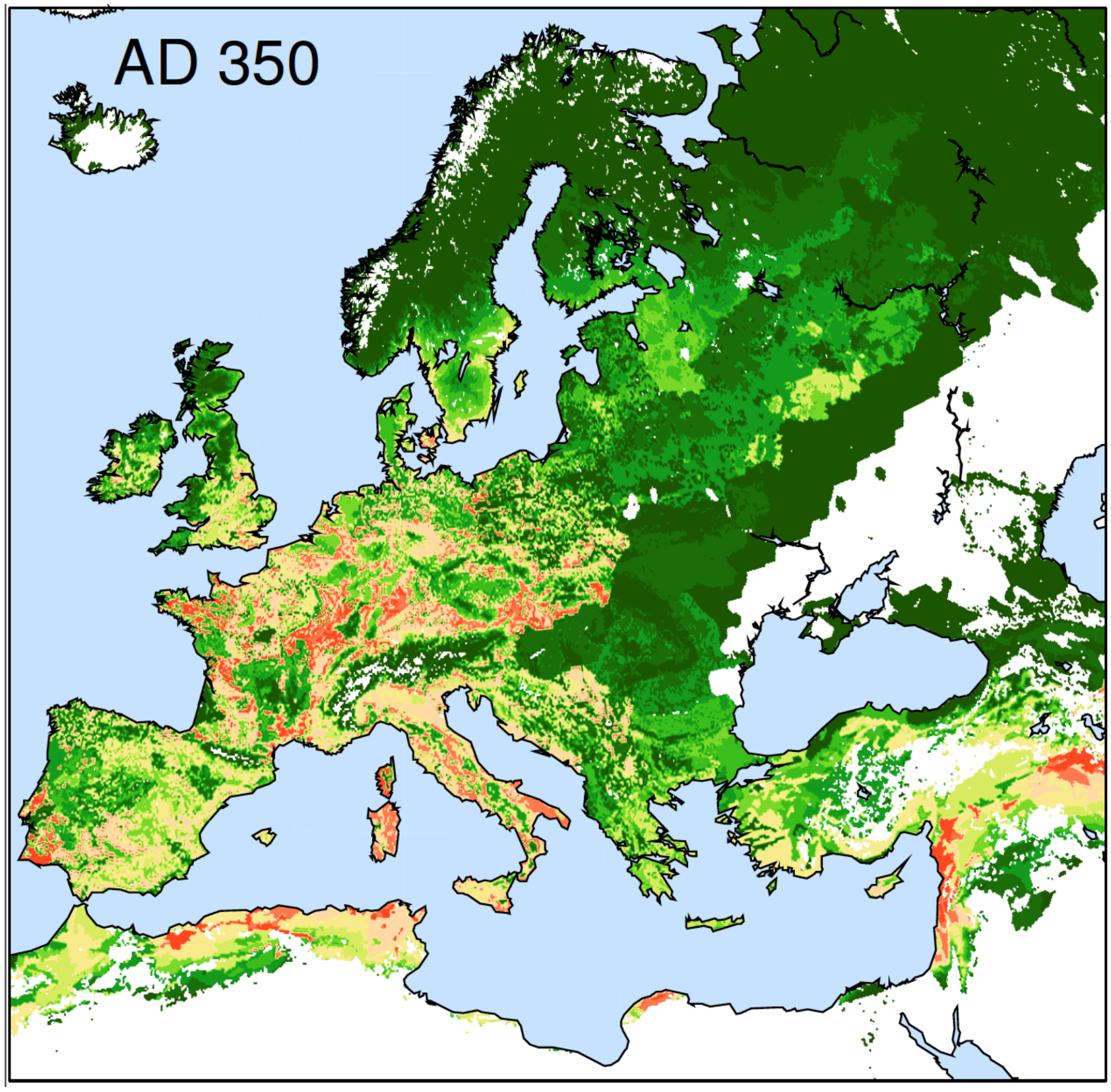


Fig. 3. Summer (JJA) average anomaly in precipitation ($m\,month^{-1}$) for simulated forest cover at 100 yr BP minus potential forest cover. The largest changes in precipitation between potential forest cover and forest cover at 100 yr BP are in Northern Europe. The shaded areas are regions where the changes in precipitation are statistically insignificant ($t(38) = 2.024$, $p = 0.05$).

Dermody et al., *Clim. Past.* 2012

Peak deforestation in classical antiquity

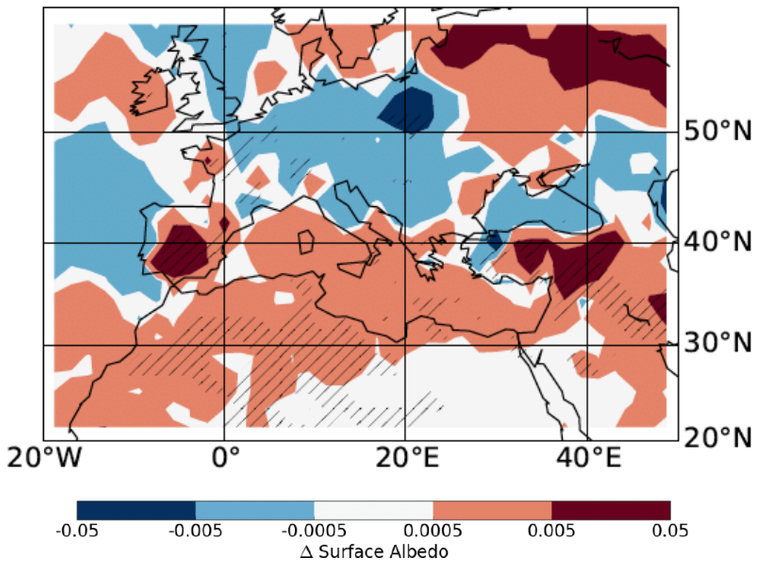


Kaplan et al., 2009

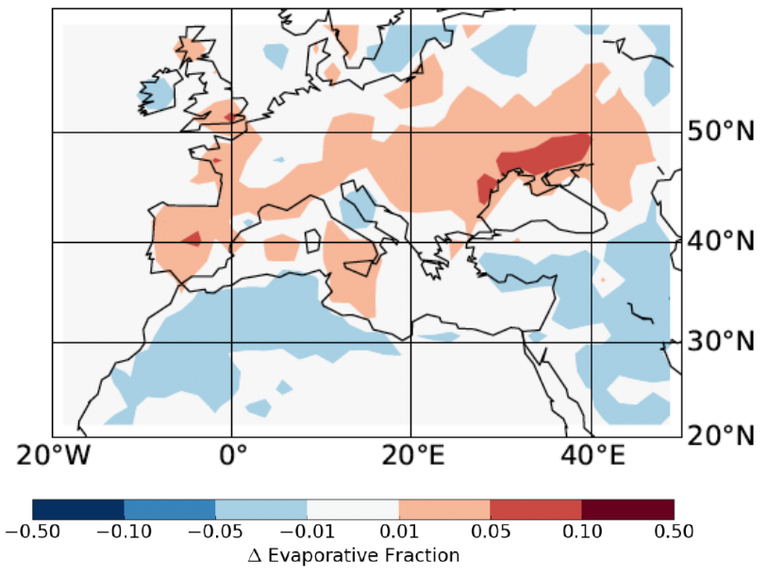
Land use impact on climate

ANOMALIES

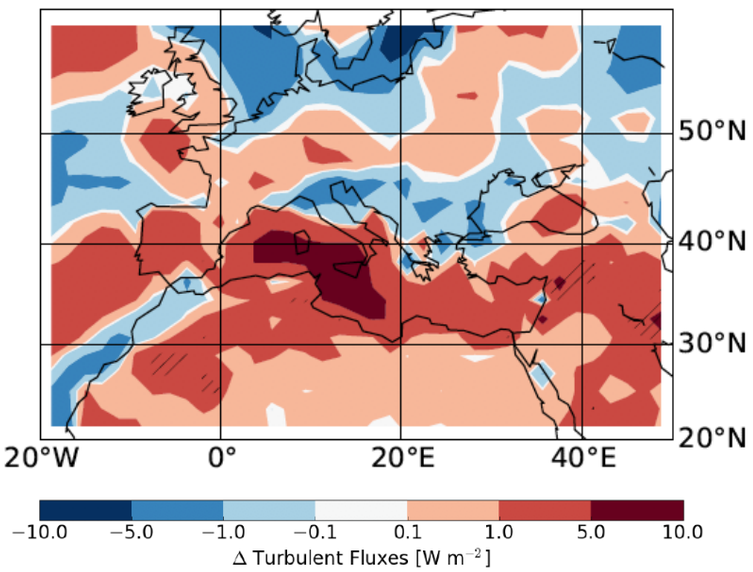
Albedo



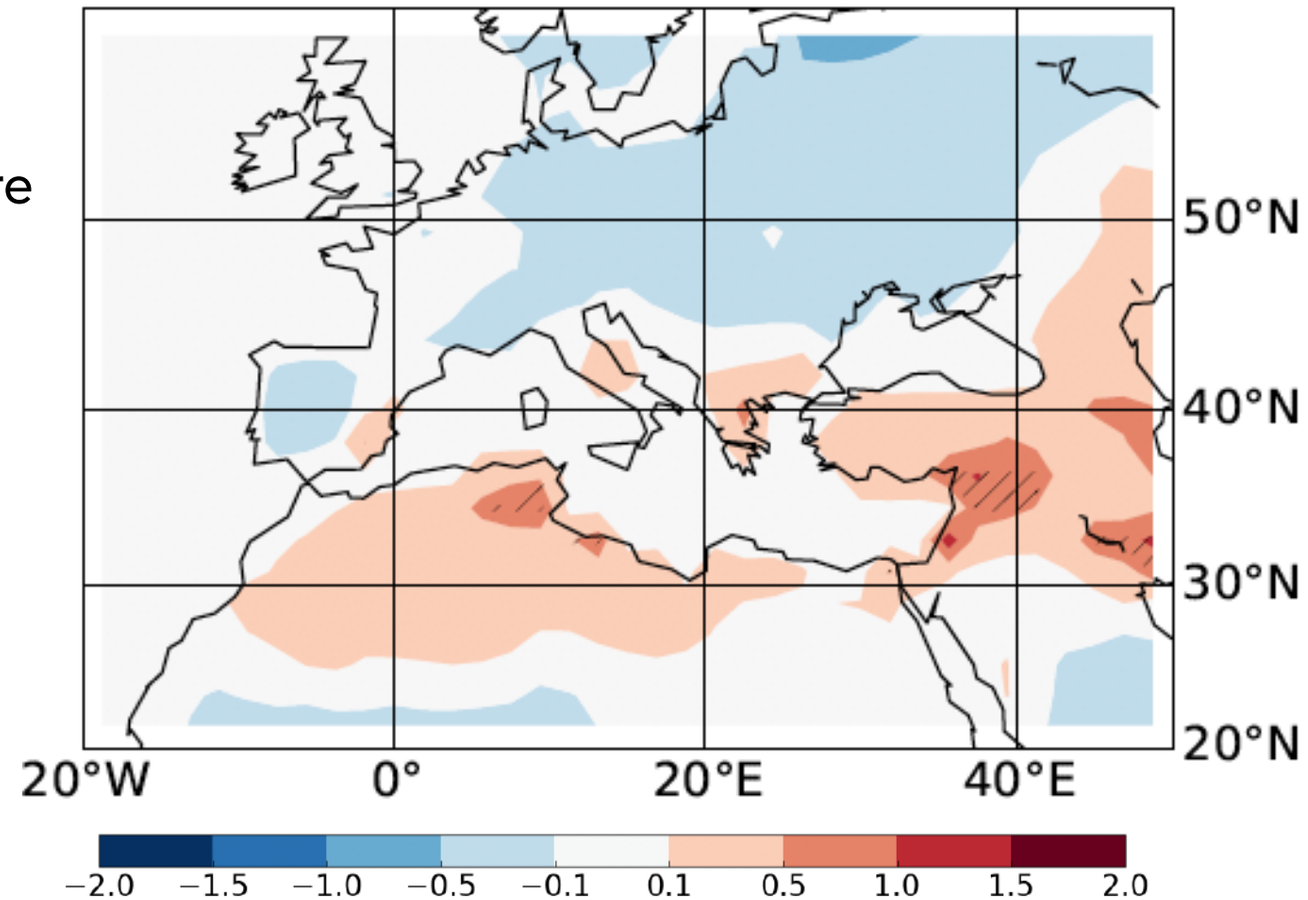
Evapotranspiration



Turbulent flux

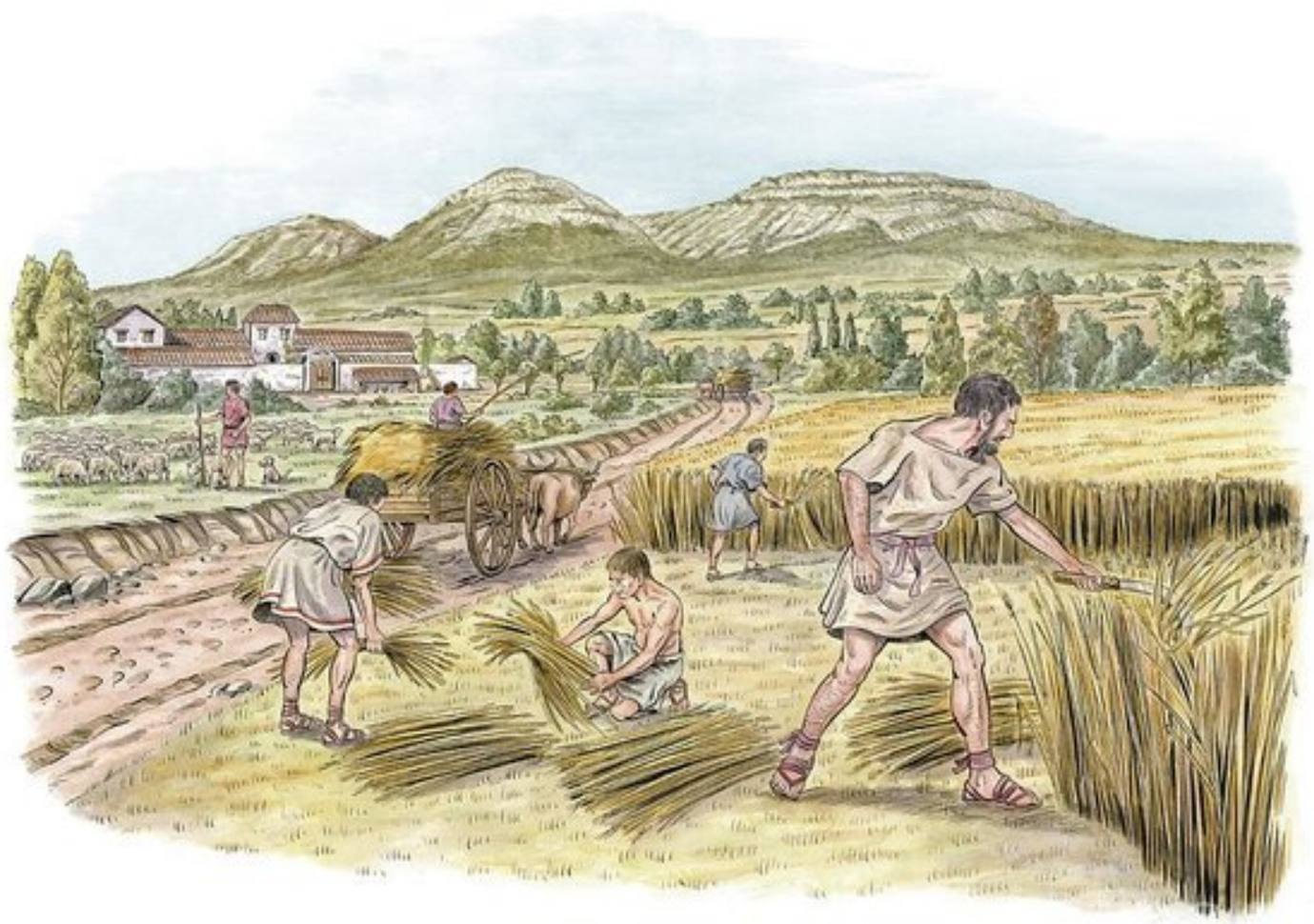


Temperature



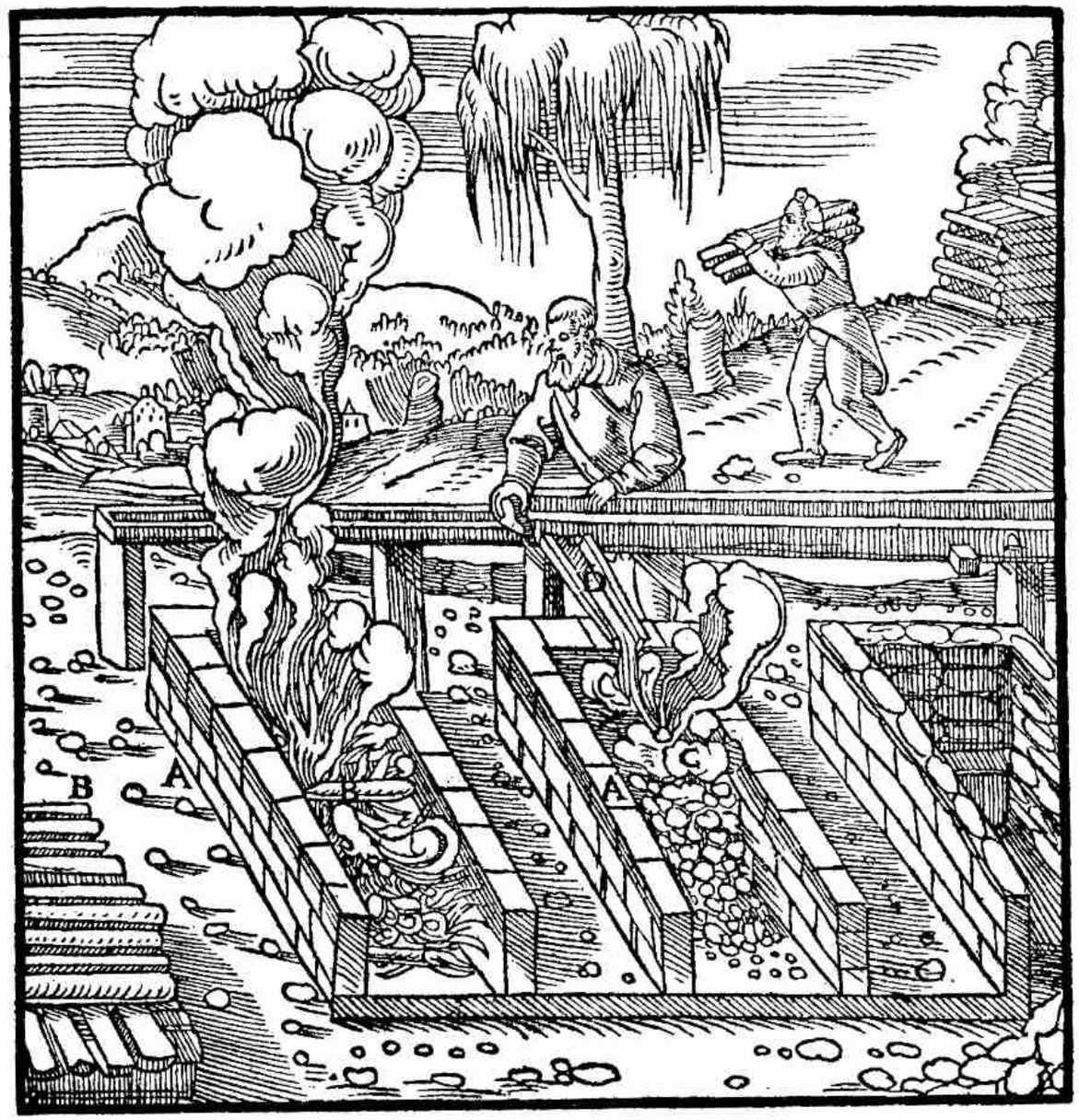
Gilgen et al., 2019

The Roman economy

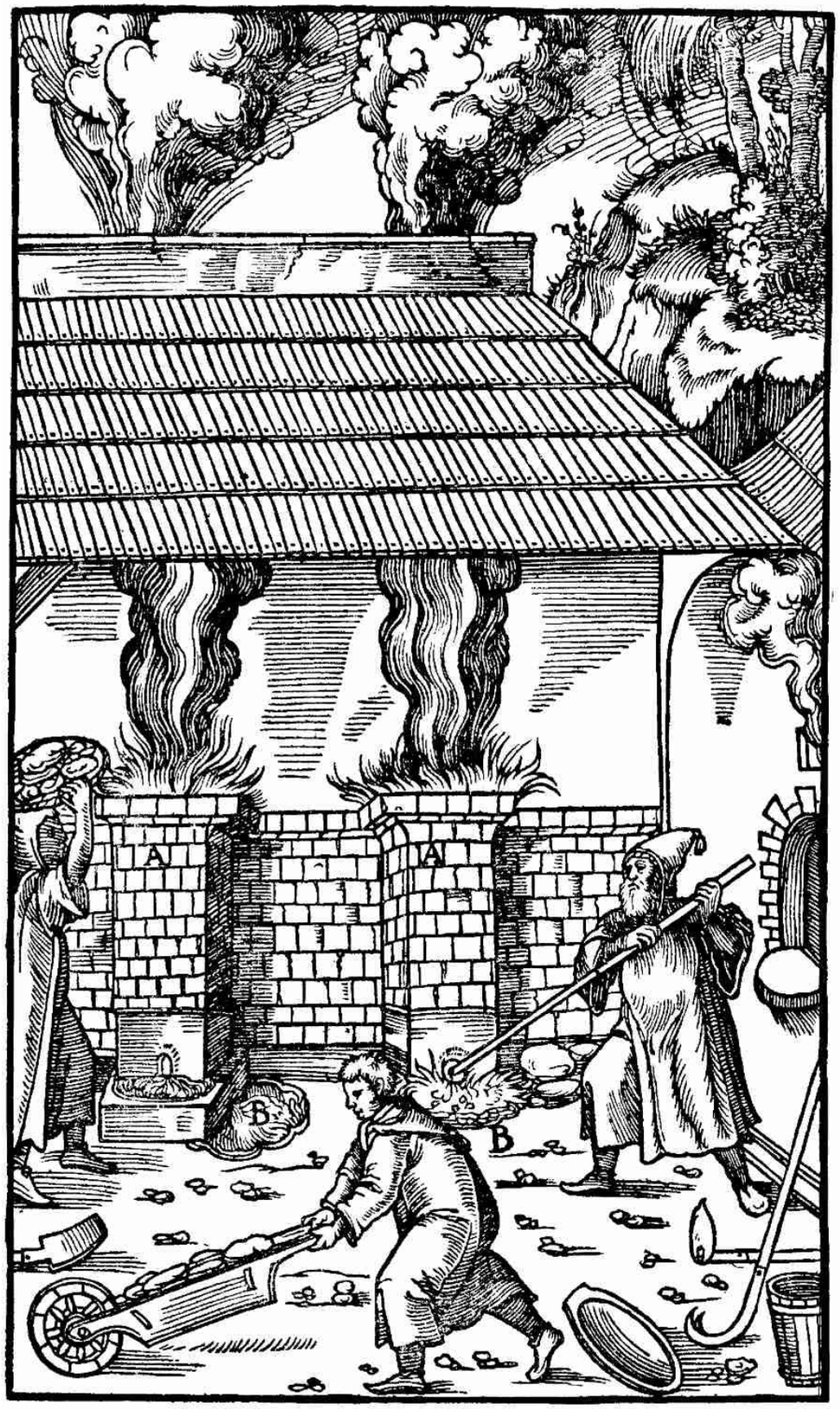


The Roman economy

Metallurgy and air pollution



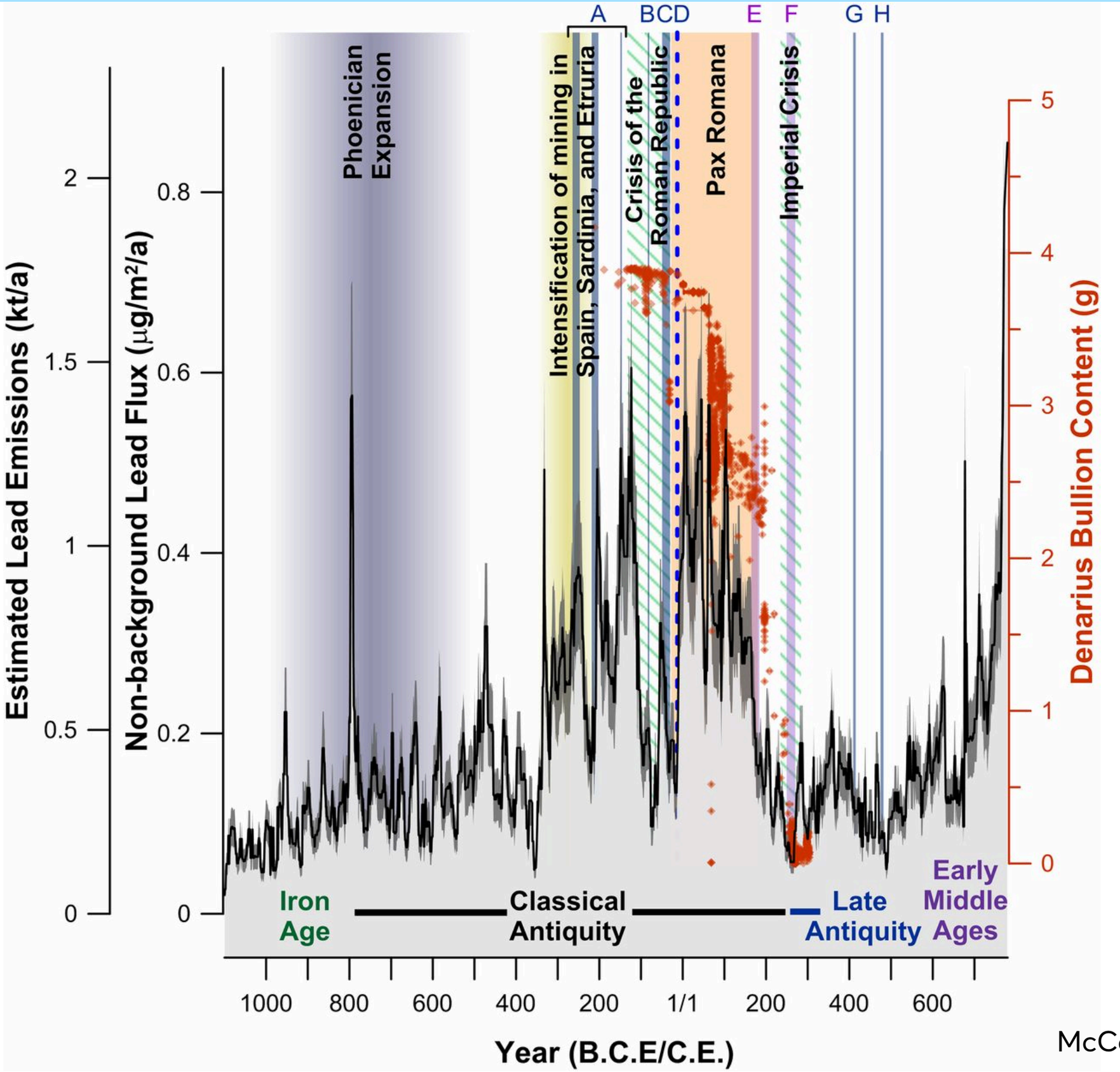
A—Pits. B—Wood. C—Cakes. D—Launder.



A—Furnaces. B—Forehearths.

Agricola, *De Re Metallica*, 1556

Land use impact on climate

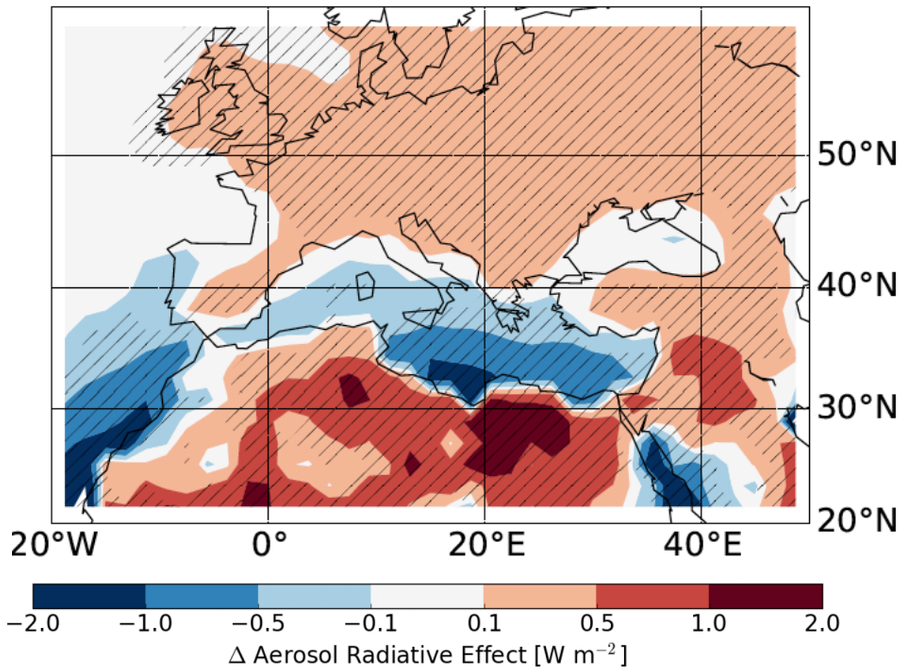


McConnell et al., 2018

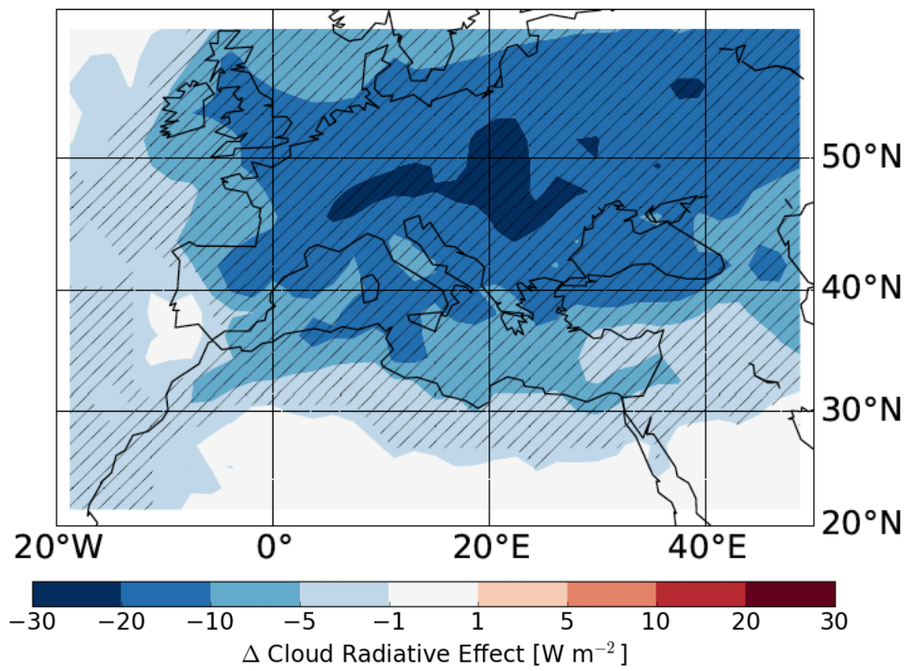
Aerosol impact on climate

ANOMALIES

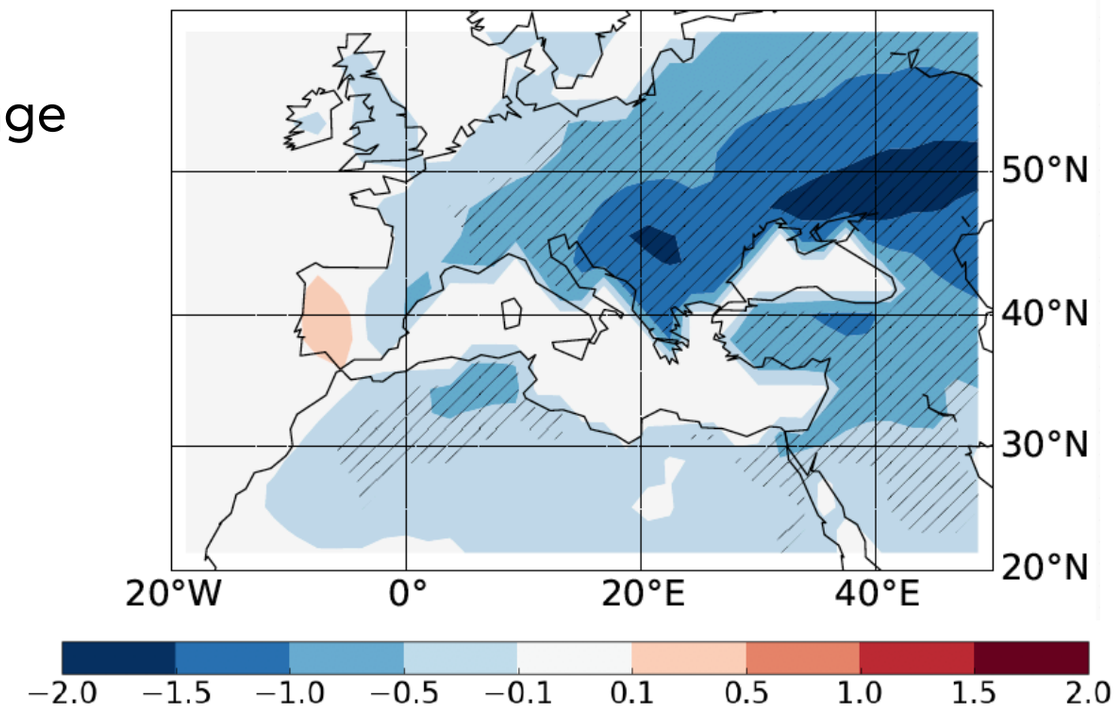
Aerosol radiative effect



Cloud radiative effect



Temperature change

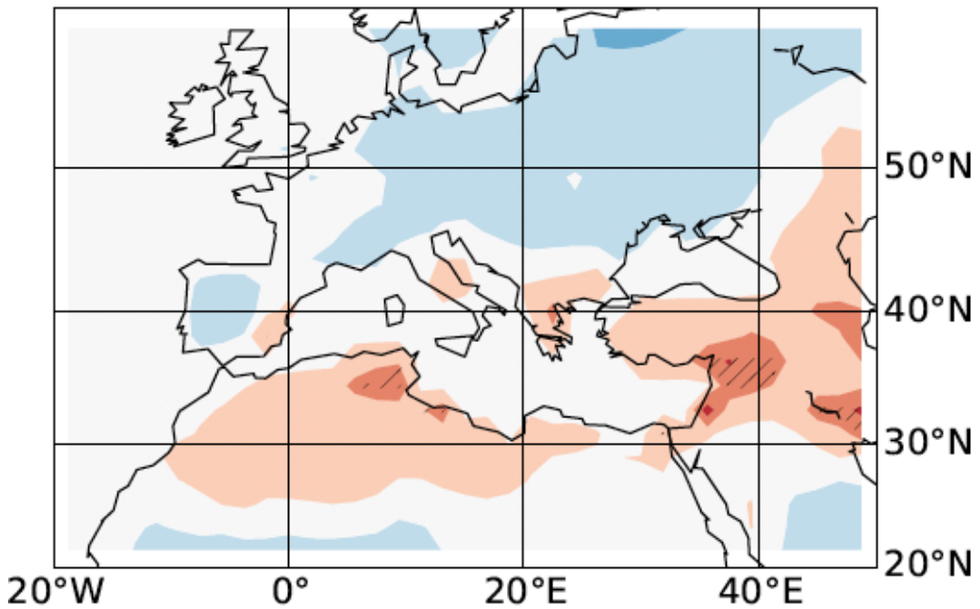


Gilgen et al., 2019

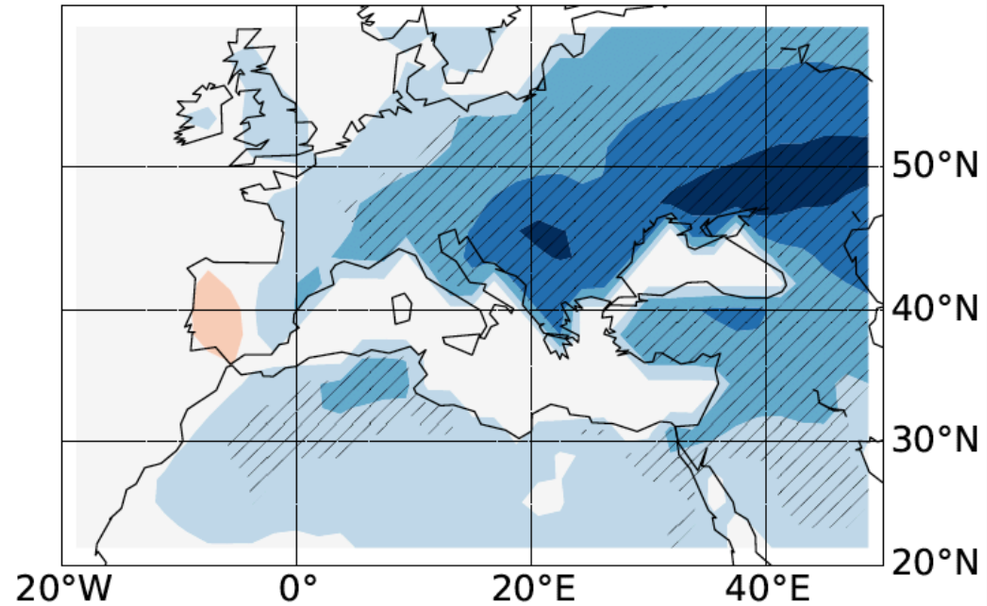
Combined impacts on climate

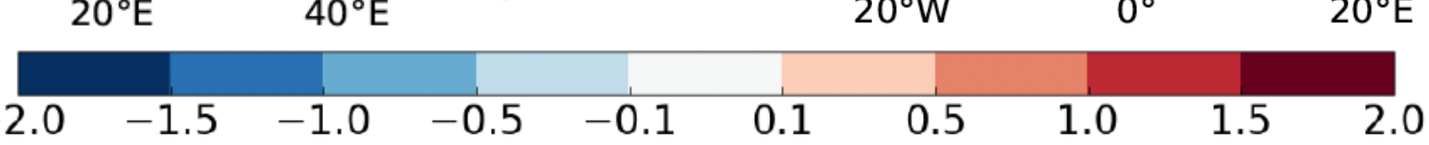
TEMPERATURE ANOMALIES

Land use effect

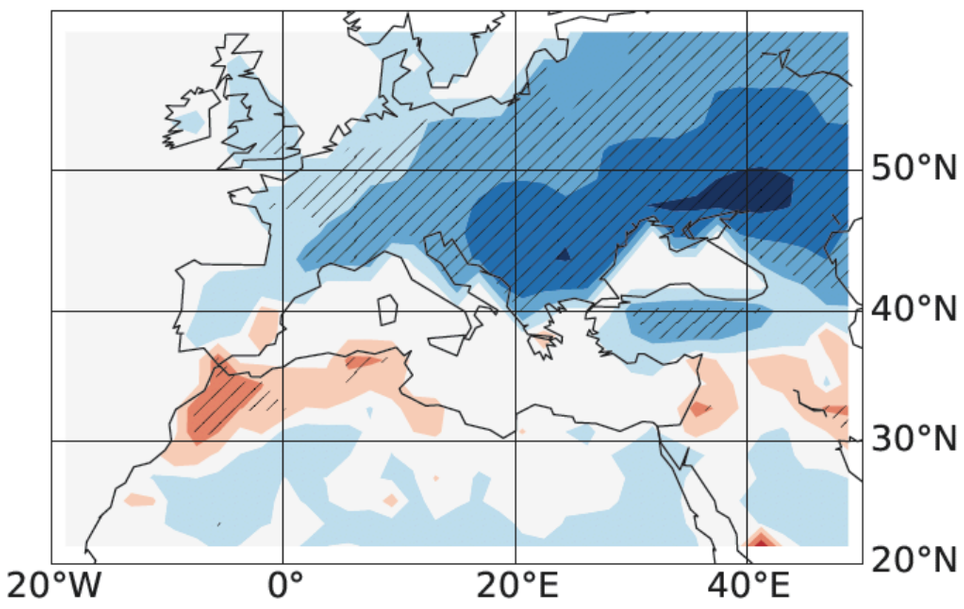


Aerosol effect

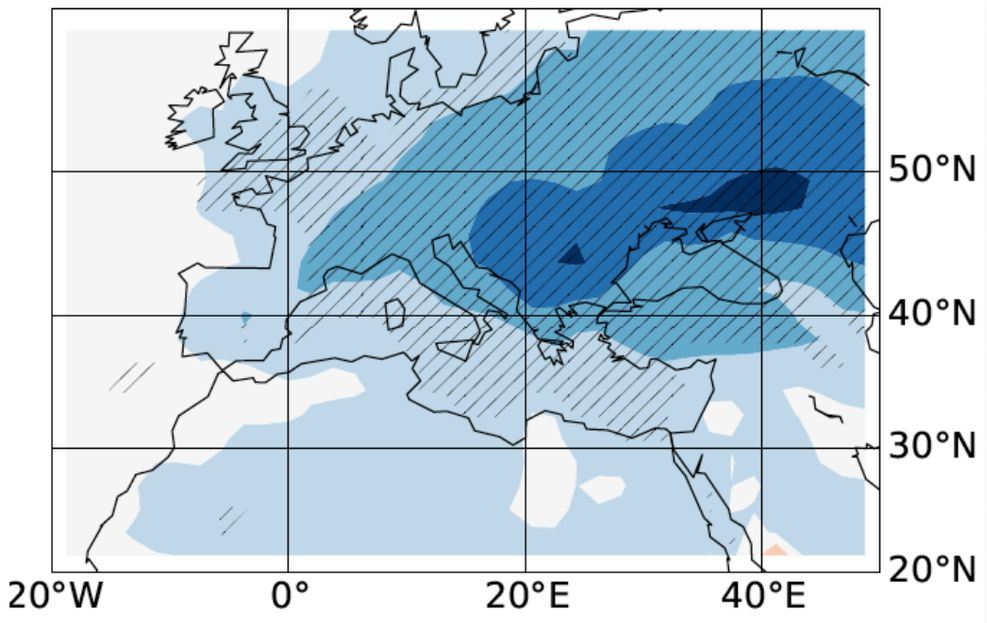




Surface temperature

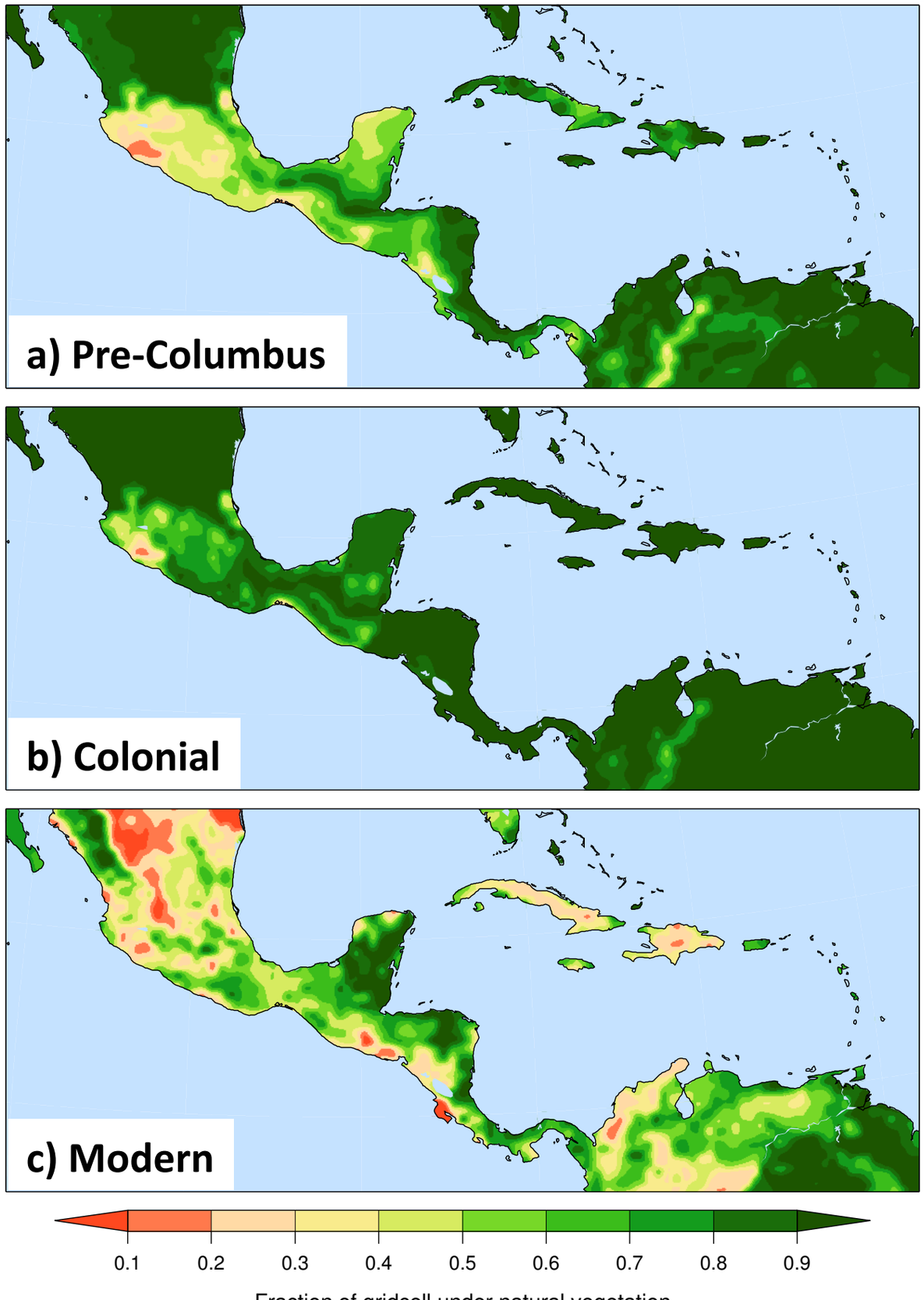


2m air temperature



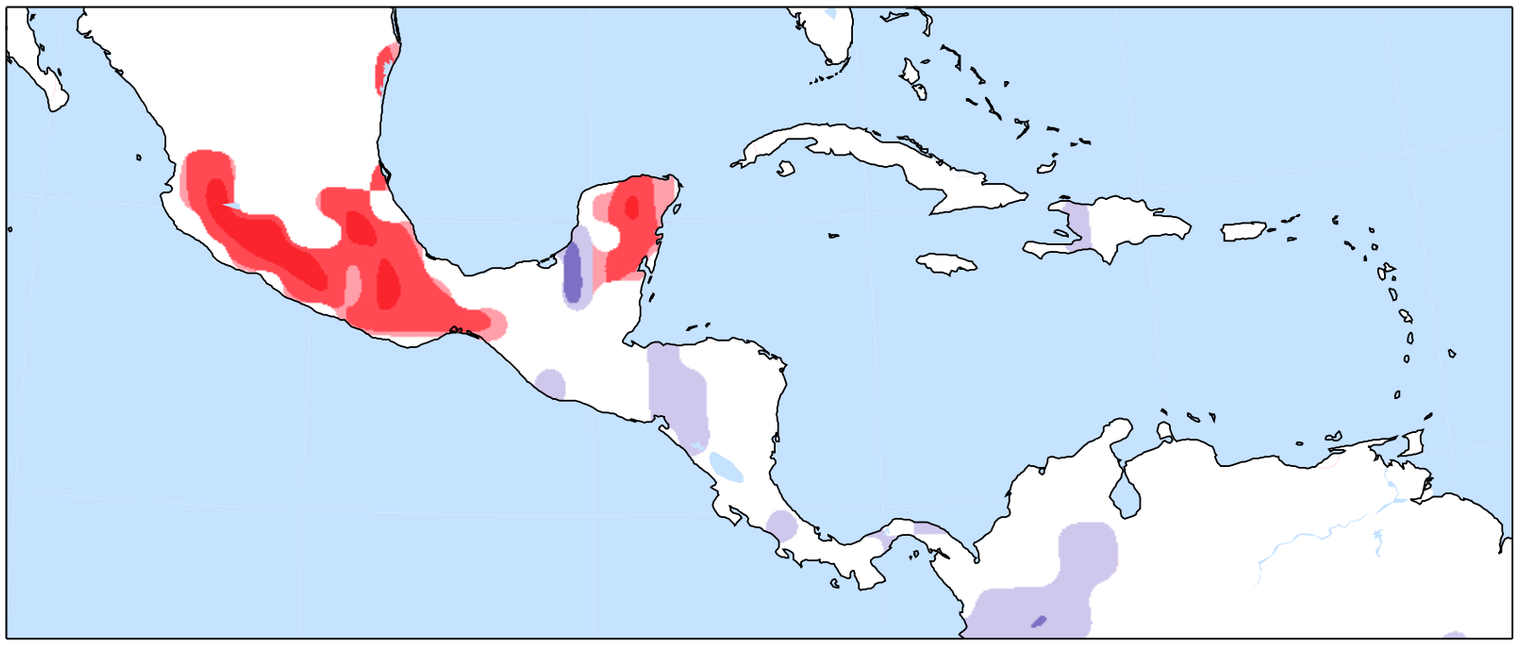
Gilgen et al., 2019

Land cover change in Mesoamerica



Kaplan et al., *The Holocene*, 2011
Cook et al., *Geophys. Res. Lett.* 2012

Effects of pre-Columbian deforestation on climate

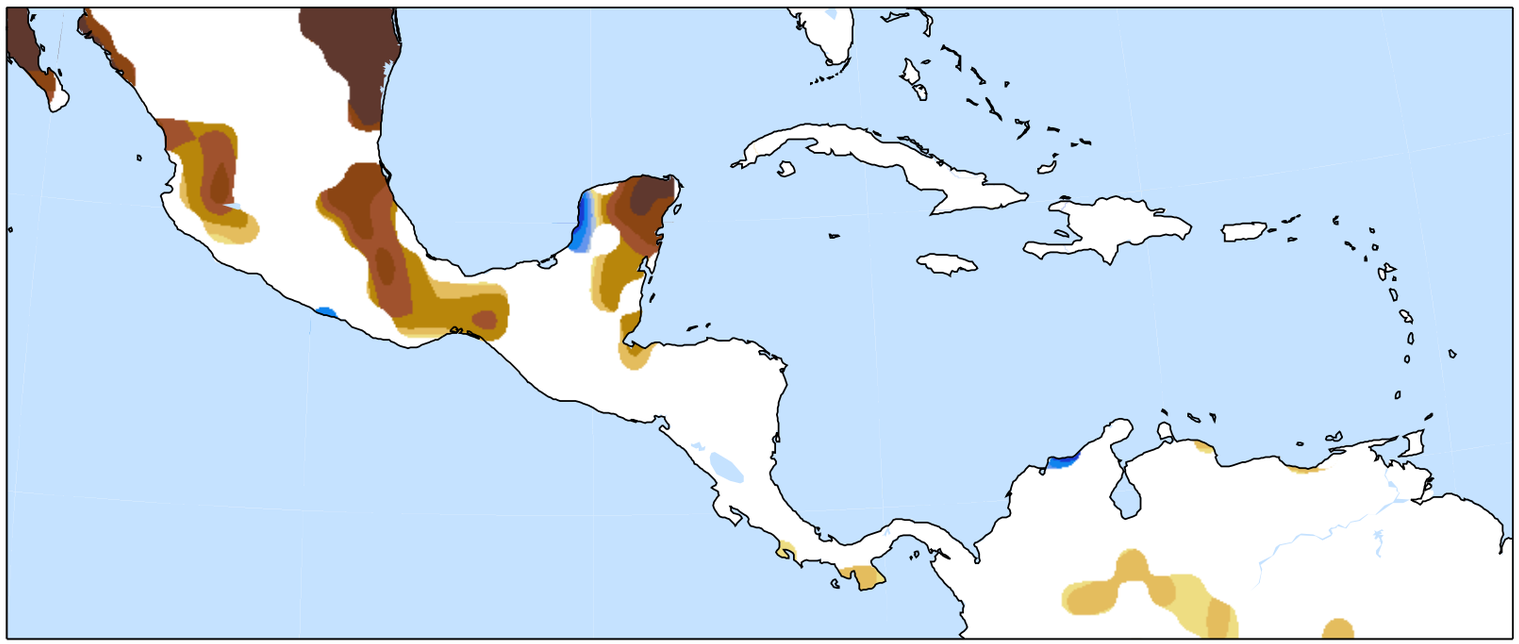


−1.0 −0.8 −0.6 −0.4 −0.2 0.0 0.2 0.4 0.6 0.8 1.0

Summer temperature anomaly (°C)

Experiments performed using the GISS Model E GCM (1° resolution), slab ocean, and KK10 land use at AD 1500

Anomalies vs. control scenario (natural vegetation)



−20 −16 −12 −8 −4 0 4 8 12 16 20

Percent departure from normal summer precipitation

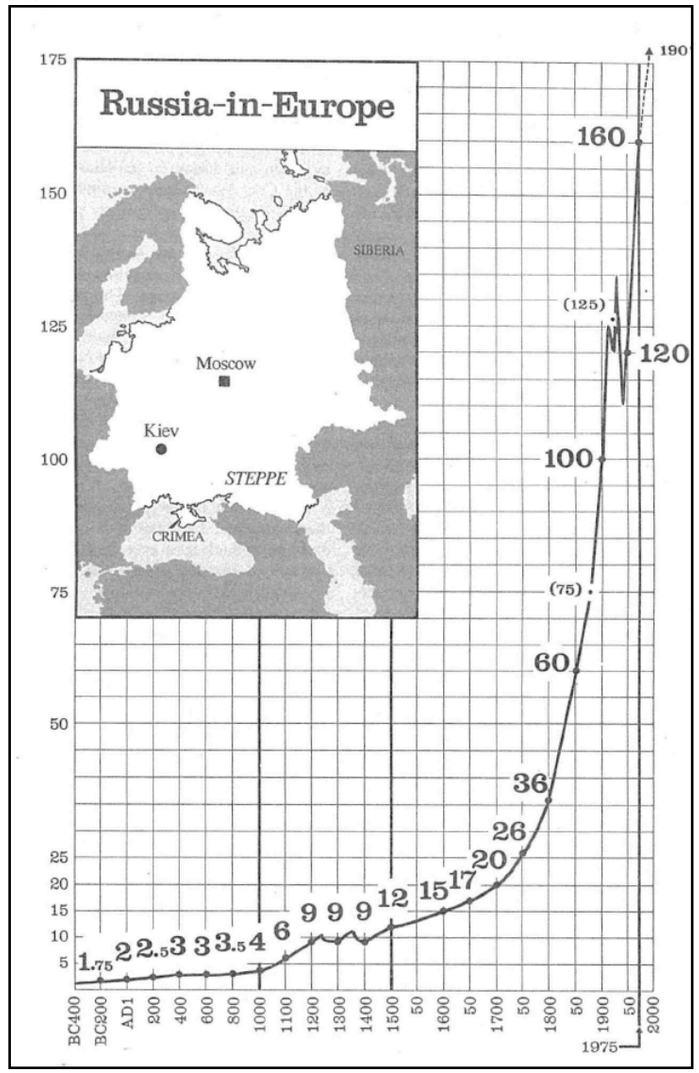
Cook et al., *Geophys. Res. Lett.* 2012

Historical Population Dataset (1000 BC to 1850)

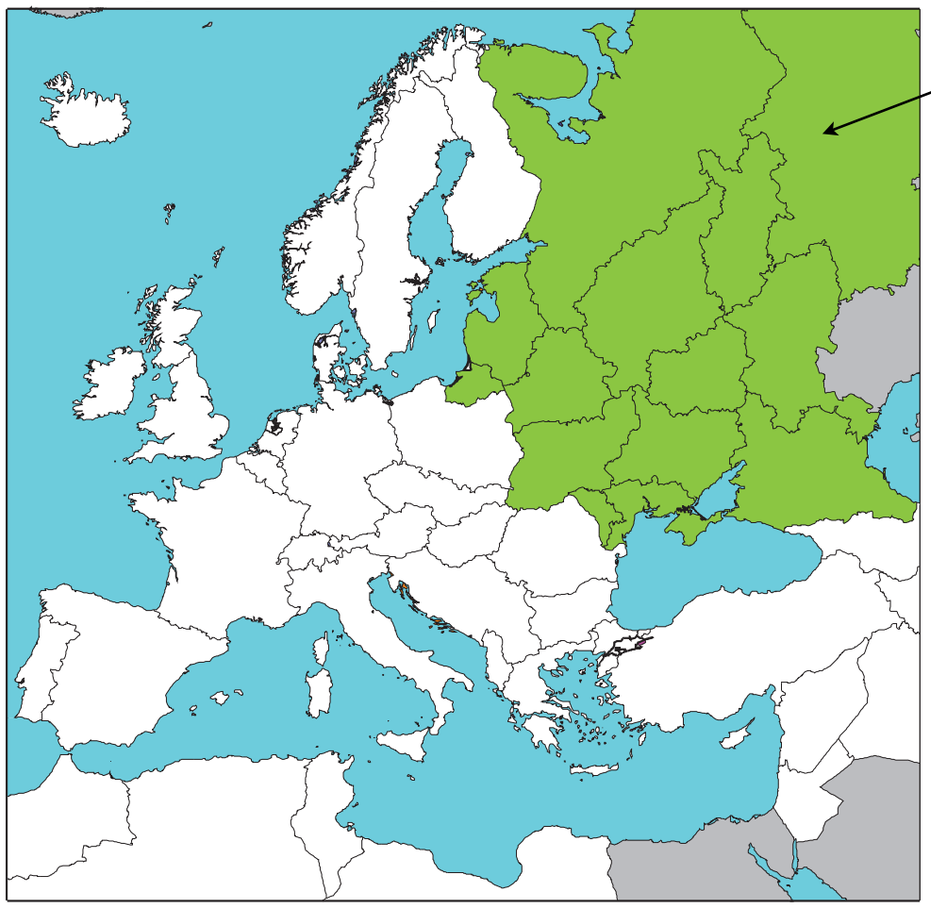
Main source of data ➤ McEvedy & Jones (1978)

- Digitize data
- Add in estimates from text prior to 400 BC
- Annual interpolation

example graph



Map of *Population*



European Russia

- Use 1851 census data
- 12 USSR economic regions
- Use relative 1851 proportions to break up European Russia estimates

Create range of population estimates

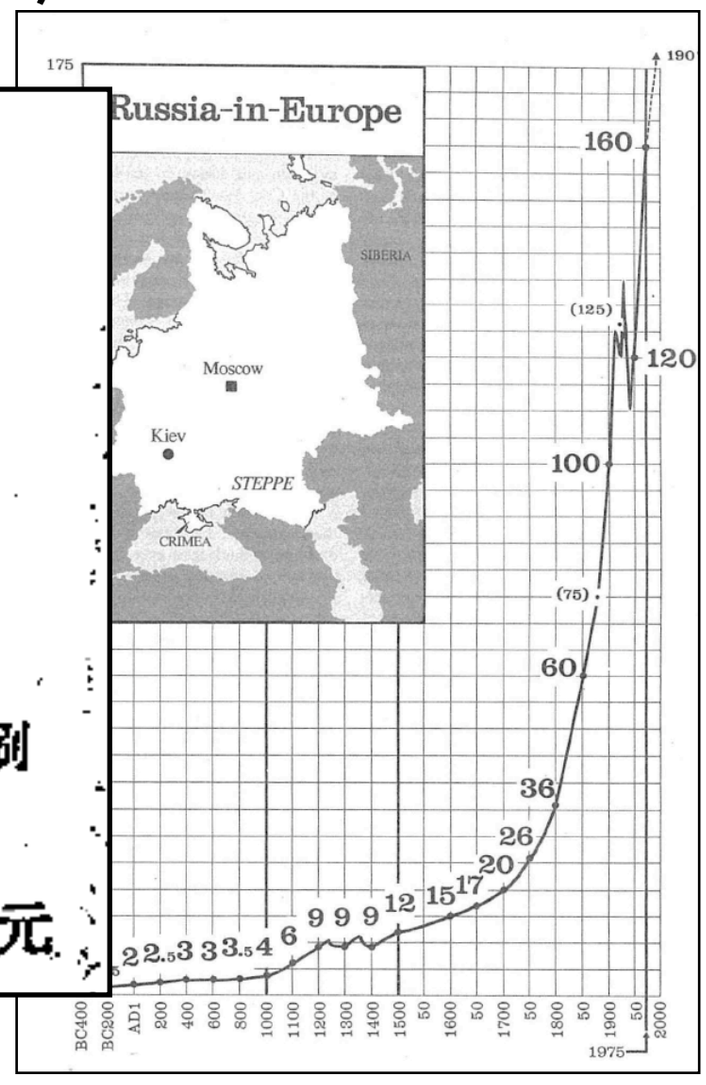
From a number of literature references for different countries and worldwide

Historical Population Dataset (1000 BC to 1850)

Main source of data ➤ McEvedy & Jones (1978)

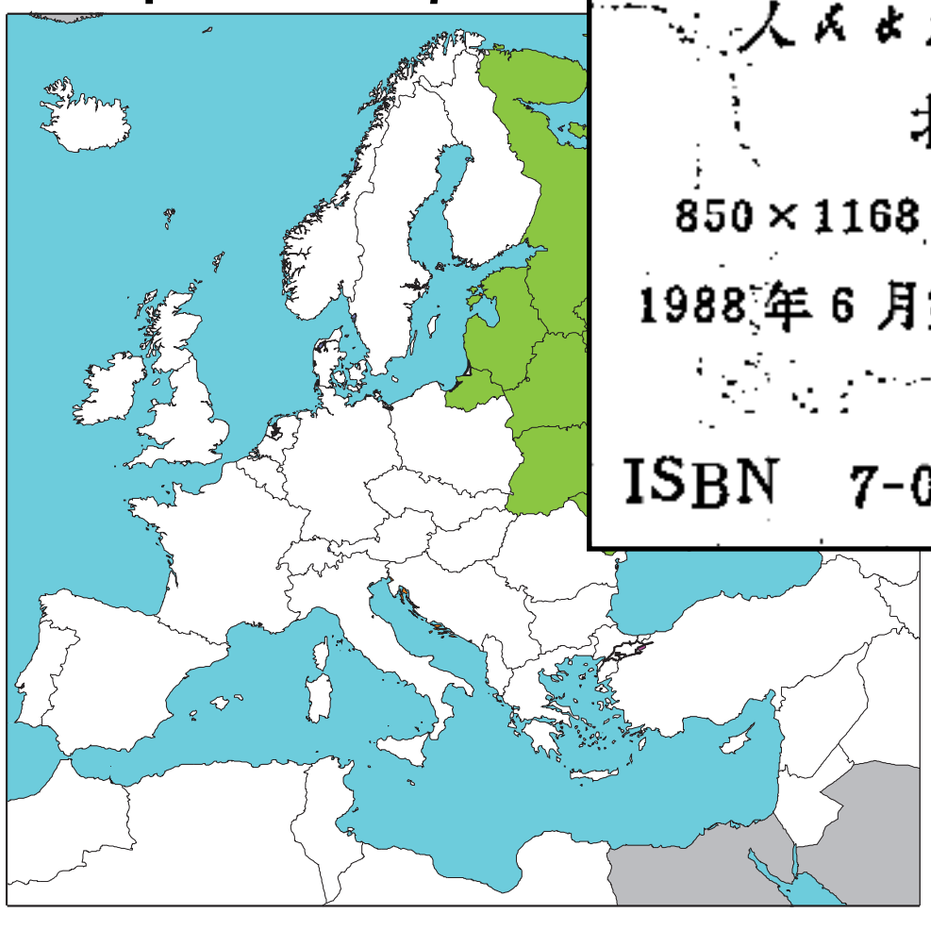
- Digitize data
- Add in
- Annual

example graph



European Russia estimates

Map of *Popula*



中国人口史

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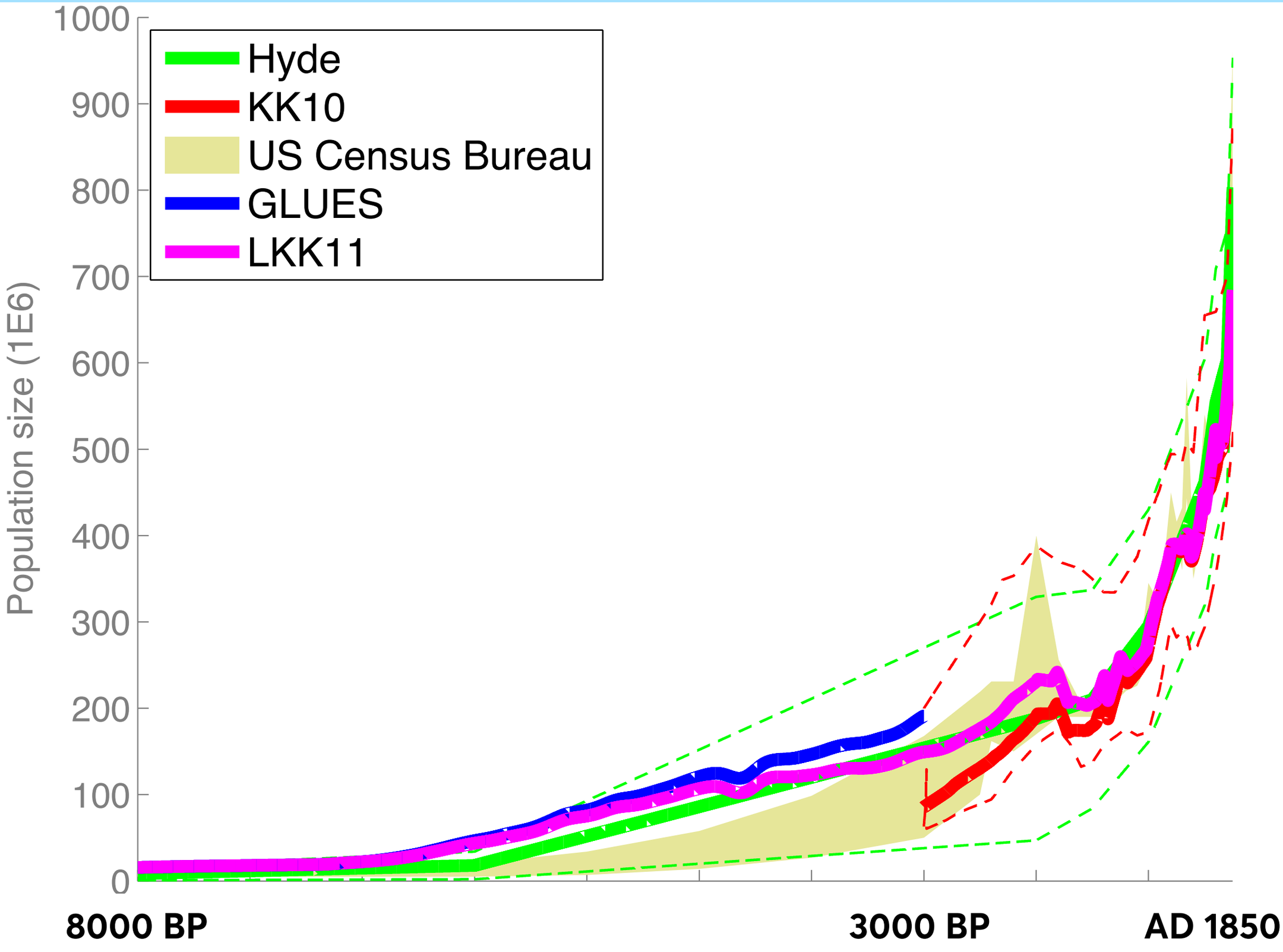
Create range of population estimates

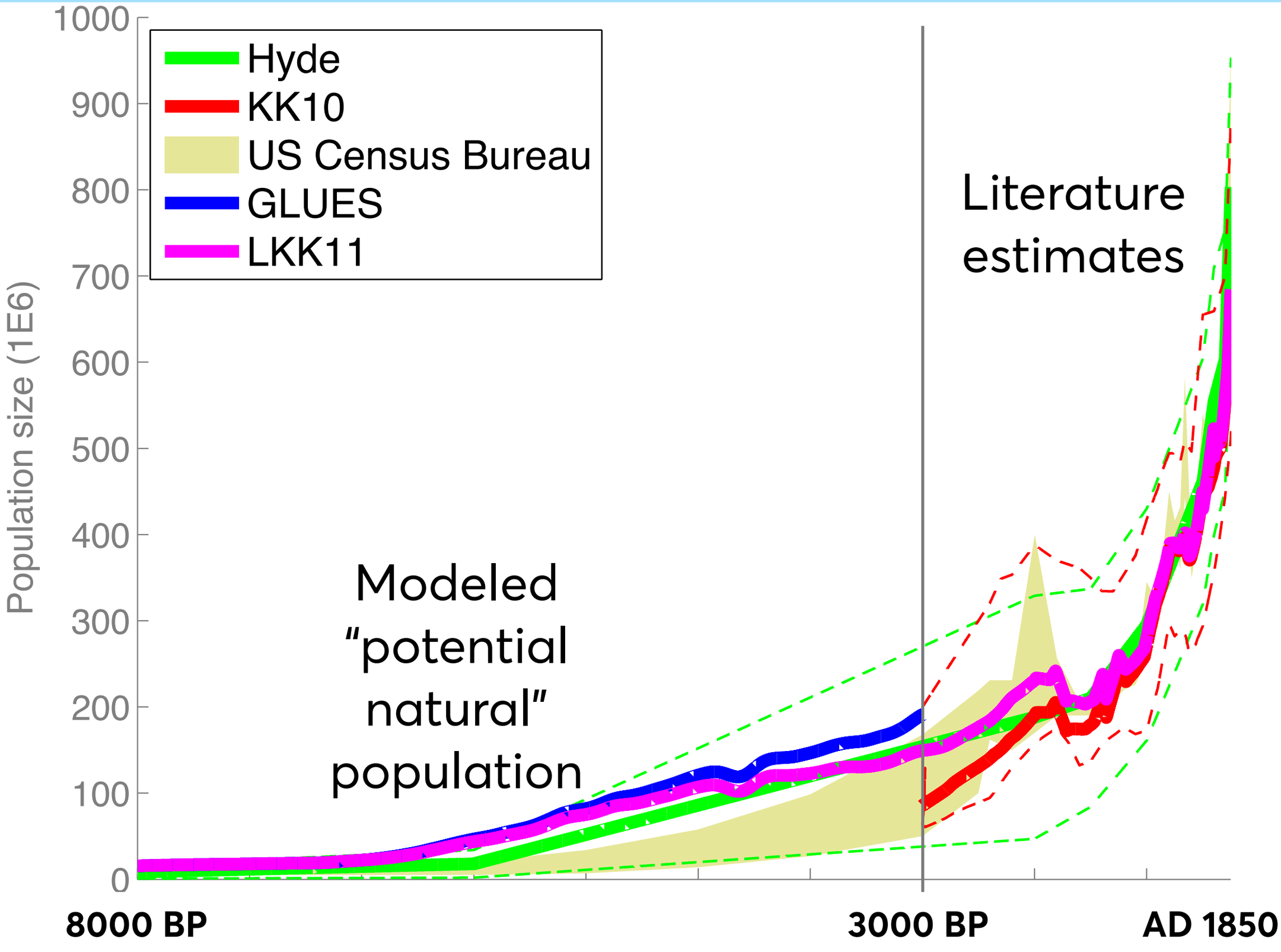
From a number of literature references for different countries and worldwide

Global historical population database



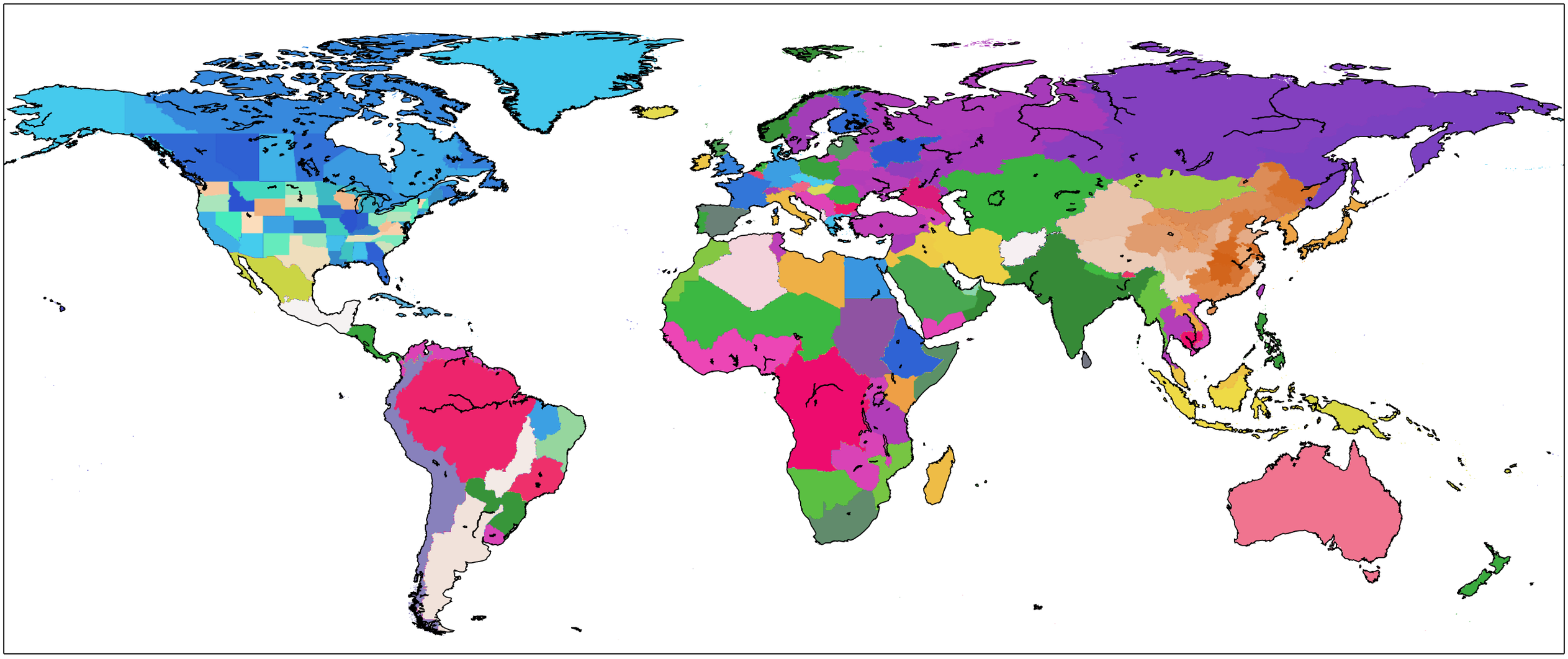
Krumhardt, 2010; Lemmen et al., in prep.

Global historical population database



Krumhardt, 2010; Lemmen et al., in prep.

Global historical population database



- 207 population regions (global)
- Merged product of literature estimates GLUES simulation potential natural population (8ka-3ka GLUES - 3ka-1850 literature)

Krumhardt, 2010; Lemmen et al., in prep.

The evolution of cities over the Holocene

- Primary data sources: Chandler (1987), Modelski (2000), Tellier (2009), Satterthwaite (2009), Geonames.org database
- Geolocation of ancient and some modern cities a major problem
- Dataset is incomplete for all time periods

Kaplan et al., unpublished

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Kaplan et al., unpublished

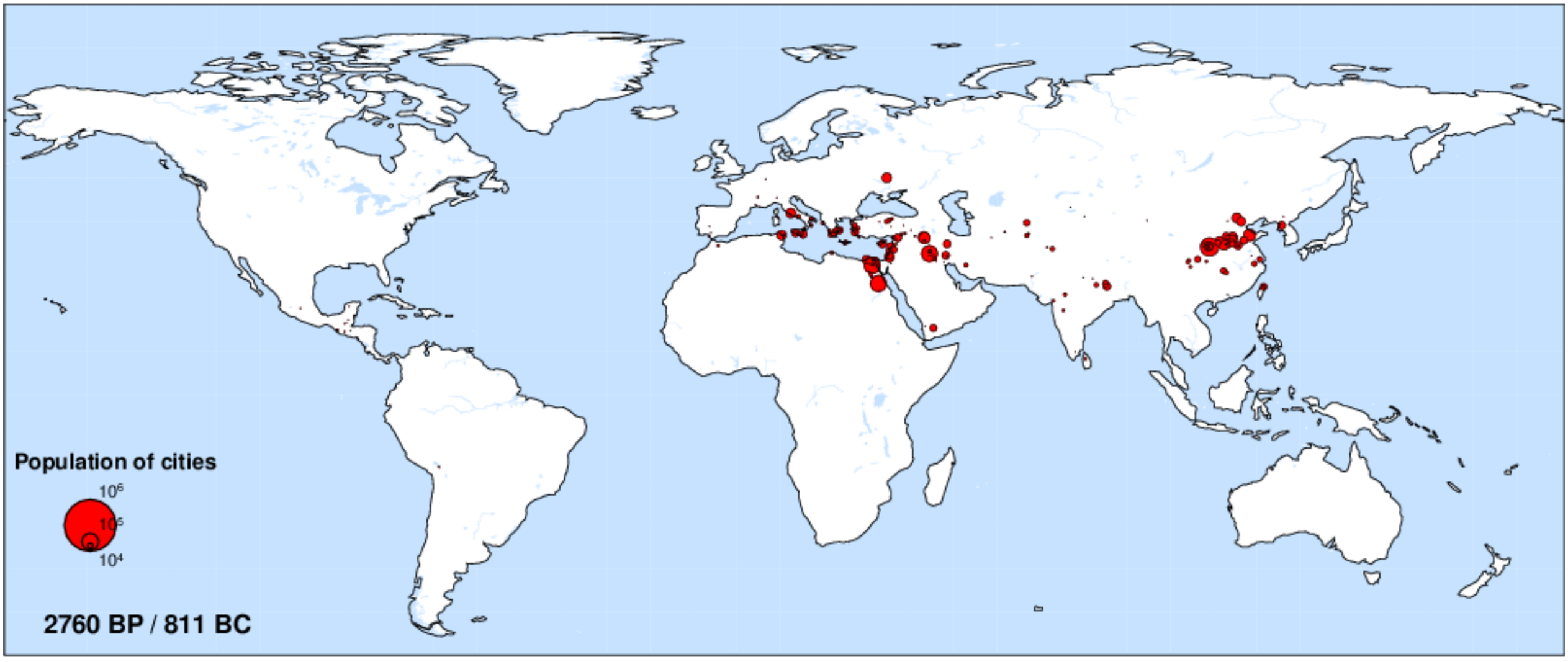

Population of cities
10⁶
10⁵
10⁴
5010 BP / 3061 BC


Population of cities
10^6
10^5
10^4
4510 BP / 2561 BC

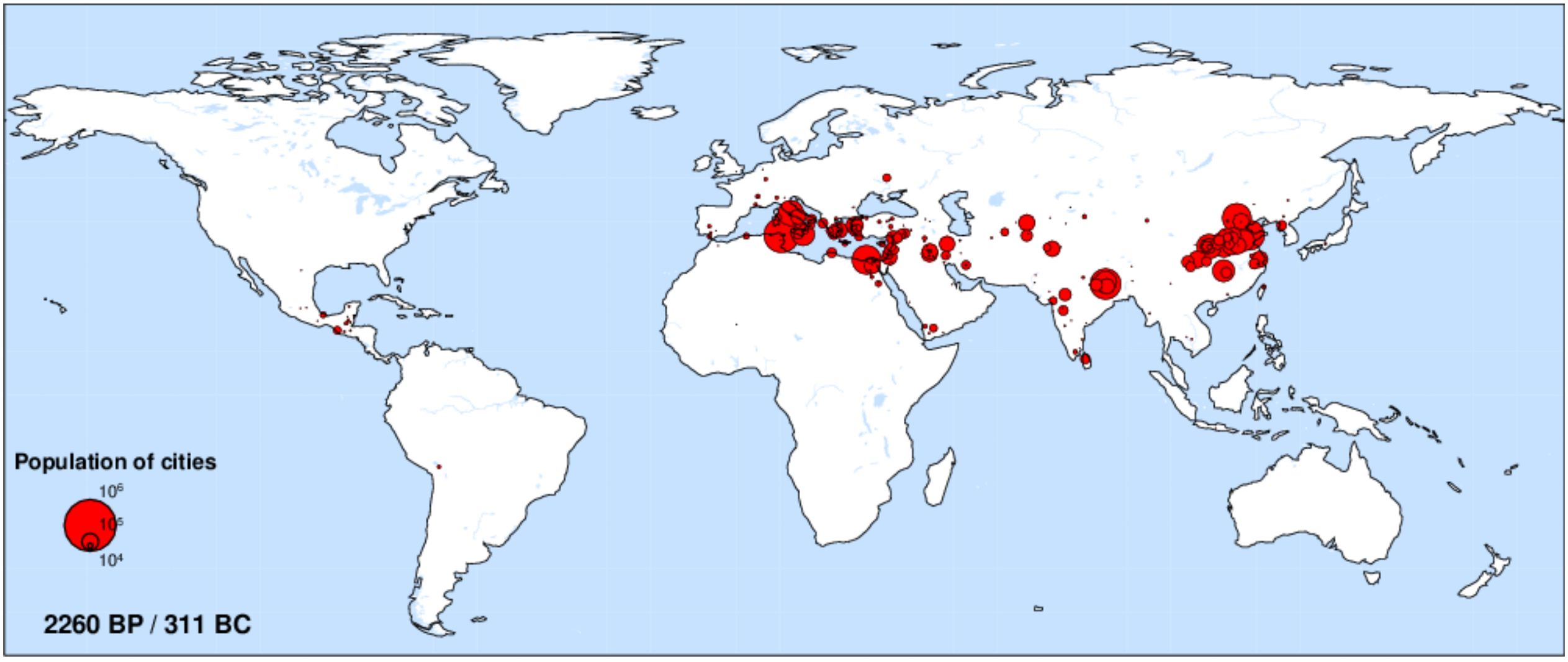

Population of cities
10⁶
10⁵
10⁴
4010 BP / 2061 BC

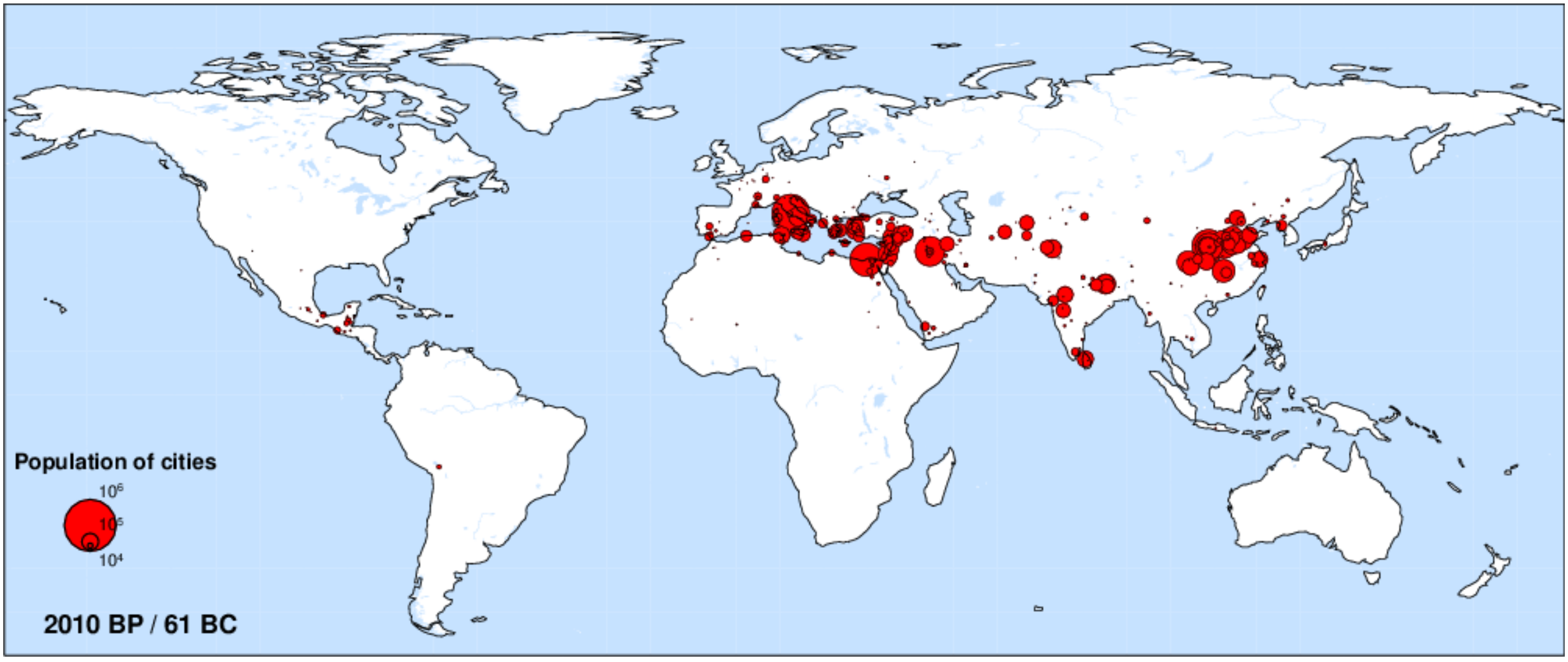

Population of cities
10⁶
10⁵
10⁴
3510 BP / 1561 BC

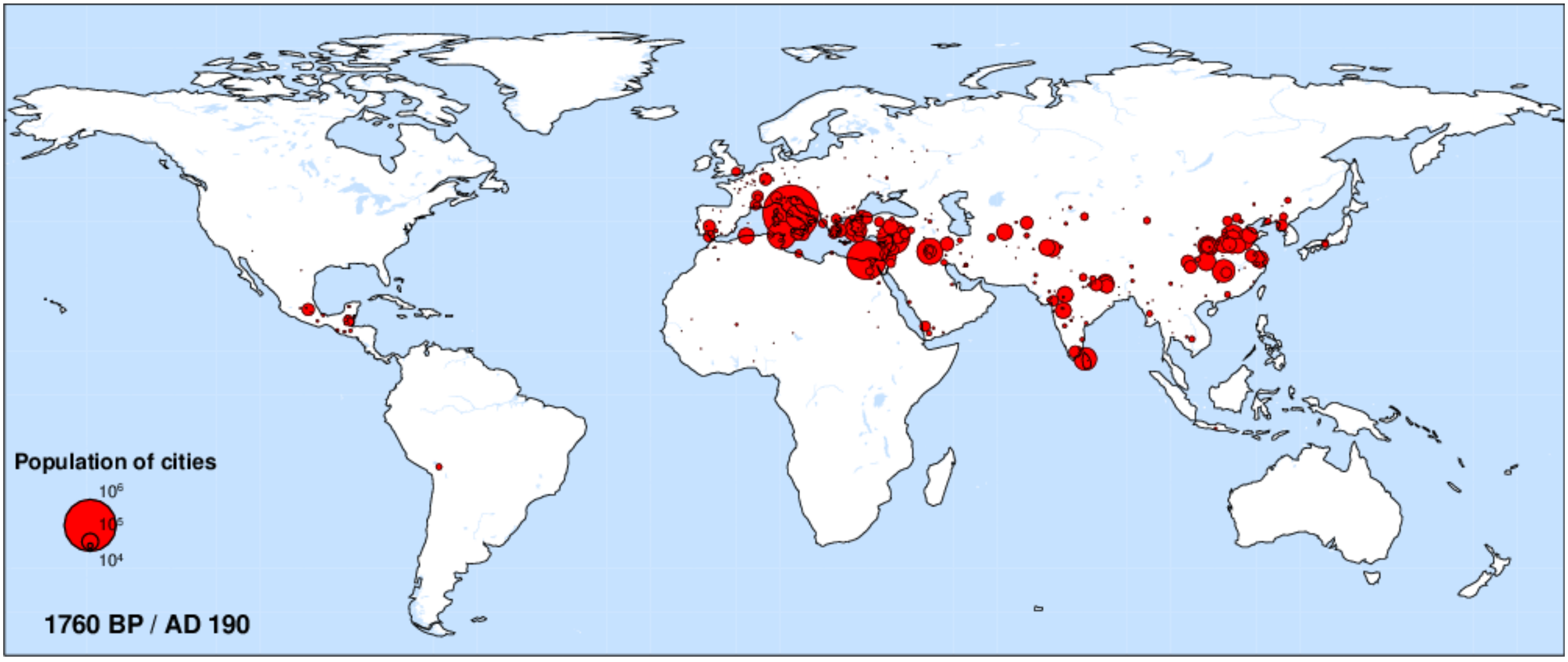

Population of cities
10⁶
10⁵
10⁴
3010 BP / 1061 BC

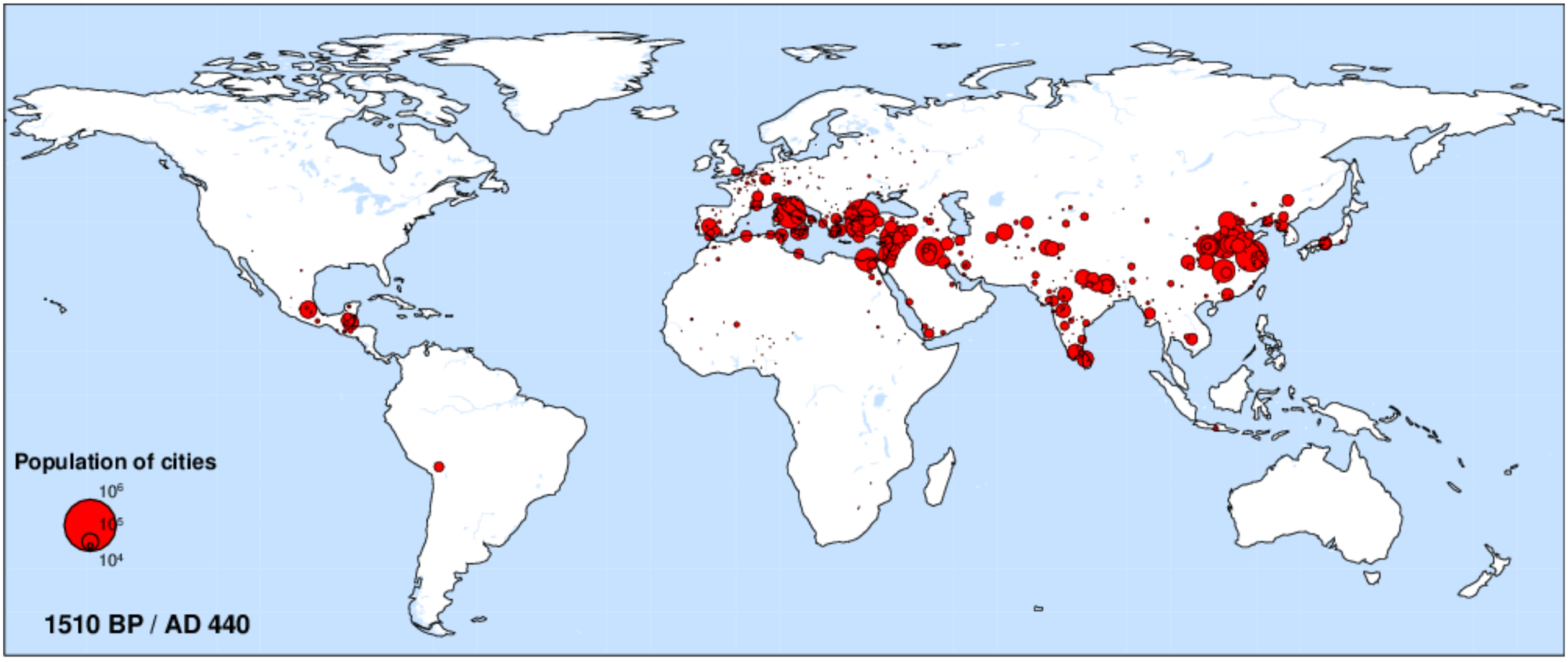

Population of cities
10⁶
10⁵
10⁴
2760 BP / 811 BC

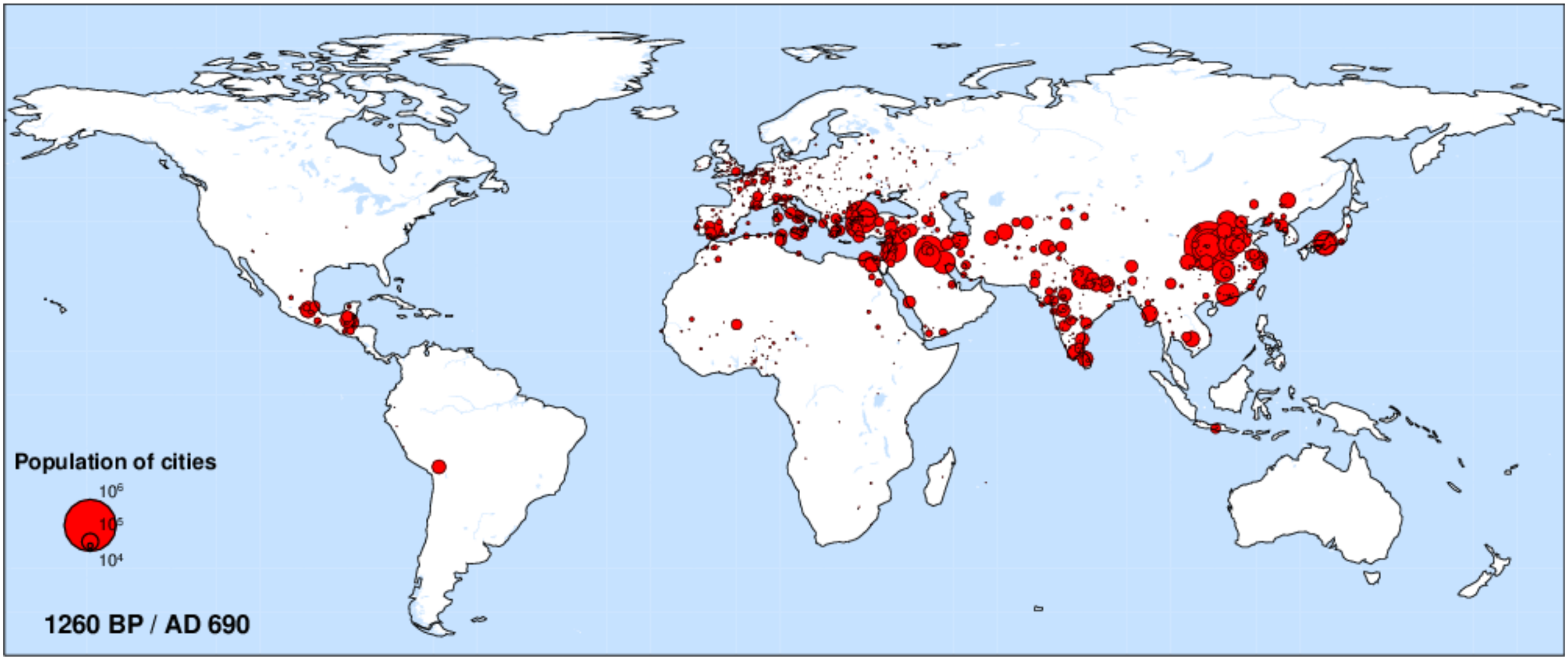

Population of cities
10^6
10^5
10^4
2510 BP / 561 BC

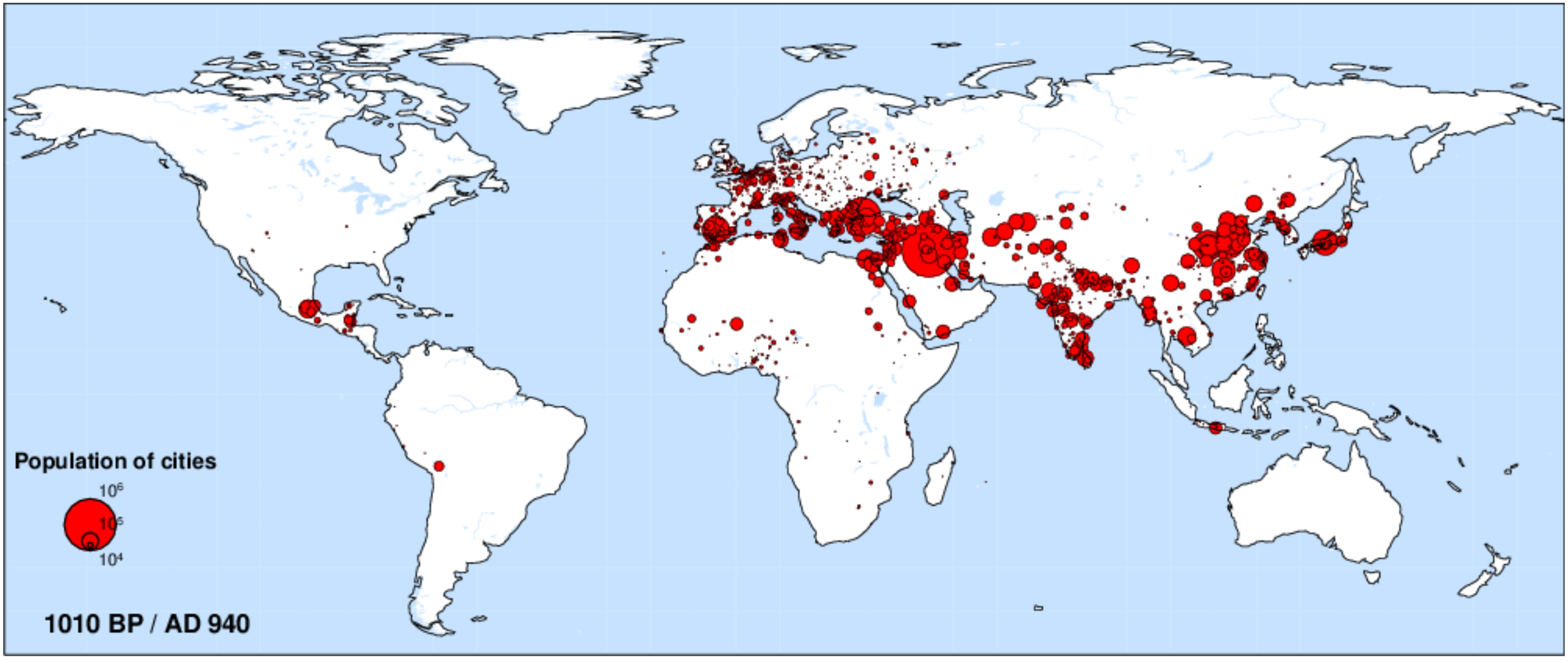

Population of cities
10^6
10^5
10^4
2260 BP / 311 BC

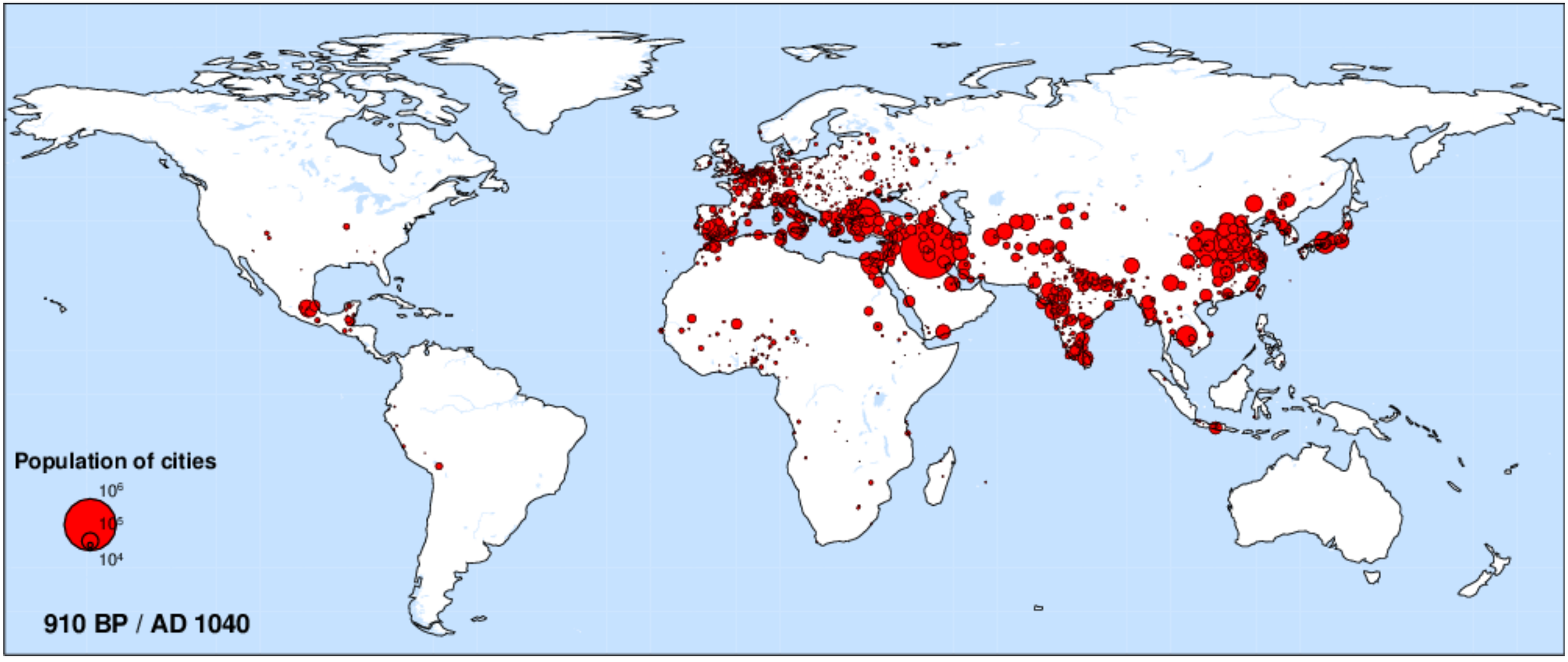

Population of cities
10^6
10^5
10^4
2010 BP / 61 BC

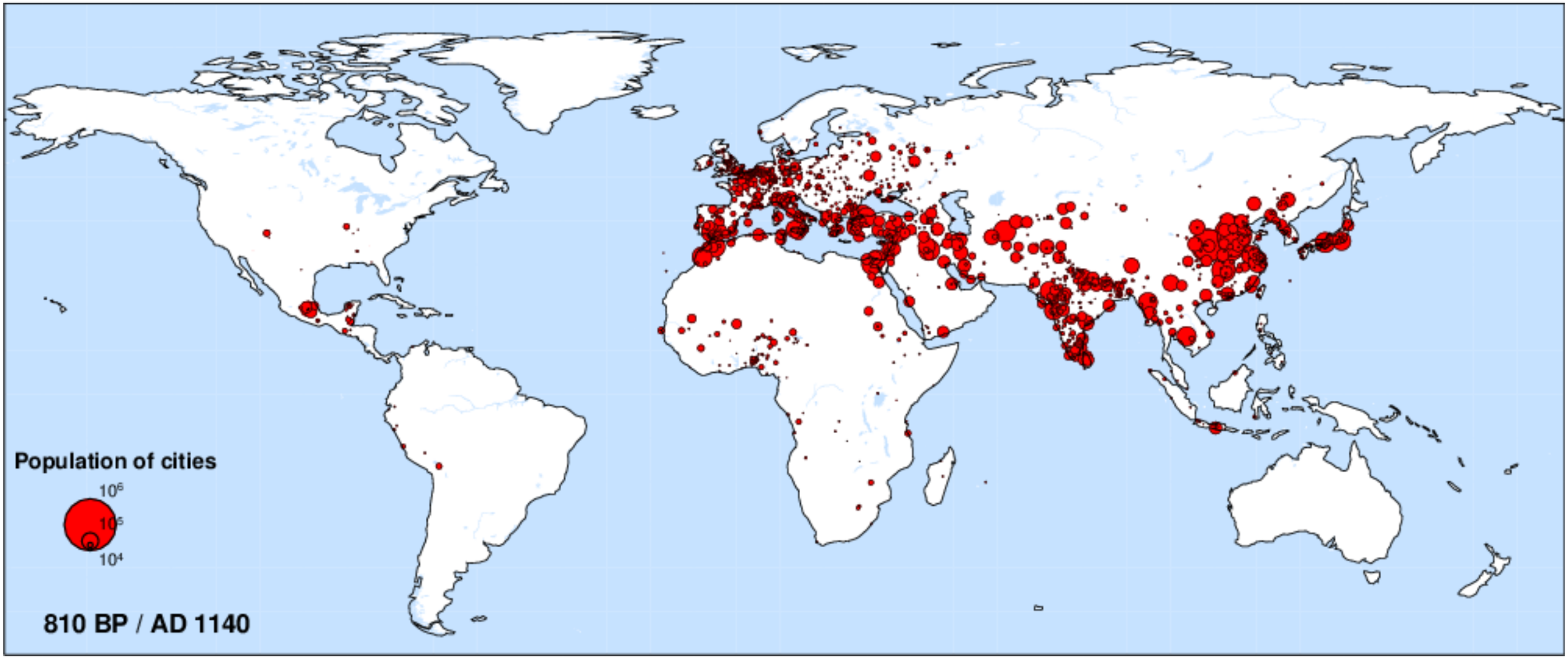

Population of cities
10⁶
10⁵
10⁴
1760 BP / AD 190

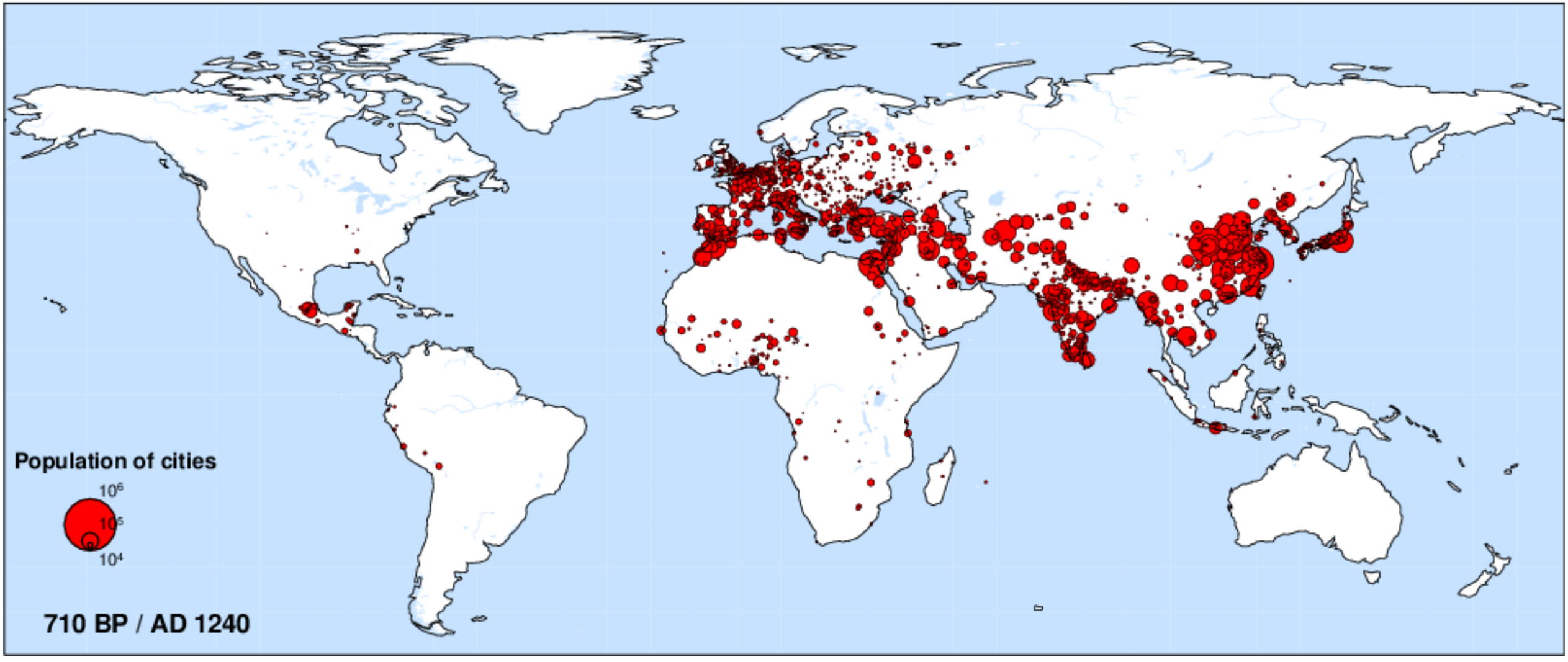

Population of cities
10^6
10^5
10^4
1510 BP / AD 440

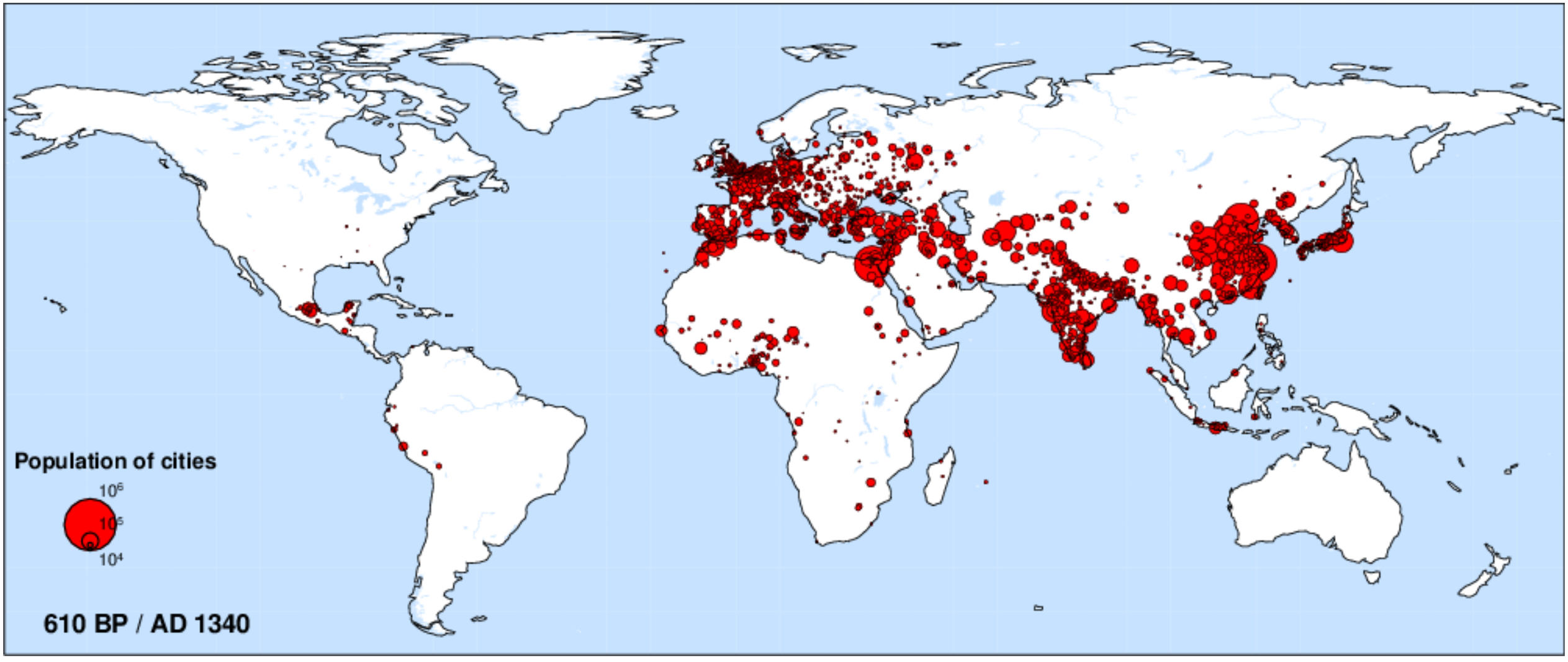

Population of cities
10⁶
10⁵
10⁴
1260 BP / AD 690

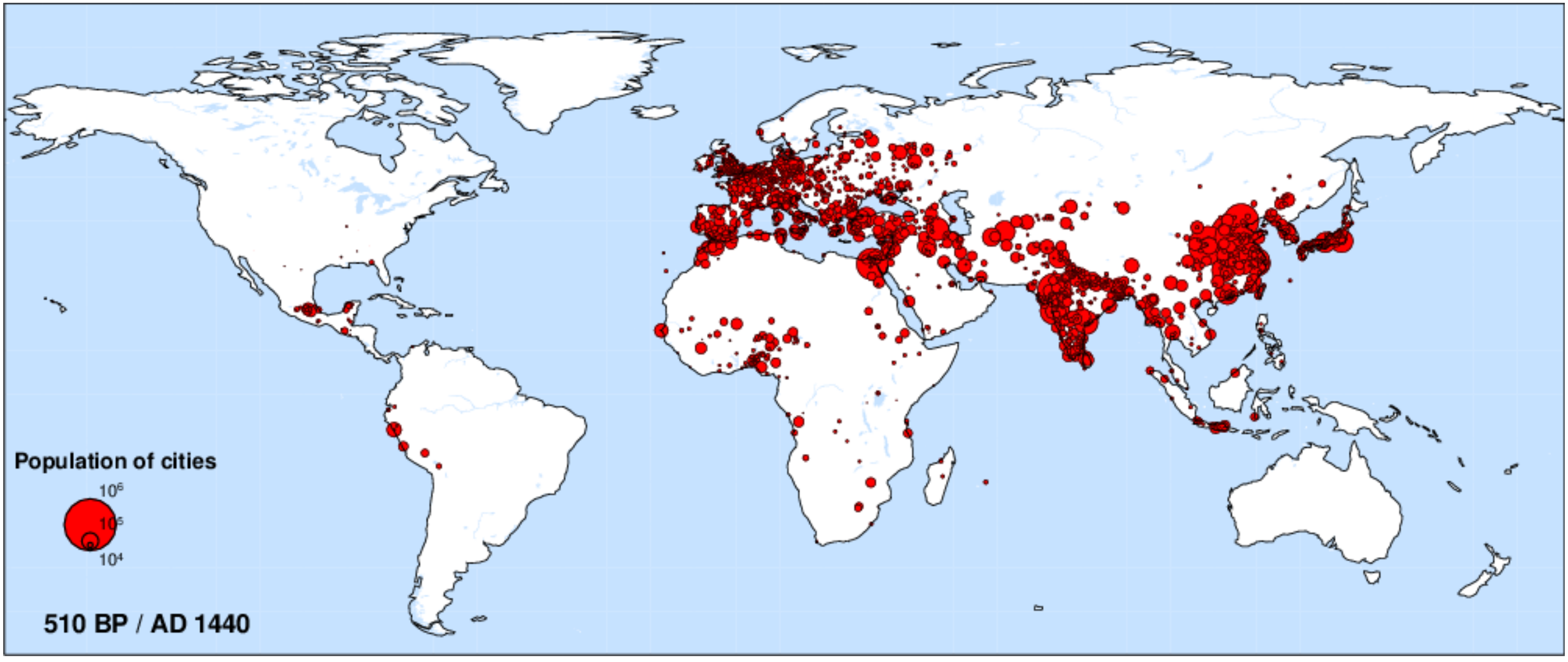

Population of cities
10⁶
10⁵
10⁴
1010 BP / AD 940

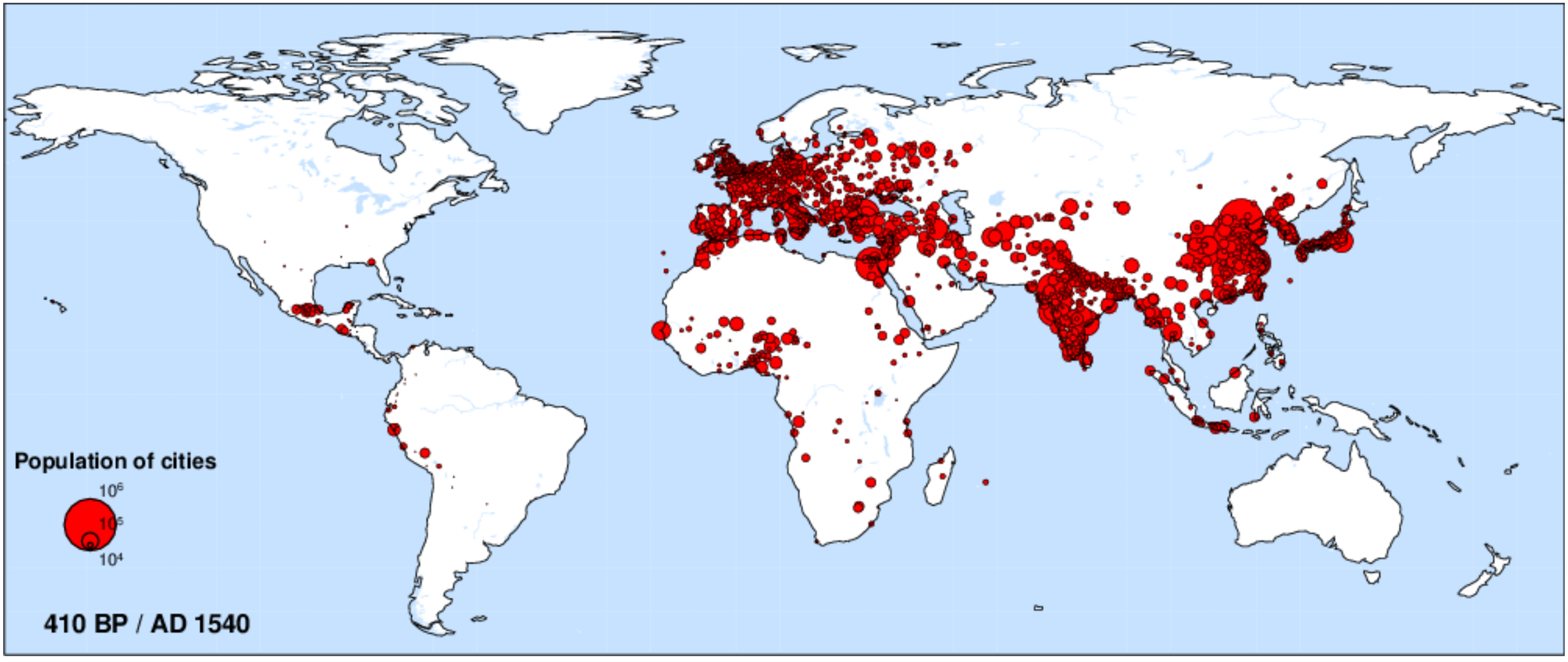

Population of cities
10^6
10^5
10^4
910 BP / AD 1040

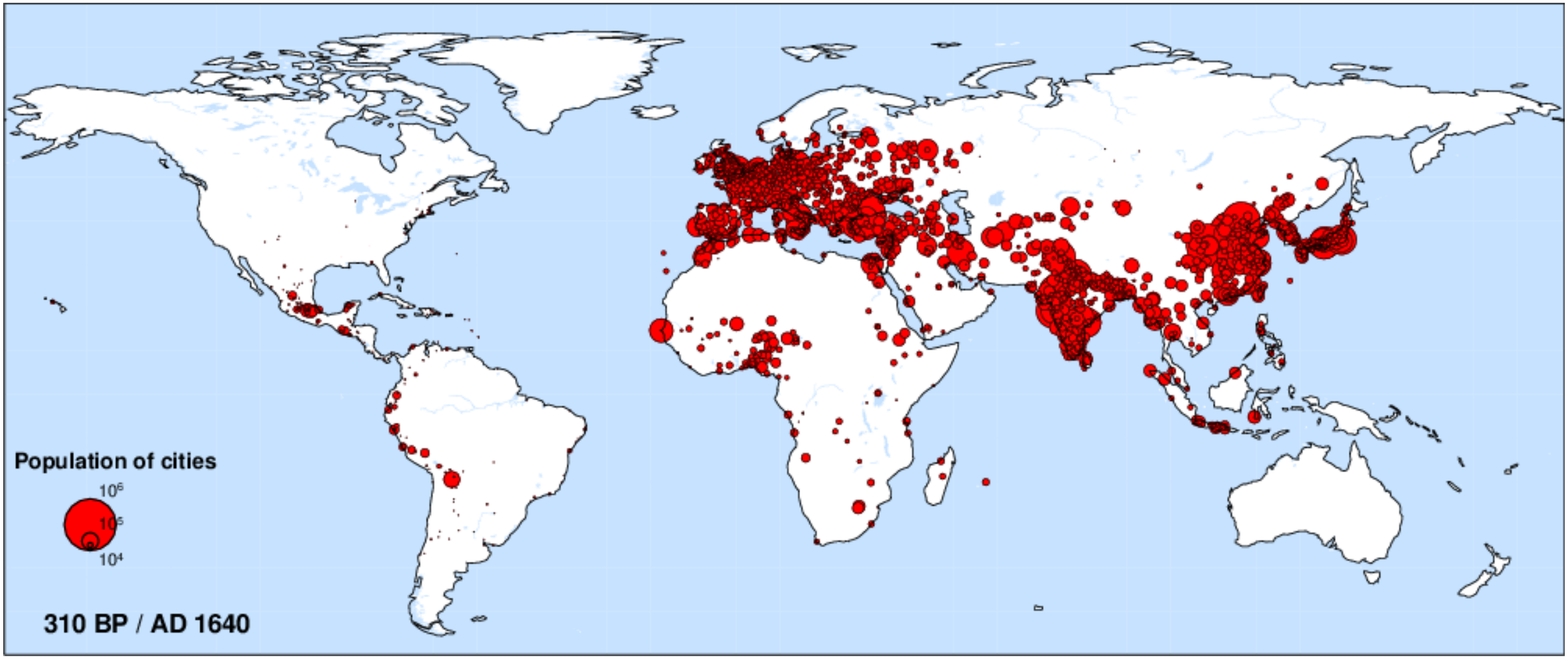

Population of cities
10^6
10^5
10^4
810 BP / AD 1140

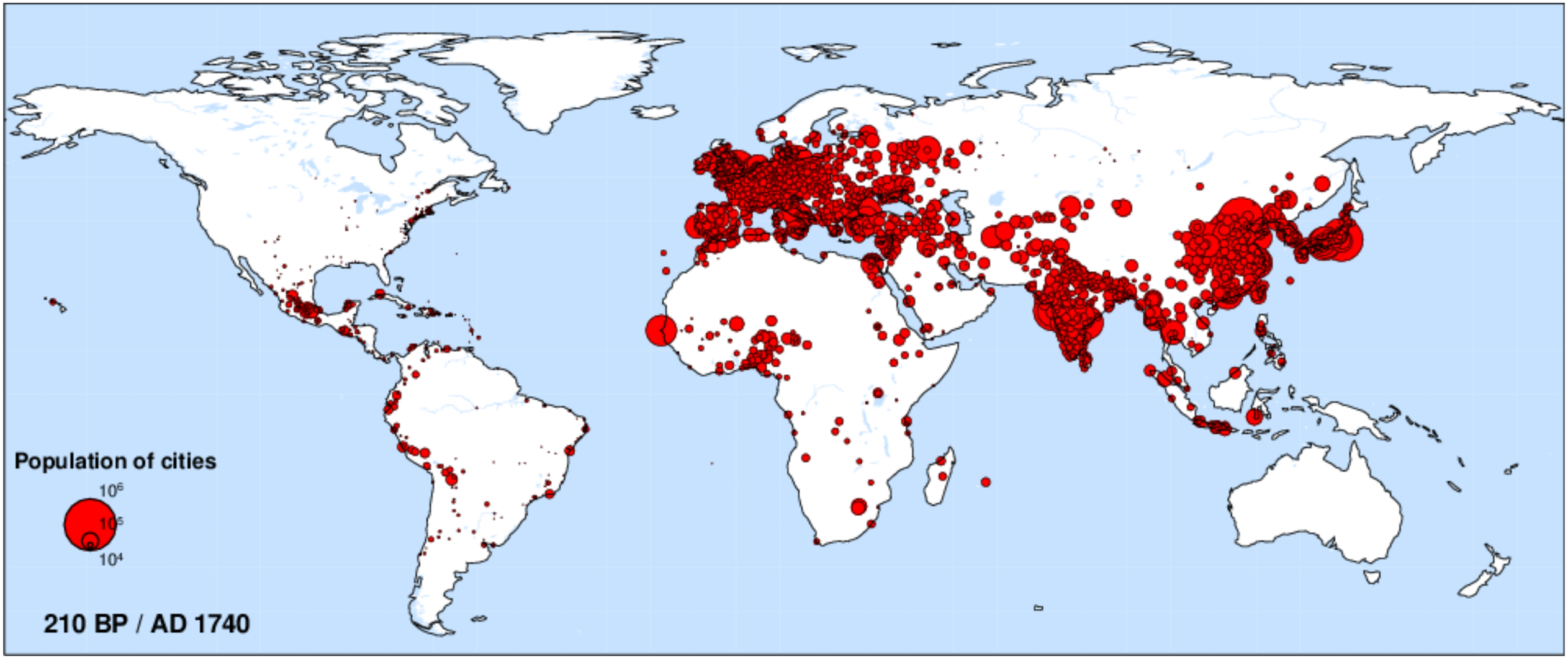

Population of cities
10^6
10^5
10^4
710 BP / AD 1240

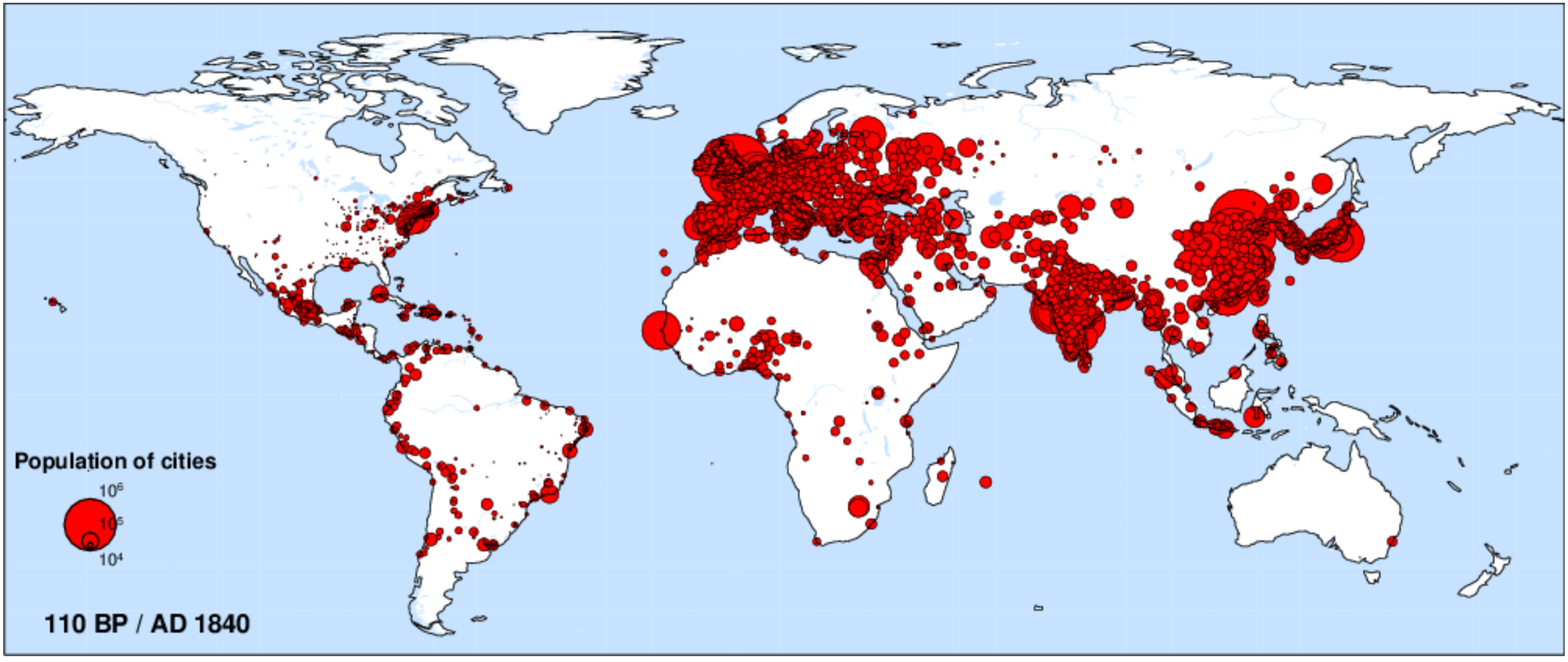

Population of cities
10^6
10^5
10^4
610 BP / AD 1340

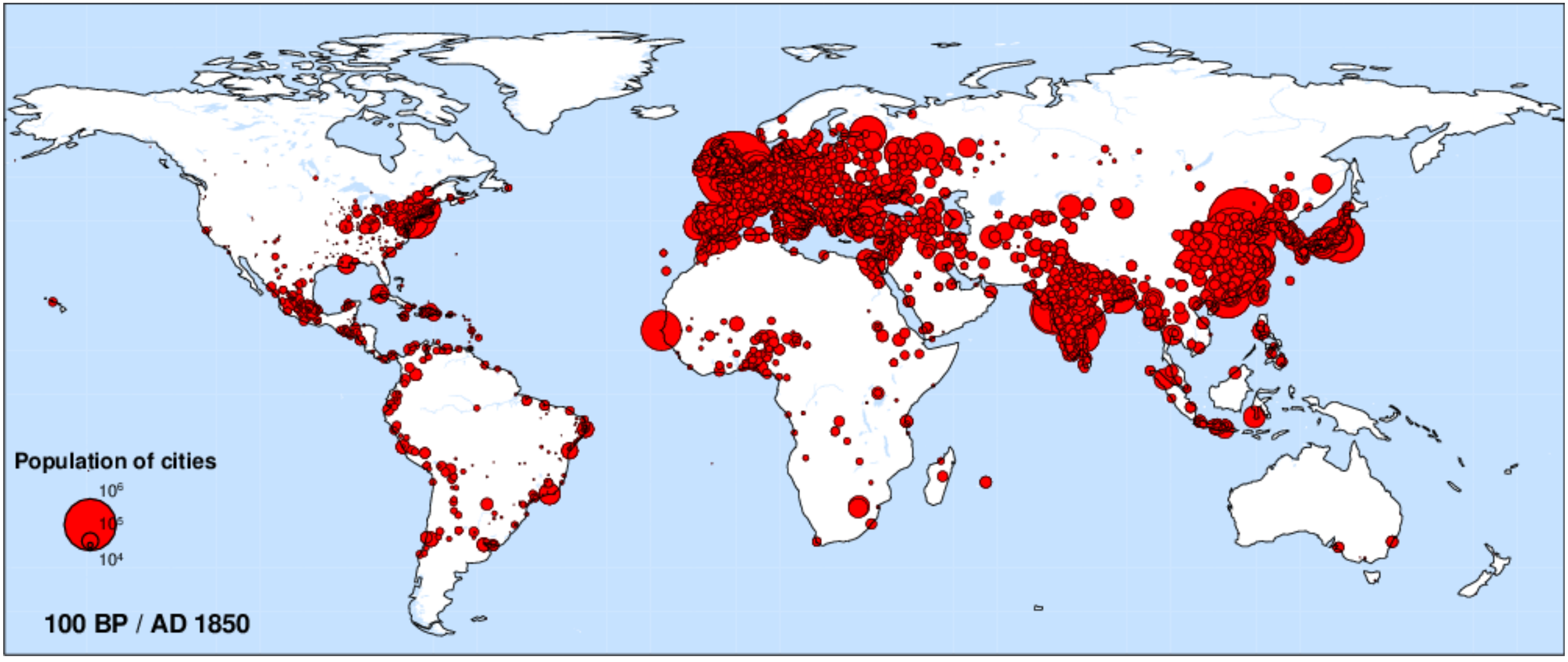

Population of cities
10^6
10^5
10^4
510 BP / AD 1440

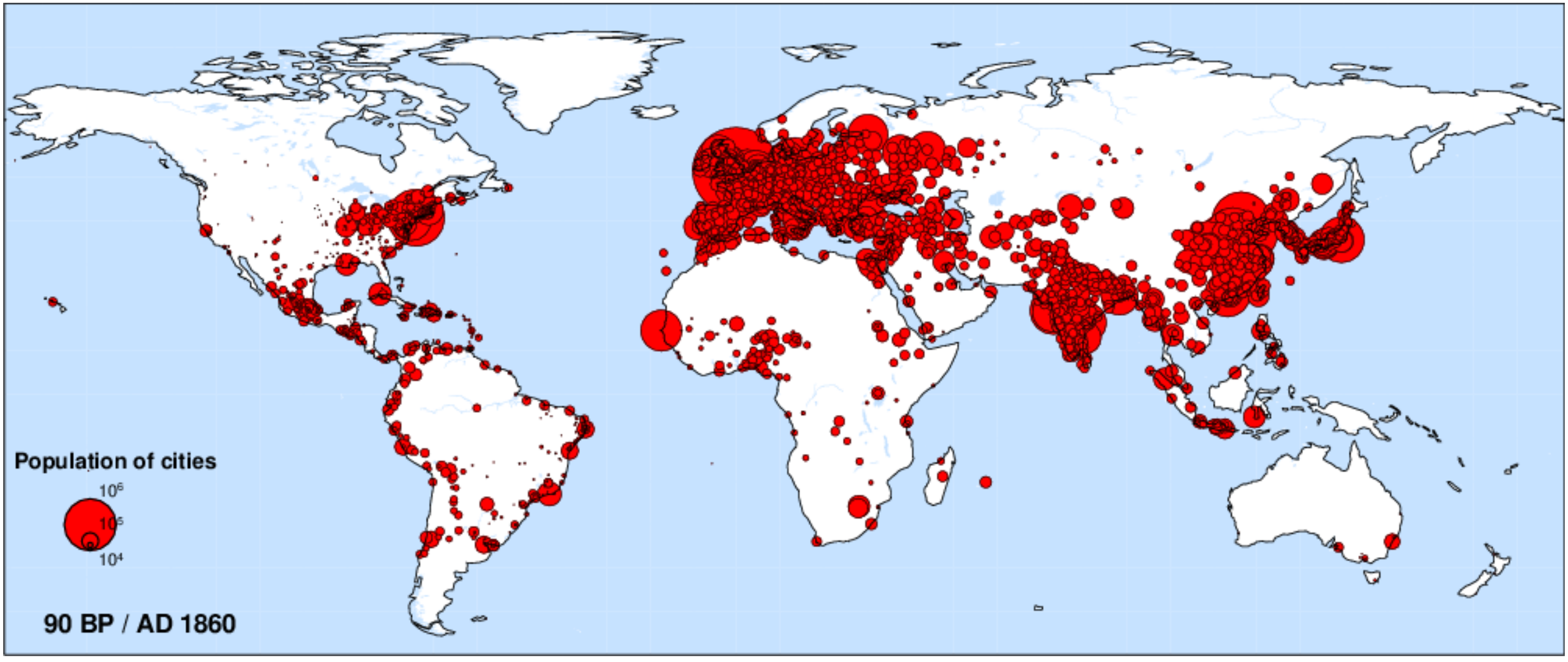

Population of cities
10^6
10^5
10^4
410 BP / AD 1540

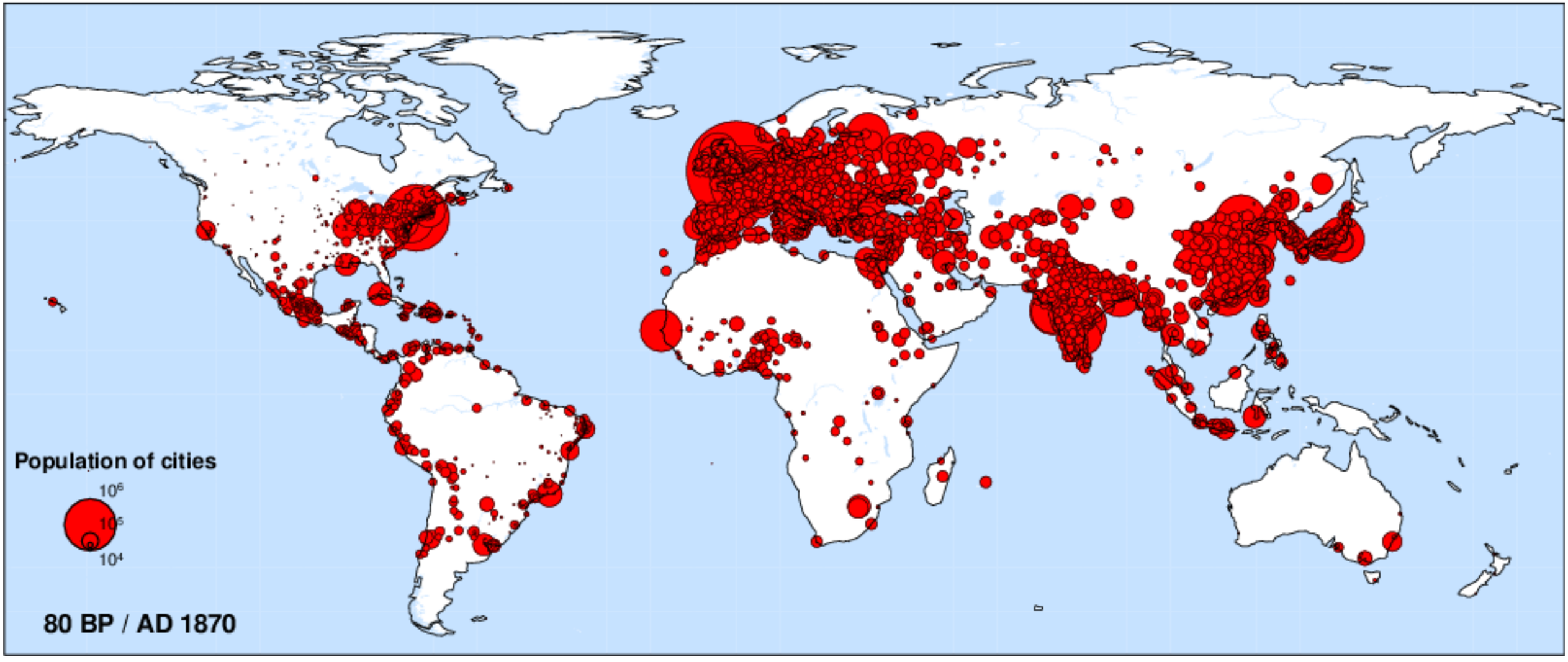

Population of cities
10^6
10^5
10^4
310 BP / AD 1640

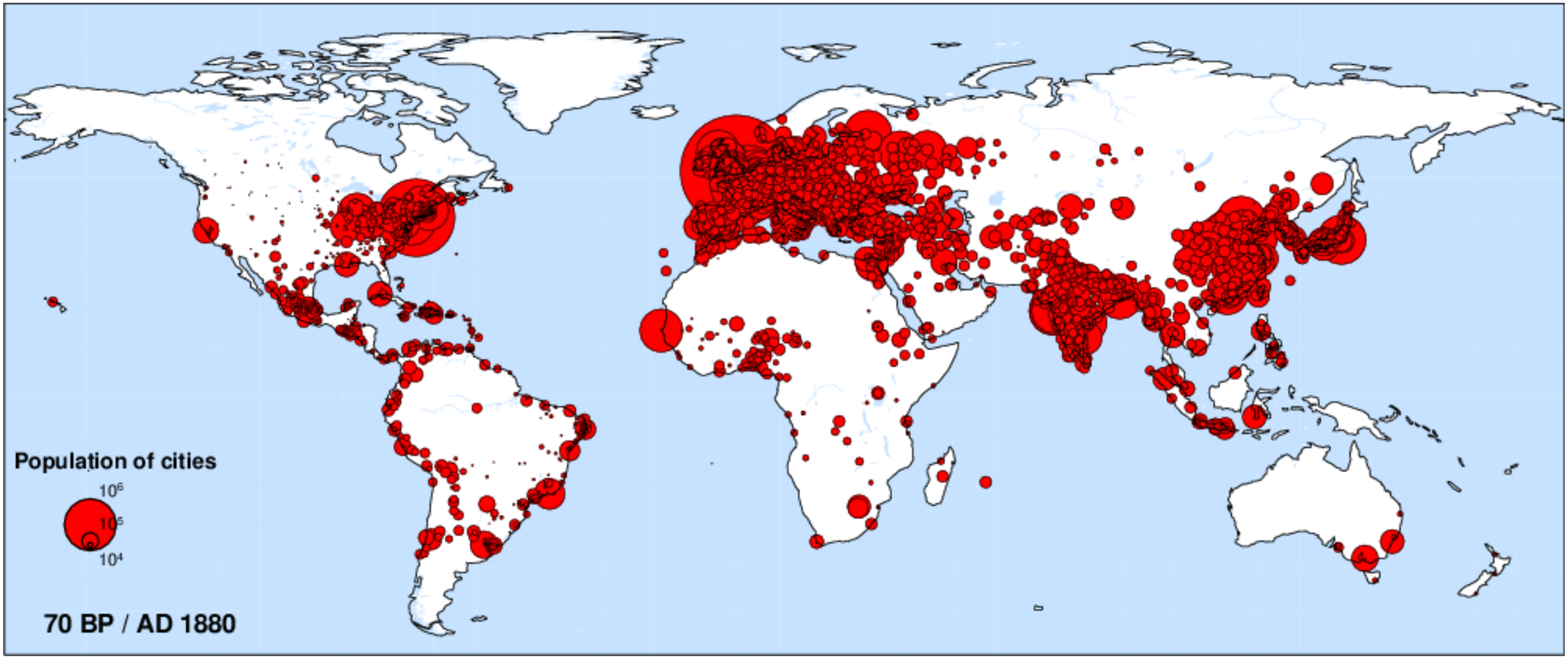

Population of cities
10^6
10^5
10^4
210 BP / AD 1740

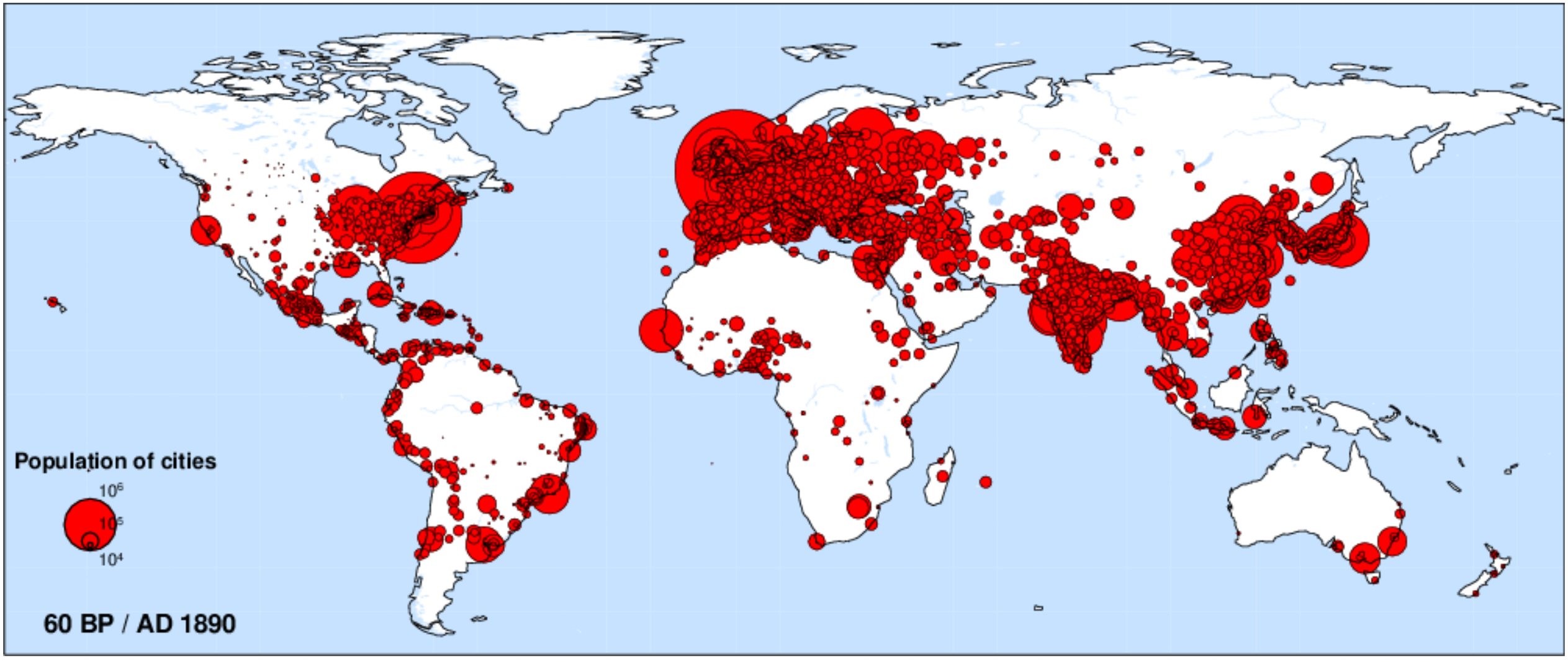

Population of cities
10^6
10^5
10^4
110 BP / AD 1840

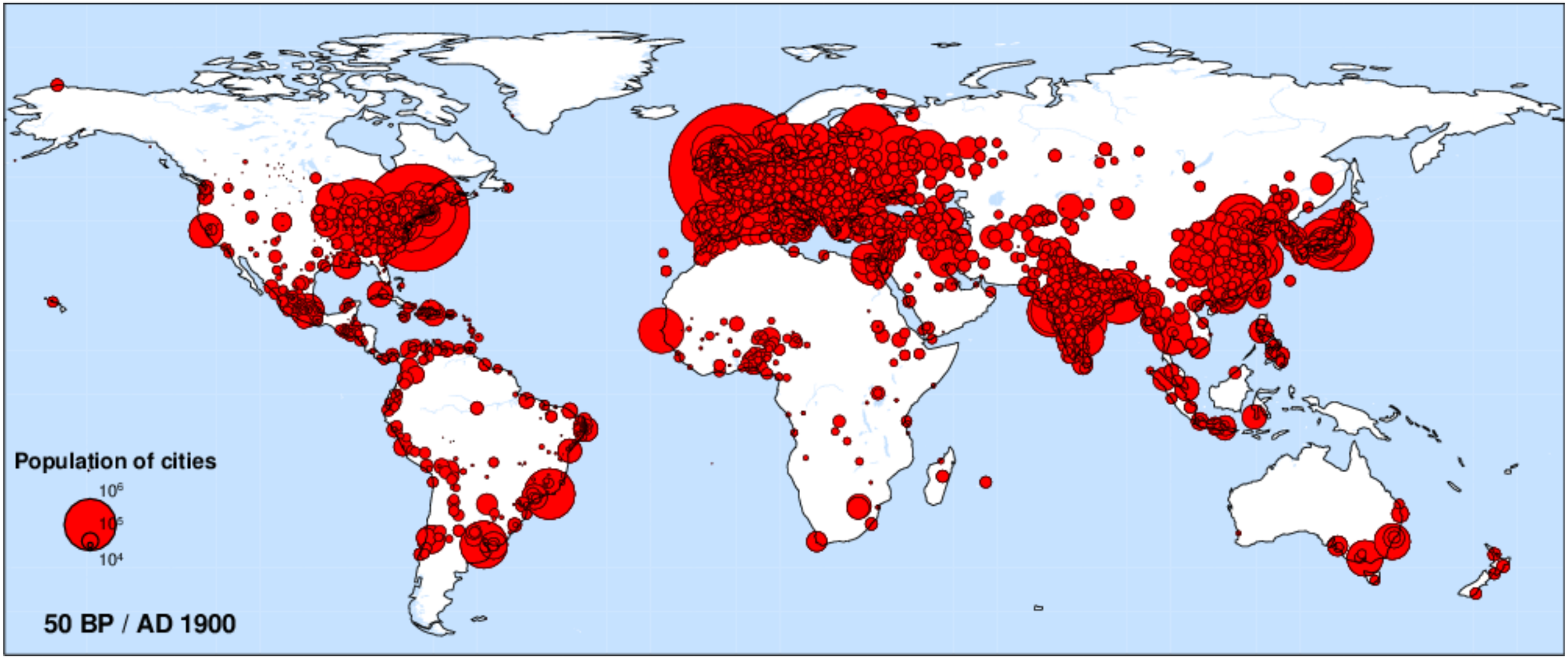

Population of cities
10^6
10^5
10^4
100 BP / AD 1850

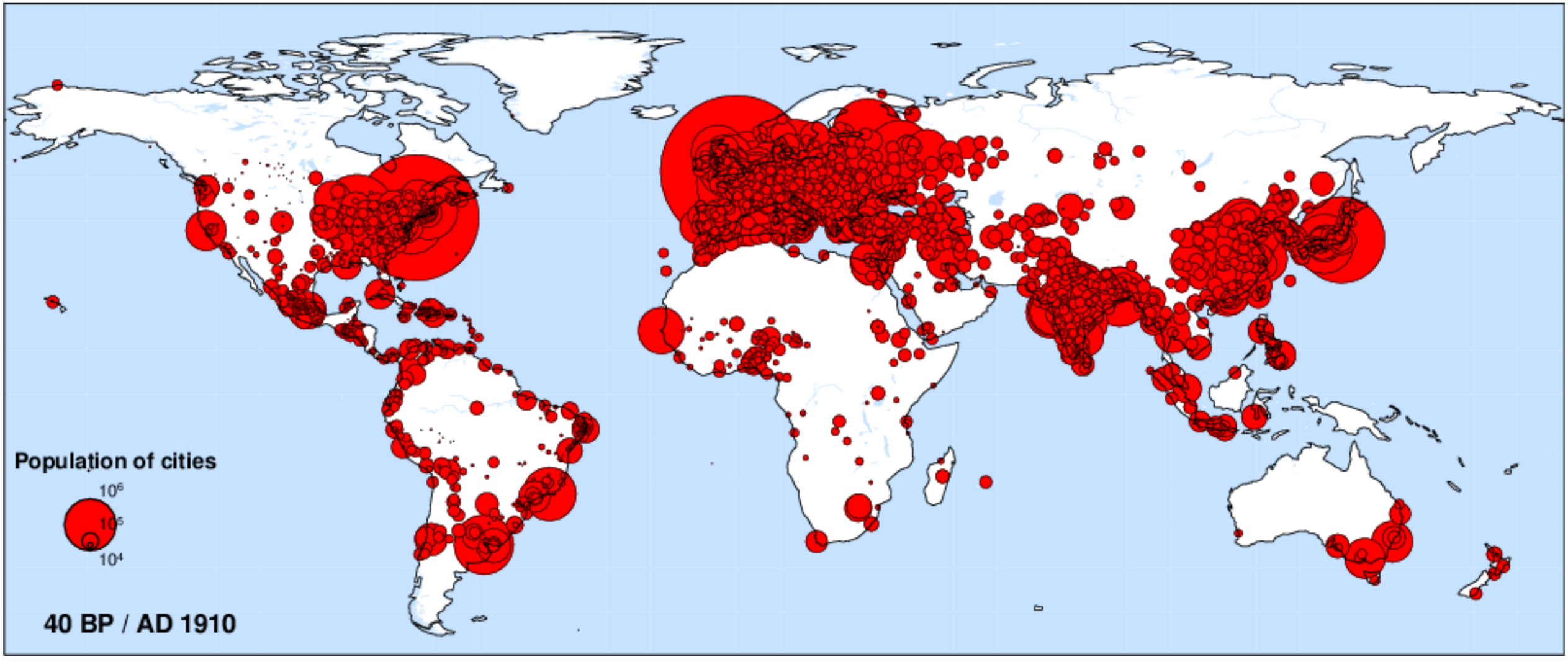

Population of cities
10^6
10^5
10^4
90 BP / AD 1860

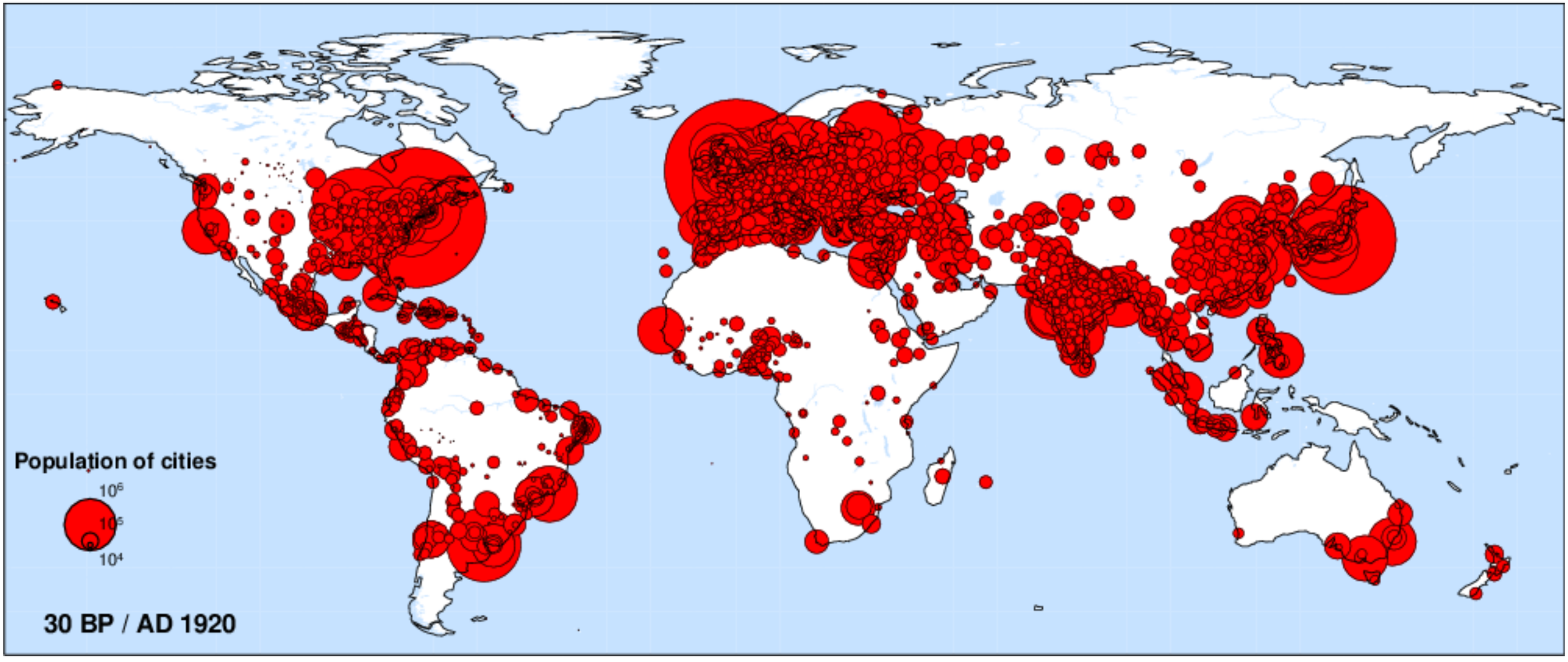

Population of cities
10⁶
10⁵
10⁴
80 BP / AD 1870

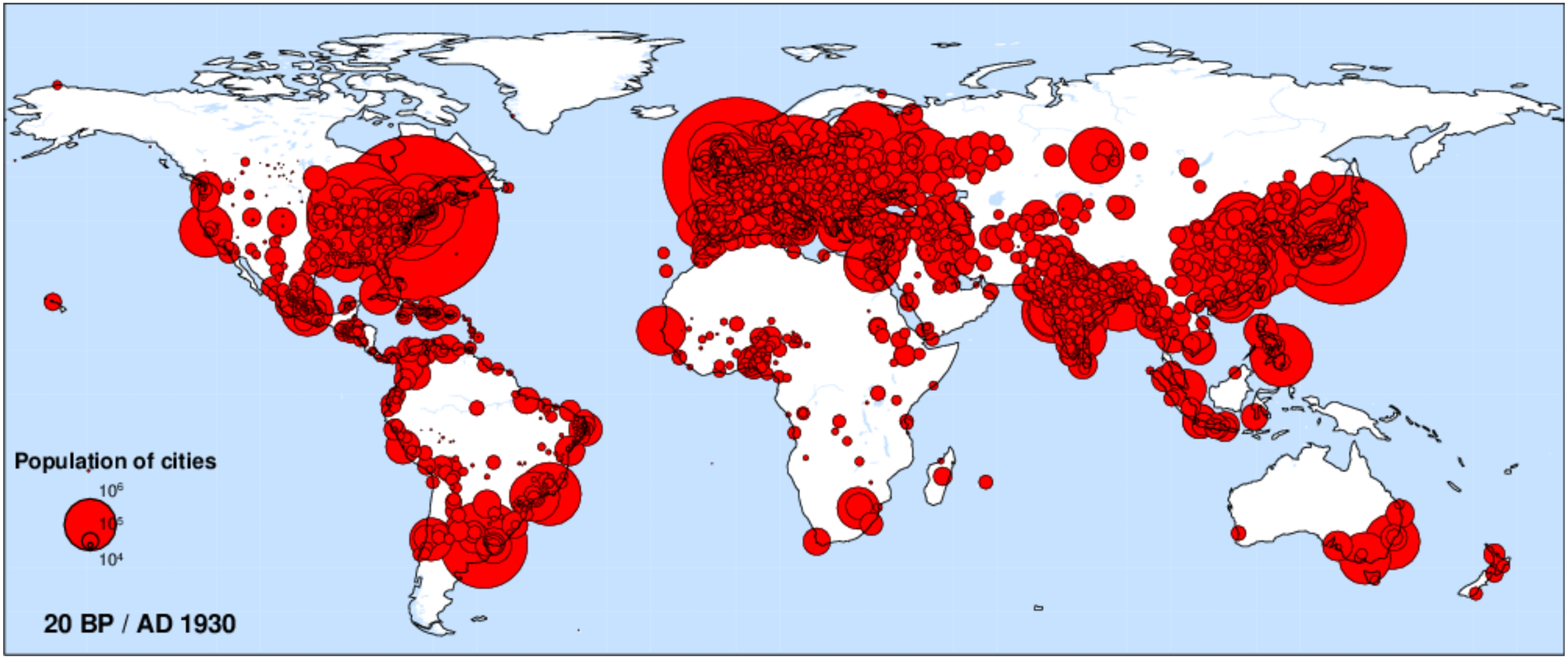

Population of cities
10⁶
10⁵
10⁴
70 BP / AD 1880

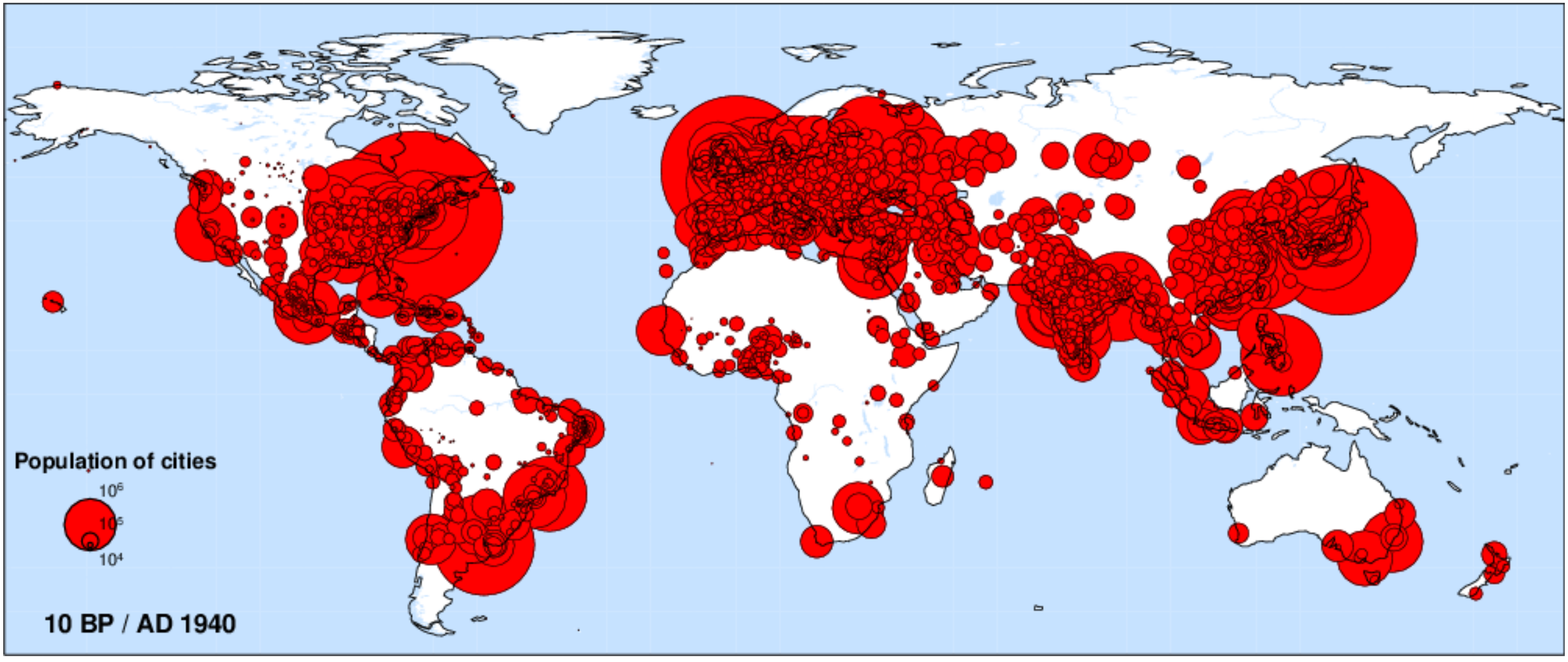

Population of cities
10⁶
10⁵
10⁴
60 BP / AD 1890

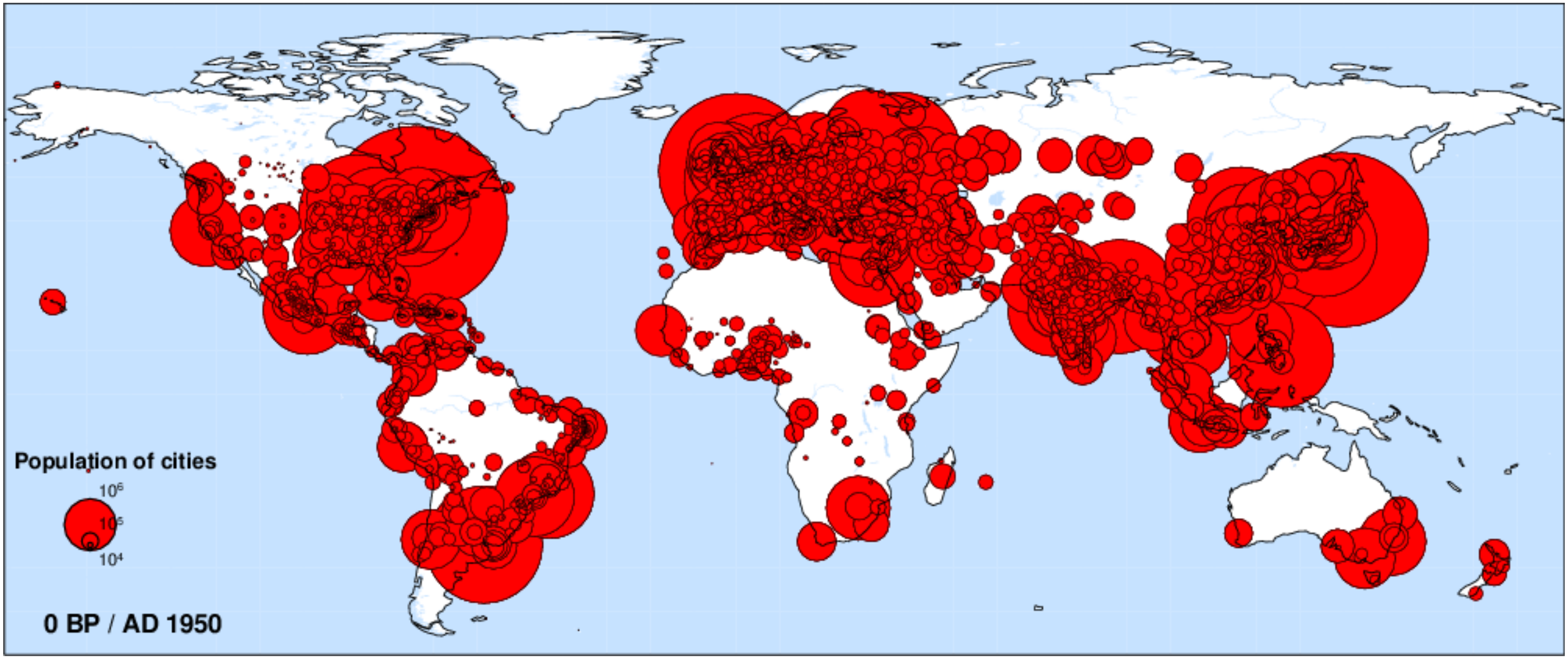

Population of cities
10^6
10^5
10^4
50 BP / AD 1900

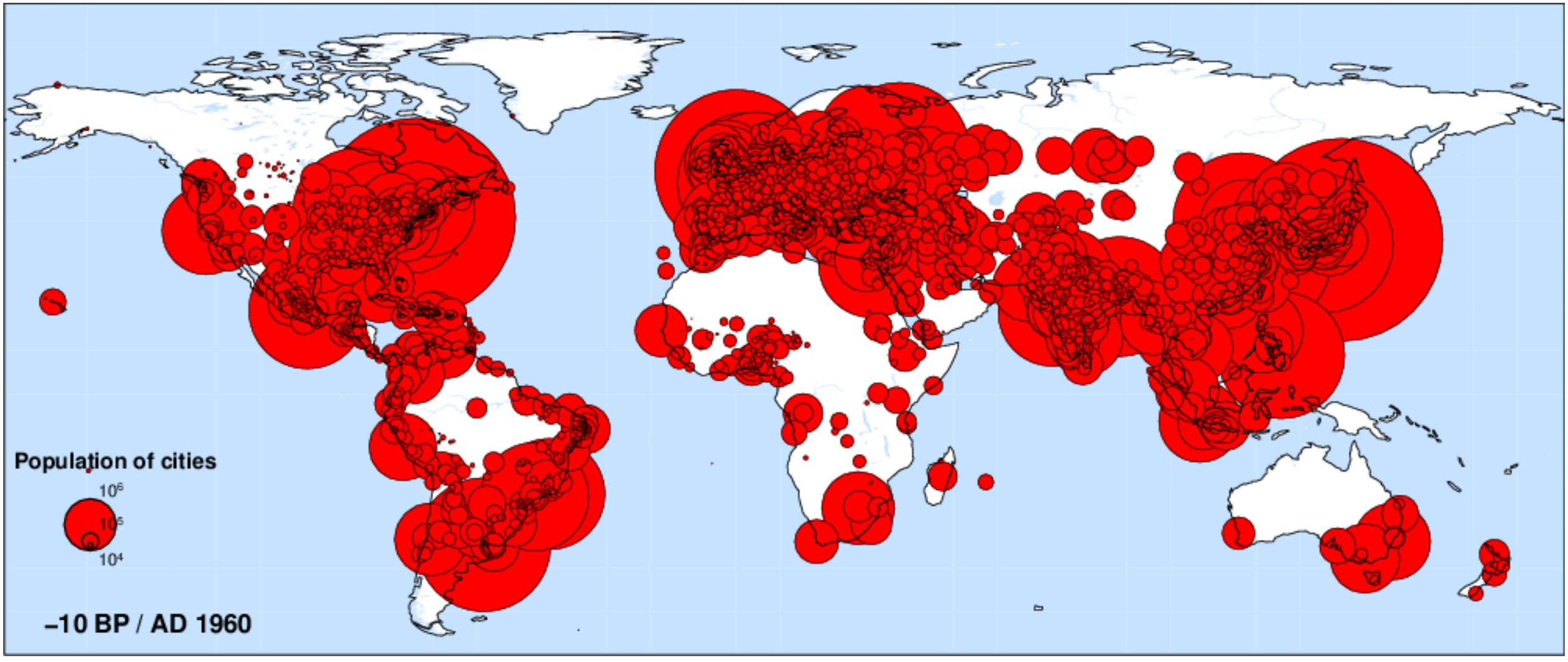

Population of cities
10^6
10^5
10^4
40 BP / AD 1910

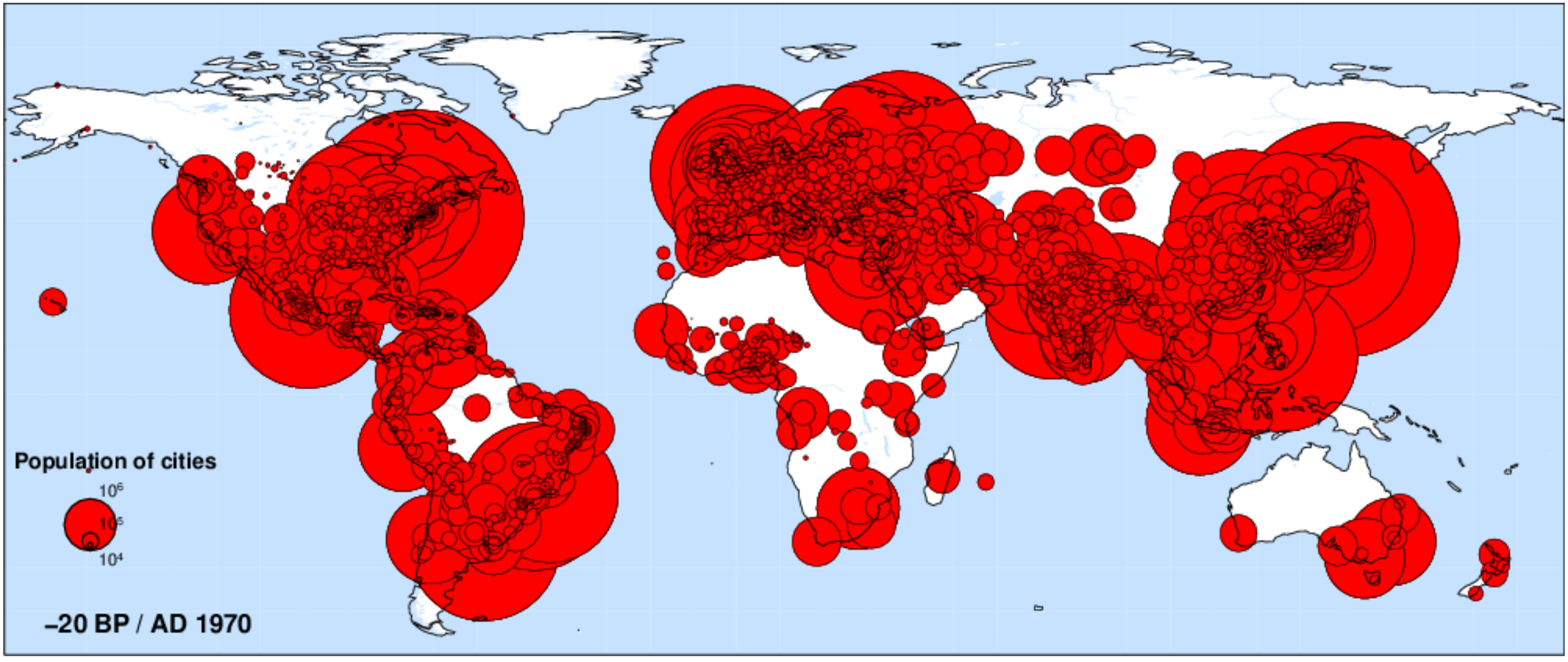

Population of cities
10^6
10^5
10^4
30 BP / AD 1920

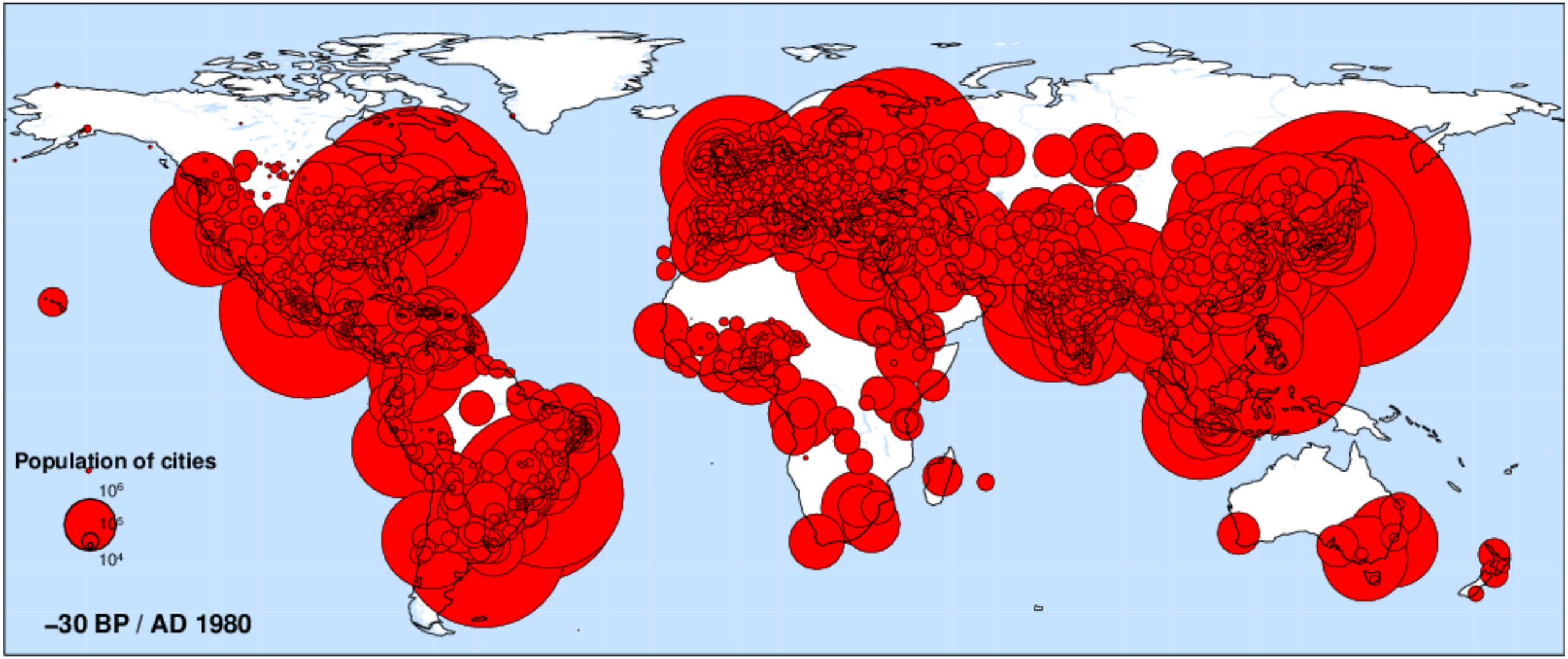

Population of cities
10^6
10^5
10^4
20 BP / AD 1930

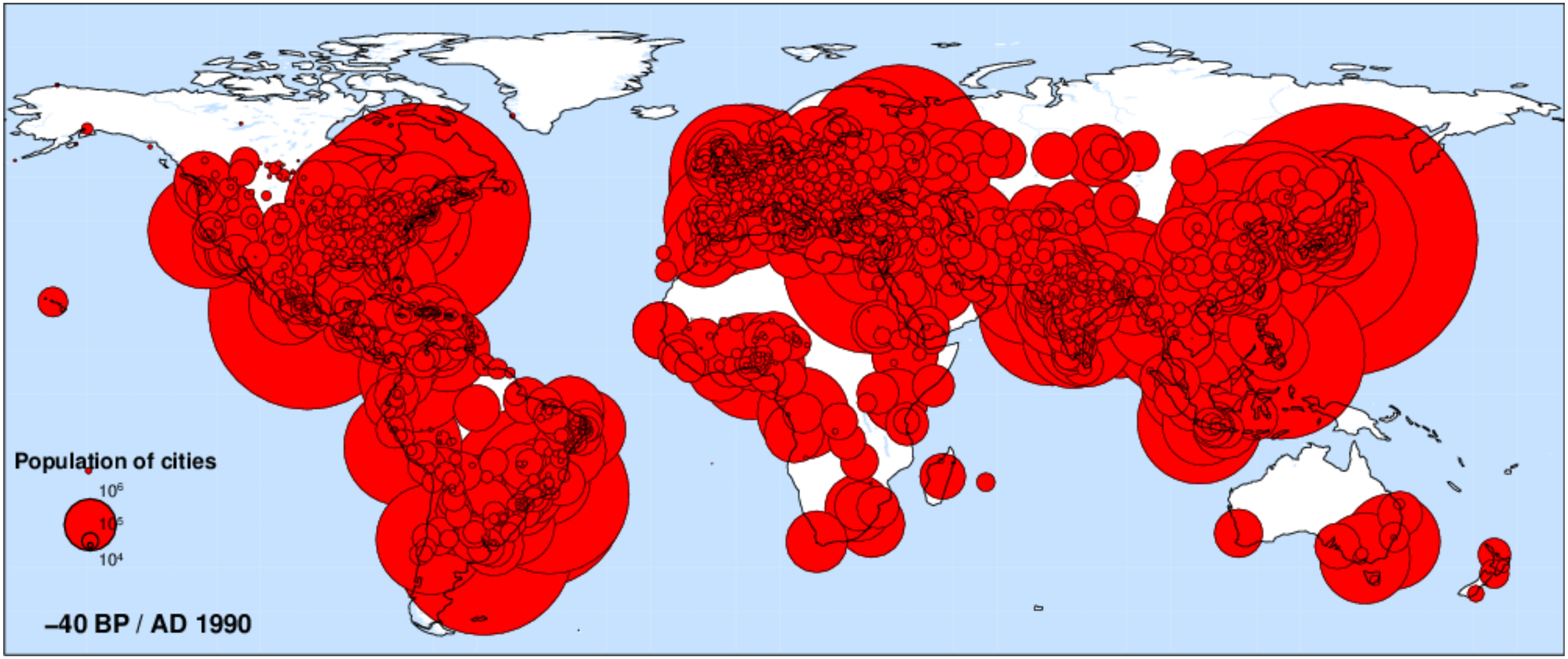

Population of cities
10^6
10^5
10^4
10 BP / AD 1940

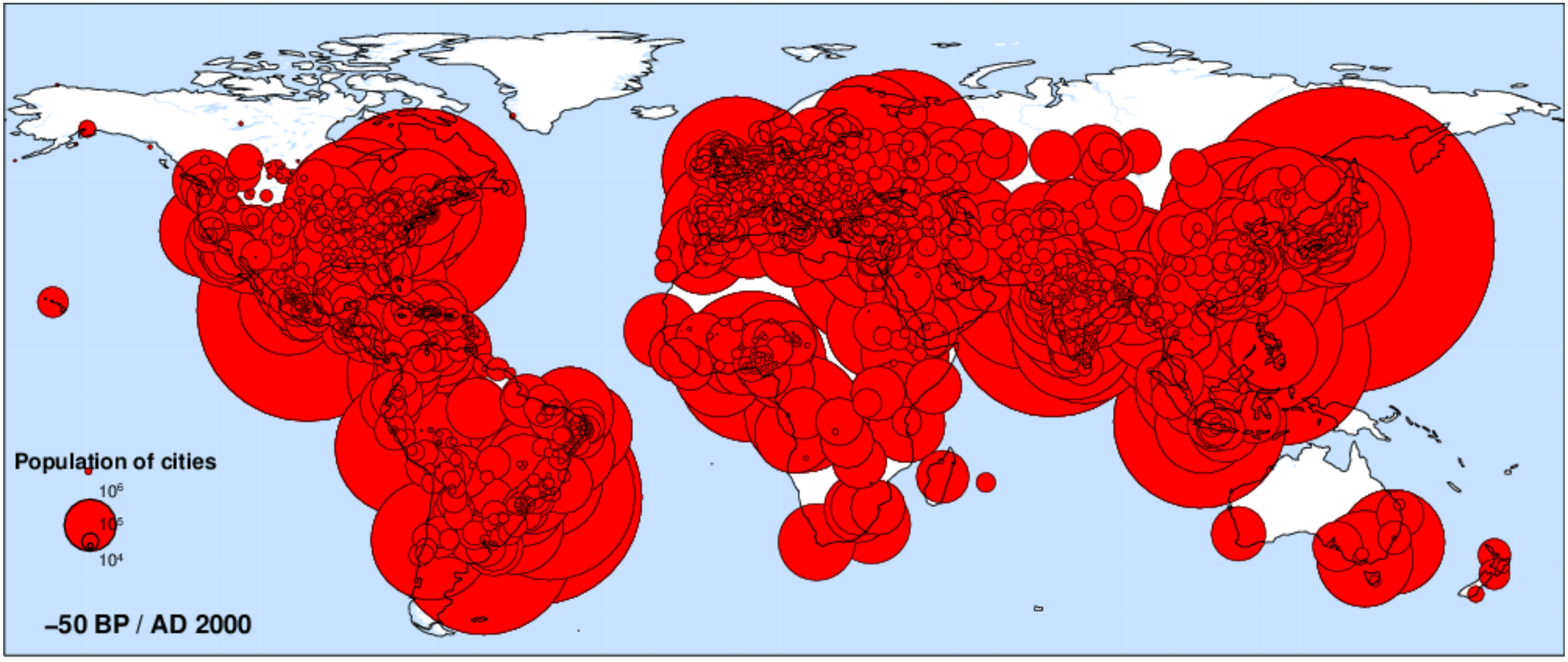

Population of cities
10^6
10^5
10^4
0 BP / AD 1950

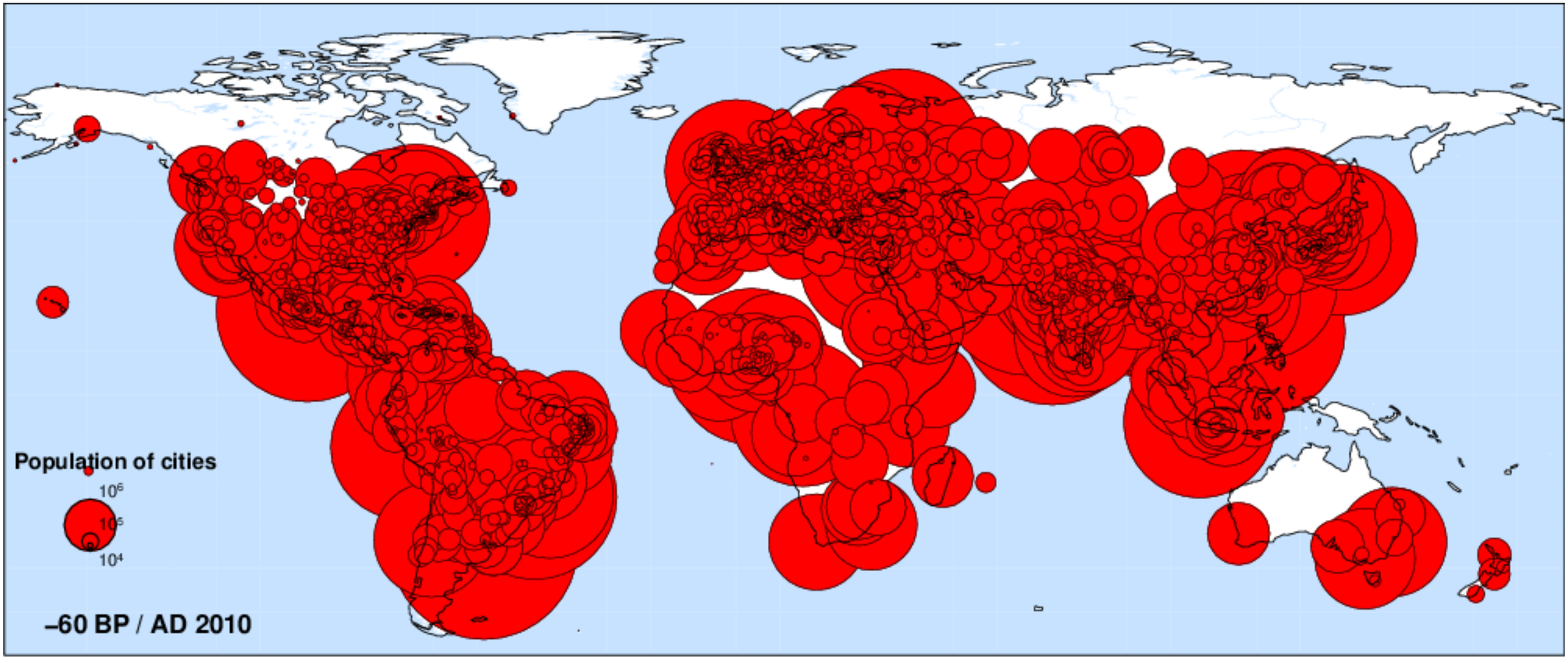

Population of cities
10^6
10^5
10^4
–10 BP / AD 1960


Population of cities
10^6
10^5
10^4
–20 BP / AD 1970

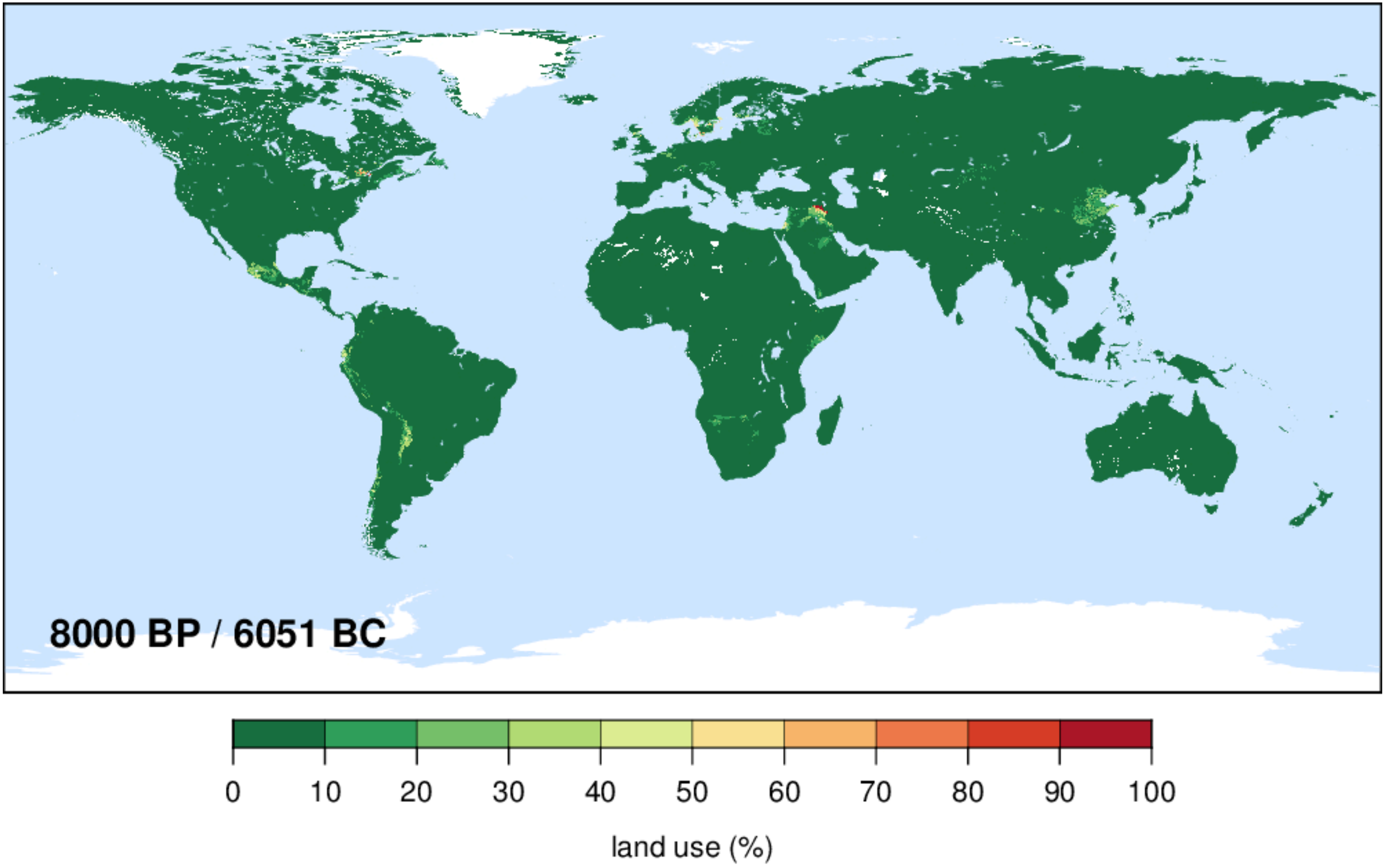

Population of cities
10^6
10^5
10^4
–30 BP / AD 1980


Population of cities
10^6
10^5
10^4
–40 BP / AD 1990


Population of cities
10^6
10^5
10^4
–50 BP / AD 2000

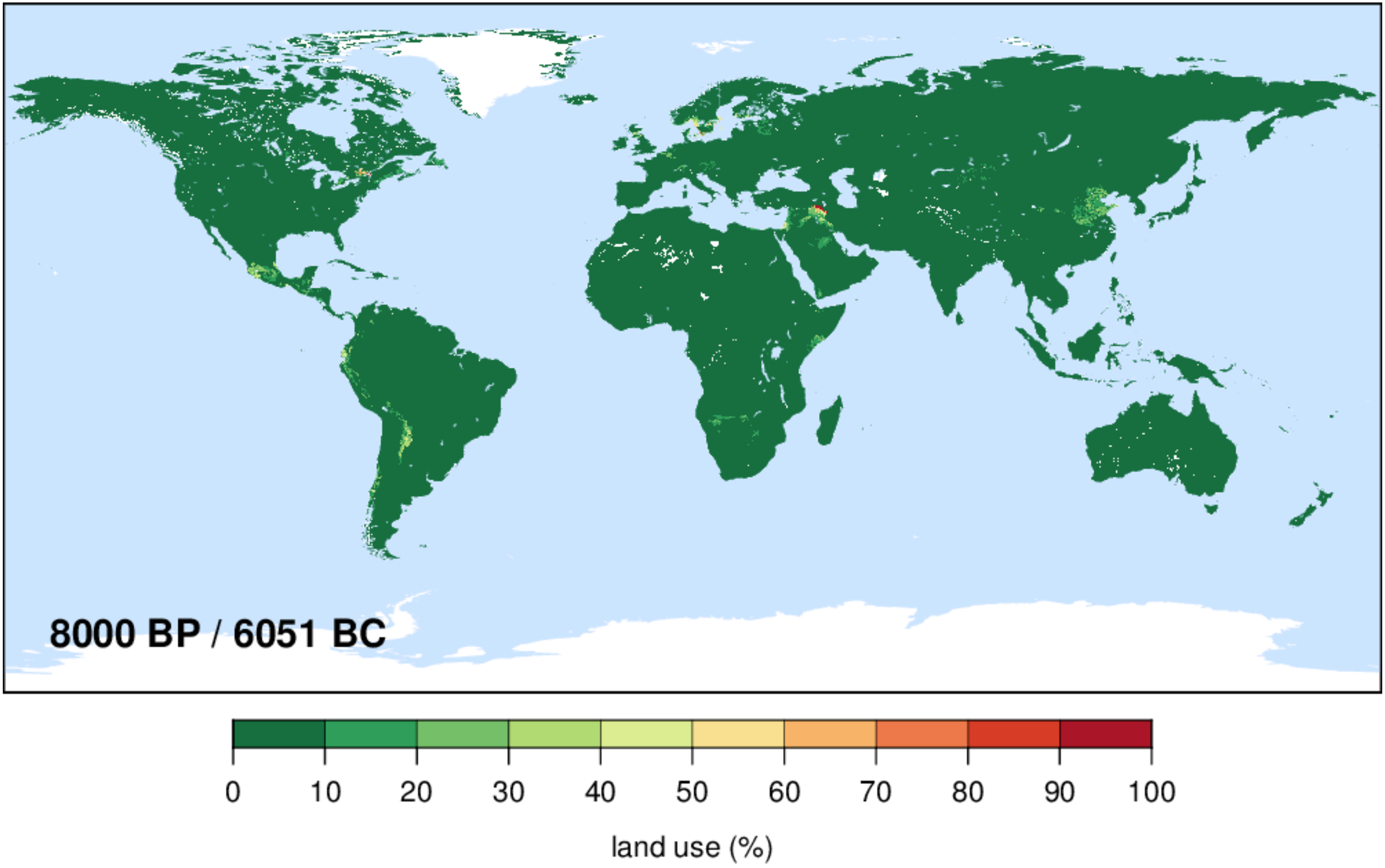

Population of cities
10^6
10^5
10^4
–60 BP / AD 2010

Anthropogenic land cover change

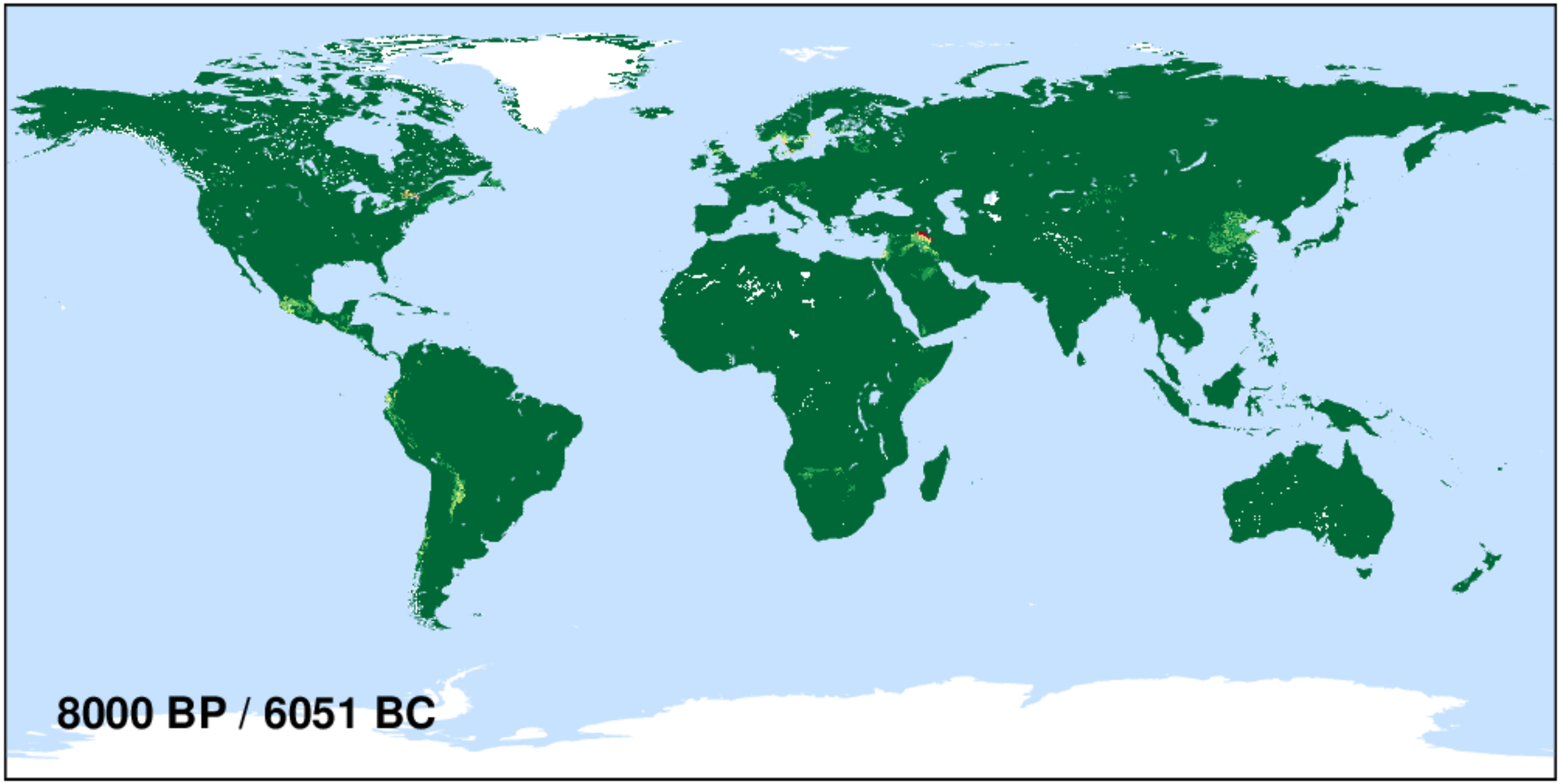


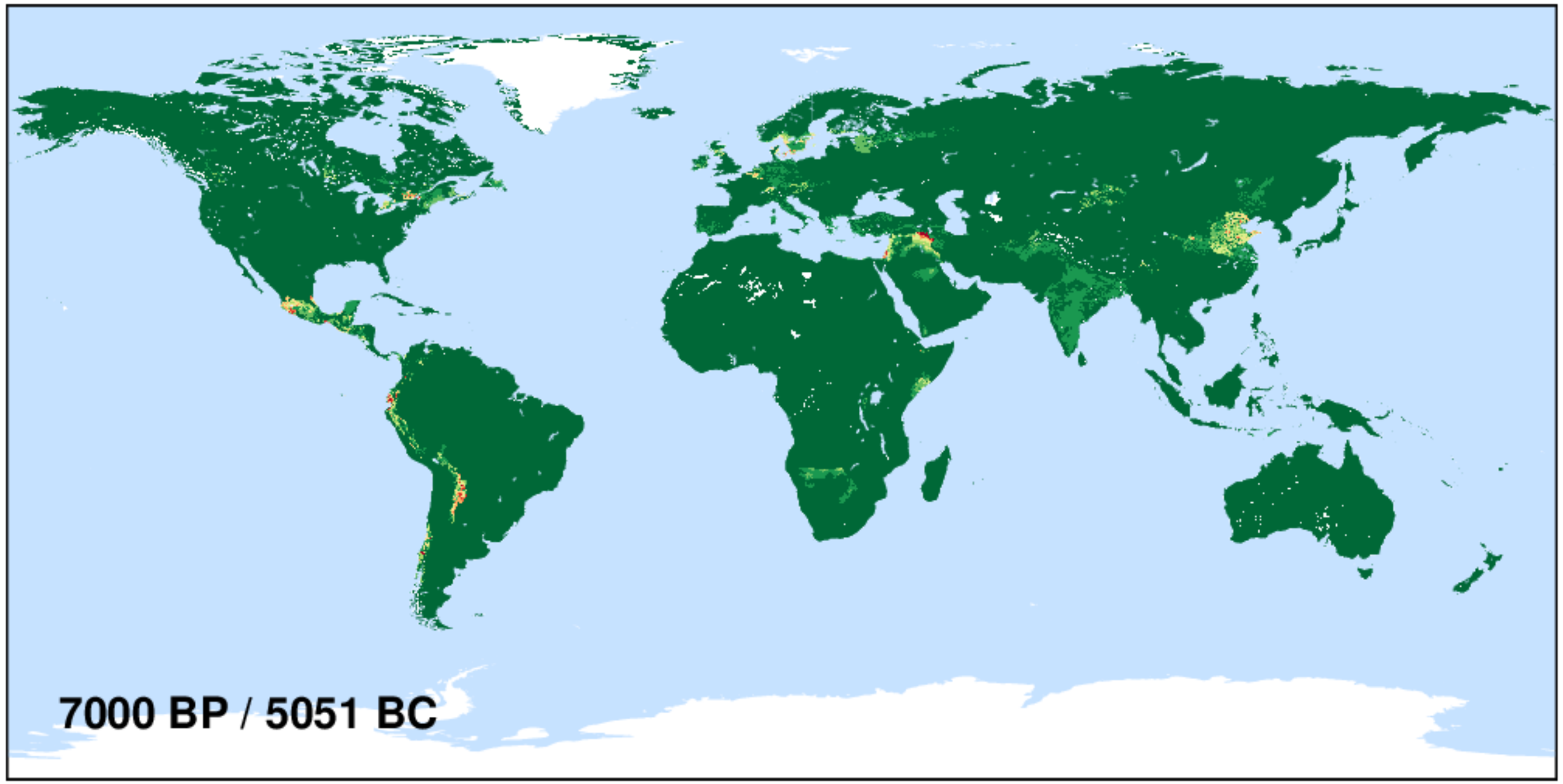
Kaplan et al., 2011

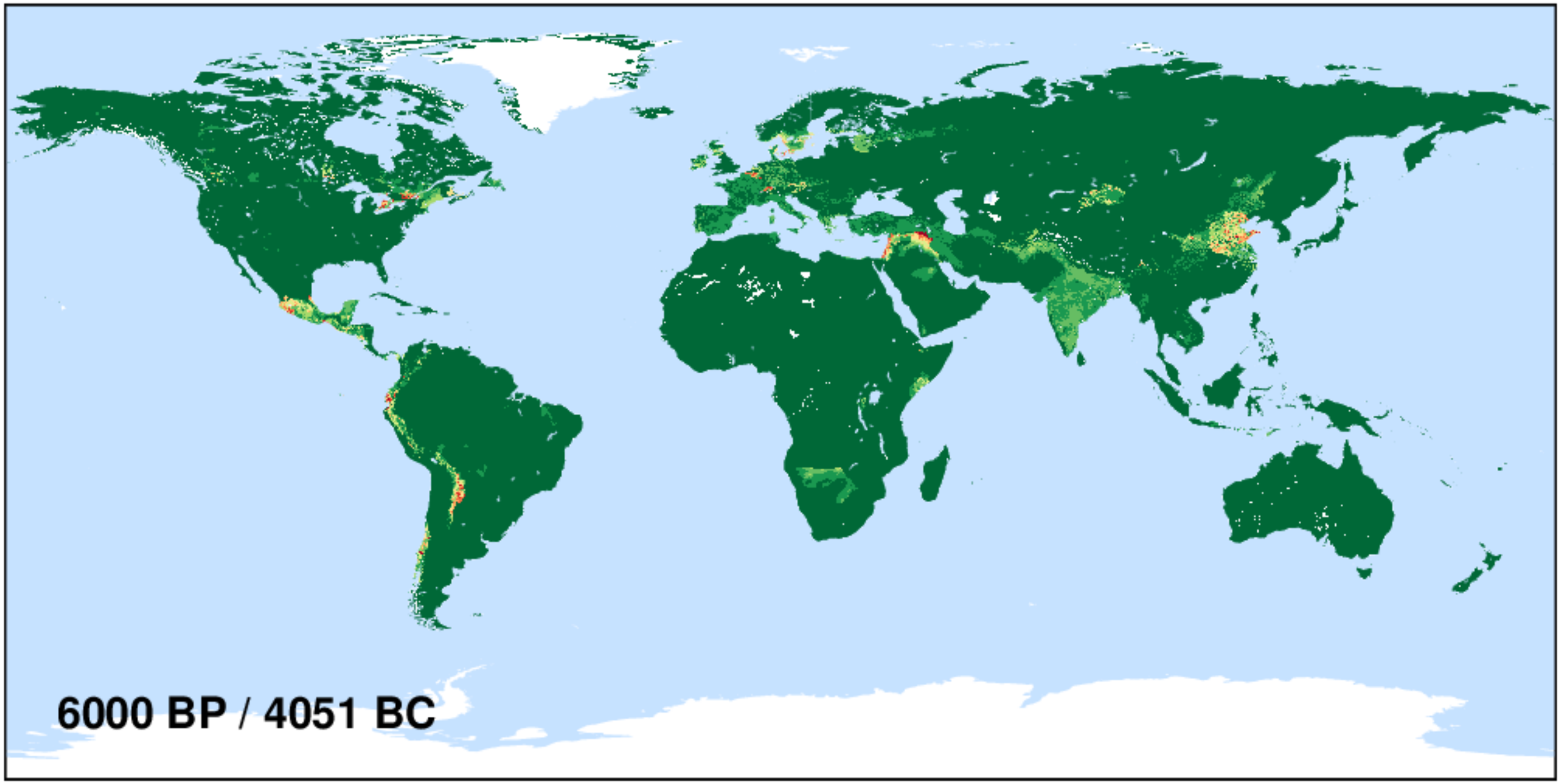
Anthropogenic land cover change

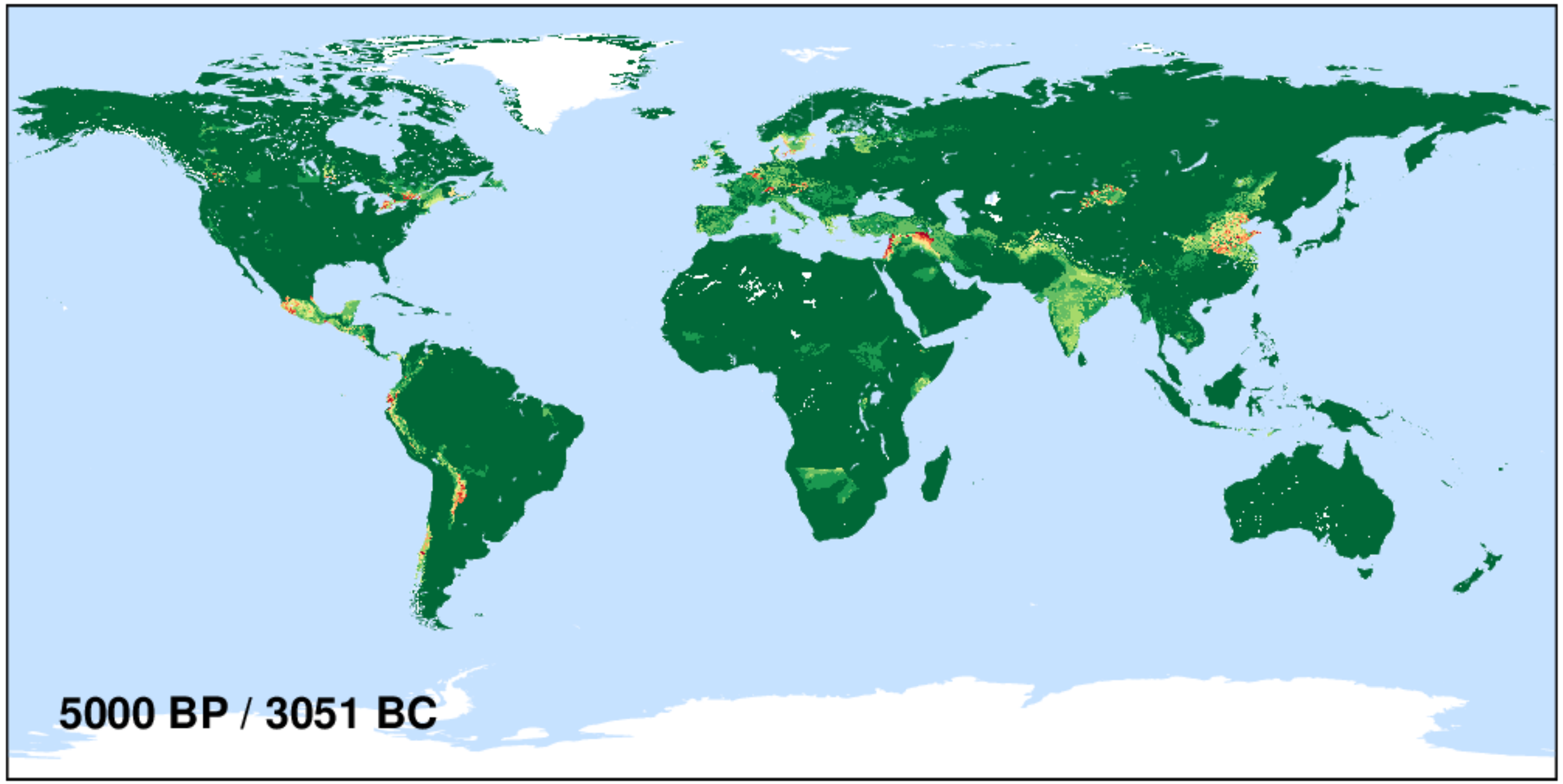


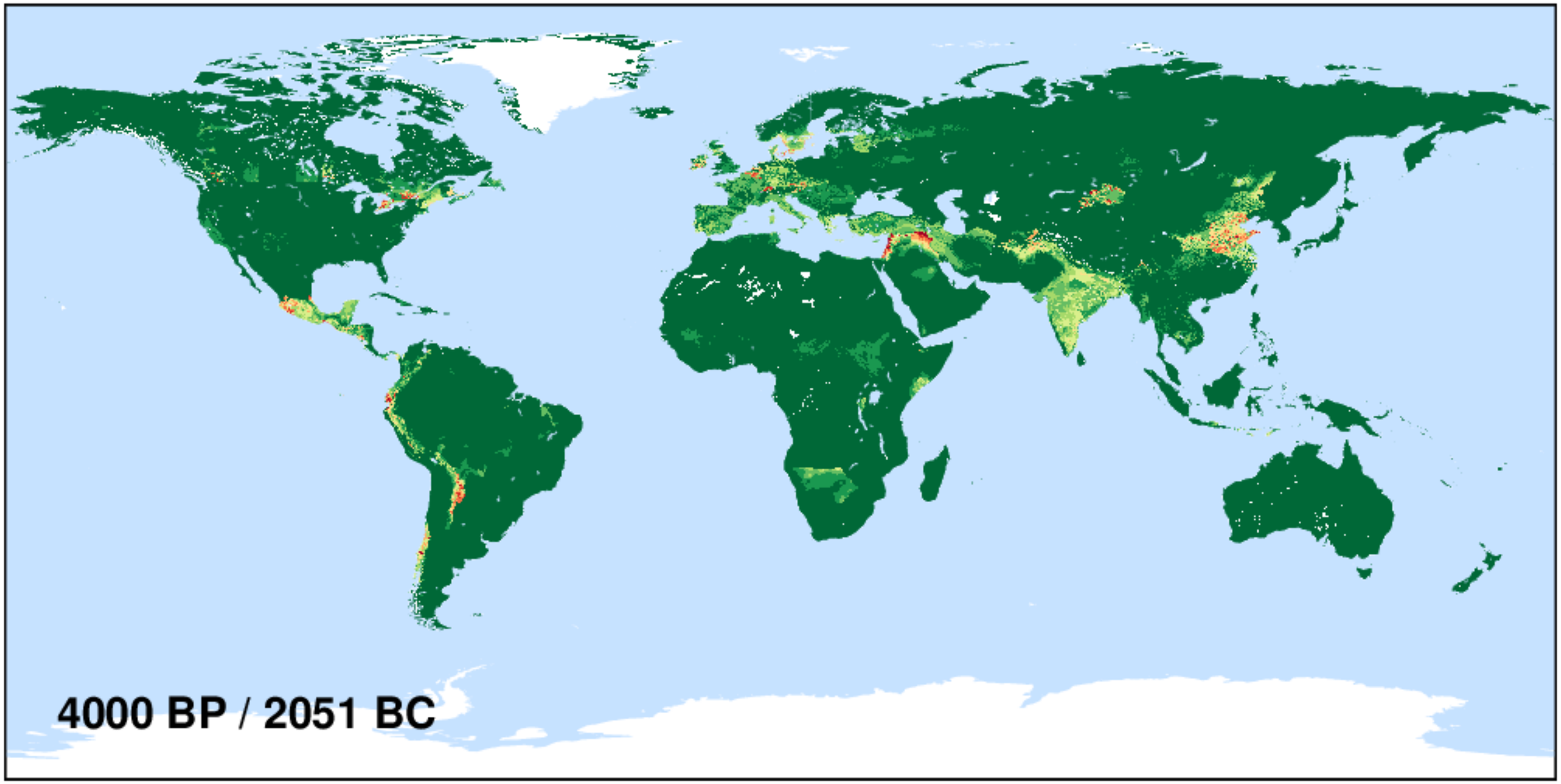
Kaplan et al., 2011

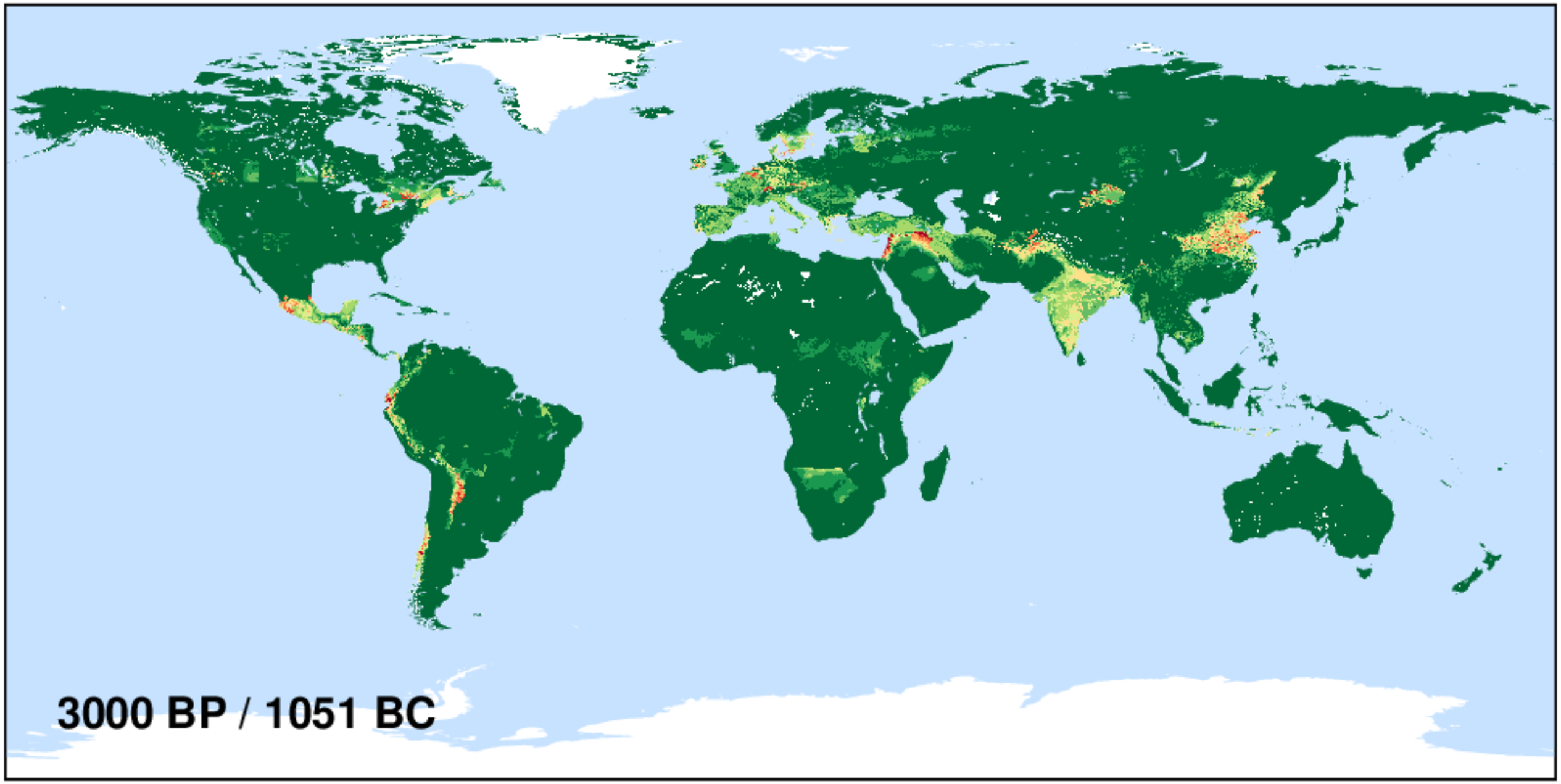

8000 BP / 6051 BC
0
10
20
30
40
50
60
70
80
90
100
land use (%)

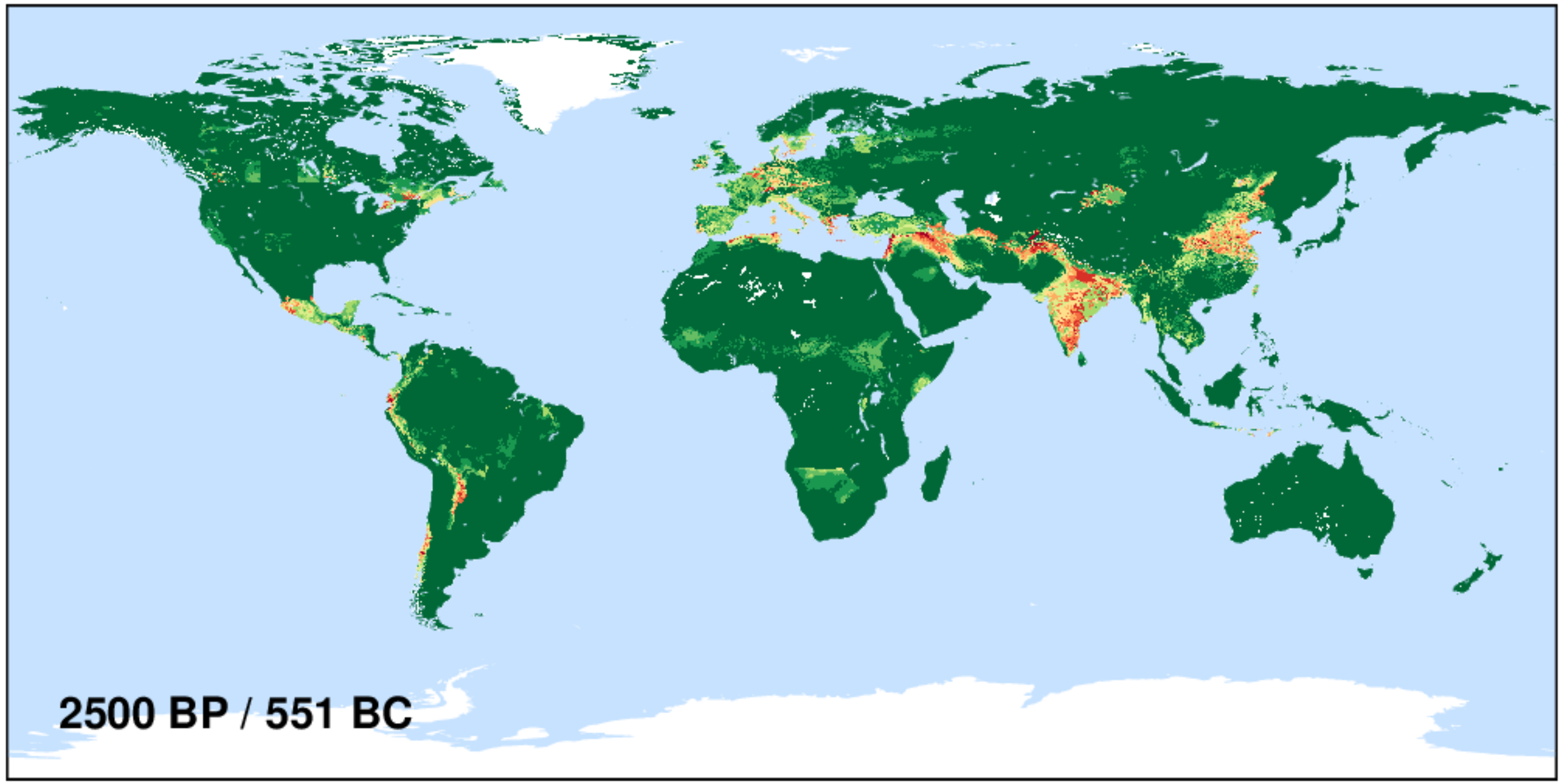

7000 BP / 5051 BC
0
10
20
30
40
50
60
70
80
90
100
land use (%)

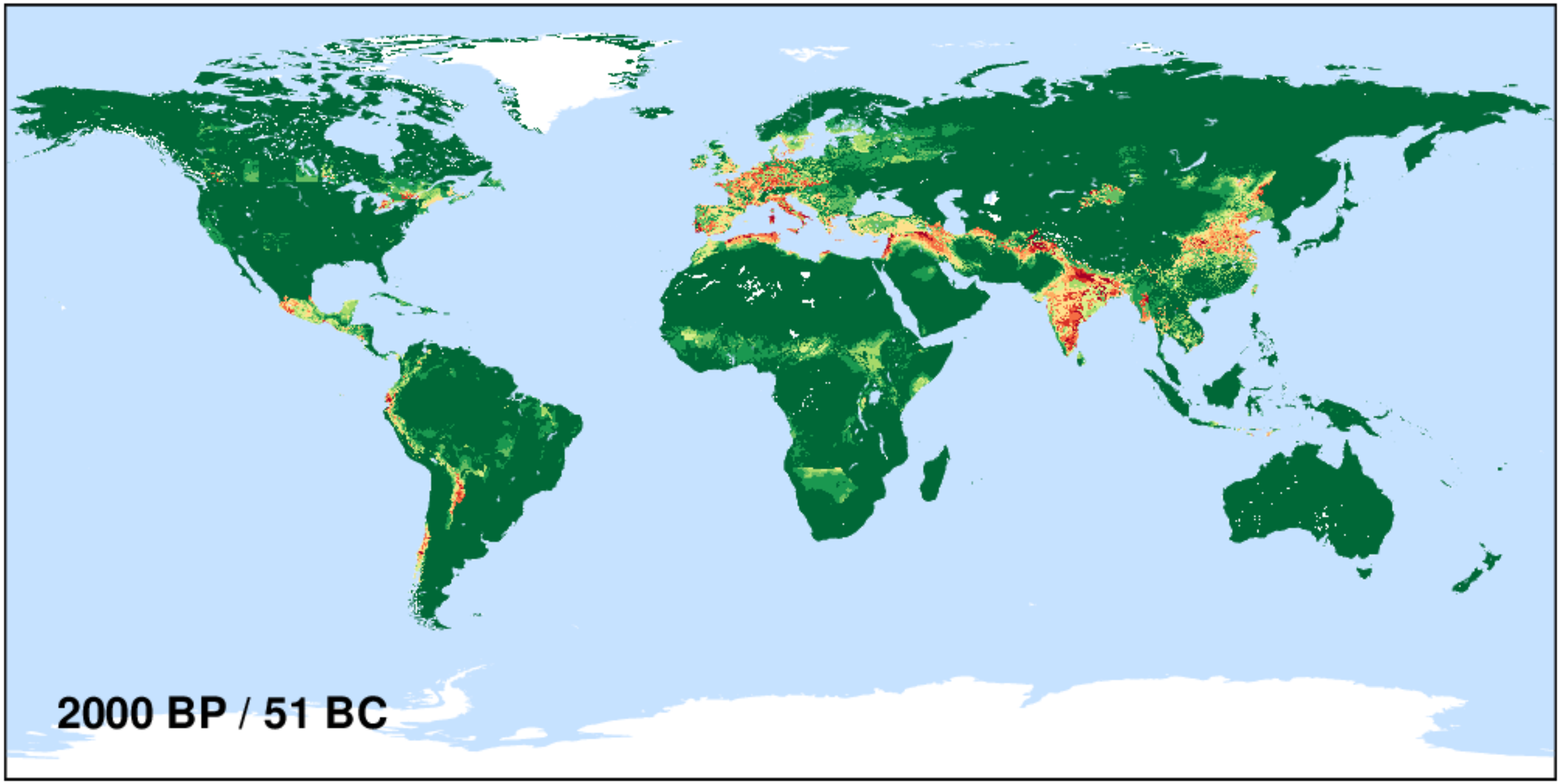

6000 BP / 4051 BC
0
10
20
30
40
50
60
70
80
90
100
land use (%)

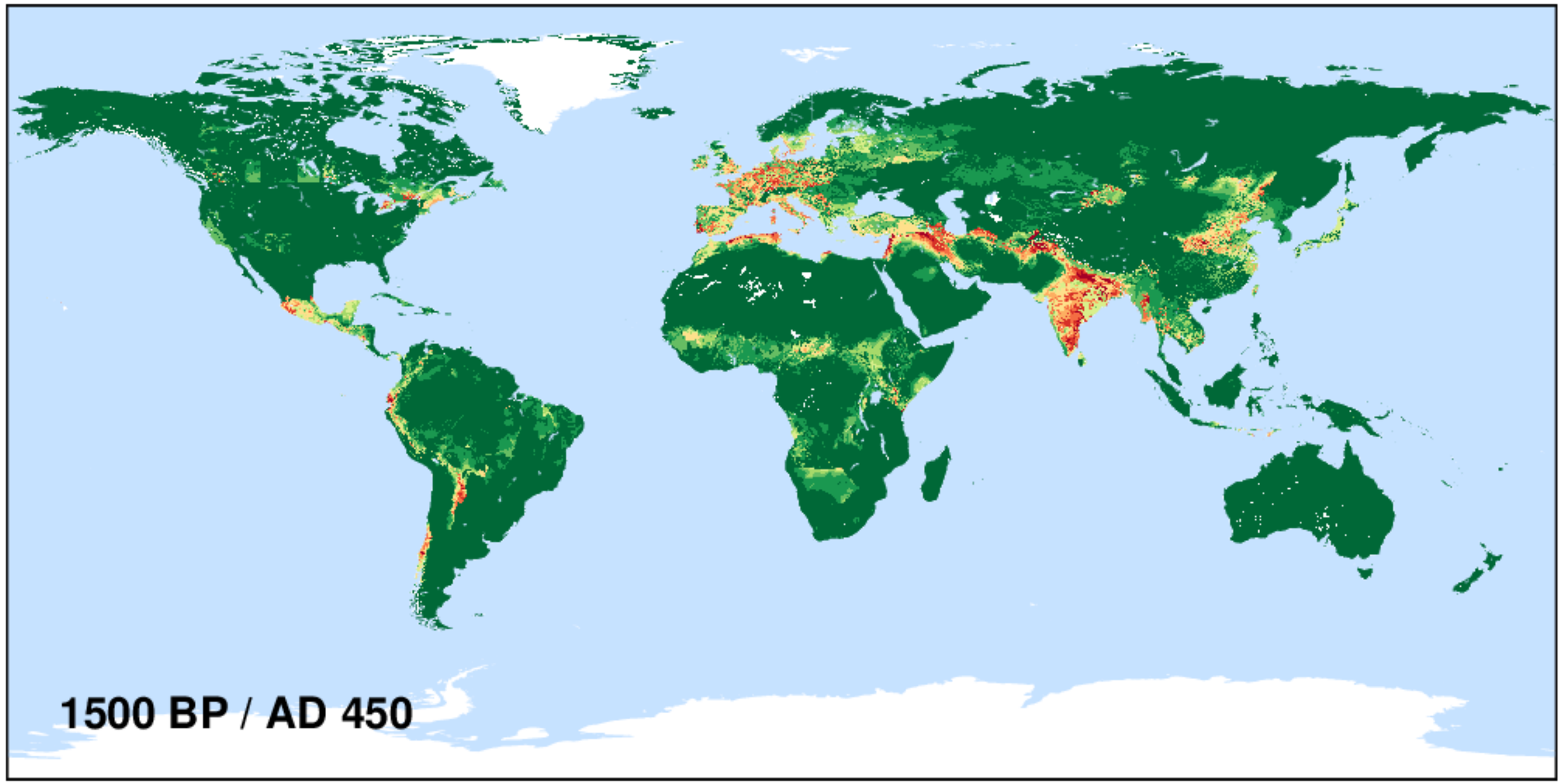

5000 BP / 3051 BC
0
10
20
30
40
50
60
70
80
90
100
land use (%)

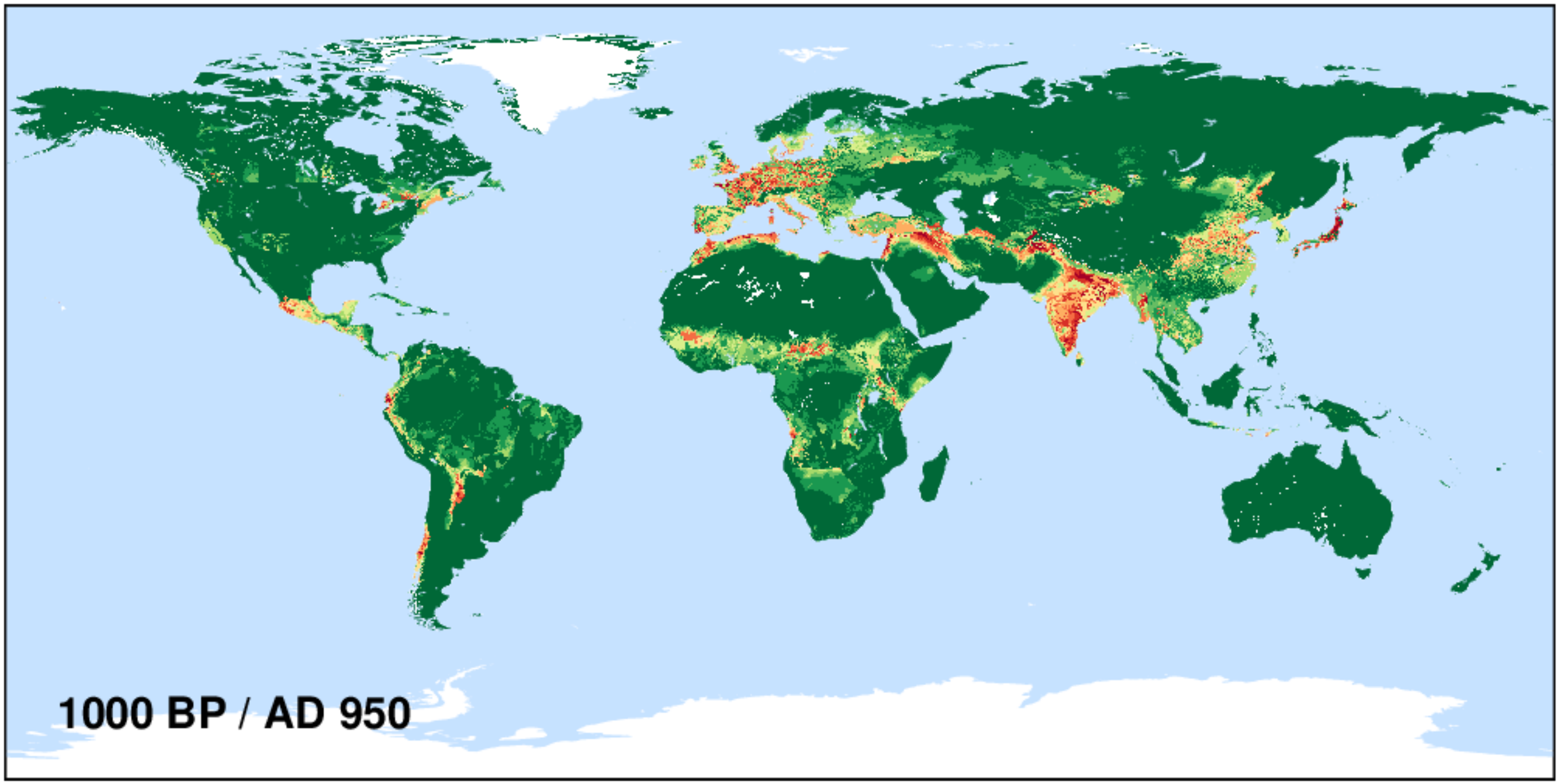

4000 BP / 2051 BC
0
10
20
30
40
50
60
70
80
90
100
land use (%)

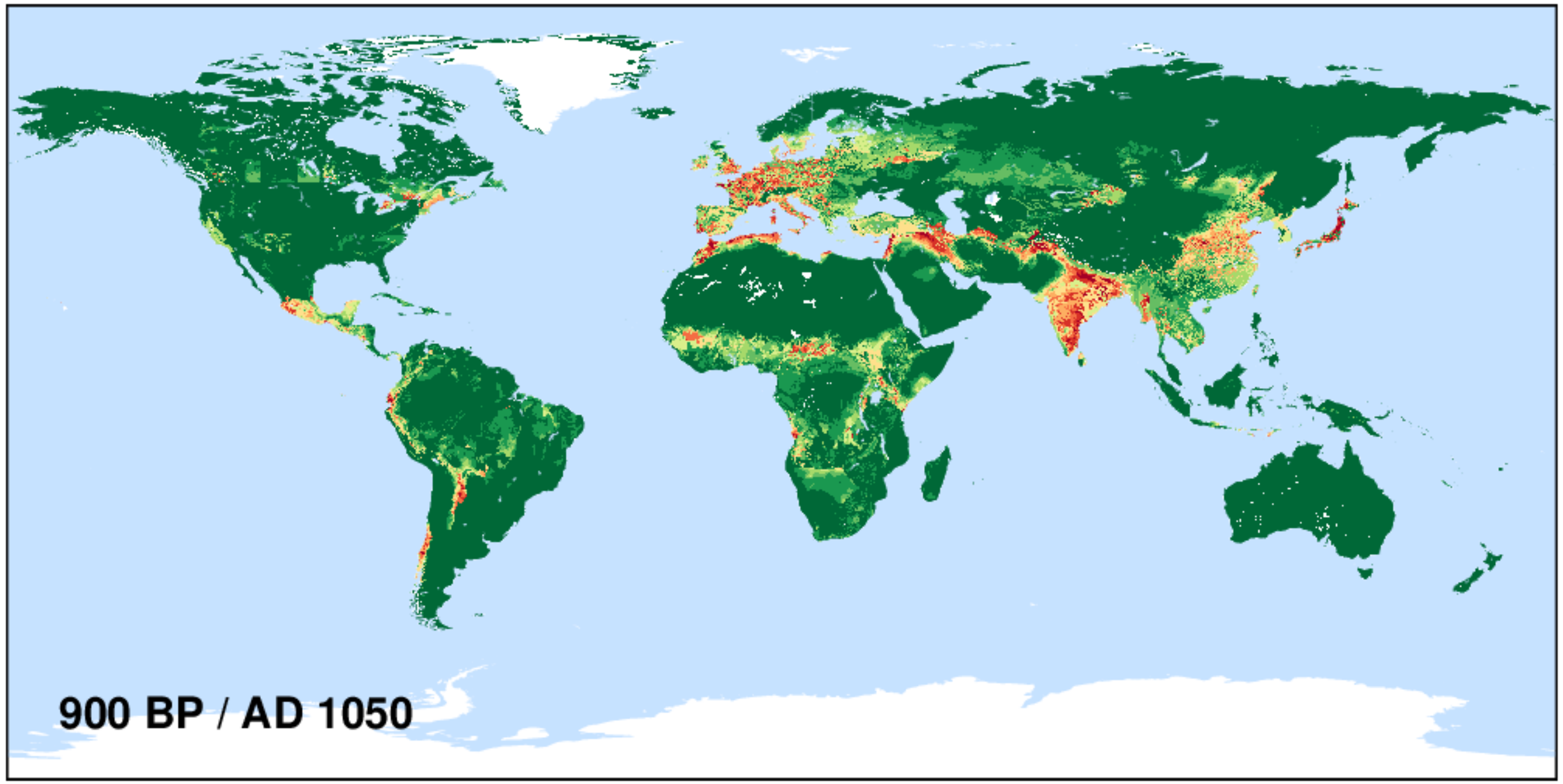

3000 BP / 1051 BC
0
10
20
30
40
50
60
70
80
90
100
land use (%)

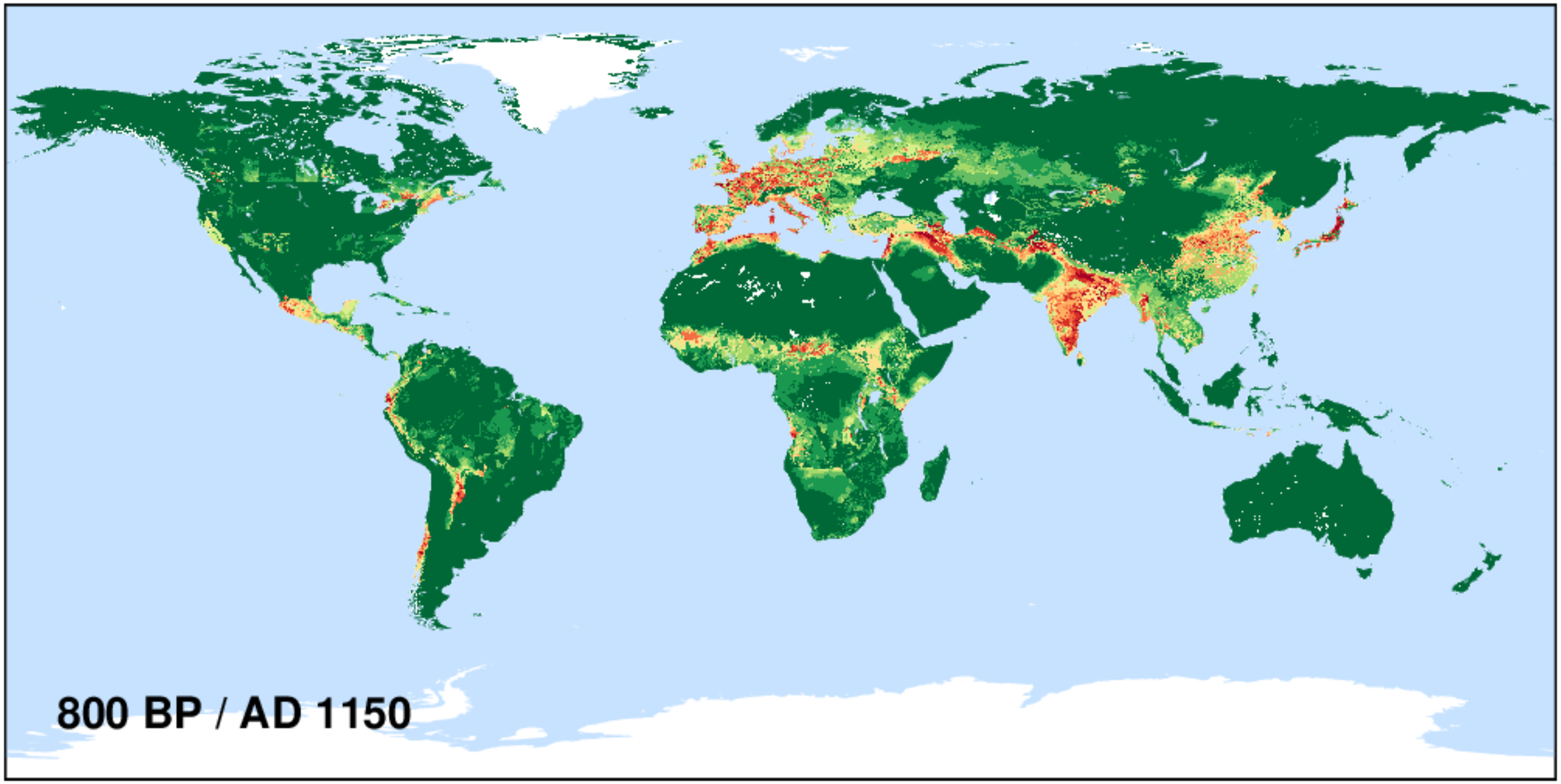

2500 BP / 551 BC
0
10
20
30
40
50
60
70
80
90
100
land use (%)

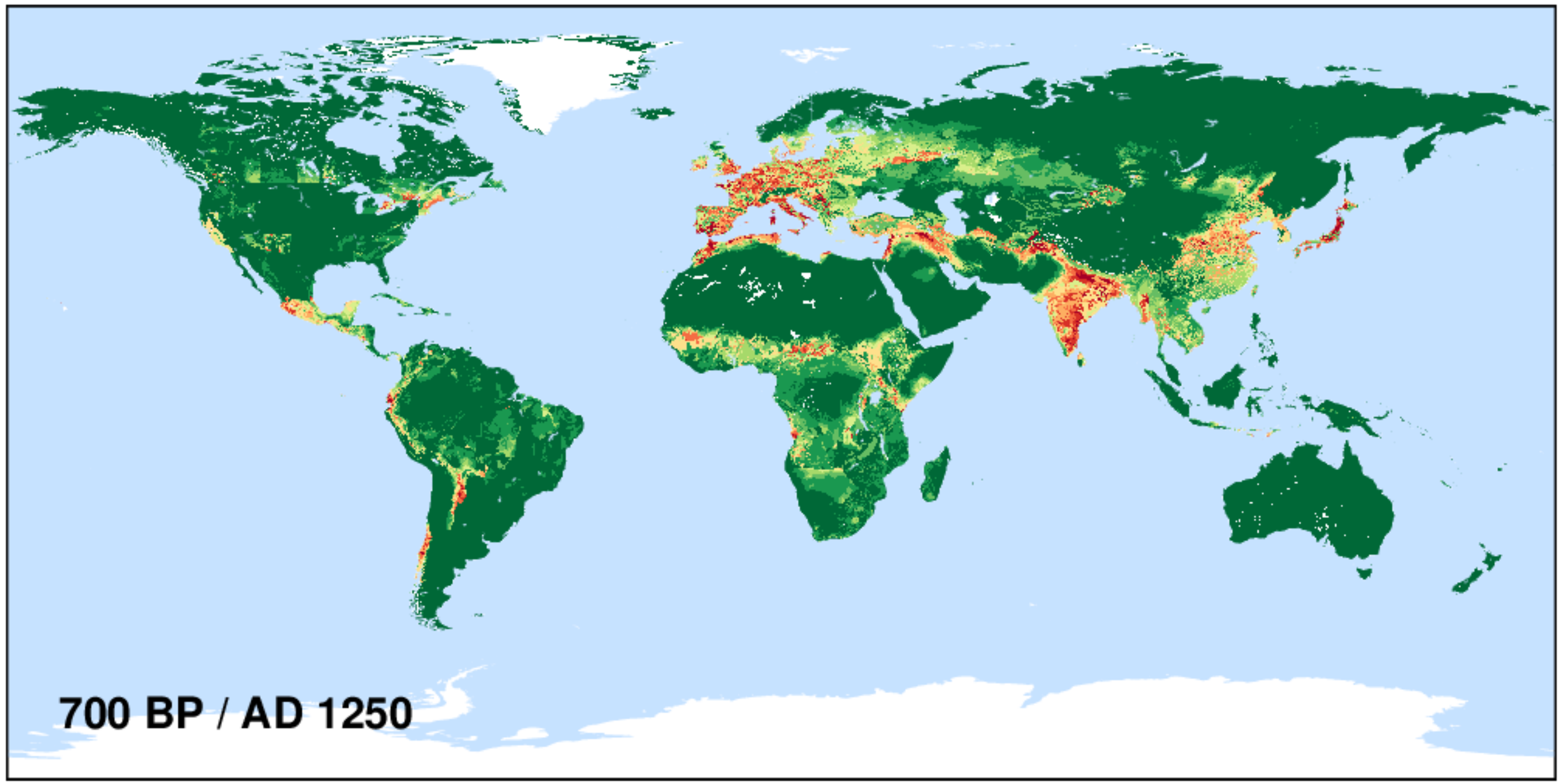

2000 BP / 51 BC
0
10
20
30
40
50
60
70
80
90
100
land use (%)

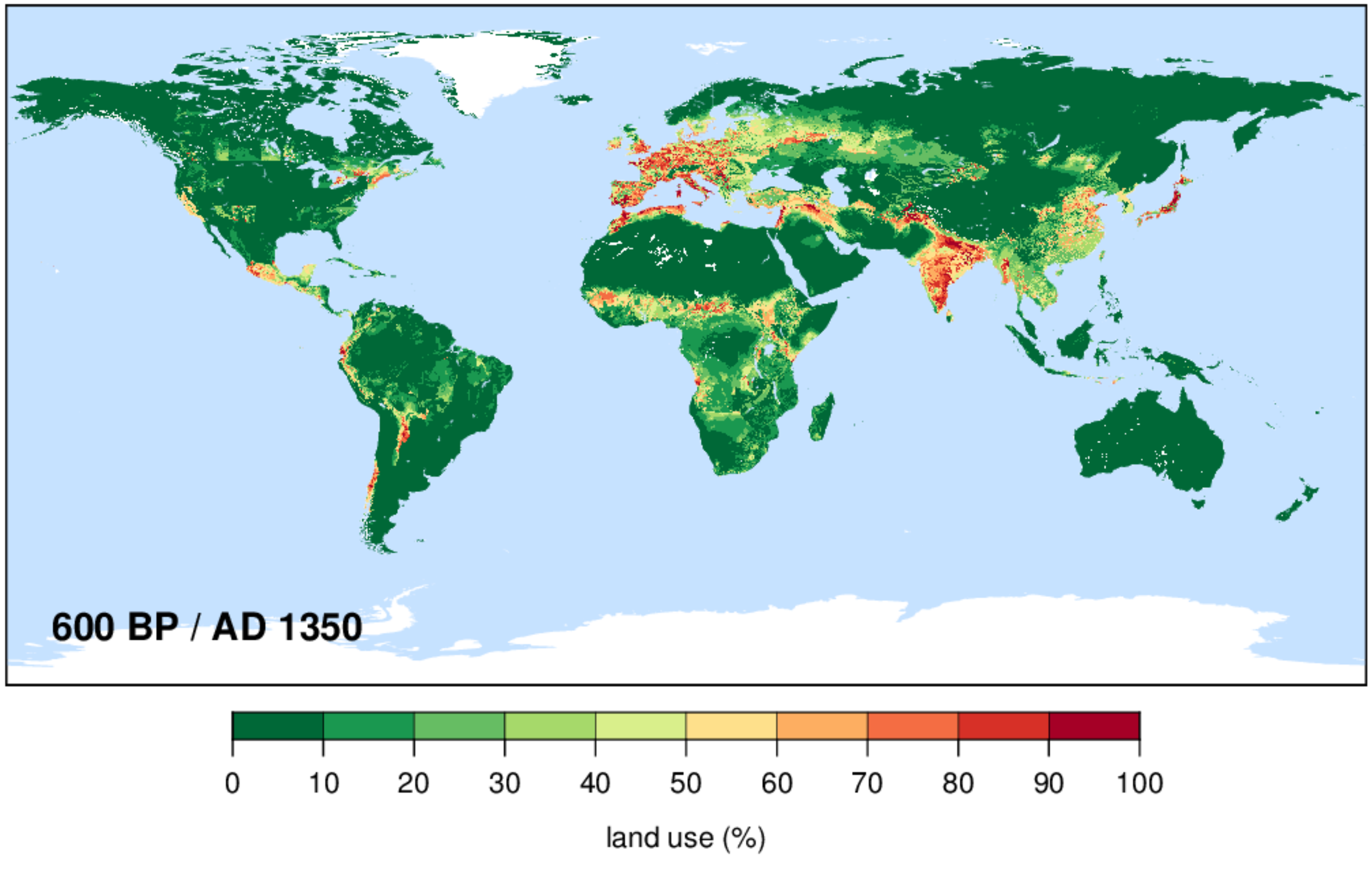

1500 BP / AD 450
0
10
20
30
40
50
60
70
80
90
100
land use (%)

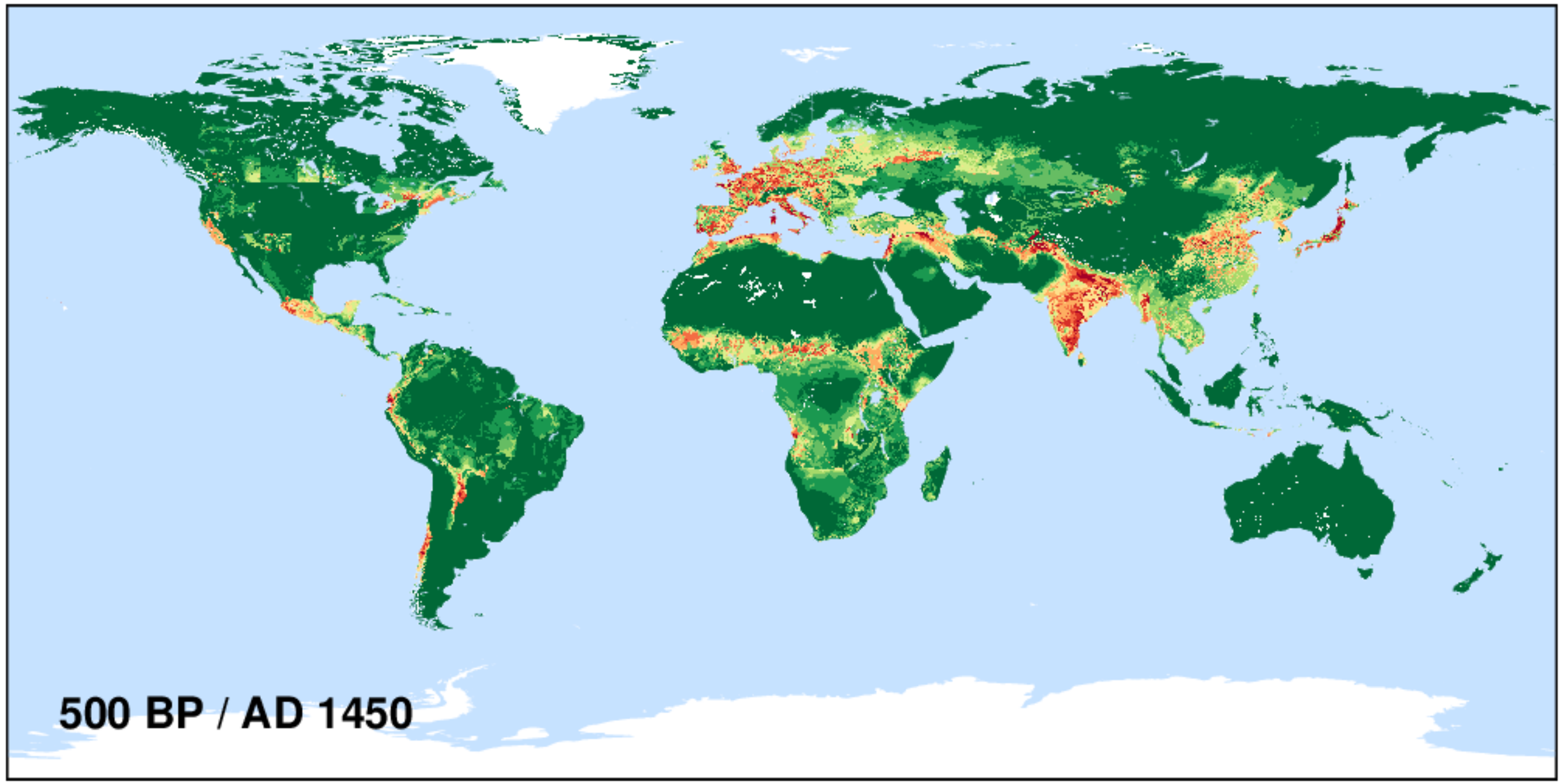

1000 BP / AD 950
0
10
20
30
40
50
60
70
80
90
100
land use (%)

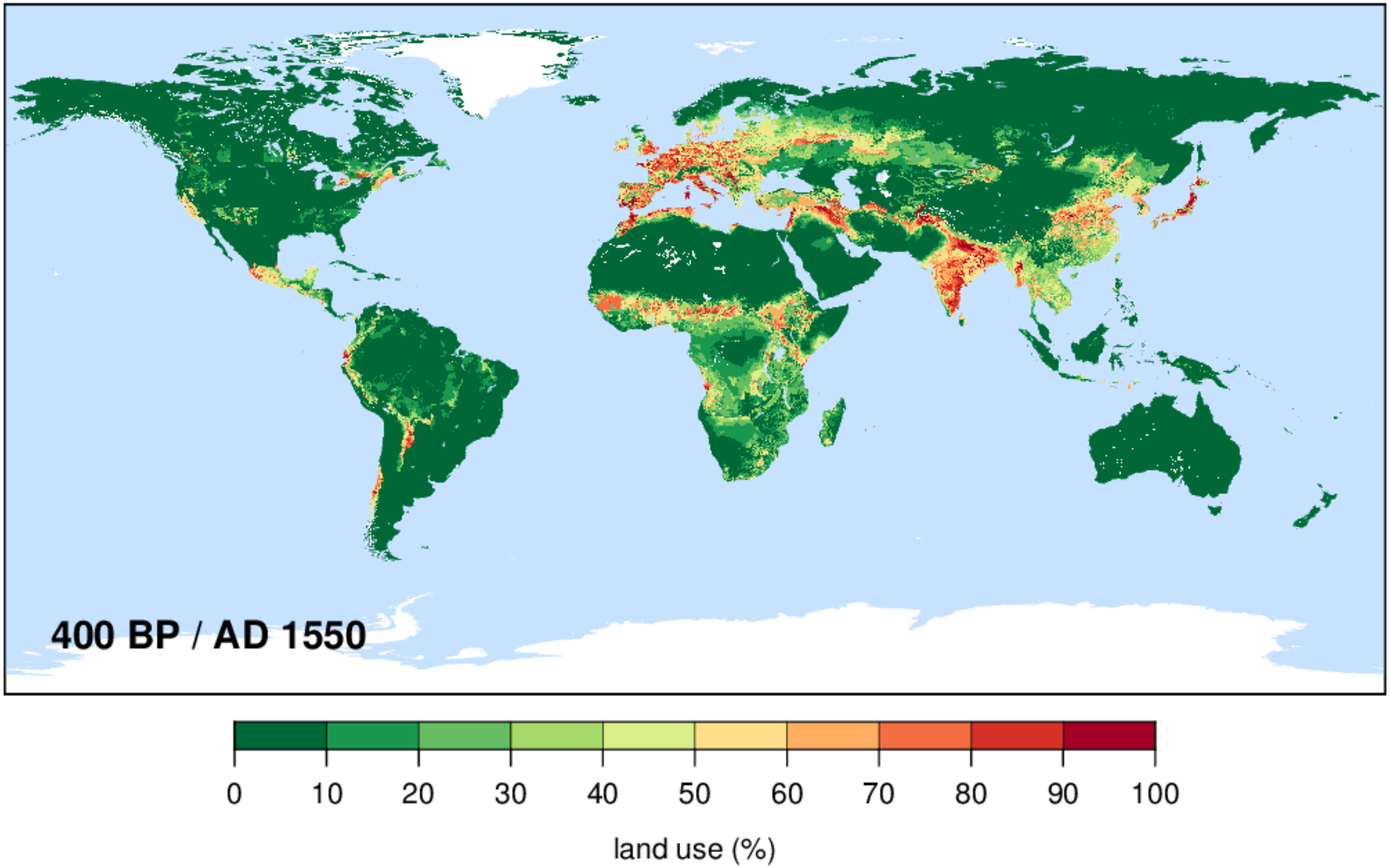

900 BP / AD 1050
0
10
20
30
40
50
60
70
80
90
100
land use (%)

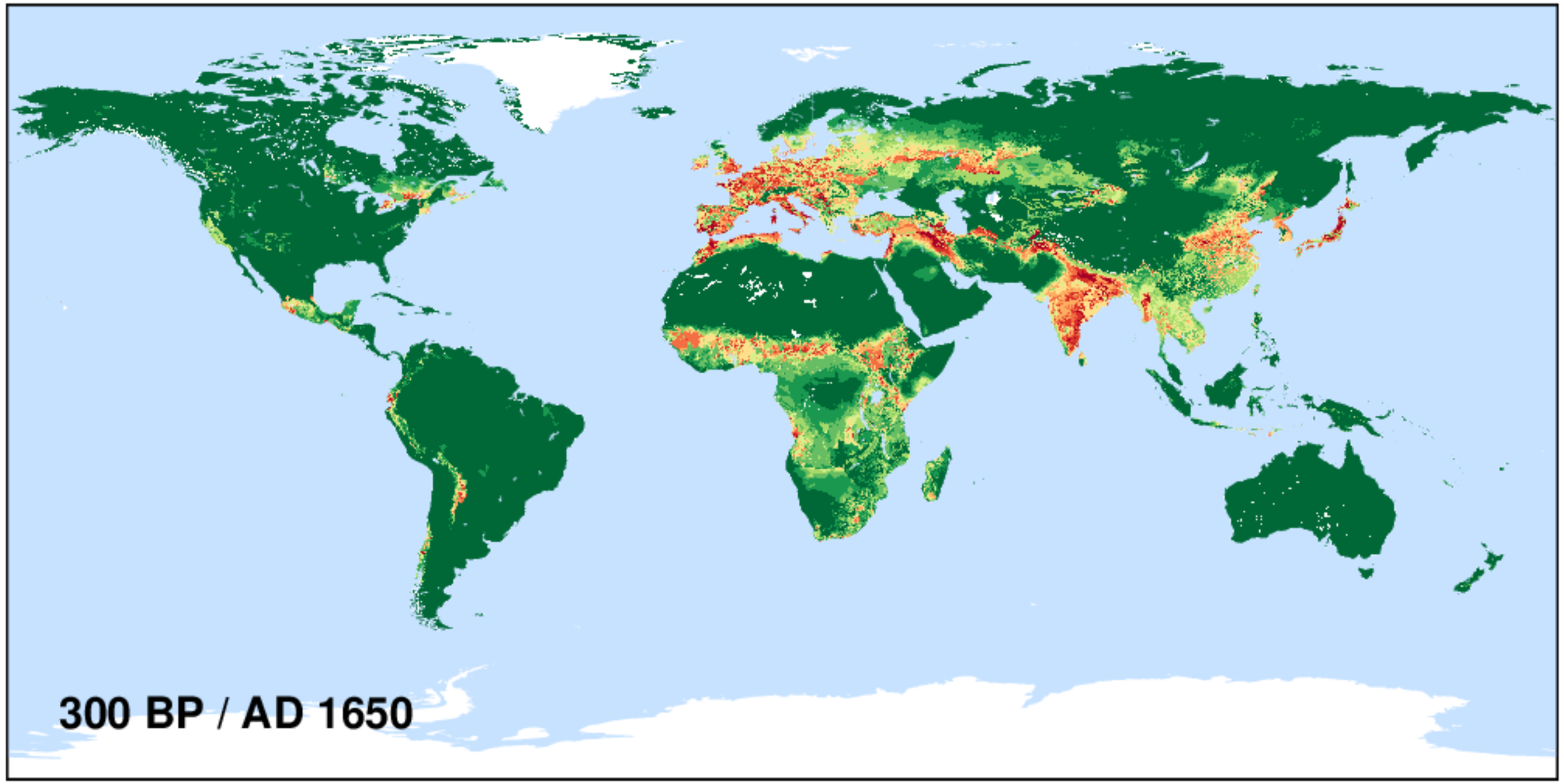

800 BP / AD 1150
0
10
20
30
40
50
60
70
80
90
100
land use (%)

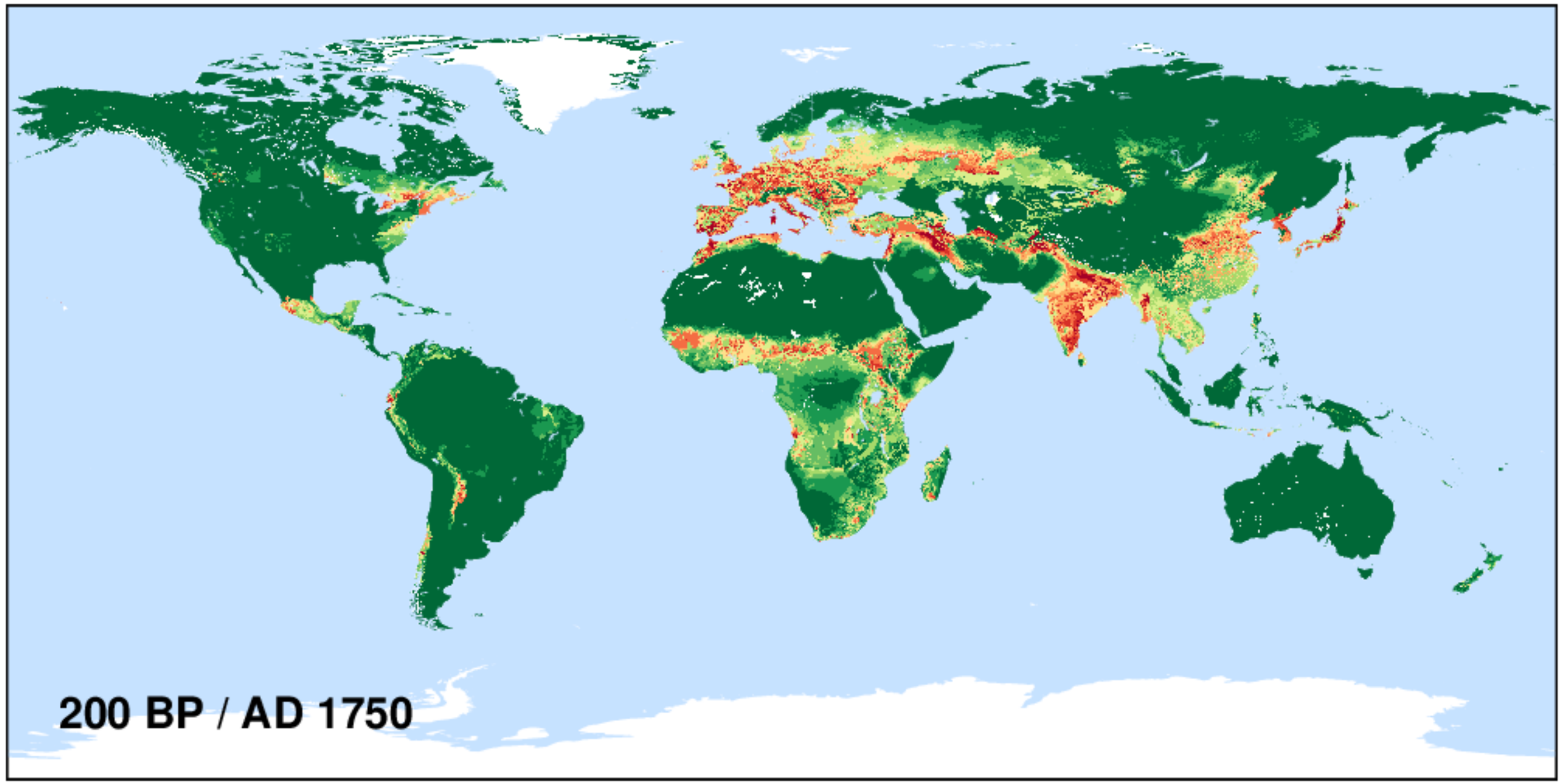

700 BP / AD 1250
0
10
20
30
40
50
60
70
80
90
100
land use (%)

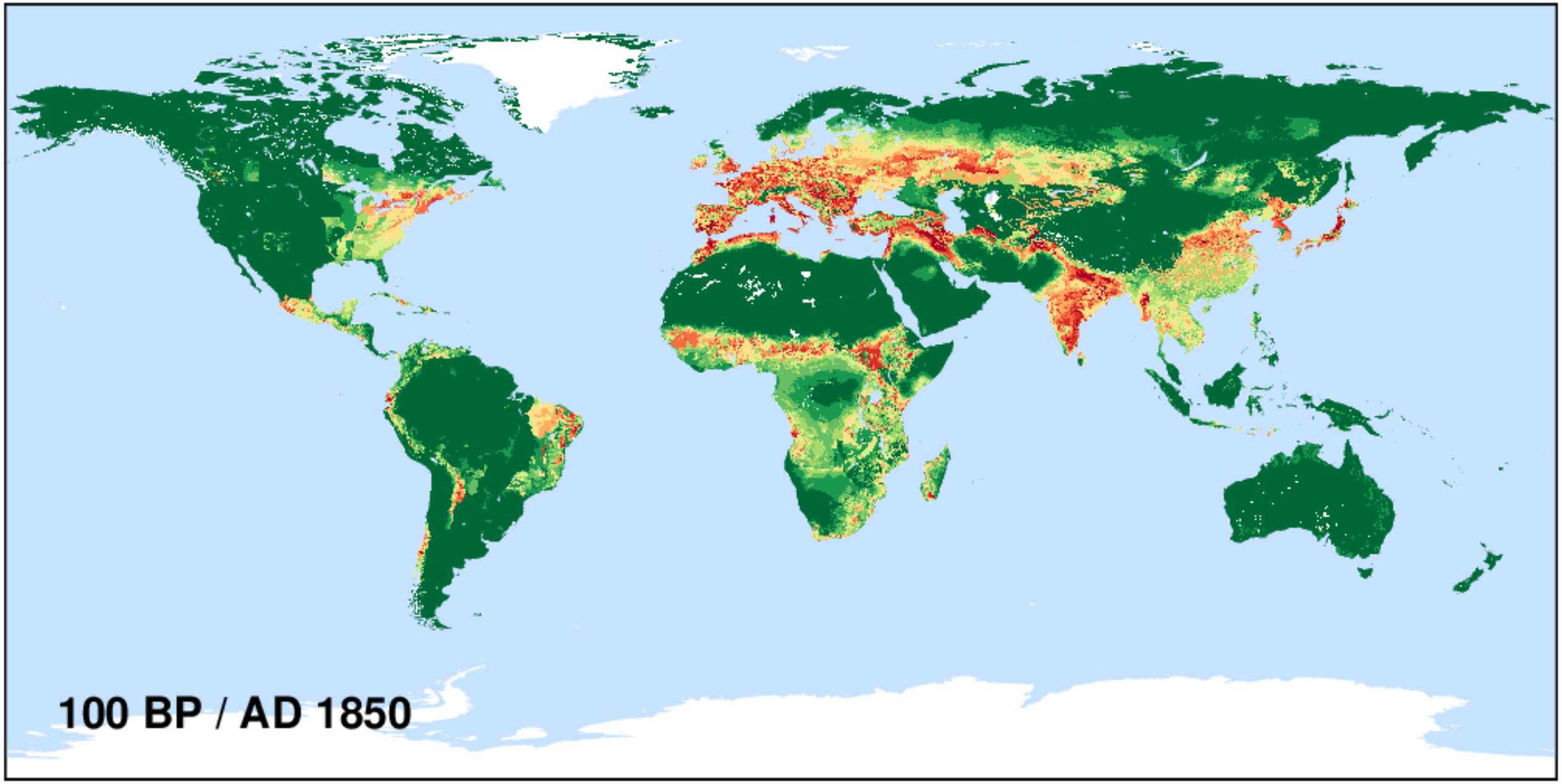

600 BP / AD 1350
0
10
20
30
40
50
60
70
80
90
100
land use (%)


500 BP / AD 1450
0
10
20
30
40
50
60
70
80
90
100
land use (%)

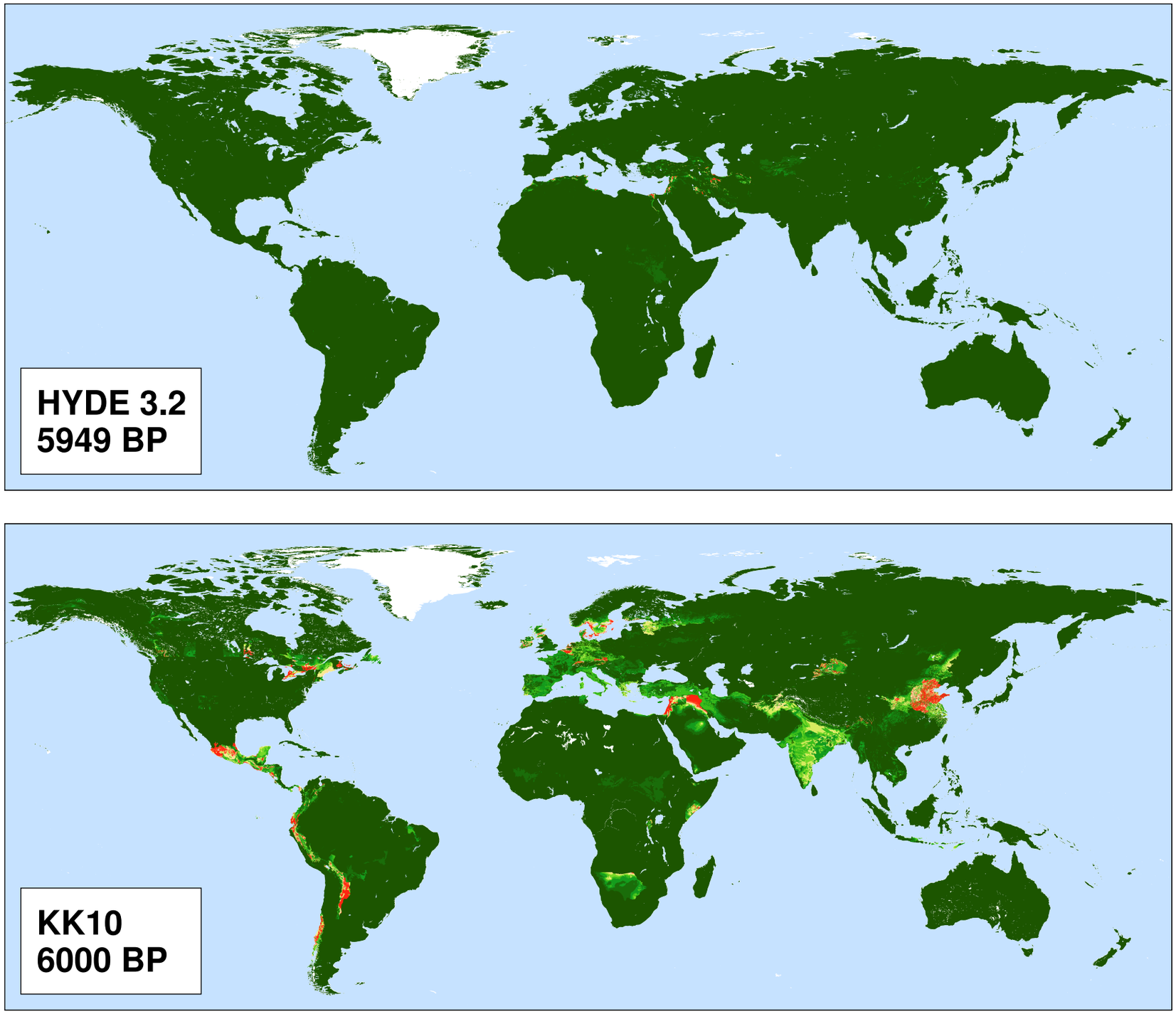

400 BP / AD 1550
0
10
20
30
40
50
60
70
80
90
100
land use (%)


300 BP / AD 1650
0
10
20
30
40
50
60
70
80
90
100
land use (%)


200 BP / AD 1750
0
10
20
30
40
50
60
70
80
90
100
land use (%)

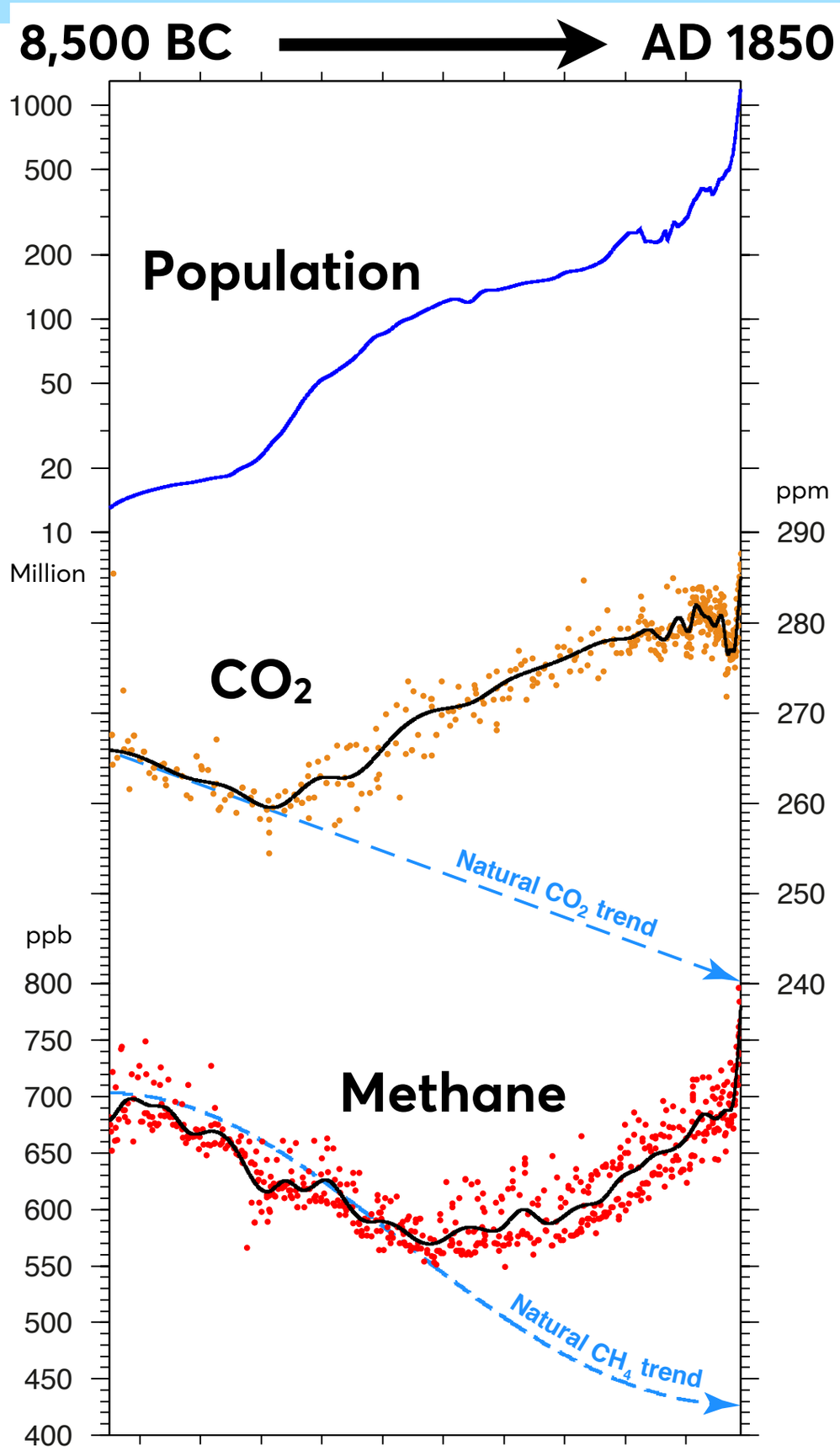

100 BP / AD 1850
0
10
20
30
40
50
60
70
80
90
100
land use (%)

Global land use in the mid-Holocene



Kaplan et al., 2011

The **enigma** of Holocene CO_2 and methane



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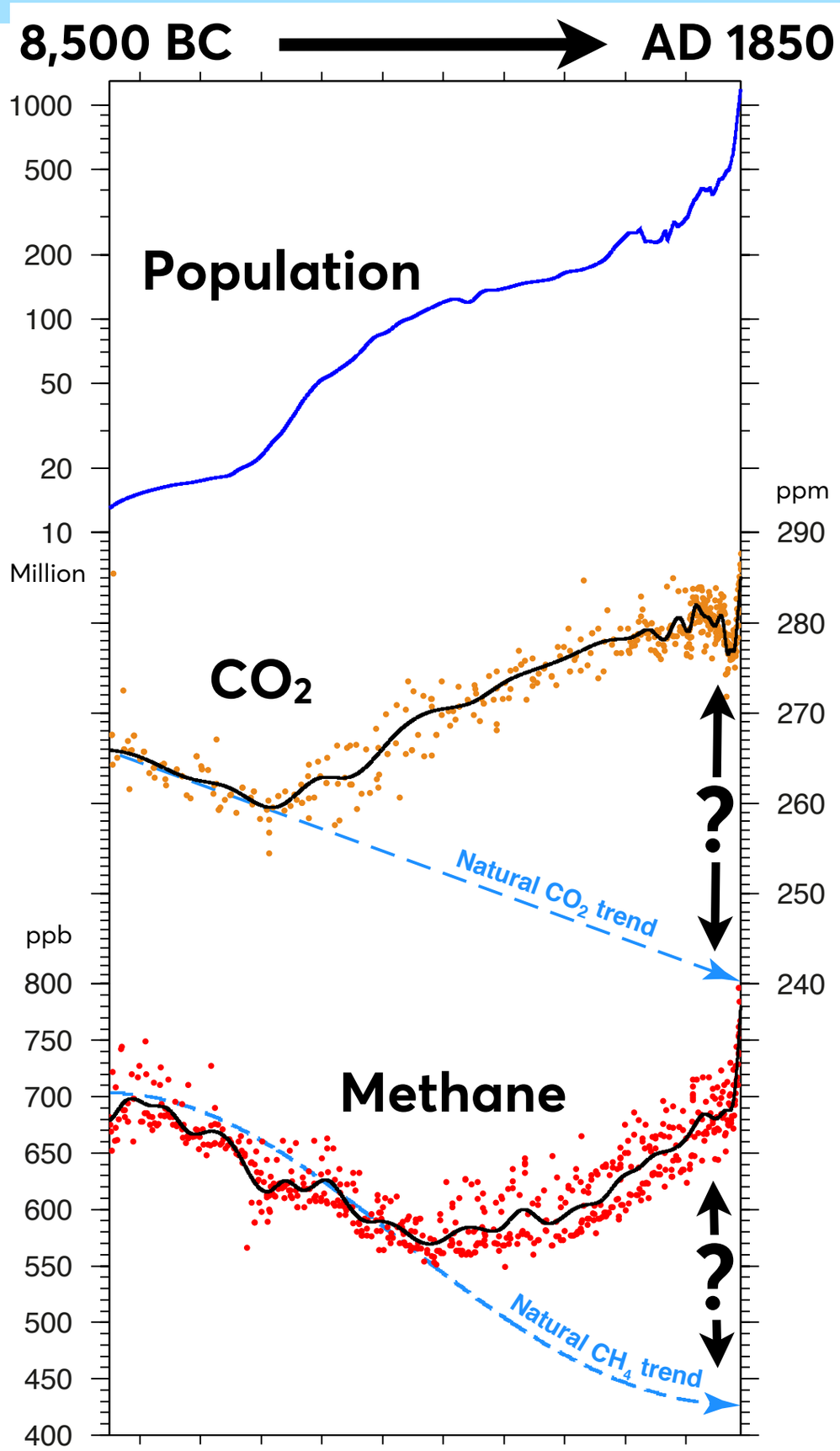
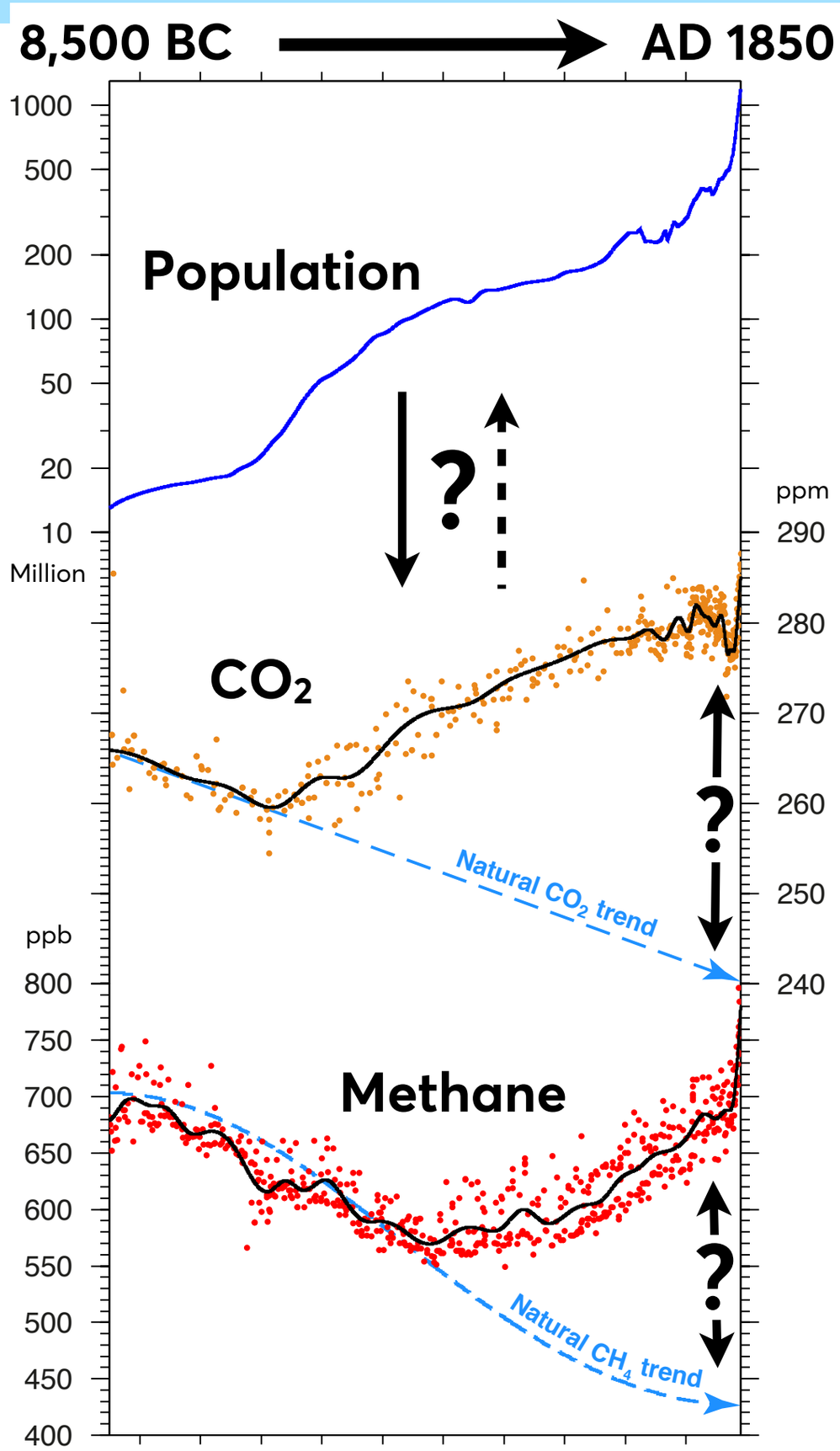
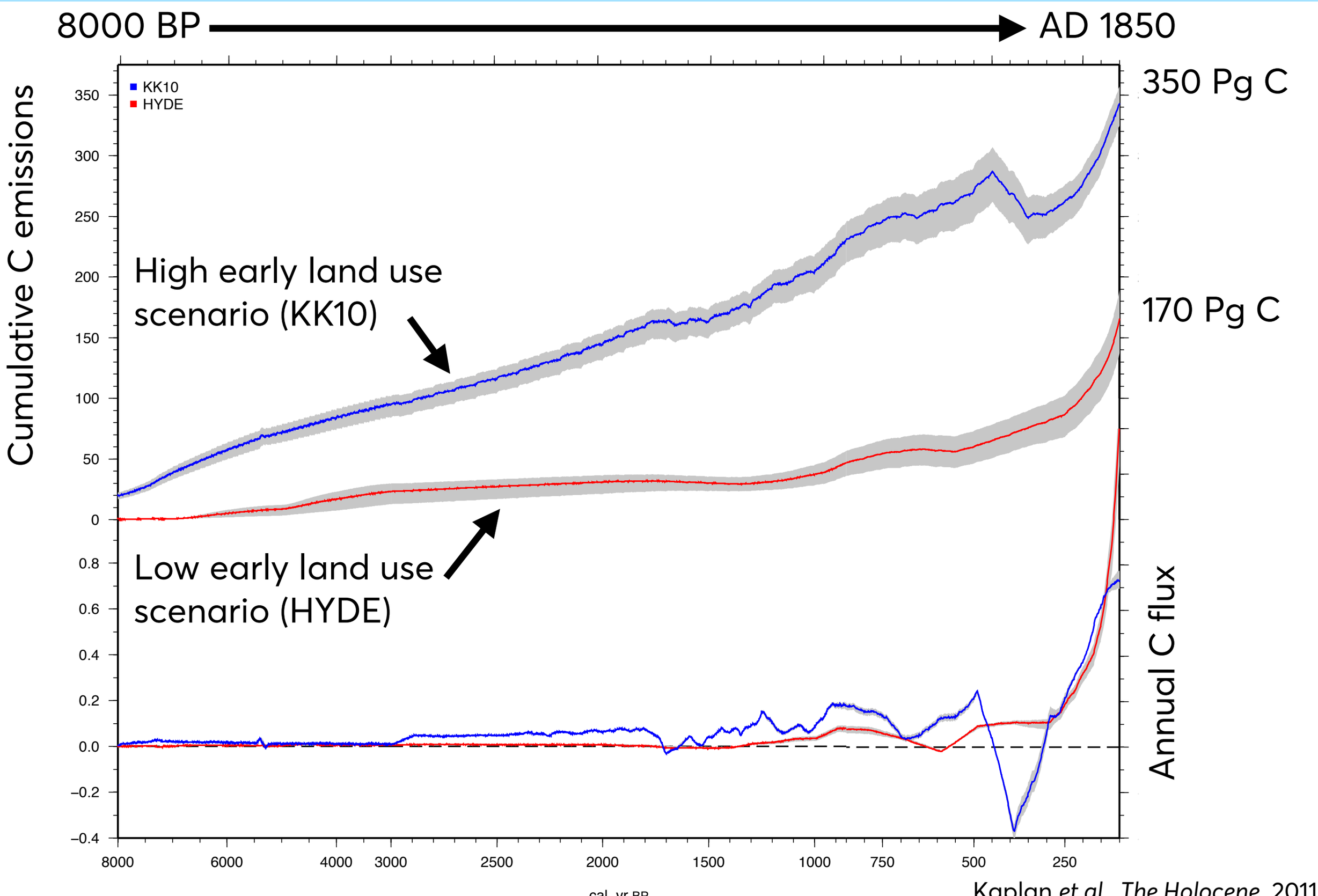


The **enigma** of Holocene CO_2 and methane



Carbon emissions from land cover change



Kaplan *et al.*, *The Holocene*, 2011

Holocene Population and Atmospheric CO_2

8000 BP → AD 1850

Global population

Atmospheric CO_2

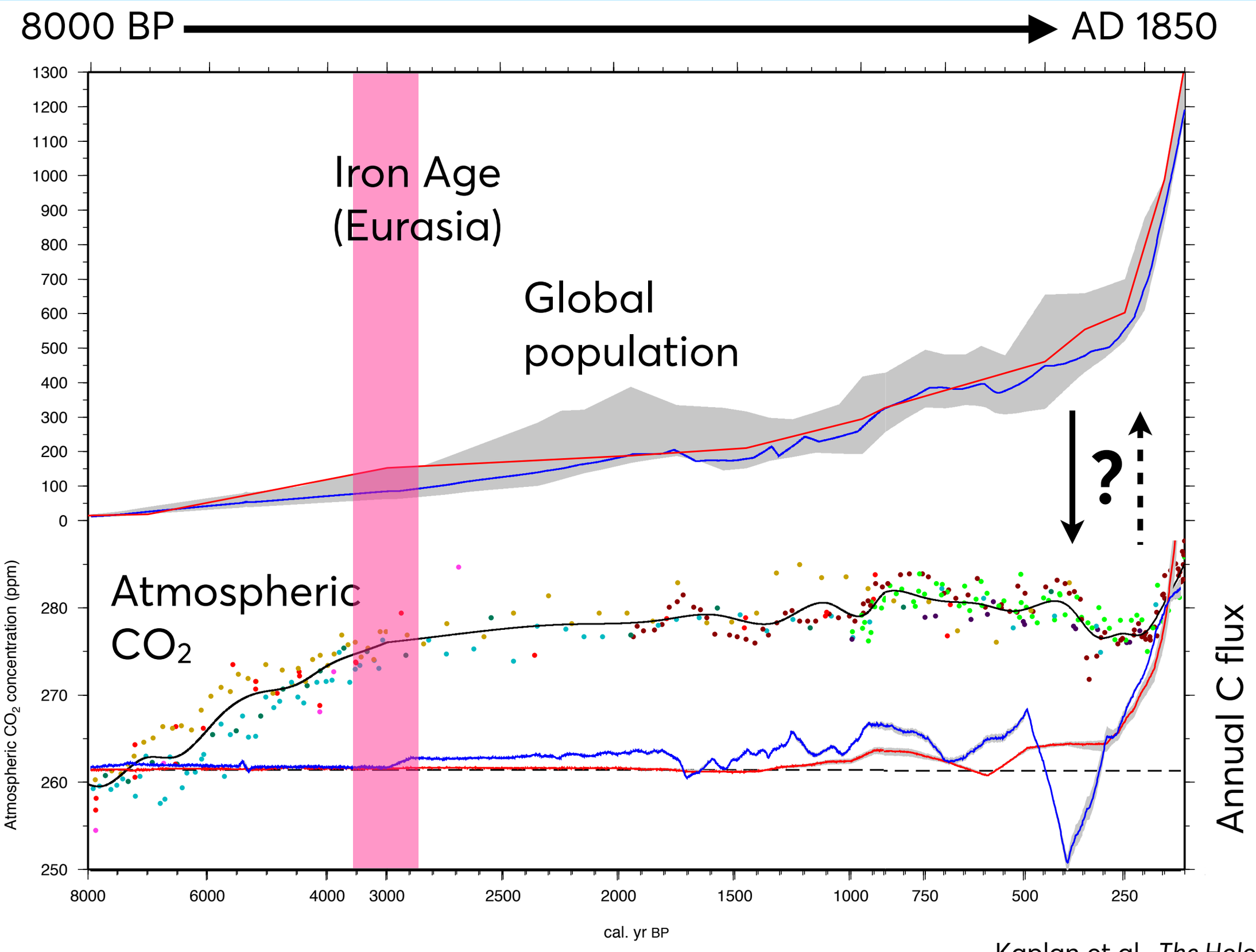
Atmospheric CO_2 concentration (ppm)

Annual C flux

cal. yr BP

Kaplan et al., *The Holocene*, 2011

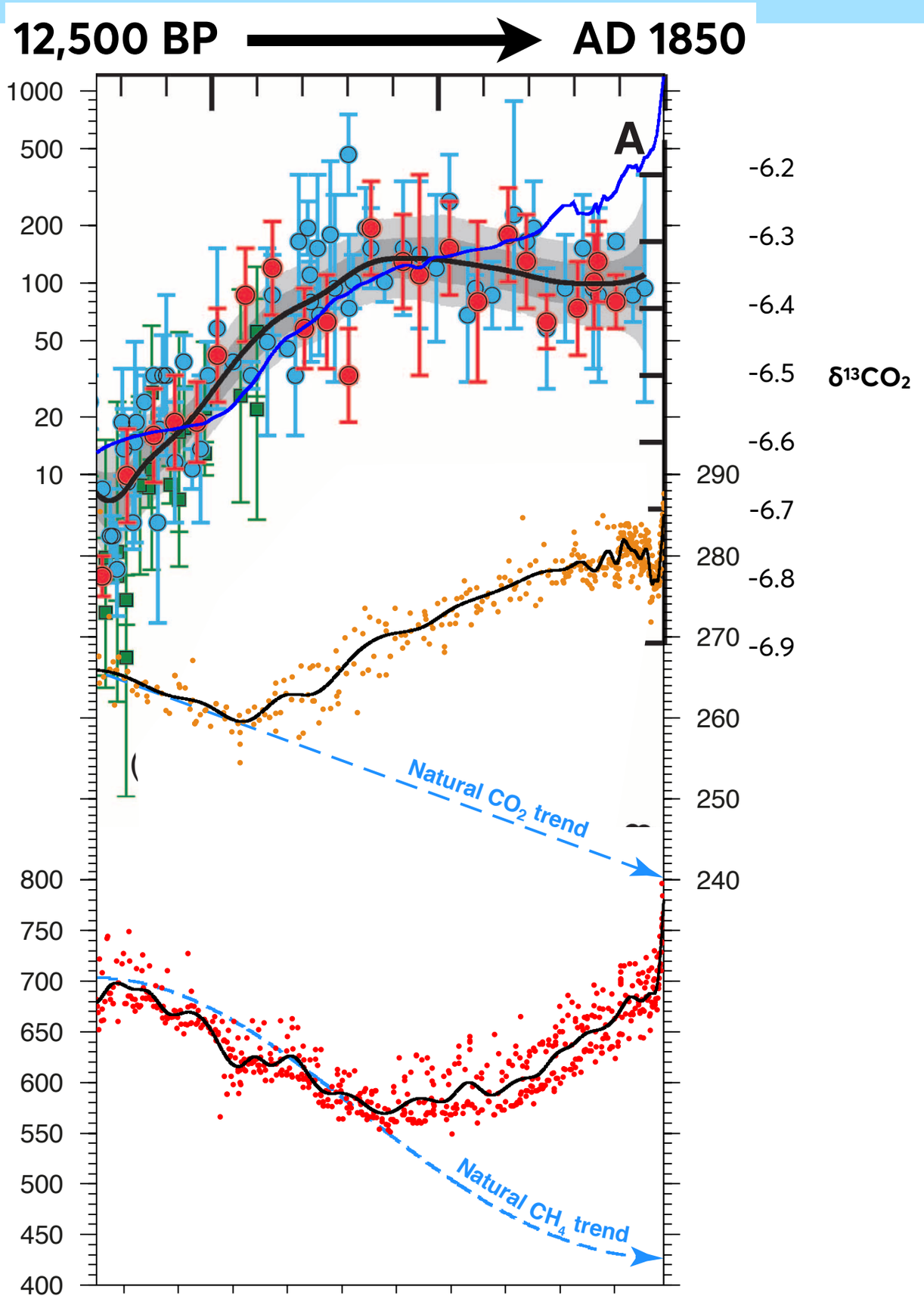
Holocene Population and Atmospheric CO_2



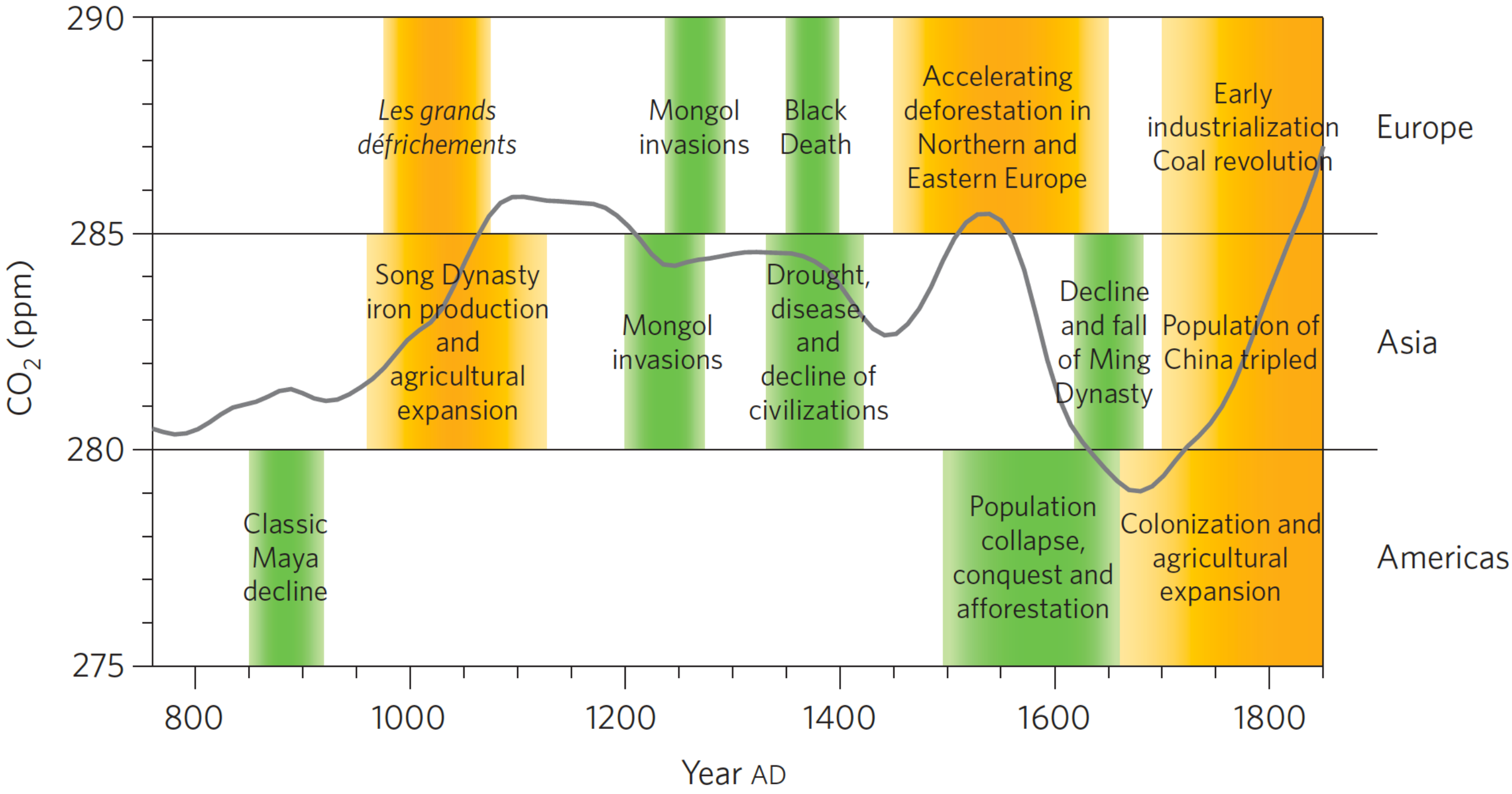
Kaplan et al., *The Holocene*, 2011

The **enigma** of Holocene CO_2 and methane

- *So what's going on*?
- In the early mid-Holocene (8-3ka) was dominated by natural processes
- After the start of the Iron Age, human emissions become globally important
- Northern hemisphere peat buildup offsets human emissions, so the net effect is small (should be ^{13}C effect)
- *But* **humans could have kept CO_2 stable at least since 3ka**

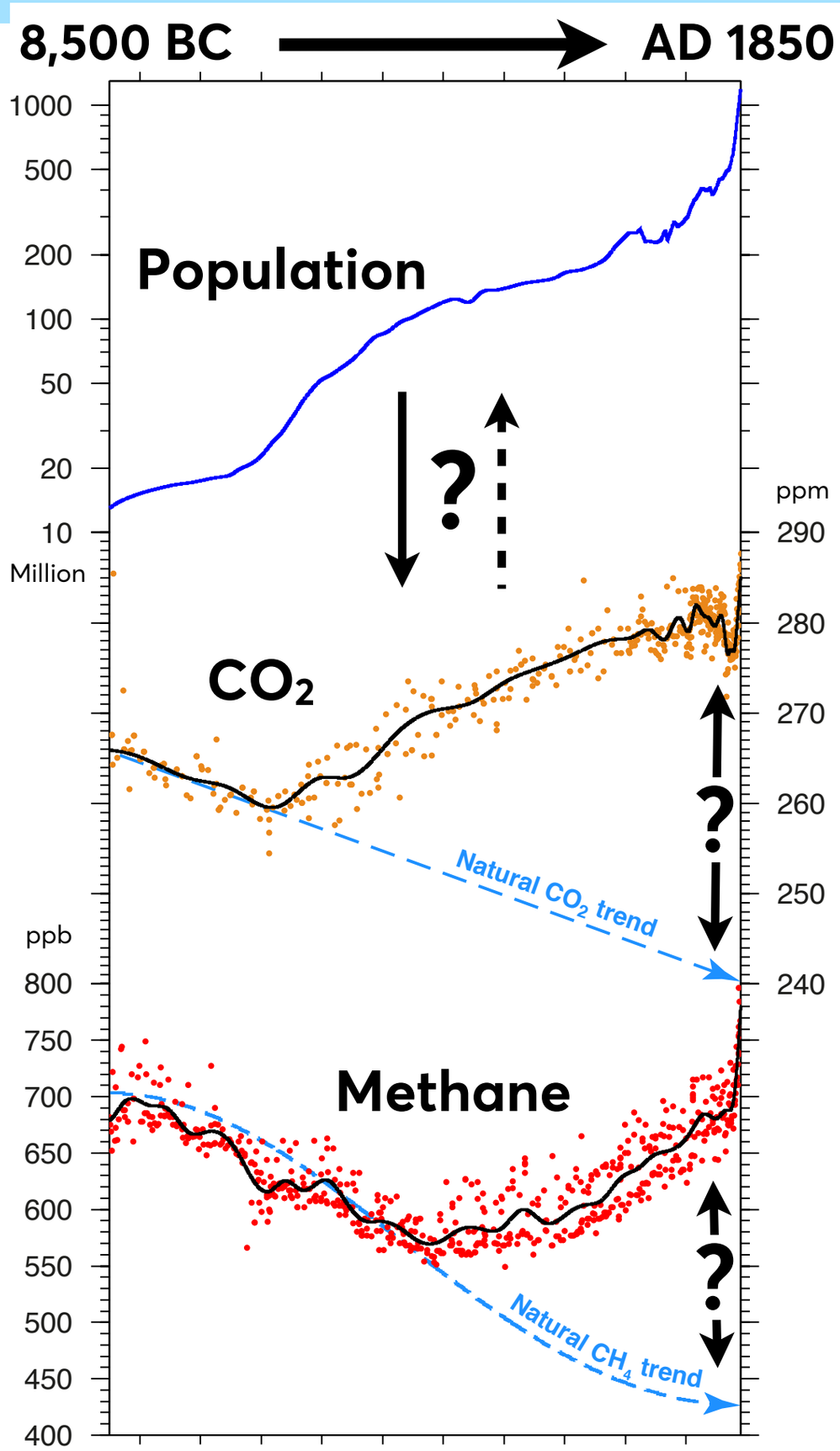


Recent history and atmospheric CO_2

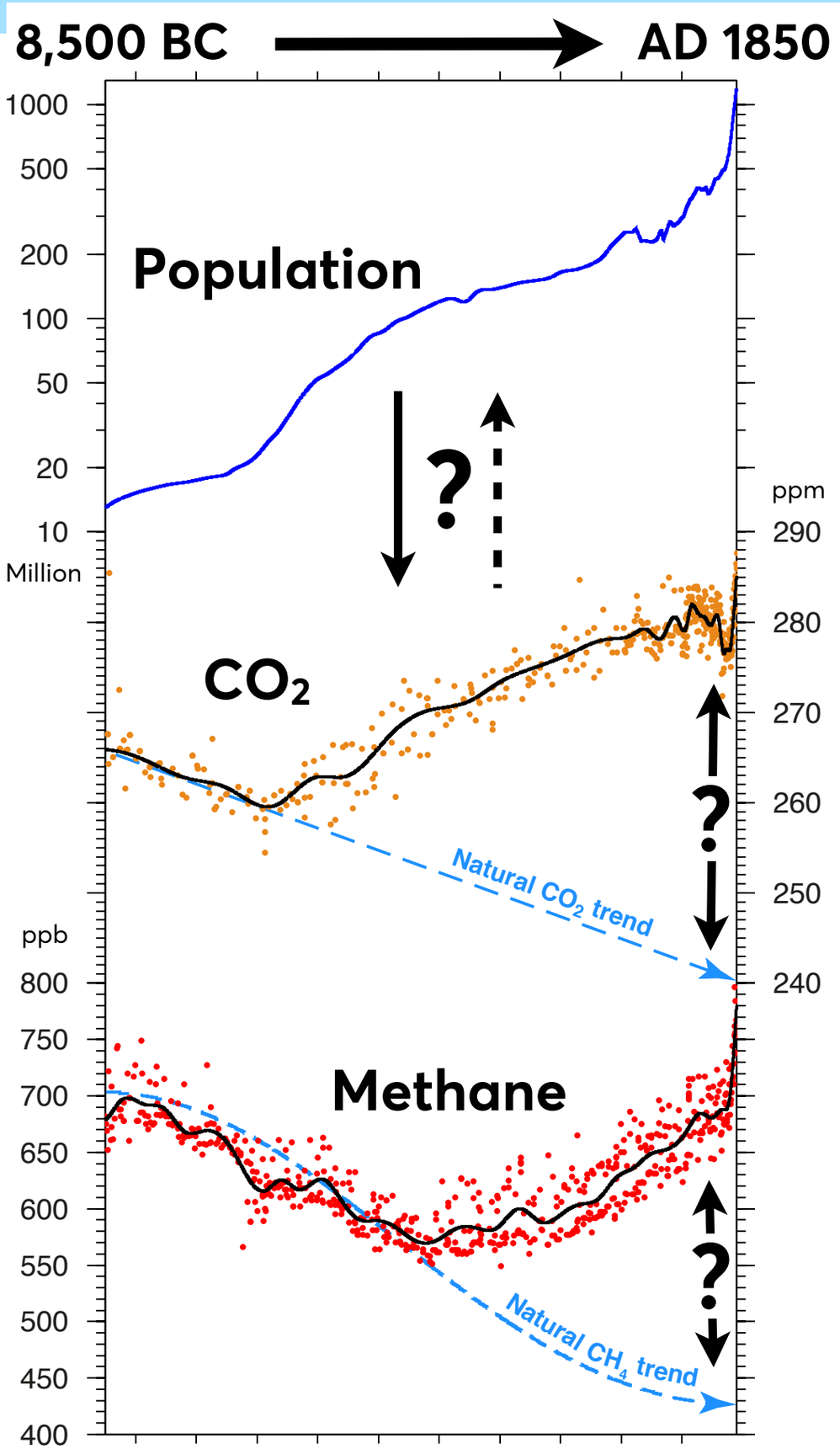


Kaplan, *Nature Geosciences*, 2015

Human influence on global climate?



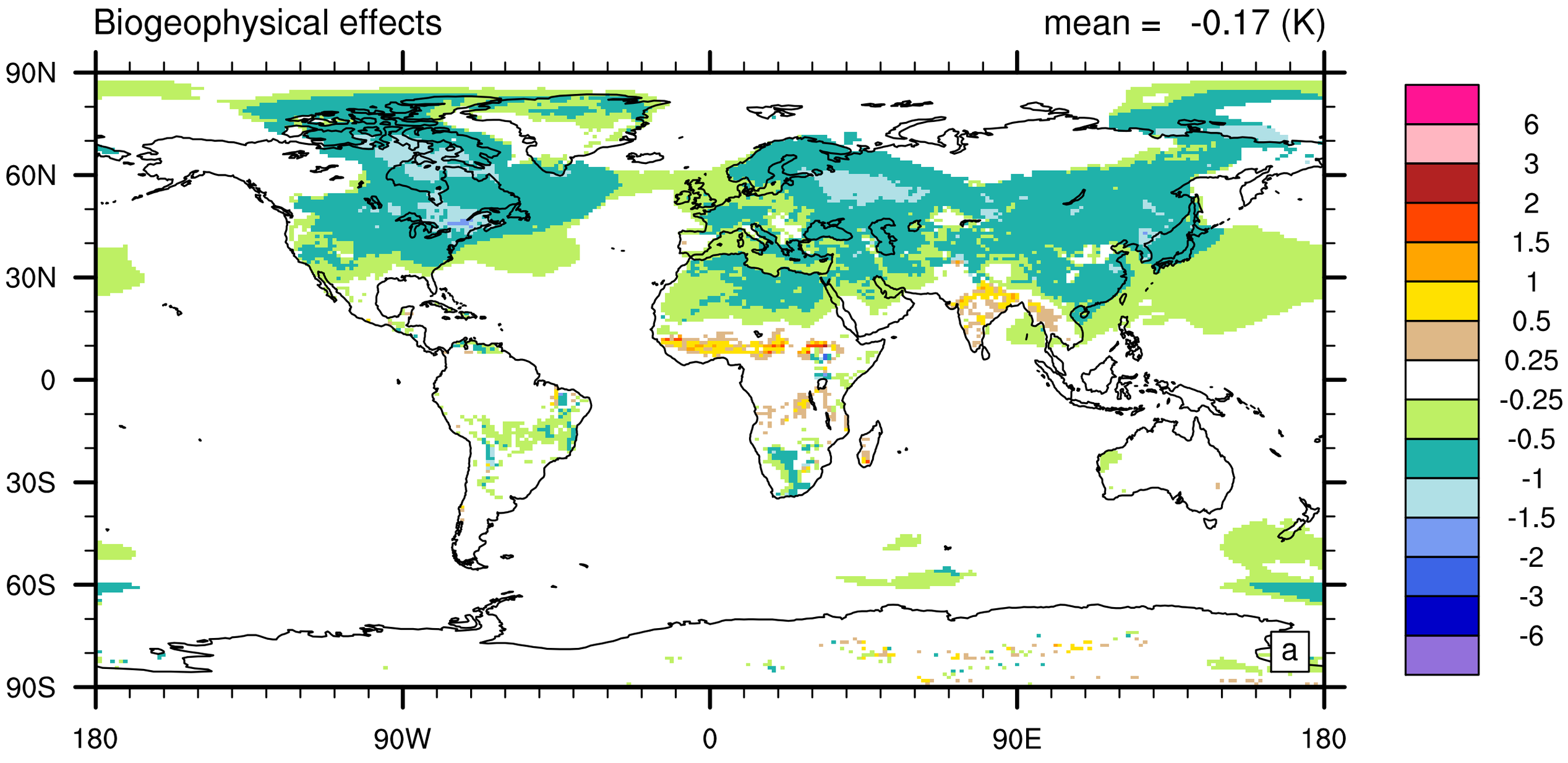
Human influence on global climate



- Experiments performed with NCAR CCSM4 GCM, slab ocean:
  - Preindustrial control: 285 ppm CO_2, 792 ppb CH_4, KK10 land use
  - "Earth without people": 245 ppm CO_2, 445 ppb CH_4, natural vegetation
- Differences highlights early human impact

Biogeophysical feedback

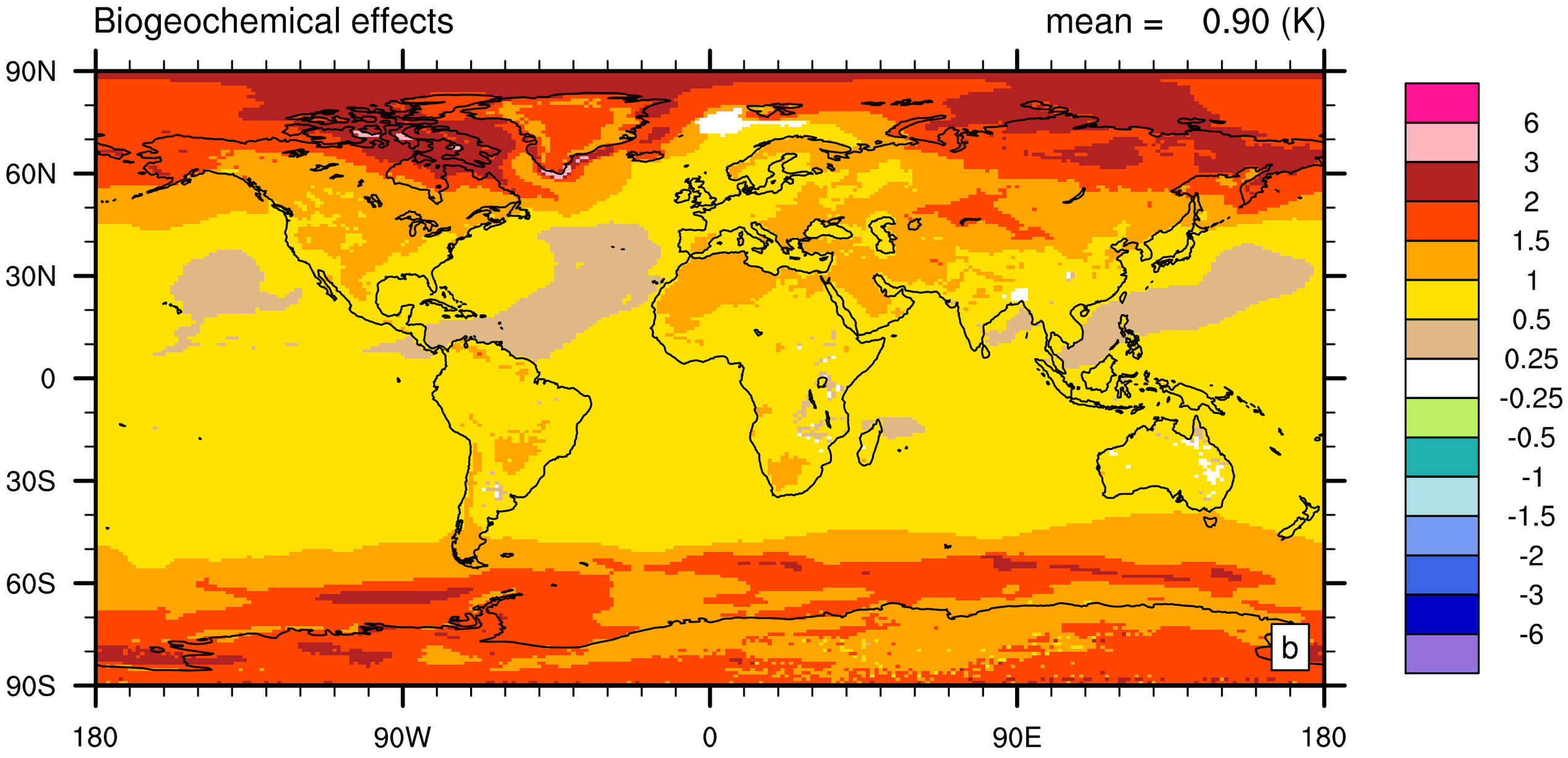
- Net cooling as a result of deforestation: -0.17 °C



Feng He *et al.*, *Geophys. Res. Lett.*, 2014

Biogeochemical feedback

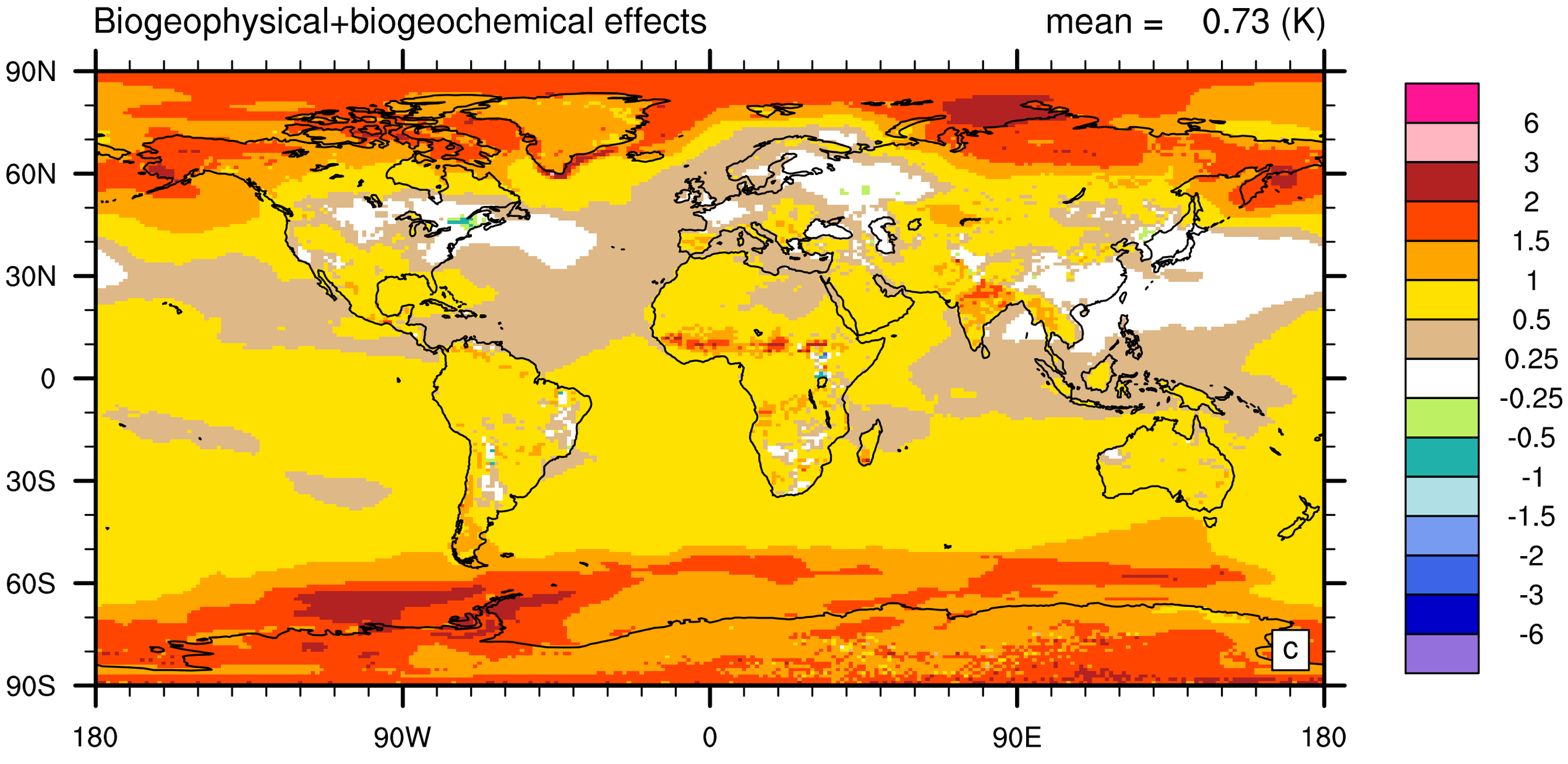
- Warming as a result of carbon emissions: 0.9 °C



Feng He *et al.*, *Geophys. Res. Lett.*, 2014

Combined effect of both

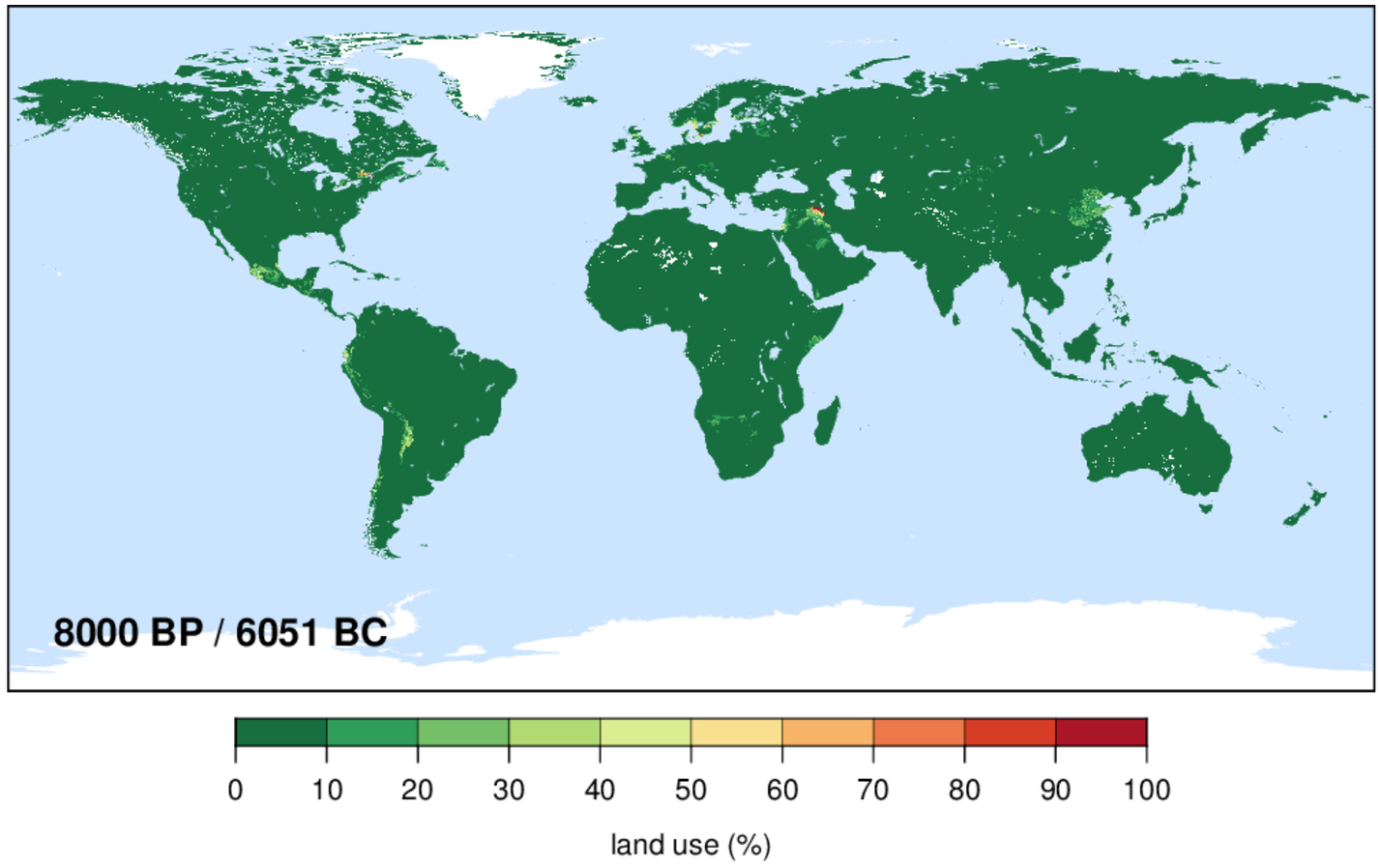
- Greenhouse warming predominates except locally
- Total warming 0.73 °C – similar to industrial era!



Feng He *et al.*, *Geophys. Res. Lett.*, 2014

Summary and conclusions

- Human activities had a substantial impact on the biosphere since the evolution of behaviorally modern humans
- During the preindustrial Holocene, persistent deforestation as a result of agriculture, pastoralism, and other land use led to widespread land cover change and greenhouse gas emissions to the atmosphere that **changed regional and global climate**
- What about the anthropocene?
  As a political concept a recent definition is useful, but as the definition of human influence, we must consider the entire late Quaternary



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