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Did the European conquest of the Americas contribute to the Little Ice Age?

Sylvia outlines recent theories about the impact of human activity on climate change during the Little Ice Age.

Accompanying online materials

Over the last decade or so, evidence has been accumulating to suggest that a significant contribution to low temperatures during the Little Ice Age may have resulted from a reduction in atmospheric carbon dioxide. Koch *et al.* (2019) concluded that this could be linked to the European arrival in the Americas in 1492 and the subsequent death of around 90 % of the indigenous peoples.

Such work makes the Little Ice Age a fantastic resource for the study of past climate change at key stages 3 and 4, bringing together the rival contributions of solar, volcanic and anthropogenic to the causes of the cold period. It also links in well to A level, with both direct changes to the carbon cycle and subsequent feedback processes playing a role (Figure 1). Being (relatively) recent, we can also find evidence in the Little Ice Age for the impact of the changes in weather patterns on people and the environment, through sources such as the TEMPEST database.

At a time when it is looking increasingly unlikely that we will manage to limit global temperature rises to less than 2˚C, let alone 1.5˚C, it is surprisingly reassuring to know that anthropogenic cooling may have been achieved in the relatively recent past.

What was the Little Ice Age?

The Little Ice Age (LIA), between 1450 and 1850, was a generally cold period with some shorter, colder events. Taking the Northern Hemisphere as a whole, temperatures were less than 1˚C colder during the LIA than during the late twentieth century. However, different regions showed different temperature patterns: for example, the seventeenth century was the coldest century in Europe, whereas the nineteenth century was the coldest in North America (Figure 2). There is little evidence for an LIA in the Southern Hemisphere. In fact, 1577–1694 was the only period of the LIA that was global in extent, with a cooling of 0.15˚C.

The main drivers of climate change – orbital changes, solar change, volcanic eruptions, changes to greenhouse gas concentrations, as well as complex feedback mechanisms between them – probably all played a part in cooling the climate during this period.

Solar and volcanic drivers of climate change

Changes in Earth's orbit around the sun (the Milankovitch cycles) have combined to give a gradual cooling over the past 2000 years of around 0.02˚C/century. Without the anthropogenic input of greenhouse gases to the atmosphere, this might have led to a glacial period in about 1500 years' time; but with current levels of greenhouse gas emissions, the next glacial won't occur for at least 100,000 years.

In general, when there is less solar activity (fewer sunspots), a little less visible and ultraviolet solar energy reaches Earth and global temperatures fall. The changes in the solar constant through an 11-year cycle are typically less than 0.1 %, with an estimated global temperature response of less than 0.03˚C. Two prolonged periods of generally lower solar activity occurred just before or during the LIA – the Spörer Minimum (1450– c.1560) and Maunder Minimum (1645–1715).

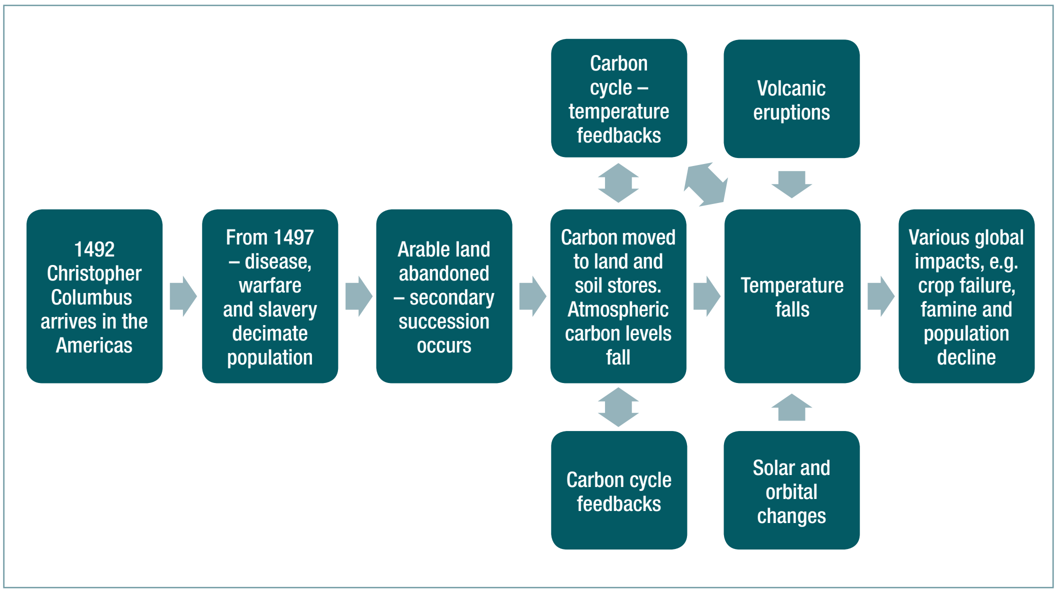

Figure 1: The possible impact of human activity on global carbon levels and climate change.

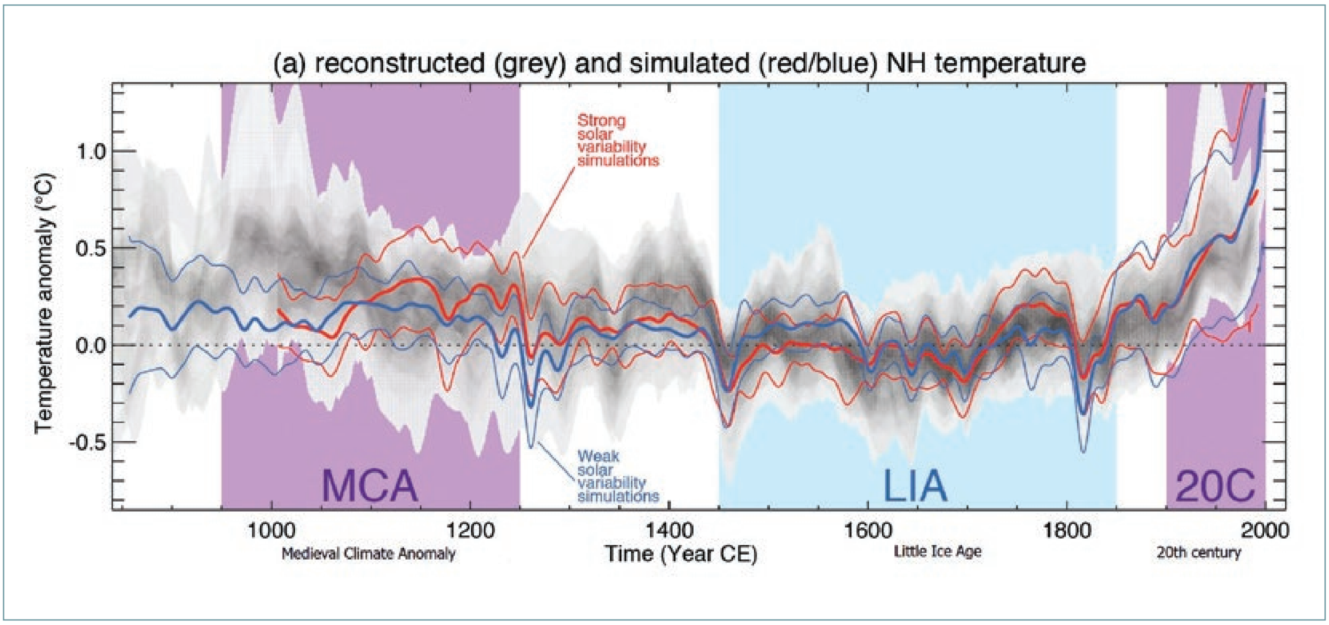

Figure 2: Northern Hemisphere temperature anomaly from 850–2000. The grey areas show an overlap of reconstructions, with the darker grey representing greater confidence in the data. **Source:** © IPCC (2013a).

There was heightened volcanic activity throughout the LIA. Explosive volcanoes cool the climate by injecting reflective sulphate aerosol into the stratosphere, which subsequently reflects the sun's light. The aerosol from volcanoes in the tropics can spread around the globe, taking a couple of years to settle out of the atmosphere. A major volcanic event in 1257 may have triggered the start of the Little Ice Age by allowing more sea ice to form in the Arctic. The 'year with no summer' at the end of the LIA was triggered by three eruptions: La Soufrière, Saint Vincent (1812), Mayon, in the Philippines (1814), and Tambora, Indonesia (1815). Other notable eruptions during the period include Laki, Iceland (1783) and Huanayaputina, Peru (1601).

However, overall, studies have suggested that orbital, solar and volcanic changes, together with the climate feedbacks they trigger, are unlikely to explain the majority of the cooling observed during the LIA (Figure 3).

Carbon cycle changes during the Little Ice Age

Ice cores reveal that global CO_2 concentrations fell by 7–10ppm in the late sixteenth and early seventeenth centuries – enough to lower global surface temperatures by 0.15˚C. Isotope analysis indicates that this anomaly was driven by a change in the terrestrial (rather than oceanic or geological) carbon sink.

The relationship between CO_2 and temperature is complex and has led to fierce debate. Increases in atmospheric CO_2 lead to an increase in global temperatures. However, less carbon dioxide can be dissolved in warmer ocean water – so as ocean temperatures increase, more CO_2 is released into the atmosphere. On historical timescales, this leads to a chicken and egg situation – what came first, the warming or the CO_2 increase? Changes to the marine and terrestrial biosphere can also complicate the CO_2/temperature relationship.

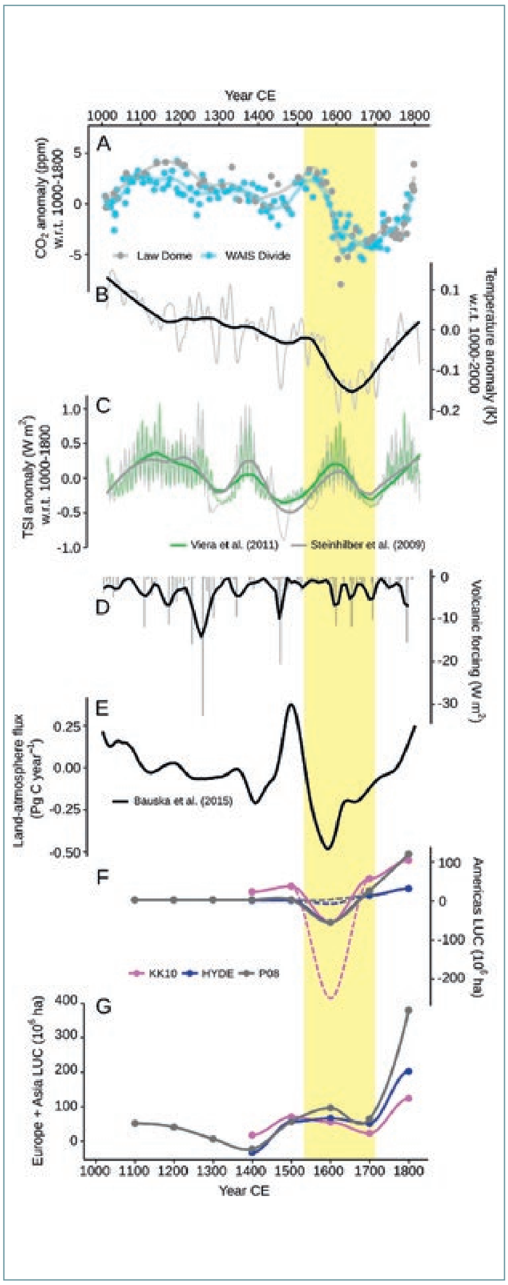

Figure 3: Impact of changes in radiative forcing on atmospheric CO_2 and temperature 1000–1800 CE. **A:** CO_2 concentrations recorded in two Antarctic ice cores: Law Dome (grey) and West Antarctic Ice Sheet (WAIS) Divide (blue). **B:** Global mean temperature reconstruction from northern and southern hemisphere proxies, anomaly compared to the means from 1000–2000 CE (grey, smoothed in black). **C:** Two total solar irradiation anomalies compared to the means from 1000–2000 CE (grey) and (green). **D:** Volcanic, radiative forcing (grey: individual eruptions; black: smoothed). **E:** Land-atmosphere flux of CO_2. **F:** Land use change (LUC) in the Americas from three reconstructions (purple, blue and grey solid lines). **G:** LUC in the two other regions with considerable agrarian societies at the time, Asia and Europe, based on the three LUC reconstructions. **Source:** Koch *et al*. (2019).

Measurements and observations made over past decades allow us to unequivocally separate cause, effect and feedbacks for current anthropogenic carbon emissions and subsequent changes to temperatures and the carbon cycle.

Koch *et al*. (2019) investigate the individual steps required for identifying a possible significant contributor to the Little Ice Age – the European conquest of America and subsequent changes to the global carbon cycle.

The impact of the Europeans on the population of the Americas

Historical anthropologists and archaeologists estimate indigenous population numbers when the Europeans arrived in the Americas using a range of sources including documentary evidence, size of armies, tribute records, colonial census estimates and the numbers of buildings found by archaeologists. All these sources have limitations. Koch *et al*. (2019) conclude that the number of people living in the Americas in 1492 was 60.5 million (with an interquartile range of 44.8–78.2 million). By 1600, this had fallen by around 90 %. A combination of warfare, enslavement and famine following social disintegration exacerbated the lethal epidemics of diseases such as smallpox, measles, 'flu, bubonic plague, malaria, diphtheria, typhus and cholera introduced from Eurasia. While most other epidemics in history have involved a single pathogen and typically lasted less than a decade, the Americas differed in that several pathogens caused multiple waves of epidemics over more than a century.

Locally, depopulation may have been as high as 99 %. In 1520, a single smallpox epidemic killed 30–50 % of the indigenous population of Mexico. Because the indigenous people had a relatively low genetic diversity, it has been suggested that the epidemics continued to have an impact far longer than would normally be expected.

The impact of depopulation on land use and the carbon cycle

The indigenous peoples of the Americas had many ways of managing the land, including terraced farming, complex irrigation and raised field systems, slash and burn agriculture and managed afforestations. Estimates of per capita land use vary hugely throughout the Americas, depending on the type of agriculture being practised, with a suggested median of 1ha per capita (only slightly more than the per capita land use in Europe at the time).

The collapse of population numbers, changes in farming practices and a decrease in slash and burn fires after 1492 will have led to large scale – over around 56 million ha – reforestation (Figure 4). Exactly how the forest will have regrown will have depended on the vegetation at abandonment, the proximity of seeds, the soil, the climate and the type of past anthropogenic land use. However, in almost all cases, the total plant biomass will have increased, increasing the carbon stored on land. Soil carbon stocks similarly increase. Koch *et al*. (2019) suggest that 7.4 x 1015g of carbon was taken up by new vegetation in the sixteenth century. This corresponds to a reduction in atmospheric CO_2 of approximately 3.5ppm. For comparison, since the Industrial Revolution the amount of CO_2 in the atmosphere has increased by over 130ppm and is forecast to rise by 2.8ppm in 2019 alone.

Secondary vegetation succession

In an area where tropical forest has been cleared to plant annual crops, the microclimate is usually too warm and dry for most tropical forest species to return immediately. When farming is abandoned, light-demanding, heat- and moisture-tolerant 'pioneer' trees establish first, changing the microclimate and facilitating the subsequent growth of tropical forest species. As succession progresses, the light available in the understorey decreases, allowing the establishment of trees which ultimately replace the pioneers. Typically, carbon stocks increase fastest over initial decades. The forest structure becomes similar to mature, undisturbed forests within 100 years.

Figure 4: New plant growth in cleared areas of forest.

The magnitude and timing of this potential reduction in atmospheric CO_2 corresponds well with the records obtained in two high-resolution ice cores from Antarctica. 35–50 % of the observed fall in atmospheric CO_2, and similarly around 50 % of the global cooling seen between 1577–1694, could be directly attributed to the depopulation of the Americas – without taking other factors (such as volcanic and solar changes, and complex feedback mechanisms including the biosphere) into account.

Of the 7–10ppm reduction in atmospheric CO_2 seen in the ice core records, around 4ppm could be linked to the observed fall in temperature (0.15°C). This is partly offset by the system's response to the increased CO_2, meaning that a fall of only around 1ppm can be accounted for.

Taking both these Earth system feedbacks into account, land use change in the Americas in the century or so after 1492 can explain 45–65 % of the observed changes in atmospheric CO_2.

There is still uncertainty about the role of the oceans as a carbon sink in this period – to the extent of not knowing whether the amount of carbon stored in the oceans increased or decreased. Scientists are still some way from balancing the carbon budget in the Little Ice Age, but the importance of land use change in the Americas is a fascinating and important component.

Does the drop in atmospheric CO_2 in 1610 mark the beginning of the Anthropocene?

Acknowledgement

With thanks to Chris Brierley for reviewing and commenting. | **TG**

Carbon cycle feedback

The last IPCC report on climate change looked in detail at the expected feedbacks from changes in temperature and changes in atmospheric carbon concentrations on the climate system (Figure 4).

As carbon dioxide concentrations in the atmosphere increase:

- the oceans will take up more CO_2 almost everywhere, but particularly in the North Atlantic and Southern Oceans
- the take-up of CO_2 by land areas will increase everywhere, particularly over tropical land and in humid regions where the amount of biomass is great. There is also a relatively large increase over Northern Hemisphere temperate and boreal latitudes, because of the greater land area and large areas of forest
- without this increased uptake of CO_2 by the land and ocean, annual increases in atmospheric carbon dioxide concentration would be around double the observed rates.

As the atmosphere warms:

- tropical ecosystems will store less carbon, as will mid-latitudes
- at high latitudes, the amount of carbon stored on land will increase, although this may be offset by the decomposition of carbon in permafrost
- as sea ice melts, more water is exposed and therefore more CO_2 can be absorbed
- as water warms, the solubility of CO_2 in water decreases and so less is taken up by the oceans
- ocean warming and circulation changes will reduce the rate of carbon uptake in the Southern Ocean and North Atlantic.

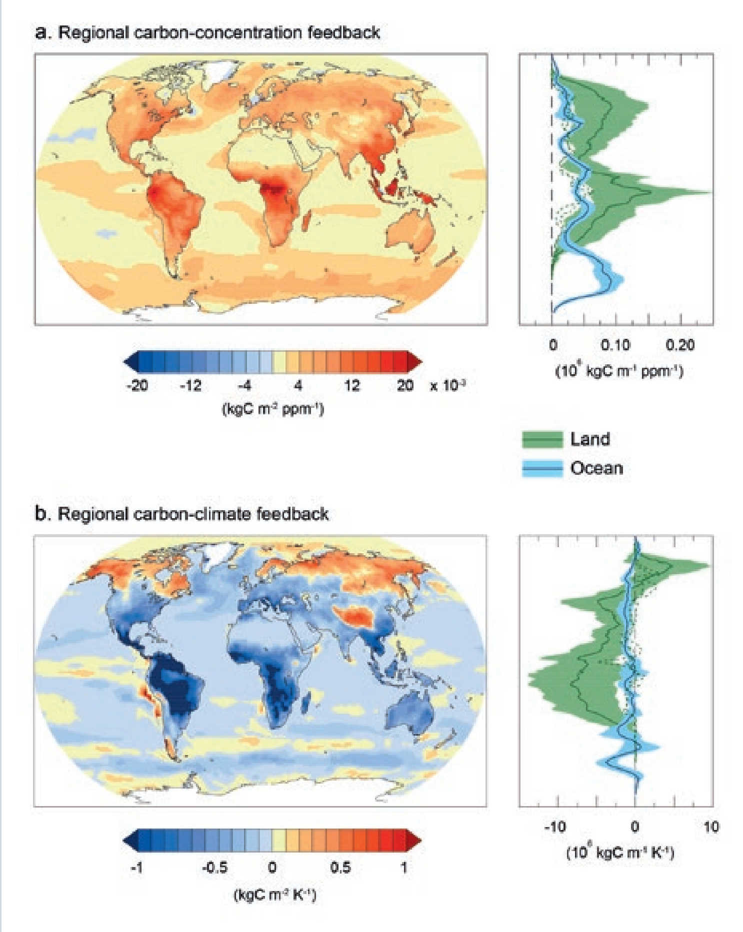

Figure 5: Maps of the changes in carbon uptake in kg of carbon/m^2 for:

a) each ppm increase in atmospheric CO_2. Orange and red colours indicate that, as the amount of carbon dioxide in the atmosphere increases, more carbon is taken up, whereas blue colours show where extra carbon is released.

b) each degree Celsius increase in temperature. Orange and red colours indicate that, as the temperature rises, more carbon is taken up, whereas blue colours show where extra carbon is released.

The graphs on the right show the mean carbon uptake by land and ocean for each latitude line corresponding with the adjacent maps. **Source:** IPCC (2013b).

References

IPCC (2013a) (Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) (eds) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Chapter 5, Figure 8.

IPCC (2013b) (Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) (eds) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Chapter 6, Figure 22.

Koch, A., Brierley, C., Maslin, M.M. and Lewis, S.L. (2019) 'Earth system impacts of the European arrival and the Great Dying in the Americas after 1492', *Quaternary Science Reviews*, 207, pp. 13–36. Available at: https://doi.org/10.1016/j.quascirev.2018.12.004 (last accessed 28/03/2019).

TEMPEST database: https://www.nottingham.ac.uk/research/groups/weather-extremes/research/tempest-database.aspx (last accessed 25/4/2019)

Further reading

IPCC (2001) *Fourth Assessment Report WGI*, section 2.3.3. Available at: https://www.ipcc.ch/report/ar4/wg1/(last accessed 28/03/2019).

Fagan, B. (2000) *The Little Ice Age: How Climate made History 1300–1850*. New York: Basic Books.

Mann, M. (2002) 'The Little Ice Age', in *Encyclopedia of Environmental Change*, Volume 1. Chichester: Wiley & Sons, pp. 504–9.

Online resources

Resources based on this paper are provided as downloads and will be available on the Royal Meteorological Society website later in 2019. Go to www.geography.org.uk/Journals/Teaching-Geography and select Summer 2019.

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