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Evidence for the Postconquest Demographic Collapse of the Americas in Historical CO_2 Levels

Franz X. Faust and Cristóbal Gnecco

Department of Anthropology, Universidad del Cauca, Popayán, Colombia

Hermann Mannstein*

Institute for Atmospheric Physics, DLR, Oberpfaffenhofen, Germany

Jörg Stamm

ECOBAMBOO, Popayán, Colombia

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ABSTRACT: This article promotes the hypothesis that the massive demographic collapse of the native populations of the Americas triggered by the European colonization brought about the abandonment of large expanses of agricultural fields soon recovered by forests, which in due turn fixed atmospheric CO_2 in significant quantities. This hypothesis is supported by measurements of atmospheric CO_2 levels in ice cores from Law Dome, Antarctica. Changing the focus from paleoclimate to global population dynamics and using the same causal chain, the measured drop in historic atmospheric CO_2 levels can also be looked upon as further, strong evidence for the postconquest demographic collapse of the Americas.

KEYWORDS: Climate; Forest; Carbon

* Corresponding author address: Hermann Mannstein, Institute for Atmospheric Physics, DLR, Oberpfaffenhofen, D-82234 Germany.

E-mail address: Hermann.Mannstein@dlr.de

1. Introduction

The influence of climate on human behavior has been a subject of discussion since Herodotus's time. Yet, the question regarding how human behavior affects climate did not surge as a public interest until the second half of the twentieth century. One way to observe the anthropogenic influence on climate is to look at phases in which we can identify a dramatic change or impact on the life of a significant number of people on vast regions. One of these eras began with the so-called discovery of the Americas by Christopher Columbus in 1492.

A variety of cultivator societies had developed in this area, which comprises about 30% of the world's land cover and nearly 50% of the forested areas, like in many other parts of the world. Agriculture in the Americas began sporadically some 10 000 yr ago, and was initially restricted to several but simple techniques such as garden plots, and slash-and-burn. By 1000–500 B.C. agricultural production has reached in some areas remarkable size due to two main factors: (a) the selection of highly productive cultigens and (b) the development of improved techniques such as irrigation, terraces, and raised fields. The majority of the cultivators in the Americas settled in natural woodland habitats and cleared large areas for their fields, which were abandoned because of the demographic collapse brought about by the European conquest. The regrowing forest provided a prominent sink for atmospheric carbon dioxide that must have also contributed to the climatic changes associated with the Little Ice Age (LIA).

A temperature decrease of ~0.2°C per millenium is reported by Johnsen et al. (Johnsen et al. 2001) beginning at the Holocene maximum about 6–8 ky BP. It ends 100 yr ago at the beginning of the last century (Mann et al. 1998; Jones and Mann 2004; Moberg et al. 2005a; Moberg et al. 2005b; see Figure 4 and also Houghton et al. 2001). Superimposed on this slow cooling trend and well expressed in the reconstruction of extratropical temperatures of the Northern Hemisphere is the so-called Medieval Warm Period (MWP) peaking around A.D. 1000–1200 and later a cold period for approximately 200 yr. Details on this period can be found in Briffa et al. (Briffa et al. 1998) and Zorita el al. (Zorita et al. 2004). On a global view the cooling was moderate, but the North Atlantic region was strongly affected. This phenomenon is known as the Little Ice Age. At its peak, around 1650 in Europe, temperatures there were 1°C lower than at present, winters were harsher, summers were cooler, snow lines descended as much as 100 m below modern levels, and the Alpine and Scandinavian glaciers advanced. Floods and droughts hit different regions of the Earth at different times, especially the temperate zones (Fagan 2000). Famines, economic disruption, and plagues were common events during those centuries. This climatic event, which produced such devastating effects even in temperate areas, is still a puzzle. Absence of sunspot activity in the so-called Maunder Minimum indicating a reduced solar radiation has been claimed by Eddy (Eddy 1976) to be responsible, but this does not explain the regional distribution. Volcanic activity might be another explanation: volcanic eruptions send particulate matter and SO_2 into the atmosphere, enhancing the aerosol load. This reduces the incoming solar radiation. Such events show up as relatively short cold periods, which add up in times of high volcanic activity. Prominent examples are the volcanic year of 1783, the explosion of Mount Tambora in 1815, which led to the year 1816 being called the "year without a summer," and the eruption of the Kuwae on Vanuatu in 1457 ± 2, which left, according to Palmer et al. (Palmer et al. 2001), the strongest footprint in the Law Dome, Antactica, ice core data and is in coincidence with the coldest period in the Northern Hemispheric surface temperature reconstruction by Mann et al. (Mann et al. 1998; shown in Figure 4 together with the reconstruction by Moberg et al. 2005a and Moberg et al. 2005b).

Zorita et al. (Zorita et al. 2004) are able to simulate the range of Northern Hemispherical temperature deviation found by Esper et al. (Esper et al. 2002) and Moberg et al. (Moberg et al. 2005a; Moberg et al. 2005b) from tree-ring data but do not reproduce the onset of the Little Ice Age at ~A.D. 1550. They use the Hamburg coupled ocean–atmosphere model ECHO-G forced by solar output and volcanic ash impact identical to the data used by Crowley (Crowley 2000) and CO_2 and methane data from Antarctic ice cores. Obviously, those more recent estimates of global or hemispherical temperatures (Zorita et al. 2004; Moberg et al. 2005a; Moberg et al. 2005b; Esper et al. 2002) show a higher variability in the last millennium, with the LIA up to 1° cooler and the MWP as warm as in the twentieth century, than the earlier ones (Crowley 2000; Mann et al. 1998; Jones and Mann 2004; Houghton et al. 2001). The *Climate Change 2001* report by Houghton et al. (Houghton et al. 2001) favors a change in the patterns of atmospheric circulation (low North Atlantic Oscillation index), resulting in more easterly winds, as the main reason responsible for the onset of the Little Ice Age. This is supported by the analysis of the Late Maunder Minimum (A.D. 1675–1710) of Zorita et al. (Zorita et al. 2004). They find a stronger continentality in Europe with low winter temperatures in the central and eastern parts. The reduction of atmospheric CO_2 resulting from forest reclamation of abandoned agricultural fields in the Americas after the conquest, which we discuss in this article, is yet another causal factor to be accounted for. The proposed causal chain leads from the demographic collapse of the indigenous population of the Americas over forest sequestration to a reduction of atmospheric CO_2. Its impact on radiative forcing and global temperature supports indirectly the "early human impact on climate" hypothesis promoted by Ruddiman (Ruddiman 2003): the agricultural fields had to be cleared from forest in the long time of expansion, releasing a good part of the carbon content into the atmosphere.

2. The postconquest demographic collapse

The most convincing proof of the isolation of Amerindian populations from those of Europe and Africa is the demographic collapse that followed the introduction of new diseases after 1492. The collapse, prompted by illnesses, expanded from the Caribbean islands to the most remote regions of the continent. The epidemics were faster than the conquerors, aiding them in the penetration of the continent. The toll taken by the exposition to diseases then unknown to native populations was devastating: smallpox alone is reported by Dobyns (Dobyns 1963) and Brothwell (Brothwell 1993) to have caused the death of millions of people even before they actually encountered the invading armies. Diseases were not the only killers. Enslavement and relocation of native populations by force, mostly to work in mines, significantly contributed to what surely is the largest demographic tragedy in history.

The breakdown of the indigenous population in the Americas in the sixteenth century is well documented, although the precise numbers are still in contention. The numbers given by Denevan (Denevan 1992a; Denevan 1992b), Newson (Newson 1993), and others range from 54 to 110 million individuals in 1492; five decades later only 3%–5% remained. Although regional variations were marked, with regions where the collapse was total and others where it was moderate, the overall picture is devastating: in the Caribbean the population disappeared within one generation; in coastal central Mexico the decline was by a factor of 26; in Peru populations fell from 9 million people to 600 000 within 80 yr. Three well-documented examples from southwest Colombia can help to illustrate the magnitude of the disaster. Friede (Friede 1982) reports that the 1539 census of the Quimbaya from the middle Cauca valley listed 15 000 tax payers; 65 yr later they had declined to 140, a mere 0.93%. The indigenous population of the Almaguer province in the Colombian Massif numbered some 40 000 people in 1552; 36 yr later the native population had almost vanished (Romoli 1962). Finally, we find in Calero (Calero 1997) that the Abads from Nariño, located near the current border with Ecuador, lost two-thirds of the population during the 12-yr period from 1558 to 1570. Quite new and not taken into account in previous estimates of pre-Columbian population is the archeological evidence for the agricultural use of the Amazon region (Heckenberger et al. 2003). Heckenberger et al. describe settlements in the Upper Xingu region with a population density of 6–12.5 per square kilometer. This population density is much higher than the density of the fishing and hunting communities that survived. The findings of anthrosols like "Terra Preta de Indio" or "Terra Mulata" (dark fertilized soils that indicate pre-Columbian human activity) in many parts of the Amazon region support the hypothesis that this area was inhabited at the time of the arrival of Columbus and was abandoned in the following decades.

Given that most Amerindian groups, from the Mississippi River in the north to the La Plata River in the south (Figure 1), were cultivators, the collapse brought about the abandonment of huge areas of agricultural fields. In regions supporting forested biota these fields were subsequently recolonized by forests. Because of the high net primary production in Central and South America (Figure 2) a fast regrowth of forests was possible.

3. Agricultural fields in the Americas

Paleobotanical data can be used to gauge the diachronic interaction between anthropogenic landscapes and forest formations. In Cardale et al. (Cardale et al. 1989), Monsalve (Monsalve 1985), and Bray (Bray 1995) we find reports on pollen data from Andean Colombia that indicate widespread forest clearing some 2000 yr BP. Although productive cultigens were known in the area long before, it is not until about two millennia ago that an anthropogenic landscape dominated by agricultural fields was created. The extant records indicate abandonment of those fields before European arrival and a rapid forest recovery starting in the fifteenth century, no doubt due to the collapse and/or relocation of the attendant population. The Calima region, in southwestern Colombia, is a good example in this regard. The area bears evidence of agricultural fields and their abandonment in pre-Hispanic times: a strong expansion occurred during the so-called Yotoco period,

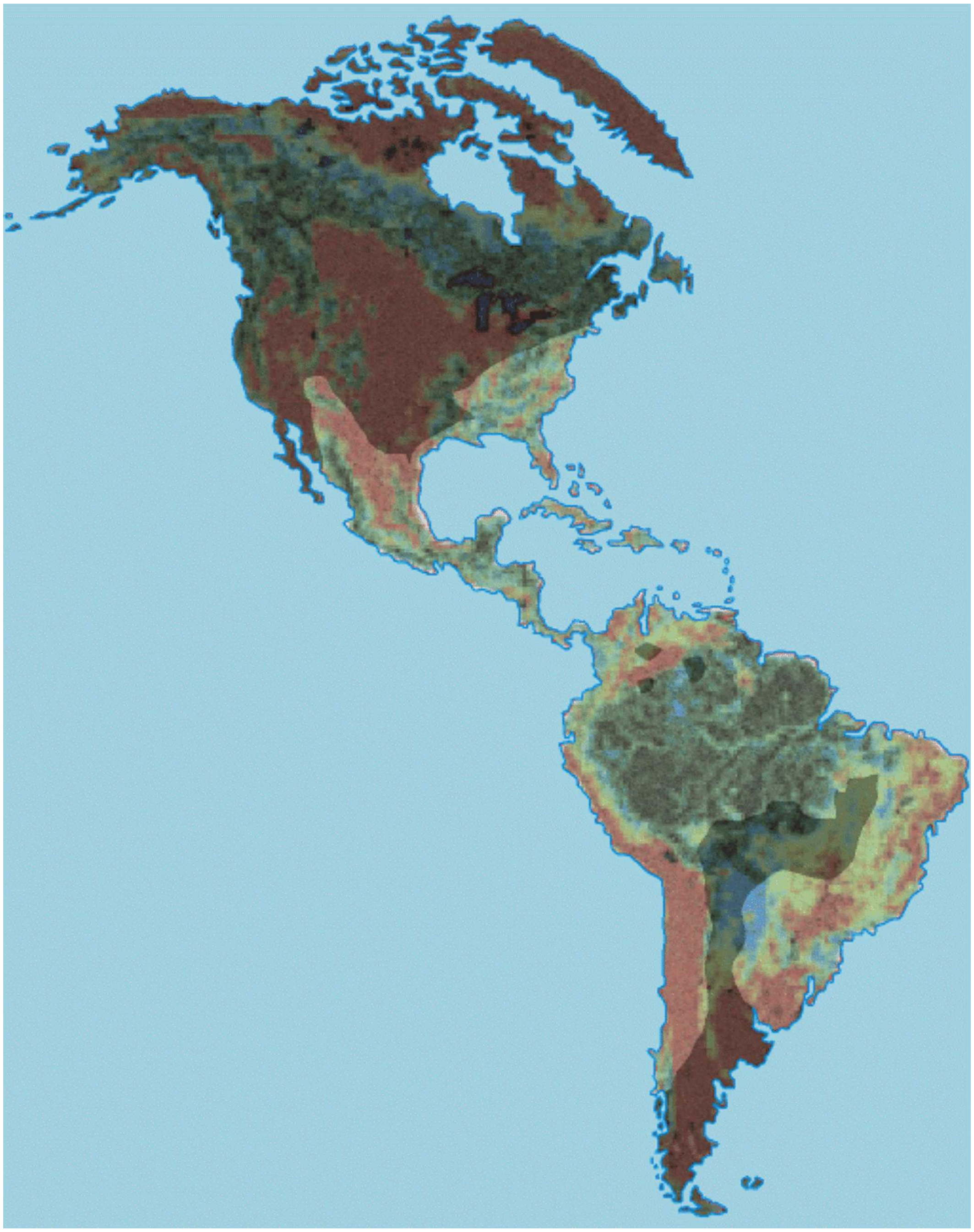

Figure 1. Area extension of agriculturalists in the Americas based on Denevan (Denevan 1992a) (bright colors), overlaid on parts of the "Global Forest Cover Map" produced by the Food and Agricultural Organization (FAO) and the U.S. Geological Survey (USGS 2003).

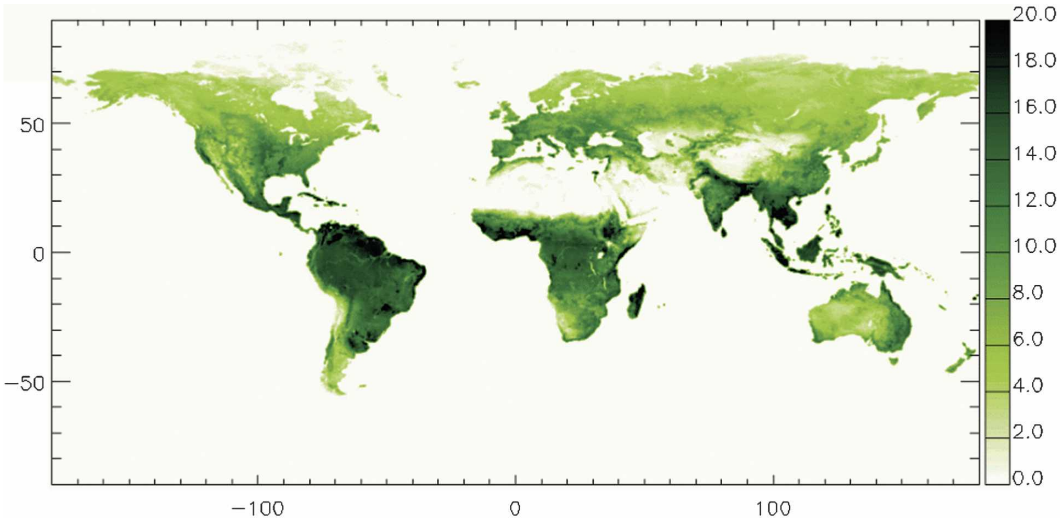

Figure 2. Global distribution of mean terrestrial net primary production in tons of carbon per hectare per year in the years 1981–2000 as derived from satellite data. Data are from Prince and Small (Prince and Small 2003).

some 2000 yr ago, especially in damp areas previously unexploited (Cardale et al. 1989). The pollen column from this area reported by Monsalve (Monsalve 1985) indicates a "massive episode of forest clearing" (Bray 1995) necessitated by the construction of those fields. All through the rest of the pre-Hispanic occupation of the area this agricultural system was maintained; with the population loss brought about by the Spanish conquest "much of the landscape was reclaimed by forest." We already mentioned the archaeological evidence for intensive agricultural usage in pre-Columbian times in the Amazonian rain forest by Heckenberger et al. (Heckenberger et al. 2003) and the findings of Terra Preta de Indio, and more knowledge about the extent of the pre-Columbian population in the forested regions will be unearthed in future. For the time being we have to keep in mind that archeological findings are strongly biased to open land and durable artifacts. Denevan (Denevan 1992a; Denevan 1992b), and more recently Mann (Mann 2005) in a popular book, describe extensively the pre-Columbian landscape of the Americas.

4. Forest recovery: Botanical data

The recovery of forest formations must have followed in many parts of tropical America after agricultural fields were abandoned because of the European-caused demographic collapse. Massive forest recovery or regrowth has occurred many times following periods of decreased moisture and temperature (the glacial periods). During the interglacials wetter conditions and milder temperatures boost the expansion of forests from their former glacial refugia. Forest regrowth also occurs in open spaces cleared intentionally by humans when those spaces, otherwise maintained, are abandoned. Pioneer weeds and low bushes take over, soon to be followed by trees. When cultivated land is abandoned a replacement occurs (more rapidly in the Tropics than in temperate zones): plants no higher than 2 m are replaced by trees as high as 30–60 m; plants living short spans, sometimes just months, are replaced by long-living communities, sometimes in the hundreds of years. Centuries may elapse before a forest reaches an equilibrium between growth and decay; during such phases of expansion the carbon fixed in the increasing vegetal biomass is extracted from the atmosphere. An average hectare of mature forest biomass in the Amazon basin may weigh some 400 tons, and 50% of that biomass is carbon (Montagnini and Jordan 2002); thus, the amount of atmospheric CO_2 needed to produce forest biomass during the reclamation phase of the abandoned fields must have been enormous.

Although several plant species are known to have rapid recovery rates, by far the fastest growing is the new world bamboo, *Guadua (*formerly known as *Bambusa Guadua* but currently identified as *Guadua angustifolia* Kunth), distributed throughout the Amazon basin, the Andean region, and the Atlantic and Pacific watersheds, from Paraguay to Panama. It grows from sea level up to 2200 m, with yearly precipitation ranging from 1400 to over 3000 mm, and grows both on damp and well-drained soils. Giant woody bamboo in subtropical and tropical forests are known for their extraordinary rapid stem growth pattern, which allows them to reach open spaces in the tree canopy at 20- or even 30-m height within 120 days (Riaño et al. 2002). *Guadua* has an astonishing soil tolerance, from relatively acid (pH 4.2) to even poor soil conditions. *Guadua* grows almost everywhere and is a traditional threat to agriculture as it rapidly takes over unattended fields and open land. According to El Bassam (El Bassam et al. 2002) *Guadua* is also one of the world's fastest biomass-producing genera. Recent research on biomass fixation by Riaño et al. (Riaño et al. 2002) on new established plantations of *Guadua* documents up to 10.8 tons of carbon fixed per year and hectare, reaching 54.3 tons in 6 yr. This productivity triples every other known species but willow. In addition *Guadua* is closely related to human settlements, as it was and is used as raw material for housing, fencing, and many other purposes. Thus we should consider *Guadua* as a "cultivated plant" that could explain an extremely fast carbon uptake as soon as agricultural fields are abandoned. The favorable conditions in Central and South America can be seen in Figure 2. Here the global net primary production (NPP) of carbon in the recent decades (1981–2000) is displayed (Prince and Small 2003). Details of this distribution might have been different 500 yr ago, but the relative importance of the Americas is clearly visible. In a state of equilibrium the NPP is nearly balanced by the release of CO_2 because of decay of plant material, but in case of forest regrowth a substantial part of the NPP is fixed as biomass for longer times.

5. Ice core CO_2 data

Measurements of the atmospheric CO_2 content from air bubbles enclosed in the ice at Law Dome, Antarctica, published by Etheridge et al. (Etheridge et al. 1996), show a decrease by 8 ppmv (from 282 to 274 ppmv) between the years 1570 and 1604 (Figure 3). The measurement precision of the ice core CO_2 mixing ratios is reported to be 0.2 ppmv. The dating of the ice in the Law Dome core has an accuracy of ±10 yr confirmed by the signals of major volcanic eruptions (Palmer et al. 2001). For the dating of the CO_2 content a pore closure of the firn at an age

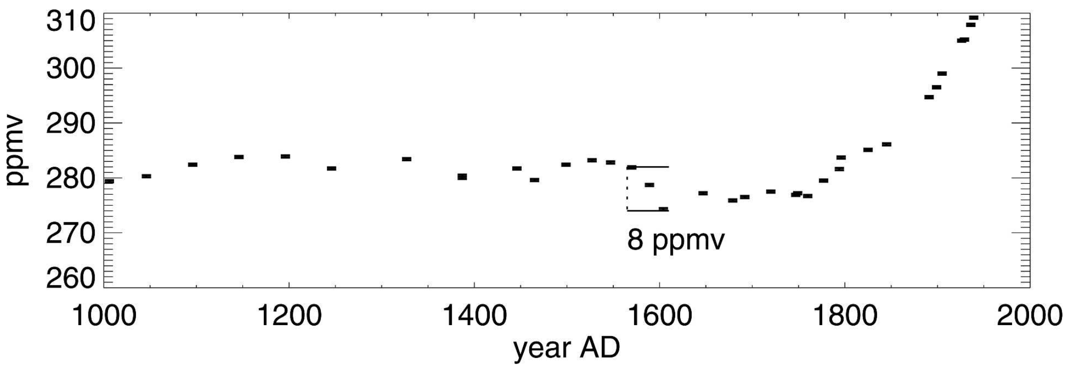

Figure 3. Atmospheric CO_2 measurements from the Law Dome ice core DSS (plotted with data from Etheridge et al. 2001). The horizontal lines indicate the drop by 8 ppmv, which we try to explain by the reforestation after the demographic collapse in the Americas.

of 68 yr is considered. Because of the diffusion before pore closure, the air enclosed in the ice refers to a time range of ~20 yr (Trudinger 2001). Thus, the time series of atmospheric constituents trapped in the ice is already inherently smoothed. Because of the low uncertainty of the single measurements, we use the original, unsmoothed data published in the World Data Center for Paleoclimatology Contribution Series by Etheridge et al. (Etheridge et al. 2001). We refer here to the Law Dome Summit South (DSS) core, as it covers the period under consideration with the highest effective temporal resolution available. Other ice core data reported by Prentice et al. (Prentice et al. 2001) in *Climate Change 2001* or Gerber et al. (Gerber et al. 2003) confirm the absolute values but cannot resolve this fast decrease of atmospheric CO_2 as their temporal resolution is not sufficient because of the much lower snow accumulation rates at these sites. Siegenthaler et al. (Siegenthaler et al. 2005) compare the Law Dome measurements to measurements from Dronning Maud Land (DML) and the South Pole and find a general good agreement: "The atmospheric CO_2 evolution recorded in the DML record confirms, within the uncertainties of the measurements and the air age resolution, the findings from the Law Dome record." Because of the smoothing effect of the low accumulation rate at DML (59 ± 5 yr width at half height) and the South Pole (95 ± 5 yr), the minimum CO_2 concentration is shifted close to the year 1700 and is only 5 ppmv lower than the maximum found 500 yr earlier. But even with the inherently smoothed data, they consider the minimum between 1600 and 1750 as "a robust feature which cannot be explained by diffusion of CO_2 from microbubbles or by production of CO_2 by chemical reactions." Even if we consider the extreme single value of 274.3 ± 0.2 ppmv CO_2 in the year 1604 ± 10 to be an outlier of unknown origin, a drop of 6 ppmv within 100 yr from 1547 to 1647 remains. On the other hand, we cannot rule out that the real drop of atmospheric CO_2 was even stronger and faster than the 8 ppmv within 30 yr we are discussing here, as the Law Dome data are also inherently smoothed and refer to a time window of ~20 yr. Until further high-resolution measurements of atmospheric CO_2 content in the last centuries become available, we will try to explain a drop of 8 ± 2 ppmv within 20–100 yr.

Prentice et al. (Prentice et al. 2001) states that “A slight contemporaneous increase of the $\delta^{13}C$ content leads to the suggestion that this effect was caused by enhanced carbon storage on land,” resulting from the investigations by Francey et al. (Francey et al. 1999) and Trudinger et al. (Trudinger et al. 1999). In Figure 6.7 of Trudinger (Trudinger 2001) we find an interpretation of the Law Dome ice core CO_2 and $\delta^{13}C$ data applying a deconvolution technique to a carbon cycle model. The input data are smoothed to a centennial scale. The biospherical carbon uptake shows a peak of ~0.3 GtC yr^{-1} in the second half of the sixteenth century. The concomitant oceanic uptake is less than 0.1 GtC yr^{-1}. In her interpretation this enhanced carbon storage on land is due to the lower temperatures during the Little Ice Age found in earlier reconstructions of the Northern Hemispherical temperature by Bradly and Jones, but she also indicates that the temperature reconstruction by Mann et al. (Mann et al. 1998) shows different variations.

Considering a global total of 2.1 GtC per ppmv of the atmospheric loss, the full range of the CO_2 dip in the Law Dome data equals a flux of 17 GtC within 30 yr or 0.5 GtC yr^{-1}. To estimate a possible ocean release of CO_2 we used the parameterized impulse response function given in Sausen and Schumann (Sausen and Schumann 2000). This function describes the reaction of atmospheric CO_2 content on release or uptake based on the results of the carbon cycle model of Meier-Reimer and Hasselmann (Maier-Reimer and Hasselmann 1987). Biospherical uptake of 20 GtC within 30 yr or 0.67 GtC yr^{-1} is necessary to explain the 8-ppmv dip, as 3 GtC are released from the ocean reservoir. On the other hand, a strong ocean surface water cooling could result in a net CO_2 uptake. As the lowest temperatures of LIA are found later than the CO_2 dip in the reconstructions by Esper et al. (Esper et al. 2002) or Mann et al. (Mann et al. 1998), and the sharp minimum in the reconstruction of Moberg et al. (Moberg et al. 2005a; Moberg et al. 2005b) in the years 1579/80 is followed by warmer years in the next decades (see Figure 4), a dominant role of ocean uptake is unlikely.

Taking into account the above-mentioned fast-growing *Guadua*, which is able to produce a biomass of 10 tons ha^{-1} yr^{-1}, 5×10^7 ha or ½ million km^2 of

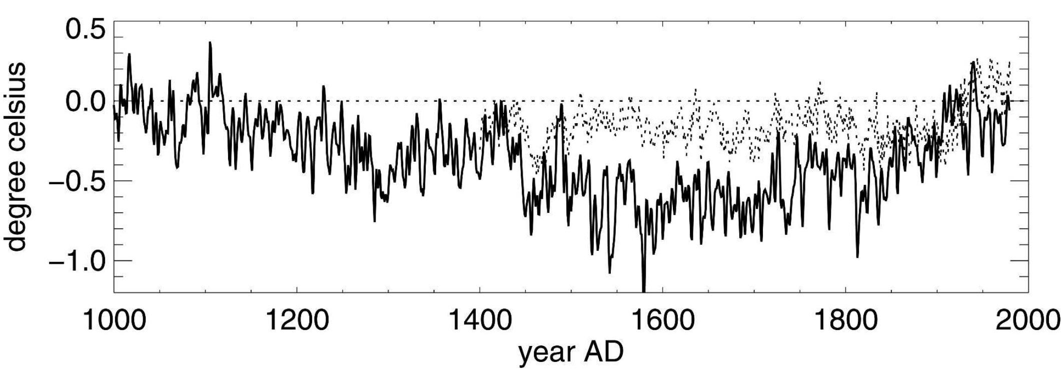

Figure 4. Two reconstructed Northern Hemispheric yearly temperature deviation time series: Moberg et al. (Moberg et al. 2005a): full line, reference period 1961–90; and Mann et al. (Mann et al. 1998): dotted line, reference period 1902–80, from A.D. 1400 to 1980. Both time series are not smoothed.

abandoned land is necessary to explain this carbon sink if all other carbon fluxes remain stable. On longer time scales we have to compare the carbon density of forests against croplands. Using the numbers given in *Climate Change 2001*, which report that the carbon density of plants is 120–190 tons ha^{-1} and that of soil is 120 tons ha^{-1} in tropical forest. For forest and for cropland it is only 2–3 tons ha^{-1} (plants) and 80–120 tons ha^{-1} (soil), we consider a difference of 160 tons ha^{-1}. With these numbers a total of 1×10^6 km^2 of tropical forest regrowth would be sufficient to explain the total atmospheric carbon loss of the late sixteenth century. This amount of forest regrowth should be compared to a total of 7×10^6 km^2 of tropical forest in the Americas of today. For temperate forests the carbon density reported in *Climate Change 2001* is between 57 and 134 tons ha^{-1}, about half of the density in tropical forests. This would double the area of forest regrowth needed to explain the atmospheric CO_2 loss. Relating these areas (0.5–2×10^6 km^2) to the loss of population in the Americas results in a usage of deforested land in the order of 0.5–4 ha per person. Williams (Williams 2000) reports for the more extensive land use in European neolithic settlements a population density of 5 per square kilometer and about 2 ha of cleared forest per person.

The loss of atmospheric CO_2 of 8 ppmv leads to a reduction of radiative forcing by 0.17 W m^{-2} at a background level of 280 ppmv. Using a climate sensitivity between 0.4 and 1.2 K (W $m^{-2})^{-1}$, which covers the range of recent climate models, and taking into consideration that these climate sensitivities refer to equilibrium conditions, we can expect a global temperature change of –0.1 to –0.2 K, explaining a small part of the cooling found at the LIA. This is in full agreement with the reconstructed Northern Hemispheric temperature data (see Figure 4) and simulations (Zorita et al. 2004; Crowley 2000).

6. Discussion

The abandonment of large expanses of agricultural fields in the Americas, due to the massive demographic collapse brought about by the European colonization and the subsequent reclaiming of those areas by forest expansion, leaves its footprints in the atmospheric CO_2 level of the seventeenth century. A necessary prerequisite for this hypothesis is the assumption that already the forest growth after the last ice age has been strongly affected by human activities. In a recent article Ruddiman (Ruddiman 2003) compares the methane and CO_2 trends of the previous interglacials to the Holocene and claims to see a strong impact of manmade deforestation on atmospheric CO_2 levels since 8000 yr ago. He scales the Bern Carbon Cycle Model (Indermühle et al. 1999), which considers oceanic uptake and the reaction of the whole biosphere to changes in atmospheric CO_2 content, to the fluctuations in a time scale of several decades resulting in 2.7 GtC to be fixed for a reduction of 1 ppmv in the atmospheric CO_2 level. This value is only 30% higher then the direct conversion of CO_2 loss into fixed carbon we use in our argumentation. In his argumentation he attributes the CO_2 reductions in the fourteenth and the late sixteenth centuries mainly to the bubonic plague that hit Europe at those times. The postconquest demographic collapse of the Americas and its impact onto this huge forested landmass accounts only for 20%–30% of the drop of CO_2 levels by 10 ppmv that he is considering. In our view Ruddiman (Ruddiman 2003) underestimates the role of the Americas both in his estimate of anthropogenic deforestation and, resulting from this, in the impact of the plague-driven reforestation in the sixteenth century. We see two major reasons for this: the restriction of "easily accessible areas for cutting" to elevations less than 1000 m in altitude excludes the main agricultural regions in Central and South America, and the "degree of deforestation" of the Americas was classified as "limited," neglecting the wide distribution of cultivating cultures (Figure 1) in forested areas. Meanwhile this view has changed; in a new article Ruddiman (Ruddiman 2005) states that "The American pandemic coincides with the largest CO_2 drop of all."

Joos et al. (Joos et al. 1999) derive a total terrestrial carbon storage of 37 GtC from spline-fitted CO_2 levels in the much longer time period between 1600 and 1750. In their model 29 GtC were released from ocean, while only 8 GtC were extracted from the atmosphere. Because of the smoothing of the CO_2 input data, the reduction in this time period was only by 4 ppmv. Our rough first guess of 17 GtC refers to the full range of the reduction of atmospheric CO_2 level by 8 ppmv as measured in the Law Dome core and does not include the feedback mechanisms like ocean uptake and release. It refers to a shorter time span, where feedback mechanisms with a slow reaction are negligible. In this longer time range also the European and Asian changes in population and resulting forest cover (Ruddiman 2003) have to be considered.

Nearly no impact of land-use changes on the Northern Hemispheric temperatures over the last millennium is found by Gerber et al. (Gerber et al. 2003). In the Bern Carbon Cycle Model used for this study, land use is parameterized directly proportional to the global population growth taken from the United Nations (United Nations 1999) data. In this dataset a steady growth of the world's population is assumed and resolved in intervals of 250 yr. The cumulative carbon emission between 1075 and 1850 is estimated to be 36 GtC, but dramatic changes in land use due to the population collapse of the Americas in the beginning of the sixteenth century cannot be resolved by these assumptions. The steady release of 0.05 GtC yr^{-1} is very small compared to the carbon fluxes imposed by other perturbations handled in this study.

In addition to the impact on the CO_2 level and the resulting radiative forcing, changes in regional climate are also probable: enhanced precipitation in the Andean highlands and the advance of the tropical glaciers, which is linked to increased moisture (Kaser 1999), might be caused by enhanced evapotranspiration and water storage in the reforested areas. This will definitely have an impact on cloud coverage counteracting the reduction of surface albedo by forest growth.

Together with the reduced radiative forcing due to lowered atmospheric CO_2 levels, the demographic collapse of the native population of the Americas can be offered as an additional factor that forced the North Atlantic region into the climate pattern known as the Little Ice Age. Our contention is that the expansion of vegetal biomass extracted enough CO_2 from the atmosphere to create a reduced greenhouse effect, which in due turn caused, together with the variations of solar irradiance and volcanic aerosols, a temperature reduction compatible to the Northern Hemispherical cooling in this period, while the changed boundary conditions (i.e., lower surface albedo, higher precipitation, evapotranspiration, and cloud coverage in the Americas) might have changed the patterns of circulation in the North Atlantic region. To shed more light on this, we propose deeper investigations using fully coupled dynamical biosphere–ocean–atmosphere models.

We are not arguing that forest expansion in abandoned agricultural fields in tropical America alone caused the Little Ice Age. Other causes have also played a role. Yet, we want to leave the founded assumption of a connection between a historic event, the conquest of the Americas; the demographic disaster of native Americans brought about by conquest-related diseases; the growth of forests due to reclamation of abandoned agricultural fields; lowering atmospheric CO_2; and the average cooling of the climate by 0.1°–0.2°C. This relationship between a historic event and the climate suggests that human behavior had a significant effect on climate centuries before the known consequences of industrialization on weather patterns.

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