Nikola Koepke and Joerg Baten, Univ. Tuebingen and CESifo: "Climate and its Impact on the Biological Standard of Living in North-East, Centre-West and South Europe during the last 2000 Years"

Please note: This is not the final version of this paper. A later version has been published in "History of Meteorology 2" (2005/06).

Abstract

We argue that historical climatology is crucial for understanding human living standards, for which anthropometric indices are an important proxy variable (given the biological relationship with quality and quantity of nutrition). For example, did climatic change cause the demographic catastrophes of the 14th and 17th centuries, as Galloway (1986) argued (see e.g. also Kelly, n.y.)? This study uses recent estimates of human stature over the last two millennia in three different European regions and compares them directly with estimates of temperature. We employ both a climatic index based on a number of series, and a recent series by Mann and Jones (2004). The basic finding is that overall, the impact of temperature is economically, but not statistically significant. Starting in the 9th century statistical significance is given, however, when population density exceeded a previous unknown level. It seems that population pressure made the European populations, especially north of the Alps, more vulnerable to climatic shocks.

Climatic influence on height

One of the most fascinating topics of long-run economic history is the relationship between climate and human living standards. Especially in pre-industrial times we would expect an impact of climate on agricultural production (especially protein production), and thus on the quality of nutrition, and therefore mean height; furthermore, due to more humid or colder winters food storage becomes more difficult in Central Europe. Indeed, the impact on human history was immense: on the 18th century climate-height effect see Baten (2002). Grove (2002) demonstrated how the switch from the medieval warm period (900 early 13th century) to the Little Ice Age, starting around the late 13th century, has decreased harvests and protein production from cattle and sheep.[1] Not only temperatures declined but as colder winters tended to be generally correlated with more frequent weather extremes, also other climatic problems created a deadly synergy. For example, cattle epidemics spread rapidly in Northern and Western Europe already in the 13th and early 14th century, killing a large part of the cattle stock. Therefore Grove argued that the agricultural production decline took place before and parallel to the Black Death of the mid-14th century.

Although plague is a highly infectious disease that is only mildly influenced by malnutrition, the lower nutritional status might have weakened the immune system of the European population, contributing strongly to the large population loss of the 14th century. In addition, during famines people often leave their households and start to move around in search of other subsistence possibilities (Mokyr and O'Grada, 2002). The most Northern, cattle- and fishery-based economies of Europe suffered most. Iceland lost most of its population, and the European population of Greenland completely disappeared.

The 15th century and the first two thirds of the 16th century were warmer again, but the 17th century represents the next climatic catastrophe. Pfister (1988) has described how climate reduced Swiss nutritional status in the last decades of the 16th and most of the 17th century. While most of the population decline of the 17th century is traditionally attributed to the Thirty Years' War as well as to the hunger and the infectious disease that accompanied it, the rapid climatic deterioration could have contributed to the large number of deaths from (at least partially) nutrition-related diseases during this devastating war. The synergy between protein malnutrition and death from a large array of diseases can also explain why the population stagnated or declined even in countries that did not directly participate in the Thirty Years' War. Milder episodes of climatic deterioration in the late 18th and mid-19th

---

[11] Grain yields were falling between 1220 and 1320, see Grove (2002), figure 2.

centuries coincided with milder demographic effects on average, even if some regions and countries were severely affected (Grove 2002).

Are - except for the results of the studies on the impact of climate on nutritional conditions during short, century-wise periods of the 2nd millennium - our expectations of the relationship of temperature and mean height confirmed also for the long run study period?

Climate series

To check this we created a climate index using different series. Recent research offers estimates from Alpine and Scandinavian glacier movements, Greenland ice kernels, oak tree rings and lake sediments to quantify climatic change over the centuries.[2] All of those series appear to be correlated in general. We used mainly the European glacier movements as explanatory variables, because they are available for the ancient period, and the evidence might be less indirect for the region under study compared with, for example, Greenland oxygen isotope ratios (see Lamb 1982; Patzelt, 1994; Heide, 1997; Grove, 2002, p. 316). However, the literature emphasizes that glacier movements reflect temperature changes with a certain time lag. Therefore we calculated the average of the previous and the current century glacier movement. Additionally, we corroborated our glacier series with tree-ring series from North Sweden that also stretches back to the ancient period (and compared both with a shorter tree-ring series on the Alpine area: they moved in accordance, see Huntley et al., 2002, p. 278).[3] For comparison, we used the recent temperature series estimates by Mann and Jones on the Northern Hemisphere (2003a, 2003b, 2004), which starts in the early 3rd century AD.

---

[2] See e.g. Frenzel et al. 1997, or for an overview of possible methods see e.g. Wigley et al., 1981.

[3] We experimented with local temperature series for the three regions North/Eastern, Central/Western and Southern Europe, but the differences between the series were extremely small, so that we abandoned this avenue of temperature measurement.

Height series

Our study has been done on the basis of mean height as an indicator for the quality of nutrition.[4] We estimated height trends for the Mediterranean, Northeastern and Central-Western Europe for the 1st to the 18th century AD. Because of dating limitations for a regular archaeological site the unit of analysis is restricted to the century. In a related study we devoted considerable space to describe our strategies, here we will only summarize them.[5] We could rely on a sample of 9477 height estimations from 314 sites. In some cases heights of two to 360 individuals were aggregated by previous investigators; thus we have 2974 separate height numbers. We used both weighted regressions (weighted with square roots) and regressions with individuals only to estimate height trends by gender and by the three European regions. The regression approach allowed us to control for migration[6] and social

---

[4] This is the common procedure in anthropometric research: see e.g. Komlos, 1989, Komlos and Baten, 1998, Steckel, 1995. But because of the study period we got our height estimations not from written sources, but from physical anthropological analysis of bones from excavated cemeteries, see Koepke/Baten 2005.

[5] Koepke and Baten, 2005.

[6] Concerning migration: A number of anthropologists are still convinced that genetic height potentials play a large role, whereas other anthropologists have doubts whether genetic height potentials explain any variation in average height of a population – in contrast to individual height which is clearly influenced by genetic factors (Bogin, 1988, Mascie-Taylor and Bogin, 1995). Anthropometric historians found that environmental circumstances during growth have the most important impact on variation in mean height. Two points are important in this respect. Firstly, most migrants experienced a different environment during their first years of life, compared with the autochthonous population. For example, if they were born in a Northern or Eastern European agricultural environment and than migrated to the Mediterranean in their later life, we would expect them to be significantly taller. Secondly, if immigration is large enough, agricultural production techniques might be transferred to the target region, if they turn out to be sufficiently efficient in the new environment. We know that the most important migration streams moved from the Mediterranean region into Central and Western Europe in the first to third century, and there was an important Germanic (and other) migration from Northern Europe to Eastern, Central and Southern Europe and later to the British Isles from the forth to sixth centuries.

Migrants from the Mediterranean to Central Europe (especially Roman soldiers and officers, as well as administrative staff) turned out to be 4 cm shorter than the rest of the population. But skeletons that could be identified as “Germanic migrants” were not significantly different from Eastern Europeans. Also not statistically significant, but economically meaningful was their coefficient in the “Mediterranean” regression: Germanic migrants, which died in the Mediterranean region, were 1.63 cm taller.

status[7], as far as we (and earlier scholars) were able to determine this using grave goods and similar information. We arrived at trends as given in Figure #1 and Figure #2. The overall picture shows stagnating heights indicating no real progress in European nutritional status until around 1800 but there is considerable variation between centuries.[8] How could we make sure that this was a reliable estimate of height development? Naturally, this kind of estimation (for non-modern periods) has many limitations – although our sample is much larger than earlier studies, the number of cases is still small in comparison to data sets on more recent periods. But it is reassuring that counterchecking height trends for separate European regions and for genders moved in similar directions, except where we expected them to diverge. For example, we expected a worsening development for Northern and Eastern Europe during the Little Ice Age (14-17th centuries) because of the more extreme impact of the temperature change there, and actually the Northeastern Eruopeans lost there favourable position during

[7] Social status is an important variable, as many studies on the 18th to 20th centuries found height differences of typically 2-4 cm among adults of lower versus middle and upper class (see e.g. Baten, 2000). In our data set, we relied mostly on the classification schemes of the original studies. If skeletons were not of higher social rank, the excavation reports often did not find this fact worth mentioning. We therefore assigned dummy variables only to the cases of middle and upper class social origin (leaving a "lower or unknown" group for the constant). This also means that we should not over-interpret the coefficient of this social status variable. However, this variable is not only important by itself, but is also necessary to control for the social composition and potential social selectivity when we analyze height trends. Although the bulk of our measurements stems from burial sites that represented all social strata, we wanted to exclude the possibility of social selectivity causing height trends as far as possible.

[8] During Roman times we have more or less stagnating heights; this is interesting as (having archaeological studies in mind) one would expect an increase in the 2nd century, and a more pronounced decline in the 4th century. Remarkably is the increase in the 5th and 6th century despite the migration period temperature pessimum. The 11th and 12th century were favourable for mean height - this is also the medieval warm period, see Crowley and Lowery, 2000. The decrease in the 13th century may be explained by bad climate (beginning of the Little Ice Age). The decrease in the 17th century could be a consequence of the thirty-year's war and parallel climatic deterioration.

these centuries.[9] In contrast the conditions were more favourable in more continental Central-Western Europe during this period.

Female mean height is naturally always lower than male height. But female growth is also determined by discrimination of females. Therefore, what also fits with our expectations: Female heights were even more depressed relatively to males during the Middle Ages than in the other epochs, whereas gender dimorphism decreased in the Renaissance period.[10]

Apart from those expected deviations, height trends moved relatively similar in the long run. Hence,we conclude that the estimates of development were reasonably reliable. But we applied an additional strategy to ascertain reliability: we checked burial sites that were in use for more than a century. If those shared the same trend with the large region, we could be sure that it was not a random regional composition effect that caused our trends. Among those cases with large sample numbers the majority pointed in this direction.

The high synchronicity of human heights by itself might suggest an influence of temperature conditions, because these probably have been more similar across European regions than economic conditions.

Comparison of temperature and height development

There are some similarities and many differences between the height and the temperature series (Figure #3). The well-documented climatic optimum of the 11th/12th centuries and lower values before and after are visible in the height series. The low values of the 7th and 8th

---

[9] In general people in the North-Eastern region are the tallest, Mediterraneans have the lowest mean height: However, not due to genetics, but due to environmental factors: The Northeast has low population density and animal protein rich diet due to cattle husbandry, whereas in the South it is the opposite (high population pressure and Mediterranean diet based on less meat consumption, in this concentrated on pork): see e.g. King, 1999. In between are the people of Central-Western Europe, which is the region that has been under Roman occupation in the beginning of our study period.

[10] See e.g. Ulrich-Bochsler, 1996.

centuries, and the crisis of the 17th century could have been caused by adverse climatic conditions.[11] Important deviations relate to the 1st to 6th and to the 13th centuries.

In our opinion the most likely interpretation is that - despite of the phase of Migration Period Pessimum - after the breakdown of the Roman Empire average height increased because of better nutritional status and improved environmental conditions due to various phenomena: (1) population density and urbanization decreased after invasions and plague epidemics. The consumers moved back to the proximity of nutrient production. Infectious disease might have appeared less frequently (although the (supposed) [12] second occurrence of the plague in the sixth century contradicts it). (2) Germanic invaders brought their agricultural methods that emphasized protein production. Even if this specialization was inefficient in the Mediterranean, the settlers might have kept them for a transitory period. In Central and Western Europe, the methods were efficient as long as population density was low.

These two developments might explain why the temperature-height relationship is not visible for the first eight centuries. The low height value of the 13th century is particularly interesting and deserves further study. Was it because of the rapid urbanization of this period (more infectious disease, less milk for rural-to-urban migrants)? Or because of more social or gender inequality? Does a measurement error bias the height variable?

A comparison of the development of mean height and the temperature index created by Mann and Jones (2004) (Fig.# 4) indicates more parallel movements. But also in this case we cannot see a connection over all the centuries of our study period. Interestingly this similar development starts with the 9th century AD, whereas it is very obvious that from the 1st until the 8th century AD both series do not move together at all.

---

[11] Around 1700 was (probably) the coldest phase of the Little Ice Age: see Bradley/Jones, 1993.

[12] The so-called Antonine plague is regarded as the first one.

Results: impact of temperature on height

Both, using our composite index or the Mann/Jones temperature index we come to the conclusion that warmer climate has a positive, but insignificant impact on mean height for our long run study period (Tab.1, col. 2-5): warmer temperature is good for harvests and protein production in the relevant range, and this is favourable for height. The difference between two standard deviations of our climatic series is 0.12, the difference between minimum and maximum is 0.20. The coefficient of the more appropriately specified model is 2.97. The difference between "good" and "bad climate" was therefore about 0.4 cm, the difference between the extremes about 0.6 cm. Both values are at the margin of being economically significant.[13] Without controls for period, this variable is economically unimportant. But the tall stature of North-Eastern Europeans in the warm 11th/12th century, and its dramatic decline afterwards lends support for the importance of this variable.

If we conduct regressions starting in the 9th century AD the relationship between temperature and height becomes statistically significant (see Tab.1, col.6 and 7). Again, this result is robust using both temperature indices. This is interesting, because in the 9th century, population density exceeded a previously unknown level. It seems as if population pressure made the European populations, especially north of the Alps, more vulnerable to temperature shocks.

One could argue that cold climate might not be harmful, but rather beneficial in the Mediterranean, because precipitation could become more frequent there, when temperature gets colder. We tested whether our results would change if we exclude the observations on the Mediterranean, and found the coefficient for temperature unchanged (the coefficient was 2.74, compared with 2.97 when the Mediterranean was included (see Tab.2).

---

[13] Temperature is statistically insignificant as explanatory variable for mean height; without controlling for period it is even economically unimportant.

Except for the bundle of explanations given above for the missing relation of temperature and mean height in the long run, it is possible, of course, that there is a measurement error - especially for the early period, for which the temperature estimates are known to be particularly imprecise. But furthermore it is also possible that the relation is truly weak. On the one hand the interpretation could be awkward, because the temperature series is not exact enough. For example, by now the discussion is still in progress, when the Little Ice Age started.[14] Thus, the question arises which is the best temperature series to use? On the other hand we have to have in mind that probably other climatic factors, like e.g. precipitation, are also important determinants, which we could not control for in detail, because no data series are available fitting with our long run study period by now.

Which other factors influenced the development of mean height? Apart from temperature, also most of the other variables are statistically insignificant, but bear the expected sign in the regression analysis (see Tab.1): Population density comes closest to statistical significance; in unweighted regressions the p-value is even as low as 0.15. It suggests that lower population density is good for the biological component of the standard of living that is reflected in stature in pre-industrial times, after controlling for large-region effects and inequality. The analysis of economic significance for population density yields a height effect of about 1.0 cm for the typical “high” and “low” population density of the time, and 2.2 cm between the most extreme observed values. In other specifications, the economic significance of population density would even be one third greater. Malthusian Theory of land as limiting factor for human development seems to be confirmed (for period until 1800). Gender inequality and social inequality both had negative signs. Given that these results are similar to those of many other studies on the 18th to 20th centuries, we tend to attribute a fairly large credibility to them. In terms of economic significance, social inequality meant 0.63 cm between high and low, and 0.74 between extremes, whereas the effect of gender inequality

---

[14] Compare e.g. deMenocal et al., 2000 ; Jones et al. 2001.

was about half of that. Also the „Roman bath/technology“-dummy in the regression without time dummies has an unfavorable impact on mean height.

In sum, population density is definitely of economic significance, but not of statistical significance. Temperature, as well as social inequality and gender inequality are at the margin of being economically significant.

Conclusion

Our study is based on the first anthropometric estimates on the biological standard of living in central Europe of the two millennia AD. In the long run no general increase in mean height took place. The height development is quite synchronic in the three "large regions" of Europe. As determinant of mean height population density is economically significant: it has a negative influence on height due to Malthusian factors; urbanization has a positive impact, if we control for population density. Roman health system/technology, social and gender inequality, as well as temperature are of marginal significance.
The results regarding temperature are robust using different temperature indices. Remarkably, we found a statistically significant relationship between temperature and height using data from the 9th century AD onwards; probably extremely increased population density made the Europeans more susceptible to climatic changes.

REFERENCES

Baten, J. (2000). Economic Development and the Distribution of Nutritional Resources in Bavaria, 1797-1839. *Journal of Income Distribution* 9, 89-106.
Baten, J. (2002). Climate, Grain Production and Nutritional Status in 18th Century Southern Germany. *Journal of European Economic History* 30.1, 9-47.
Bogin, B. (1988). *Patterns of Human growth*. Cambridge: Cambridge University Press.
Bradley, S., and Jones, P. (1993). 'Little Ice Age' summer temperature variations: their nature and relevance to recent global warming trends. *The Holocene* 3,4, 367-376.

Crowley, T., and Lowery, T. (2000). How warm was the Medieval Warm Period? *Ambio* 29, 51-54.

deMenocal, P., et al. (2000), Coherent High- and Low-Latitude Climate Variability during the Holocene Warm Period. *Science* 288, 5474, 2198-2202.

Frenzel, B., et al. (1997). *Glacier fluctuations during the Holocene*. Stuttgart.

Galloway, P. (1986). Long-Term Fluctuations in Climate and Population in the Pre-Industrial Era. *Population and Development Review* 12.1, 1-24.

Grove, J. (2002). Climatic Change in Northern Europe over the Last Two Thousand Years and its Possible Influence on Human Activity. In: Wefer, G. et al. (eds.). *Climate Development and history of the North Atlantic Realm. Hanse Conference on Climate History*. Berlin/Heidelberg: Springer. 313-326.

Heide, A. (1997). *Das Wetter und Klima römischer Antike im Westen des Reiches*. Unpublished Ph.D. thesis. Mainz.

Huntley, B., et al. (2002). Holocene Climatic History of Northern Europe as Recorded by Vegetation Changes: Possible Fluctuations upon Human Activity. In: Wefer, G. et al. (eds.). *Climate Development and history of the North Atlantic Realm. Hanse Conference on Climate History*. Berlin/Heidelberg: Springer. 223-232.

Jones, P., et al. (2001). The Evolution of Climate Over the Last Millennium. *Science* 292, 5517, 662-667.

Kelly, M. (no year given). *Climate and Pre-Industrial Growth*. working-paper on: http://www.ucd.ie/economic/staff/mkelly/papers/climate.pdf.

King, A. (1999). Meat Diet in the Roman World: A Regional Inter-Site Comparison of the mammal bones, *Journal of Roman Archaeology* 12, 1999, 168-202.

Koepke, N., and Baten, J. (2005). The Biological Standard of Living in Europe During the Last Two Millennia. *European Review of Economic History* 9.1, 61-95.

Komlos, J. (1989). *Nutrition and Economic Development in the Eighteenth Century Habsburg Monarchy: An anthropometric History*. Princeton, NJ : Princeton University Press.

Komlos, J., and Baten, J. (1998). Height and the Standard of Living. *Journal of Economic History* 57.3, 866-870.

Lamb, H. (1982). *Climate, History and the Modern World*. London: Methuen & Co.

Mann, M., and Jones, P. (2003a). Global Surface Temperatures over the Past Two Millennia. *Geophysical Research Letters* 30.15, 1820.

Mann, M., and Jones, P. (2003b). 2,000 Year Hemispheric Multi-proxy Temperature Reconstructions, IGBP PAGES/World Data Center for Climatology. Data Contribution Series 2003-015. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.

Mann, M., and Jones, P. (2004). 2,000 Year Hemispheric Multi-proxy Temperature Reconstructions, IGBP PAGES/World Data Center for Climatology. Data Contribution Series 2004-##. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA

Mascie-Taylor, C., and Bogin, B. (1995). *Human Variability and Plasticity*. Cambridge Studies in Biological Anthropology, Cambridge: Cambridge University Press.

Mokyr, J., and O‘Grada, C. (2002). What Do People Die of During Famines? The Great Irish Famine in comparative perspective. *European Review of Economic History* 6.3, 339-363.

Patzelt, G. (1994). Die klimatischen Verhältnisse im südlichen Mitteleuropa zur Römerzeit. In: Bender, H., ad Wolff, H. (eds.), *Ländliche Besiedlung und Landwirtschaft in den Rhein-Donau-Provinzen des Römischen Reichs*. Espelkamp.

Pfister, C. (1988[3]). *Klimageschichte der Schweiz 1525 – 1860. Das Klima der Schweiz von 1525 – 1860 und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft*. Bern/Stuttgart. Haupt Verlag.

Steckel, R. (1995). Stature and the Standard of Living. *Journal of Economic Literature*, 33,4, 1903-1940.

Ulrich-Bochsler, S. (1996). *Anthropologische Befunde zu Frau und Kind in Mittelalter und Neuzeit unter besonderer Berücksichtigung der Stellung der Früh- und Neugeborenen:* soziobiologische und soziokulturelle Aspekte im Lichte von Archäologie, Geschichte, Volkskunde und Medizingeschichte. Basel, Univ., Diss. Mikrofiche.

Wigley, T., et al. (1981), *Climate and History. Studies in Past Climates and their impact of Man*. Cambridge: Cambridge University Press.

TABLES & FIGURES

Table #1

TWO REGRESSIONS: DETERMINANTS OF MEAN HEIGHT IN EUROPE

1	2	3	4	5	6	7
Constant	144.24	*0.00*	164.37	*0.00*	-14.03	*0.00*
Climate warm	2.97	*0.52*	0.82	*0.84*	18.94	*0.02*
Gender inequality	- 0.31	*0.50*	- 0.29	*0.46*	1.60	*0.02*
Urban share	0.16	*0.23*	0.2	*0.14*	0.25	*0.08*
Population density	- 0.06	*0.37*	- 0.08	*0.20*	-0.03	*0.55*
Roman Bath/ Technology			- 2.05	*0.01*		
Social inequality			- 0.17	*0.58*		
Mediterranean	- 1.66	*0.05*	- 1.67	*0.04*	-3.56	*0.01*
North-Eastern Europe	1.17	*0.03*	0.89	*0.07*	0.92	*0.17*
Antiquity	- 1.68	*0.01*				
Late Medieval Period	- 0.48	*0.52*			-3.00	*0.02*
Modern (15th to 18th c.)	- 0.76	*0.59*			-0.79	*0.49*
Adj. Rsq	0.33		0.38		0.60	
N	36		36		17	

P-Values in columns 3, 5, 7 in italics.
Weighted Least Squares Regression: number of cases adjusted for aggregated observations using square roots.
Constant refers to a hypothetical height value for the Early Middle Ages, and Central/Western Europe.
Columns 2 - 5: 1st - 18th century AD. Columns 6-7: 9th - 18th century AD

Source: see Koepke/Baten 2005.

Table #2

TWO REGRESSIONS: DETERMINANTS OF MEAN HEIGHT IN WESTERN AND NORTH-EASTERN EUROPE, 1st TO 18th CENTURIES AD

1	2	3
Constant	146.51	*0.01*
Climate warm	2.74	*0.60*

Gender inequality	- 0.32	*0.53*
Urban share	0.17	*0.29*
Population density	- 0.07	*0.37*
North-Eastern Europe	1.15	*0.06*
Antiquity	- 1.76	*0.02*
Late Medieval Period	- 0.36	*0.67*
Modern (15th to 18th c.)	- 0.56	*0.72*
Adj. Rsq	0.21	
N	30	

P-Values in columns 3, in italics.
Weighted Least Squares Regression: number of cases adjusted for aggregated observations using square roots.
Constant refers to a hypothetical height value for the Early Middle Ages, and Central/Western Europe.

Source: see Table 1.

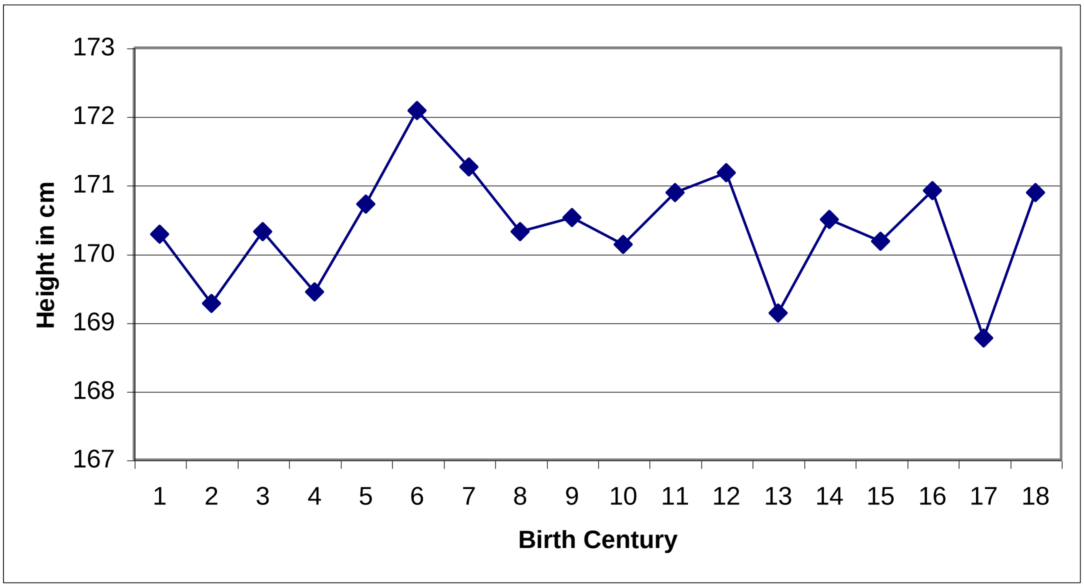

Figure #1

HEIGHT DEVELOPMENT, 1st TO 18th CENTURIES AD
(IN CM, MALE AND FEMALE)

Source: see Table 1. The level of heights was adjusted to male heights of an average European (using the regional coefficients and weighting them with sample weights).

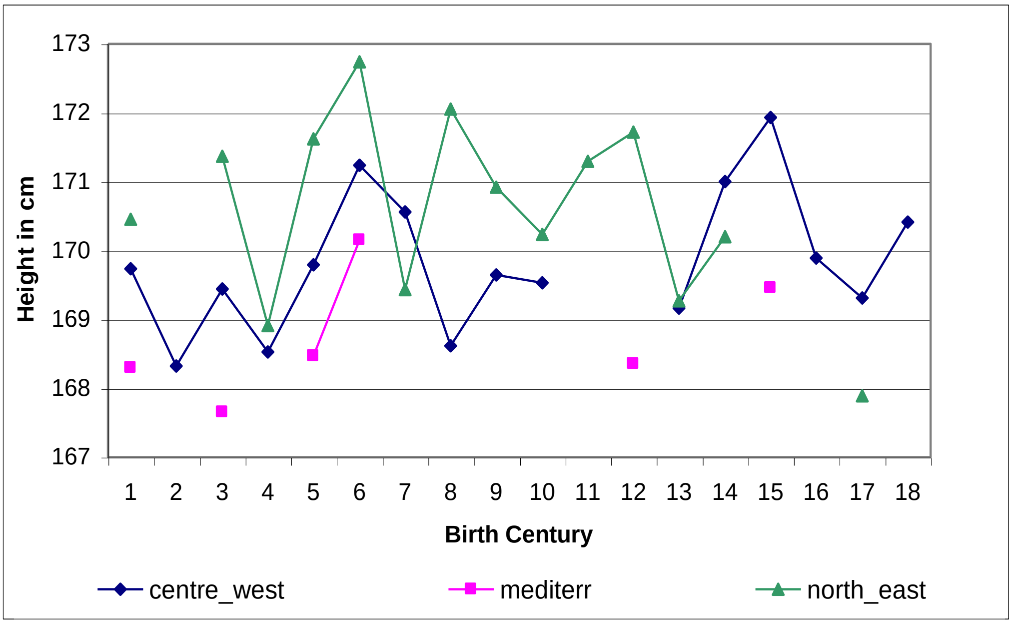

Figure #2

HEIGHT DEVELOPMENT BY MAJOR REGIONS (IN CM), 1st TO 18th CENTURIES AD
Source: see Table 1.

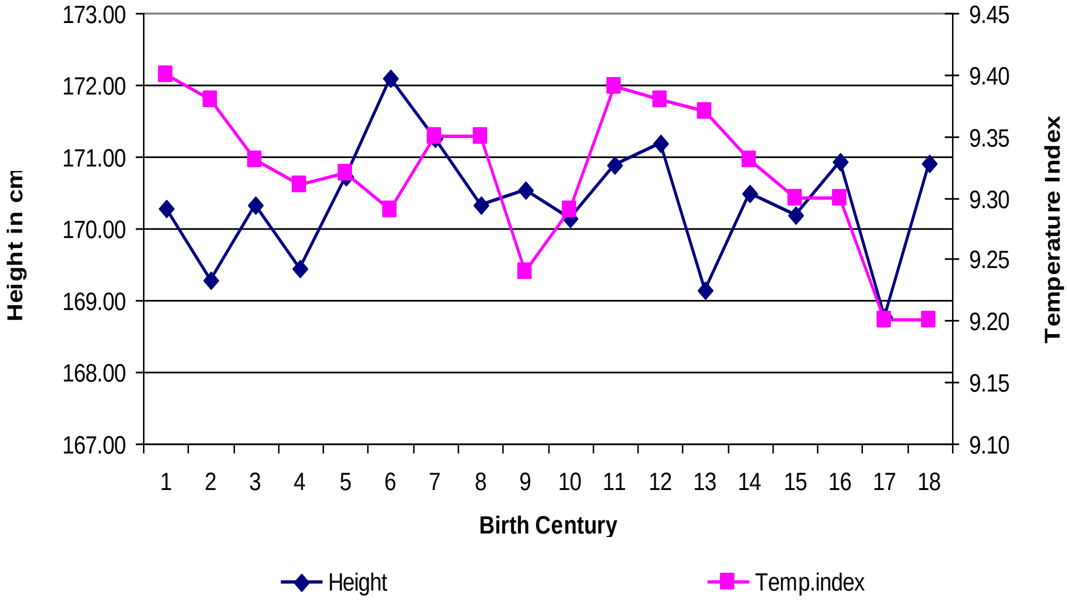

Figure #3

HEIGHT (IN CM) AND TEMPERATURE DEVELOPMENT (BASED ON GLACIER MOVEMENTS AND TREERINGS), 1st TO 18th CENTURIES AD

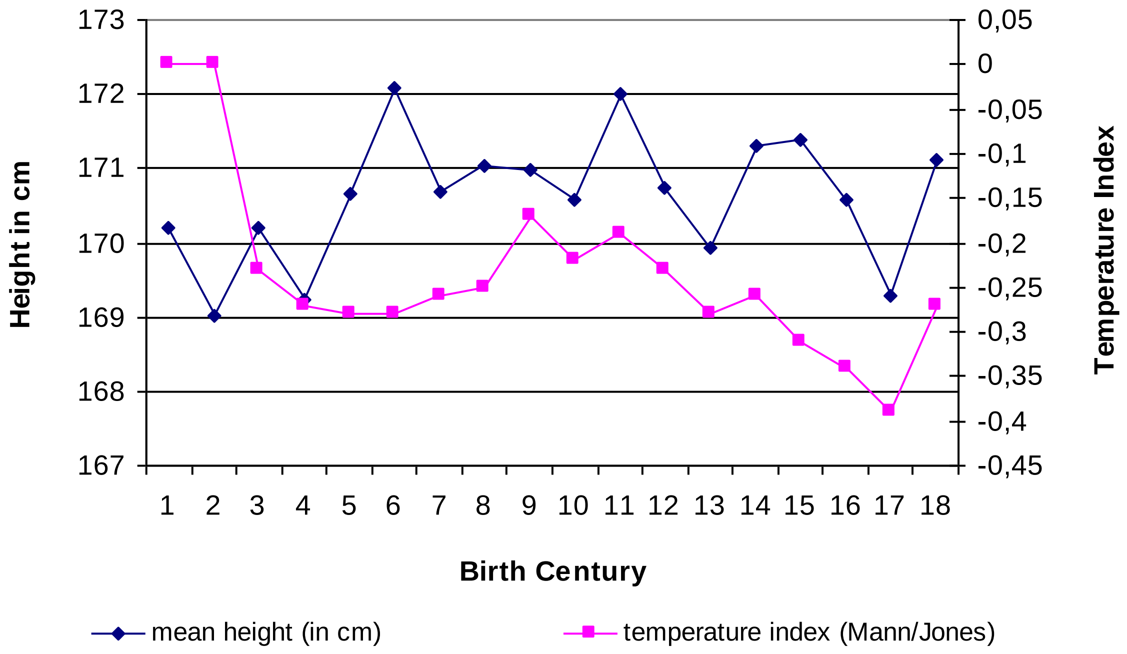

Figure # 4

HEIGHT (IN CM) AND TEMPERATURE DEVELOPMENT (INDEX BY MANN/JONES), 1st TO 18th CENTURIES AD