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Kulturelle Konsequenzen der »Kleinen Eiszeit«

Cultural Consequences of the »Little Ice Age«

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Mit 14 Abbildungen, 13 Tabellen und 33 Grafiken

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Weeping in the Snow

The Second Period of Little Ice Age-type Impacts, 1570–1630

by

CHRISTIAN PFISTER[1]

1. Which Climate Histories Are Needed?

On the morning of April 26, 1688, fresh snow covered the ground around the Swiss convent at Einsiedeln (Canton Schwyz). The snow continued to fall relentlessly all day long. Weeks before most of the peasants living nearby had already run out of hay. During the previous days, the exhausted animals still had to be driven out on the bare ground, where they at least had a chance to find some rotting blades of grass. With deep snow again covering the ground, most of the peasants were at their wit's end. Many of them broke out into tears, as Father Joseph Dietrich noted in the diary which he kept in the Einsiedeln monastery. To make things worse, the hungry animals throughout the villages were crying night and day, thus causing an unbelievable stress on the inhabitants. The local people suffered not only with their animals. They knew from experience that the vociferous protest of hungry animals announced an approaching dearth for humans. Joseph Dietrich was a gifted and alert observer of nature and humans. His account – perhaps for the first time – enables a more detailed glimpse at one of the typical situations of physical and psychological stress in which people were thrown by the vagaries of the "Little Ice Age" climate.[2] It is very likely that such incidents were common during the period 1570–1630, however thus far no such record is known.

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[1] Christian Pfister and Jürg Luterbacher were supported by the Swiss NCCR »Climate« Program: http://www.nccr-climate.unibe.ch (9 February 2004). Paul-Anthon Nielson is acknowledged for carefully reading the manuscript for style corrections. Dr. Franz Mauelshagen is acknowledged for helpful suggestions.

[2] CHRISTIAN PFISTER, Das Klima der Schweiz von 1525–1860 und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft, 2 vols. (Academica Helvetica, vol. V), (Bern, 1984), vol. II, p. 53.

This episode exemplifies the lesson learned from microhistory during the last two decades: that it is quite often necessary to get pretty close to events in order to grasp their meaning and their significance for others. This claim also needs to be made for the history of climate. In the language of sources, climatic events are usually coined in terms of weather histories which deal with processes having a duration from hours to seasons. Climate anomalies are frequently mentioned in autobiographical sources because the writers believed that God gave warning and punished humanity for digression from His commandments.[3] Weather is notably an overarching component in peasant memory books because it was a fundamental experience of daily life for the rural population.[4]

On a whole, weather observations in documentary sources are known to be copious. They are the raw material for reconstructions of climate which are tailored to the needs of the historian. People in the early modern period had even less the ability to comprehend an abstraction such as "climate", let alone "climatic change", from their sensory perception, i.e. not arranged through the media. It is characteristic that such terminology was not known at that time. Rather than climate, weather extremes and anomalies are known to have affected everyday life in the early modern period. Episodes that were thought to be "unnatural" were particularly prone to arouse existential anxieties and fears.

This has been impressively demonstrated in two episodes pointed out by Wolfgang Behringer. On 3 August 1562, a hailstorm hit central Europe. It destroyed crops and vineyards, killing birds and some animals, including a number of unprotected horses and cows. The fields were pictures of devastation. Since observers of the period had no recollection of similar climatic disasters "for a hundred years", many considered this hailstorm as "unnatural" and looked for an explanation. Three possible interpretations arose: the hailstorm could be seen as a sign from God, as the work of the Devil or as the result of witchcraft. Although a number of official councils' decisions since the early Middle Ages had banned the idea of weather-making by human beings, there had always been reluctance to accept this negation of human influence on climate. Behringer proposes that the hailstorm initiated a chain

[3] Kaspar von Greyerz, "Religion in the Life of German and Swiss Autobiographers (Sixteenth and Early Seventeenth Century)", in Id., ed., Religion and Society in Early Modern Europe (London, 1984), p. 228.

[4] Klaus-Joachim Lorenzen-Schmidt / Bjørn Poulsen, Bäuerliche (An-)Schreibebücher als Quellen für die Wirtschafts- und Sozialgeschichte (Neumünster, 1992); Paul Münch, Lebensformen in der Frühen Neuzeit (Frankfurt a. M., 1992), pp. 127–54.

of events which – under the influence of the ongoing second "Little Ice Age-type events" – lead to a wave of witch hunts. Small political entities in particular turned out to be susceptible to the popular demands for witchcraft persecution. The little Barony of Illeraichen set the trend in 1562. Count Hans von Rechberg (†1574) finally yielded to the demand of his peasants to imprison some women suspected of weather-making and having caused crop failure, inundations and cattle disease.[5]

The second episode is documented in the diary of the astronomer Friedrich Rüttel (1579–1634):[6] on 24 May 1626, Rüttel reported a hailstorm in the Stuttgart area which accumulated hailstones the size of walnuts to an alleged depth of seven feet. In the afternoon of 26 May, he observed a sharp icy wind. The subsequent night was so bitter cold that on the morning of 27 May, ice was found on the water in several locations.[7] This is perhaps the most spectacular late spring cold relapse ever registered in southern Germany. It almost annihilated the vine harvest. It also affected the rye and barley. Even the leaves on many trees turned black. Although the cold relapse of May 1626 lasted but only a few hours, it triggered the most important witch hunt in southern Germany considering the number of victims.[8] The occurrence of a polar-frost night on the eve of summer was a shock for most people and justly considered to be "unnatural", i.e. far outside the known spectrum of extremes.

In comparing these two episodes, the following observation needs to be stressed: in retrospect the hailstorm of 1562 is situated in the final phase of a multi-decadal phase of favourable climate, whereas the episode of extreme frost in 1626 occurred in the final phase of a multi-decadal phase of enhanced climatic stress. This may have had an affect on the reaction of people. Whereas the initial witch hunt of 1562 still had a local dimension, the

[5] Wolfgang Behringer, "Climatic Change and Witch-Hunting. The Impact of the Little Ice Age on Mentalities", in Christian Pfister / Rudolf Brázdil / Rüdiger Glaser, eds., Climatic Variability in Sixteenth-Century Europe and Its Social Dimension (Dordrecht, 1999), pp. 323–34.

[6] Rüttel was a physician and astronomer who was engaged in the administration of the Duchy of Württemberg. He was a correspondent of Johannes Kepler (1571–1630). Between 1625 and 1633, Rüttel kept a detailed weather diary that was analysed in an unpublished licentiate thesis. Philipp Stämpfi, Nasses Korn, saurer Wein. Witterungsrekonstruktion für Württemberg 1625–1633, anhand des Tagebuches von Friedrich Rüttel und der Einfluss der Witterung auf Wirtschaft und Bevölkerung (Lizentiatsarbeit, Institute for History, University of Bern, 1992).

[7] Ibid., p. 52; Wolfgang Behringer, Hexen. Glaube, Verfolgung, Vermarktung (München, 1998), p. 54.

[8] Ibid.

upsurge against the witches in the late 1620s swept through several territories in southern Germany. Was this collective angst rooted in the experience of knowing that earlier shocks of "unnatural weather" had turned out to be forerunners of subsistence crises (which again proved true in the case of 1626 when seen in view of the extreme hardships during the years of 1627 and 1628)? Or was it rather due to the fact that the witchcraft paradigm had become more widely known since the late sixteenth century? Regardless of the answers, the climatic context in which such episodes occurred is of importance. It is for this reason that it needs to be interpreted with reference to the history of climate, one which is close to people's minds, past and present. Such a history of climate should focus on building bridges between micro-weather histories based on record sources and the macro-reconstructions of climatic change.

Most historians became acquainted with the history of climate through the path-breaking work of Emmanuel Le Roy Ladurie. Having been a student of Fernand Braudel (1902–1985), the French historian wrote his *History of Climate* according to the Braudelian scheme of historical temporalities. It is well known that Fernand Braudel defined three levels of history (*res gestae*) which were both chronological and operational. The superficial level is one of short-term historical events and individuals; the middle level comprises conjunctures (cyclical phenomena) which occur over medium-length time-scales; and the basal level is of long-lasting structures. The short-term, rapidly changing levels of historical events, chance occurrences and individual men and women comprise what Braudel viewed as the traditional approach to history, and it was against this that he reacted. He played down its importance, seeing events and individuals as the "ephemera" or "trivia" of the past. Among the temporalities of very long duration, Braudel mentioned changes in climate.[9] Emmanuel Le Roy Ladurie took up his concept.

Indeed, Le Roy Ladurie's classical historiographical concept of the "Little Ice Age" fits perfectly into the Braudelian scheme of "long duration". From evidence concerning glaciers and based on vine harvest dates, Le Roy Ladurie concluded that all seasons had undergone a more or less synchronous cooling at the end of the sixteenth century. He likewise assumed that the warming from the late nineteenth century was more or less synchronous in all seasons.[10] His book leaves the impression that there was a distinct "Little

[9] Fernand Braudel, The Mediterranean and the Mediterranean World in the Age of Philippe II, trans. by Sian Reynolds (Fontana, 1995).

[10] Emmanuel Le Roy Ladurie, Times of Feast, Times of Famine. A History of Climate Since the Year 1000, trans. by Barbara Bray (London, 1972), p. 237.

Ice Age" climate which was predominantly cold and rainy. The French historian impressively illustrated his point from pictorial representations of historical glaciers. The Rhone Glacier near Gletsch (Canton Valais) is undoubtedly the most spectacular example in this respect. At the time of its largest expansion (shortly after 1600 and again in 1856), the valley was filled with an enormous block of ice. Today, the Rhone Glacier has melted so far back that it no longer can be seen from the valley. Consequently, Le Roy Ladurie was looking for human impacts of the hypothesized changes in long-term average climate. He concluded that "*in the long term* [emphasis added by the author] the human consequences of climate seem to be slight, perhaps negligible, and certainly difficult to detect".[11] For several decades this claim of an influential pioneer has served as a key argument to shun attempts to assess the human significance of past climate change.

Whereas the macro-history of climate aims at reconstructing temperature and precipitation for the period prior to the creation of national meteorological networks both in terms of time series and spatial patterns, a history of climate tailored to the needs of the historian should rather highlight changes in the frequency of those climate patterns which are known to have affected everyday life in the early modern period. This mainly regards such spells of temperature and precipitation as were known by contemporaries to bear the risk of widespread weather-related crop failures.

These two kinds of accounts on climate are difficult to bring in line. Reports on the micro-level focus on single climate anomalies and are close to the sources. They show in which ways extreme events affected humans and their decision making. However, such episodes are too fragmented to be integrated into narratives of climatic change over a long period of time.

Histories of climate, on the other hand, provide impressive overviews of climatic change but without providing conclusive links to human history. Differences in average temperature and precipitation over several decades are not convincing in this respect. Rather, they come up against the argument that in such situations people may adapt their way of living to a changing climate. Innovations will become accepted that are better suited to the new situation, whereas older outdated practices may tacitly disappear.[12] Rather, climate history on the macro-level should offer an interpretative frame in which significance may be attached to individual climate anomalies. It is im-

[11] Ibid., p. 119.

[12] This issue is discussed more detailed in: Tom M. L. Wigley et al., "Historical Climate Impact Assessments", in Robert W. Kartes / Jesse H. Ausubel / Mimi Berberian, Climate Impact Assessment. Studies of the Interaction of Climate and Society (Chichester, 1985), pp. 529–64, here pp. 530–1.

portant for human perception and interpretation, as well as for the measures being taken, to know whether such episodes occur surprisingly after a pause of several decades, whether they remain isolated outliers or whether they occur repeatedly.

This article suggests how the frequency and severity of short-term climate impacts may have become an important element of an integrated history of climate and human history. The arguments are structured as follows: in the subsequent section the methodology for obtaining continuous and quantitative high-resolution data on both past weather and climate from documentary evidence is outlined. The third section deals with the "Little Ice Age" both in terms of glacier fluctuations and seasonal climates. It is argued that there is no single long-term climatic trend which agrees with the advanced position of glaciers during the "Little Ice Age". Rather, this period is made up of a manifold spectrum of monthly and seasonal temperature and precipitation patterns, including warm phases and extremes. In certain periods which Heinz Wanner has named "Little Ice Age-type Events" (LIATE)[13], temperature and precipitation patterns promoted far-reaching glacier advances. The issue of climate impacts is discussed in the fourth section with regard to food production. An ideal type-model of "Little Ice Age-type Impacts" (LIATIMP) is developed from monthly temperature and precipitation indices on the basis of crop-specific considerations. In the fifth section the output of this model is compared to fluctuations of grain prices and vine production. A focus is placed on the period between 1585 and 1597 in which chilly summers became the dominant climatic mode. The final section discusses whether the seven decades between 1570 and 1630 are to be understood as "a period of crisis" or whether the term of "Second Period of Little Ice Age-type Impacts, 1570 to 1630" seems to be more appropriate.

Climate history and human history are usually written separately. Many historians understand history as being limited to an account of what man does to mankind. Environmental history has put this focus into perspective, at first in the United States from the 1980s, subsequently in Europe and elsewhere.[14] The quasi natural environment of man is increasingly accepted as being the fourth basic category of history on an equal level with governance,

[13] Heinz Wanner, "Vom Ende der letzten Eiszeit zum mittelalterlichen Klimaoptimum", in Heinz Wanner / Dimitrios Gyalistras / Jürg Luterbacher / Ralph Rickli / Esther Salvisberg / Christoph Schmutz / Stefan Brönnimann, eds., Klimawandel im Schweizer Alpenraum (Zürich, 2000), p. 77.

[14] The European Society for Environmental History (ESEH, http://www.eseh.org (February 2004)) was founded in 2001, and as of early 2005 has more than 420 members.

economy and culture, as Wolfram Siemann recently argued.[15] Though climate and environmental change is gradually being accepted as a part of the historical narrative, such aspects are often still ignored or faded out. For example, recent respectable textbooks on "Early Modern Europe" do not contain a single index entry for "climate".[16] During the last two decades, the mainstream of historiographers has moved away from dealing with the facts of material life in order to explore the promising new field of cultural history.[17] This has been the case even in fields such as demography and agrarian history, where climate change was previously given at least some consideration.[18] Some early modern historians still stick to the argument brought forth in the 1970s and 1980s, namely, that the needed climate data for sophisticated analyses of economic or demographic data is insufficient.[19] Although this may have been true at that time, a lot of things have changed since then Historical climatology has made astonishing progress since the early 1990s,[20] even though the fact has generally not been noticed by historians because most new results are published in scientific journals.

Whereas the study of future climatic impacts on humankind has developed into a well-funded area of research, the climatic vulnerability of past societies has only received limited attention.[21] According to oceanographer Wolfgang H. Berger, there is good reason why many historians are disinclined to tackle climate as a factor "in history". One is that effects of climatic fluctua-

[15] Wolfram Siemann / Nils Freytag, "Umwelt. Eine geschichtswissenschaftliche Grundkategorie", in Wolfram Siemann, ed., Umweltgeschichte. Themen und Perspektiven (München, 2003), pp. 7–19, here p. 10.

[16] Euan Cameron, ed., Early Modern Europe. An Oxford History (Oxford, 1999); Anette Völker-Rasor, ed., Frühe Neuzeit (München, 2000).

[17] Stefan Militzer, "Sachsen. Klimatatsachen und Umriss von Klimawirkungen im 17. Jahrhundert", in Uwe Schirmer, ed., Sachsen im 17. Jahrhundert. Krise, Krieg und Neubeginn (Beucha, 1998), pp. 69–100. Militzer is one of the very few who dealt with the issue in the 1990s, however he was not further supported upon the completion of his thesis.

[18] E.g., neither in: Neithard Bulst, "L'essor (Xe-XIVe siècles)", in Jean-Pierre Bardet / Jacques Dupâquier, Histoire des Populations de l'Europe, 3 vols. (Paris, 1997), vol. I, pp. 168–84, nor in: Wim Blokmans / Henri Dubois, "Le temps de crises (XIVe et XVe siècle)", in ibid., pp. 185–217, are the issues of climate addressed. Likewise, Massimo Livi Bacci, The Population of Europe. A History (The Making of Europe) (Oxford, 1999), does not quote one single reference concerning the history of climate.

[19] Le Roy Ladurie, Times of Feast (see note 10).

[20] Rudolf Brázdil / Christian Pfister / Heinz Wanner / Hans von Storch / Jürg Luterbacher, "Historical Climatology. The State of the Art", Climatic Change (accepted).

[21] The term "vulnerability" designates the extent to which climatic extremes and natural disasters may damage or harm a group or a society. It depends on the group's sensitivity and ability to adapt to new climatic conditions. See: http://www.grida.no/climate/vital/25.htm (13 September 2003).

tions "on the course of history" are difficult to show because societies and their economies have many internal mechanisms compensating for adverse climatic effects.[22] To some, the reluctance of historians to view climatic variability as a factor of historical explanation is connected to the long tradition of climatic determinism, which postulated that climatic factors have been among the greatest factors in determining the course of human history.[23] It needs to be emphasized that investigating past climate and its significance for and its perception by humans does not imply as a matter of course that climate is considered to be a determinant factor. Rather, it is assumed that climate is among those conditions - like population and wars - which may be potentially significant to account for a given situation. Dealing with exogenous shocks - be it climate impacts or natural disasters - offers the opportunity to assess the significance of non-anthropogenic contingencies as factors in human history as opposed to structural restraints. In emergency situations, mental and structural barriers are significantly lowered when attempting novel solutions to given problems. Alert persons involved thus often use crises as windows of opportunity to expand the power of their institution at the expense of others. There is no doubt whatsoever that climate is part of the basic natural conditions for life and human culture. Dealing with vicissitudes of climate has been among the most fundamental challenges human groups have had to face, and the experience of crises has contributed to the development of a keen sense of the properties of local environments prior to the Industrial Age.

[22] Wolfgang H. Berger, "Climate History and the Great Geophysical Experiment", in Gerold Wefer et al., eds., Climate Development and History of the North Atlantic Realm (Berlin, 2002), pp. 1-16, here p. 13.

[23] E.g., Ellsworth Huntington / Sumner W. Cushing, Principles of Human Geography (New York, 1924 [1907]); Sidney Frank Markham, Climate and the Energy of Nations (London, 1947); and Robert Clairborne, Entscheidungsfaktor Klima. Der Einfluß des Wetters auf Entwicklung und Geschichte der Menschheit (Wien, 1973 [1970]). Particularly crude and unscientific examples of this position were recently provided by Richard A. Beck, "Climate, Liberalism and Intolerance", Weather, 48 (1993), p. 63-4, and in a work by ETH emeritus Kenneth Hsü, Klima macht Geschichte. Menschheitsgeschichte als Abbild der Klimaentwicklung (Zürich, 2000).

2. How to Convert Narratives into Quantitative Data on Weather and Climate

Information on past climates is obtained from data on two different time-scales: palaeoclimatological data cover a time-scale of 10^3 years and longer,[24] whereas historical climatology focuses on high-resolution documentary evidence in the last millennium of the pre-instrumental period. Proxy data[25] from "natural archives" are of little value to assess the human significance of climate. The historian would need evidence that offers a high resolution in terms of time, space and climate elements. Most natural proxy data, however, have a low temporal resolution and effects of temperature and precipitation often cannot be disentangled. Moreover, scientists preferably provide smoothed curves on a high level of spatial aggregation. Outliers in which historians would have the most interest are suppressed. Given this situation, historians had to develop their own approach of climate reconstruction. Unfortunately the implementation of such a concept was hampered for a long time by the role which history seemed to play as the "handmaiden" of such sciences as seismology, climatology and hydrological engineering.

According to Emmanuel Le Roy Ladurie, a conclusive investigation of the impact of climatic variations on societies should involve two steps. Firstly, climate in the pre-instrumental period should be studied for its own sake, separately from its possible impacts on societies. In a second step, the evidence obtained should be used to set up models enabling the exploration of the impacts of climatic variations upon economies and societies. He suggested that such a picture of climate without mankind in the historical period might be reconstructed from data describing the meteorological nature of certain years, seasons, months and days, i.e., from long series of documentary proxy data. The ultimate goal of such a reconstruction should be setting up series of continuous, quantitative and homogeneous climatic indicators.[26]

An approach to quantify qualitative observations in a more or less standardized way was developed from the late 1960s. It consists of deducing con-

[24] Raymond S. Bradley, Paleoclimatology. Reconstructing Climates of the Quaternary (Orlando, 1999).

[25] The term "proxy" is used to denote any material that provides an indirect measure of climate in contrast to instrumental measurement or descriptions of weather patterns. For example, this applies to the date of a vine harvest. Such information needs to be calibrated, i.e. statistically compared with series of temperature measurement before it can be used for reconstructions of climate.

[26] Le Roy Ladurie, Times of Feast (see note 10).

tinuous, quantitative and more or less homogeneous time-series of intensity indices for temperature and precipitation from documentary data that are used as substitutes for instrumental measurements.[27] The classical procedure of data analysis and reconstruction starts with the search of suitable climatic evidence. In most cases a reconstruction involves different kinds of documentary data supplemented by high-resolution natural proxy data. The characteristic nature of reports from western and central Europe, including northern Italy, can be summarized as follows:[28]

- Prior to 1300: reports of socio-economically significant anomalies and natural disasters.
- 1300 to 1500: more or less continuous reports on the characteristics of summers and winters (as well, to some extent, as those of spring and autumn), including references to "normal" conditions.
- 1500 to 1800: nearly complete descriptions of monthly weather patterns, including a number of daily weather reports and a growing number and diversity of continuous proxy records related to the increase of early local, regional and state bureaucracies.
- 1680 to 1860: instrumental measurements made by separate individuals and the first short-lived international network of observations (Breslau-Network 1717–1726[29] and Palatina-Network 1780–1792).[30]
- Since 1860: instrumental observations in the framework of national and international networks.

This list needs to be understood in a cumulative way. Older kinds of weather and climate observations are not replaced by, but rather superposed on more recent ones. In sum, the quality of the data improves with time, and its density, spatial coverage and time resolution increases.

The entire set of data available for each month or season is then transformed into intensity indices of temperature and precipitation that are either

[27] Brázdil et al., "Historical Climatology in Europe" (see note 20).

[28] Christian Pfister / Rudolf Brázdil / Mariano Barriendos, "Reconstructing Past Climate and Natural Disasters in Europe Using Documentary Evidence", in Christian Pfister / Heinz Wanner, eds., Documentary Evidence (PAGES [Past Global Changes] News 10/3) (2002), pp. 6–8.

[29] Gustav Hellmann, "Die Vorläufer der Societas Meteorologica Palatina", Beiträge zur Geschichte der Meteorologie 1, 5 (1914), pp. 139–47. The articles were published in: Sammlung von Natur- und Medicin, wie auch hierzu gehörigen Kunst- und Literatur-Geschichten, a review edited by Johann Kanold (1679–1729), a physician in Breslau between 1718 and 1729 (see Jan Munzar, "Environmental History of Central Europe in the First Half of the 18th Century" [according to the so-called 'Wrocław' collection], Moravian Geogr. Reports, 10 [2002], pp. 37–45).

[30] John Kington, The Weather of the 1780s over Europe (Cambridge, 1988).

on a three-degree classification (e.g., 1 = warm, 0 = normal, -1 = cold) or on a seven-degree classification (e.g., 3 = extremely warm, 2 = very warm, 1 = warm, 0 = normal, -1 = cold, -2 = very cold, -3 = extremely cold).[31] This process is not to be understood as a mathematical problem because it involves methodological, source-specific, ecological and context-specific considerations.[32] At present, such series are available for Switzerland,[33] Germany,[34] the Low Countries,[35] the Czech Republic,[36] Hungary,[37] Andalusia,[38] Portugal[39] and Greece.[40]

The approach of deducing numbers from weather narratives needs to be adequately documented. In order to check the quality of the procedure, the wording of the basic sources should be made available along with the climatological quantification being made from it. At the same time, such source texts provide valuable evidence for cultural historians investigating biographies and world views of the authors who were writing diaries or looking for the ways in which people responded to climate anomalies and impacts. Quite often, such narratives provide a bridge between the micro- and the macrolev-

[31] Brázdil et al., "Historical Climatology in Europe" (see note 20); Christian Pfister, "Klimawandel in der Geschichte Europas. Zur Entwicklung und zum Potenzial der historischen Klimatologie", Österreichische Zeitschrift für Geschichtswissenschaften (ÖZG) 12, 2 (2001), pp. 1–43.

[32] E.g., ibid.; Rüdiger Glaser, Klimarekonstruktion für Mainfranken, Bauland und Odenwald anhand direkter und indirekter Witterungsdaten seit 1500 (Stuttgart, 1991).

[33] Pfister, Das Klima der Schweiz (see note 2); Id., Wetternachhersage. 500 Jahre Klimavariationen und Naturkatastrophen 1496–1995 (Bern, 1999), pp. 44–6.

[34] Rüdiger Glaser, Klimageschichte Mitteleuropas. 1000 Jahre Wetter, Klima, Katastrophen (Darmstadt, 2001).

[35] Jan Buisman / Aryan van Engelen, Duizend Jaar weer, wind en water in de lage landen, 4 vols. (Franeker, 1995–2000): vol. I, to 1300 (1995); vol. II, 1300–1450 (1996); vol. III, 1450–1575 (1998); vol. IV, 1575–1675 (2000).

[36] Rudolf Brázdil / Petr Dobrovolny / Oldrich Kotyza, "Climate Fluctuations in Czech Lands during the 16th Century in the Central European Context", Zeszyty Naukowe Uniwersytetu Jagiellonskiego, Prace Geograficze-Zeszyt, 102 (1996), pp. 497–502.

[37] Lajos Racz, Climate History of Hungary since the 16th Century. Past, Present and Future (Pécs, 1999).

[38] Fernando Rodrigo Sanchez / Maria Jesus Esteban-Parra / Yolanda Castro-Diaz, "The Onset of the Litte Ice Age in Andalusia (Southern Spain). Detection and Characterization from Documentary Sources", Climatic Change, 27 (1994), pp. 397–418.

[39] Maria Alcoforado / Maria Fatima Joao Nuñes / Joao Carlos Garcia / Joao Paulo Taborda, "Temperature and Precipitation Reconstructions in Southern Portugal during the Late Maunder Minimum, 1675–1715", The Holocene, 10 (2000), pp. 333–40.

[40] Eleni Xoplaki / Panagiotis Maheras / Jürg Luterbacher, "Variability of Climate in Meridional Balkans during the Periods 1675–1715 and 1780–1830 and Its Impact on Human Life", Climatic Change, 48 (2001), pp. 581–614.

el, between the quantitative and the qualitative dimension of climate history, as it is demonstrated in the introductory paragraph.

In view of putting these objectives into practice, a specific data-base named *Euro-ClimHist* has been developed by Urs Dietrich of the NCCR "Climate" (University of Bern). It allows accessing climate and environmental evidence at different levels of time (year, season, month, day) in different areas of Europe. The results of queries are displayed in terms of original source texts, time-series of ordinal indices or charts on the basis of a geographical information system (GIS). In this way, observations at the microlevel can be linked to time-series of ordinal indices on temperature and precipitation at the level of seasons and months derived from a multitude of so-called proxy information in the same region. At the same time, such a multi-level data-structure allows the definition of properties of climate on a time scale of decades and highlights the characteristics of extreme seasons, months and days or even short-term events of merely a few hours.[41]

The latest and perhaps most spectacular step in climate reconstruction was achieved by Jürg Luterbacher and his colleagues at the University of Bern. They demonstrated that a few spatially well-distributed instrumental series of temperature, precipitation and air pressure are sufficient for assessing the field of air pressure at sea-level throughout Europe and the adjacent North Atlantic, thereby enabling the positioning of low and high pressure.[42] Luterbacher and his fellow scientists were able to statistically derive spatial charts of monthly (back to 1659) and seasonal (back to 1500) air pressure and surface temperature for the whole of Europe from early instrumental observations and series of indices.[43]

The problem of data availability that has plagued the history of weather and climate for a long time thus seems to be solved. Without a doubt, many historians will hardly be able to fully grasp the statistical procedures that are behind these results. For example, the environmental historian Joachim Rad-

[41] URS DIETRICH, "Using Java and XML in Interdisciplinary Research. A New Data-Gathering Tool for Historians as Used with EuroClimHist", Historical Methods 10,2 (2004), pp. 174–85.

[42] Each temperature chart consists of 5050 grid points (distance between grid points, 60 km) (see graphs 2, 3, 4); in the case of sea-level pressure, 135 grid points. See: JÜRG LUTERBACHER / ELENI XOPLAKI / DANIEL DIETRICH / RALPH RICKLI / JUCUNDUS JACOBEIT / CHRISTOPH BECK / DIMITRIOS GYALISTRAS / CHRISTOPH SCHMUTZ / HEINZ WANNER, "Reconstruction of Sea-Level Pressure Fields over the Eastern North Atlantic and Europe Back to 1500", Climate Dynamics, 18 (2002), pp. 545–62.

[43] JÜRG LUTERBACHER / DANIEL DIETRICH / ELENI XOPLAKI / MARTIN GROSJEAN / HEINZ WANNER, "European Seasonal and Annual Temperature Variability, Trends, and Extremes since 1500", Science, 303 (2004), pp. 1499–1503 (DOI: 10.1126/science.1093877).

kau cast doubt on the quality of the reconstructions because "outsiders may find it difficult to understand them".[44] Fortunately, Luterbacher's results have been scrutinized by statisticians and climatologists,[45] and are widely used by many scholars from different scientific fields.

3. Was There a Little Ice Age Climate?

This paragraph tackles the issue of defining the Little Ice Age (LIA), dealing with whether weather and climate from the fourteenth to the late nineteenth century was somehow different from that prevailing in the preceding "Medieval Warm Period" (from about 900 to the fourteenth century) and in the "warm twentieth century". The Little Ice Age was the most recent period during which glaciers maintained an expanded position on most parts of the globe, whereas their fronts oscillated about in advanced positions.[46] The concept of LIA was coined in 1939 by US-American François Matthes and only related to the position of glaciers.[47] As of the late nineteenth century, the Little Ice Age gave way to the "warm period of the twentieth century" (until about 1988),[48] during which most glaciers melted back about to the position of the "Medieval Warm Period", and even farther back.[49]

The LIA was a simultaneous, world-wide phenomenon which nonetheless allowed for considerable regional and local variation. According to the sophisticated reconstructions made by Hanspeter Holzhauser, it is known that the Aletsch Glacier, the largest in the Alps, was in an advanced position from the late fourteenth to the late nineteenth centuries. This epoch was the longest period of glacial expansion in the Alps for at least 3000 years.[50]

[44] JOACHIM RADKAU, Natur und Macht. Eine Weltgeschichte der Umwelt (München, 2002), p. 48.

[45] JÜRG LUTERBACHER ET AL., "Reconstruction of Monthly Mean Sea Level Pressure over Europe for the Late Maunder Minimum period, 1675–1715", International Journal of Climatology 20, 10 (2000), pp. 1049–66; ID. ET AL., "The Late Maunder Minimum, 1675–1715. A Key Period for Studying Decadal Scale Climatic Change in Europe", Climatic Change, 49 (2001), pp. 441–62.

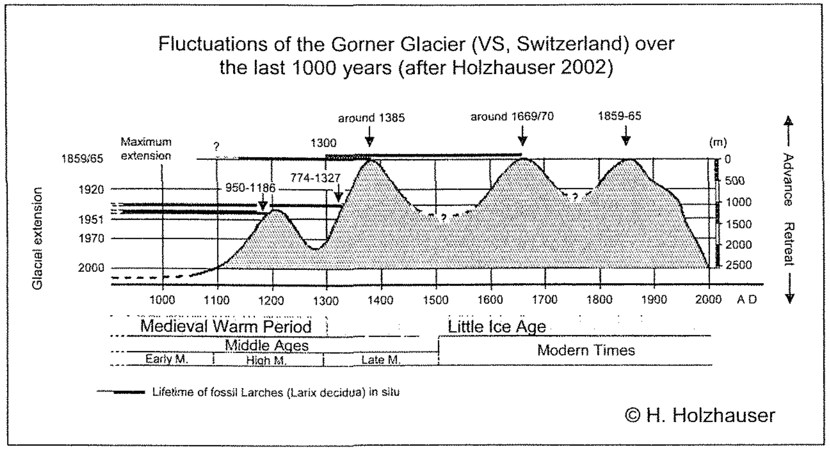
[46] JEAN M. GROVE, "The Initiation of the 'Little Ice Age' in Regions round the North Atlantic", Climatic Change, 49 (2001), pp. 53–82.

[47] FRANÇOIS MATTHES, "Report of the Committee on Glaciers", Transactions American Geophysical Union, 20 (1939), pp. 518–23.

[48] Since that time, climate changed sensitively and increasingly by global warming.

[49] BRÁZDIL ET AL., "Historical Climatology in Europe" (see note 20).

[50] HANSPETER HOLZHAUSER, "Gletscherschwankungen innerhalb der letzten 3200 Jahre am Beispiel des Grossen Aletsch- und Gornergletschers. Neue Ergebnisse", in SCHWEIZERISCHE GLETSCHERKOMMISSION, ed., Gletscher im ständigen Wandel (Zürich, 1995), pp. 101–22.



Graph 1. The Three Peaks of the Little Ice Age: Fluctuations of the Gorner Glacier (Canton Valais, Switzerland) since the Middle Ages (Holzhauser, "Dendrochronologische Auswertung fossiler Hölzer zur Rekonstruktion der nacheiszeitlichen Gletschergeschichte", [see note 51] Exh. 9).

The fluctuations of Gorner Glacier (Canton Valais in the Swiss Alps) were precisely dated from the dendrochronological analysis of logs found in the forefront by Hanspeter Holzhauser. The Gorner Glacier displays three phases of maximum expansion over the last millennium: the first one occurred around 1385, the second one about 1669/70 and the third one between 1859 and 1865.[51] The occurrence of the first maximum in the late fourteenth century confirms an earlier assumption made by the author,[52] who had related the main thrust for the far-reaching glacial advance in the fourteenth century to a cluster of three chilly summers from 1345 to 1347, which were followed by a subsequent period of cool-moist summers through 1370.[53] The second maximum of Alpine glaciers during the seventeenth century was related to frequent cold and wet summers between 1566 and 1605 and again from 1616 to 1645 (see graph 4). The first phase was more intensive: the Lower Grindelwald Glacier – the best documented glacier in the

[51] The approach is explained in detail in: Id., "Dendrochronologische Auswertung fossiler Hölzer zur Rekonstruktion der nacheiszeitlichen Gletschergeschichte", Schweizerische Zeitschrift für Forstwesen, 153 (2002), pp. 17–28.

[52] Christian Pfister, "Variations in the Spring-Summer Climate of Central Europe from the High Middle Ages to 1850", in Heinz Wanner / Ulrich Siegenthaler, eds., Long and Short Term Variability of Climate. Lecture Notes in Earth Sciences 16 (Berlin, 1988), pp. 57–82.

[53] Holzhauser, "Dendrochronologische Auswertung fossiler Hölzer" (see note 51).

Alps – reached its maximum around 1603, after advancing more than a kilometre since 1580.[54] There is good agreement on the existence and, to some extent, on the duration of the LIA in Europe as a glacial feature.

Whereas the Little Ice Age is well defined, the term "Little Ice Age Climate" causes confusion. It is a misleading construction of the natural sciences, a labeling which should reduce complexity but which is rather inappropriate in this respect. The term suggests that the expansion of glaciers can be related to some set of long-term average climate conditions which differ from those prevailing in the preceding and subsequent warm periods. Such a view is inadequate. An explanation must be made as to why the term "Little Ice Age climate" should be avoided and why the expression "climate during the LIA" seems to be more appropriate. Primarily, it must be stressed that the six centuries between 1300 and 1900 were not continuously cold. The cold phases were repeatedly interrupted by phases of "average climate". In central Europe, for example, this refers to the period between 1630 and about 1670. In some periods, e.g., from 1380 to 1420 and again from 1718 to 1730, the summer half-year was even somewhat warmer than the "warm twentieth century". Secondly, fluctuations in the front of a glacier may not be readily interpreted in terms of specific climatic parameters. Rather, the ice-body integrates positive and negative climate stimuli on its mass balance.[55] The mass balance varies according to seasonal temperature and equivocal precipitation patterns. When a surplus of ice accumulates in the upper parts of a glacier, it takes some time until it reaches the front end of the ice and causes an expansion. The response of a glacier tongue to climatic stimuli varies according to the size, the altitude and the orientation and individual properties of the glacier from between one or two years to a decade or more. This must be kept in mind when interpreting the evidence.[56]

It is in this context that Heinz Wanner coined the term of "Little Ice Age-type events" (LIATE) to designate the three far-reaching advances known

[54] Christian Pfister / Hanspeter Holzhauser / Heinz J. Zumbühl, "Neue Ergebnisse zur Vorstossdynamik der Grindelwaldgletscher vom 14. bis zum 16. Jahrhundert", Mitteilungen der Naturforschenden Gesellschaft Bern, NF 51 (1994), pp. 55–79.

[55] This term designates the difference between the accumulation (i.e., the "income") and the ablation (i.e., the "expenditures") of ice in the mass of the glacier.

[56] For example, Le Roy Ladurie described the 1640s as follows: "This decade characterized by extremely cool and damp summers, late wine harvests and famines, and by a very low rate of ablation, gave great impulse to the growth of Alpine glaciers, already voluminous enough." (Le Roy Ladurie, Times of Feast [see note 10], p. 173). This statement draws from known glacier expansion and vine harvest dates. However, the decisive climatic impulse for the glaciers came in the late 1620s and, as Le Roy Ladurie could not yet know when he wrote his best-seller, the timing of the vine harvest depended mainly on the temperatures in May and June.

from the last millennium[57] (see graph 1). Reconstructions of glacier and climate history have yielded the result that each of the three LIATE was the outcome of a specific combination of seasonal patterns of temperature and precipitation.[58] Besides these individual properties, of course, there is a set of overarching factors promoting LIATE. The mass balance of Alpine glaciers is positively affected by the following seasonal patterns: a moist winter, cold relapses in spring, a cool and rainy summer with frequent snow-falls down to low altitudes and a lack of warm anticyclonic situations in autumn. Conditions in midsummer are crucial.[59] These conditions should be understood as an ideal-type model in the Weberian sense.[60]

There are several episodes in the history of climate during the last millennium which approach these ideal-type conditions. The best known example is 1816, the famous "year without a summer".[61]

Examples of Years Without a Summer

From the reconstruction of spatial temperature patterns it can be concluded that the extreme cold of the summer of 1816 was the result of a persistent large anomalous low covering large parts of the European continent, in conjunction with the advection of cool and moist air masses from the northwest and the north. The Azores anticyclone remained at the western fringe of the continent (see graph 2-1). Considering Europe as a whole, this summer was around 0.3 °C cooler than the average of 1901–1995.[62] It snowed in the Alps clear down to the valleys every fortnight and sledges had to be used until mid-July. The weather in the Geneva region was so oppressive that nineteen-year old Mary Shelley (1797–1851) was inspired to write the story of Frankenstein.[63] It is well known that the frosty summer was mainly a consequence of the explosion of the volcano Tambora (Indonesia) in April of 1815. Tambora blew between 37 and 100 cubic kilometers of dust, ashes, cinders and sulphur-dioxide gas into the stratosphere, generating a globe-girdling veil of volcanic dust.[64]

[57] Wanner, "Vom Ende der letzten Eiszeit" (see note 13), p. 77.

[58] Jürg Luterbacher, "Die Kleine Eiszeit ('Little Ice Age', AD 1300–1900)", in Klimawandel im Schweizer Alpenraum (see note 13), pp. 101–102.

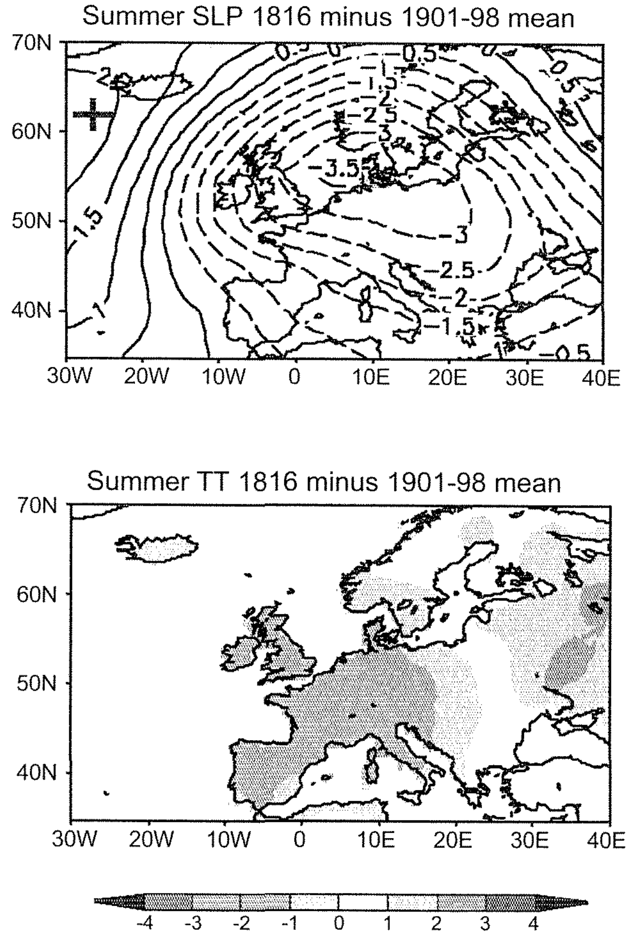
[59] Bruno Messerli / Paul Messerli / Christian Pfister / Heinz J. Zumbühl, "Fluctuations of Climate and Glaciers in the Bernese Oberland, Switzerland, and their Geoecological Significance, 1600–1975", Artic and Alpine Research 10, 2 (1978), pp. 247–60; Pfister, Das Klima der Schweiz, II (see note 2), p. 144.

[60] Stephen Kalberg, Max Weber's Comparative-Historical Sociology (Cambridge, 1994), p. 46.

[61] Numerous articles in: Charles Richard Harington, ed., The Year Without a Summer? World Climate in 1816 (Canadian Museum of Nature, Ottawa, 1992).

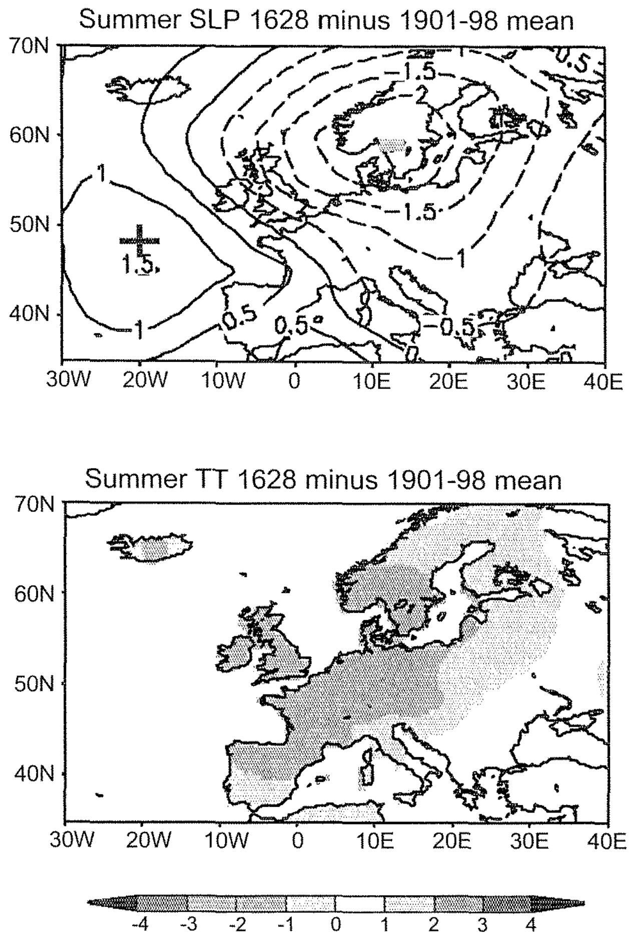
[62] Luterbacher et al., "European Temperature Variability" (see note 43); Id. et al., "Reconstruction of Sea Level Pressure Fields" (see note 42).

[63] http://www.kimwoodbridge.com/maryshel/summer.shtml (Karl W. Britton, 21 June 2001).



Graph 2-1 Deviations of Temperature and Air Pressure at Sea Level in Europe from the Twentieth Century Average during the Summer of 1816.

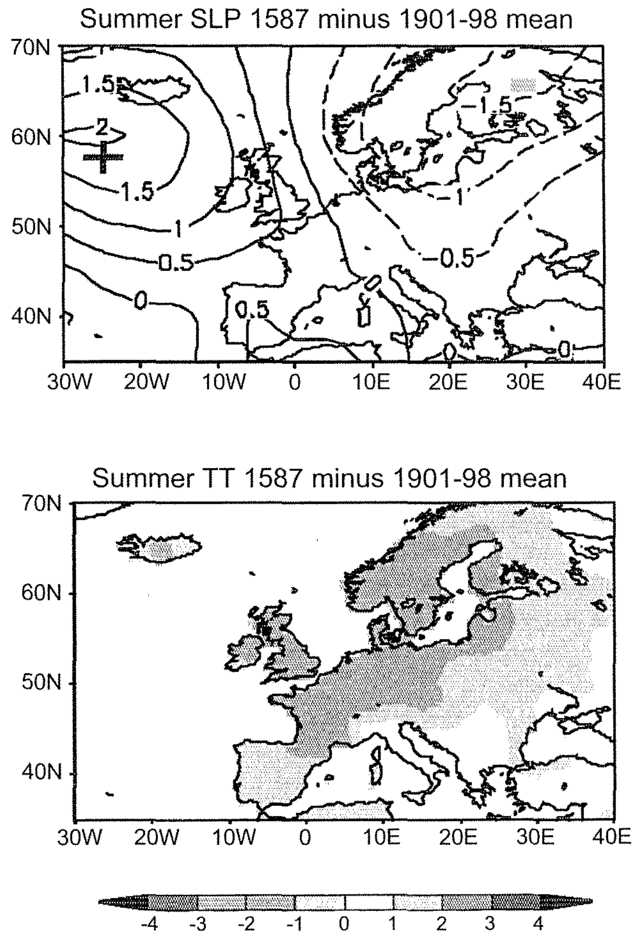
[64] Micheal R. Rampino, "Eyewitness Account of the Distant Effects of the Tambora Eruption of April 1815", in The Year Without a Summer? (see note 61), pp. 12–15; Vladimir Bruzek, "Major Volcanic Eruptions in the Nineteenth and Twentieth Centuries and Temperatures in Central Europe", in The Year Without a Summer? (see note 61), pp. 422–8.



Graph 2-2. Deviations of Temperature and Air Pressure at Sea Level in Europe from the Twentieth Century Average during the Summer of 1628.

Aerosol particles thrown into the stratosphere are rapidly distributed around the globe through advection. They form a veil that back-shatters part of the incoming solar radiation. The result is a cooling during the summer half-year which can take as long as two years to appear[65] and can then per-

[65] Anne S. Palmer / Tas D. van Ommen / Mark A. J. Curran / Vin Morgan / Joe M. Sourney / Paul A. Mayewksi, "High Precision Dating of Volcanic Events (AD 1301-1995). Using Ice Cores from Law Dome, Antarctica", Journal of Geophysical Research 106, D 22 (2001), pp. 28089–96.



Graph 2-3. Deviations of Temperature and Air Pressure at Sea Level in Europe from the Twentieth Century Average during the Summer of 1587.

sist for anywhere from one to three years on certain parts of the globe.[66] Undoubtedly, such events have a substantial positive impact on the glacial mass balance and in this way they contributed to triggering far-reaching glacier advances.

[66] Hans-F. Graf, "Klimaänderungen durch Vulkane", Promet 28, 3/4 (2002), pp. 133–8; Alan Robock, "Volcanic Eruptions and Climate", Review of Geophysics 38, 2 (2000), pp. 191–219; Gregory A. Zielinski, "Use of Paleo-Records in Determining Variability within the Volcanism Climate System", Quarternary Science Review, 19 (2000), pp. 417–38.

The cold summer of 1628 was likewise the result of a lower-than-average sea level pressure centered over southern Scandinavia and extending far into the south. With this pressure constellation, low pressure systems were often heading from the Atlantic towards the European continent and bringing precipitation and lower than usual temperatures. Snow fell in the village of Frutigen (Bernese Oberland, 770 m) in every month of the entire year. It snowed in the Swiss town of St. Gallen (670 m) on 1 July. Up on the Engstligen-Alp (Bernese Oberland, 2000 m), it snowed no less than 23 times between 10 July and 23 August. The fresh snow was so deep on three separate occasions that the cows began to starve and had to be driven downhill. A deep layer of fresh snow covered the Swabian mountains (about 1000 m) in Germany three times during the month of July. The flowering of the grapes in the valleys took five weeks.[67] Rooms in Stuttgart had to be heated. Landgrave Hermann IV of Hesse (1607–1658) recorded 21 rainy days in his diary.[68] August was somewhat better. Nevertheless, oats and grapes did not ripen completely.[69] Considering the delay of vegetation, the summer half-year of 1628 may only be compared to those of 1675 and 1816. Conditions in the previous summer had not been much better.[70] The clustering of cold and rainy spells in the summer half-years of 1627 and 1628 must have provided an important thrust to the Alpine glaciers which advanced during the following three decades. It looks like the fingerprint of a volcanic impact, but the pertinent explosion has not yet been detected.

The year 1587 included another cold mid-summer. Compared to normal summer conditions, over the eastern Atlantic, between Iceland and the Azores Islands, the sea level pressure was higher. On the other hand, over Scandinavia the pressure was below normal. Between these two anomalous pressure systems, frequent incursions of (sub-) polar air was advected towards central Europe (graph 2-3). Snow fell in the Swiss lowlands (450m) in June and July, and again in September, whereas August was warm and dry.[71] The summer was also cold in northern Germany.[72] The subsequent summer

[67] STEFAN MILITZER, Klima – Umwelt – Mensch (1500–1800). Studien und Quellen (ClimDat) zur Bedeutung von Klima und Witterung in der vorindustriellen Gesellschaft. Abschlussbericht zum DFG Projekt MI-493 (Leipzig, 1998).

[68] GLASER, Klimageschichte Mitteleuropas (see note 34), p. 141.

[69] ID. / RUDOLF BRÁZDIL / CHRISTIAN PFISTER, "Seasonal Temperature and Precipitation Fluctuations in Selected Parts of Europe during the Sixteenth Century", in Climatic Variability (see note 5), pp. 169–200, here p. 196.

[70] Ibid.; GLASER, Klimageschichte Mitteleuropas (see note 34), p. 141.

[71] ID. ET AL., "Seasonal Temperature and Precipitation Fluctuations" (see note 69), p. 198; ID., Klimageschichte Mitteleuropas (see note 34), p. 143.

of 1588 was dominated by westerly winds, floods and hailstorms.[73] In the Swiss town of Lucerne, it rained on 77 of the 93 days during June, July and August.[74] This cluster of two bad summers is related to the 1586 eruption of Kelut (Java).[75]

Admittedly, "years without a summer" were the most crucial elements underlying the LIATE, i.e., the far-reaching glacier advances. However, these episodes were not a consistent element of the LIA climate. Rather, they were counterbalanced from time to time by clusters of warm and dry summers (e.g., in the 1720s) or more general conditions in other seasons, which caused melting on the glaciers. Another example is seen in Norway, where winter and summer precipitation seem to be dominant elements for glacier expansion. This prevalent situation caused glaciers in southern Norway to reach their maximum during the early eighteenth century, i.e., out of phase with those in the Alps, mainly as a consequence of mild wet winters.[76] These facts all lead to the remarkable conclusion that in the long run, in the Alps summers during the LIA were not significantly cooler than those in the "short twentieth century", i.e., up to 1988.

Rather than cool summers, extended cold spells during the winter half-year (October through March or April) were the ear-marking feature of climate during the LIA.

Examples of Severe Winters in the Little Ice Age and Beyond

Such spells are a consequence of blocking anticyclones in high latitudes. Heavy winters include both an element of duration and severity. During such climatic modes, cold and dry air masses extend over large parts of the European mainland and block the warm and humid westerly winds from penetrating the continent. The last severe winter occurred in 1962/63. The cold air mass extended from Paris to Minsk. The bitter cold lasted about two months and caused Lake Constance to become ice-bound. The ice cover was so thick that small airplanes were able to land on it. The intensity and duration of the cold and the extension of the cold air mass was more pronounced during the winter of 1829/30. In the winter of 1694/95, the cold – in conditions very similar to those during the winter of 1572/73[77] – possibly reached

[72] Ibid., p. 125.

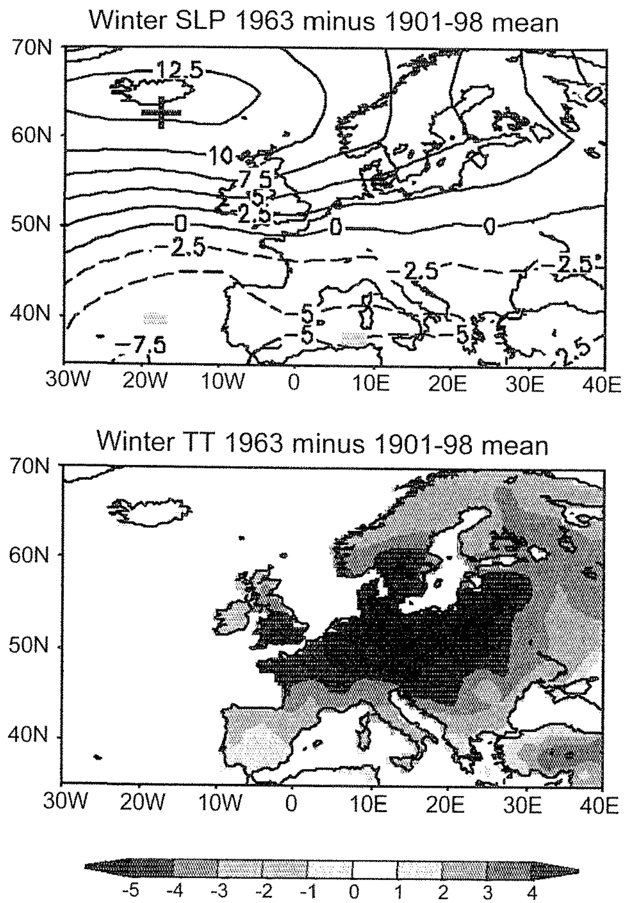
[73] Ibid., p. 126.

[74] GLASER ET AL., "Seasonal Temperature and Precipitation Fluctuations" (see note 69), p. 198.

[75] ANNE S. PALMER ET AL., "High Precision Dating of Volcanic Events" (see note 65).

[76] ATLE NESJE / SVEIN OLAV DAHL, "The 'Little Ice Age'. Only Temperature?" The Holocene, 13 (2003), pp. 139–45.

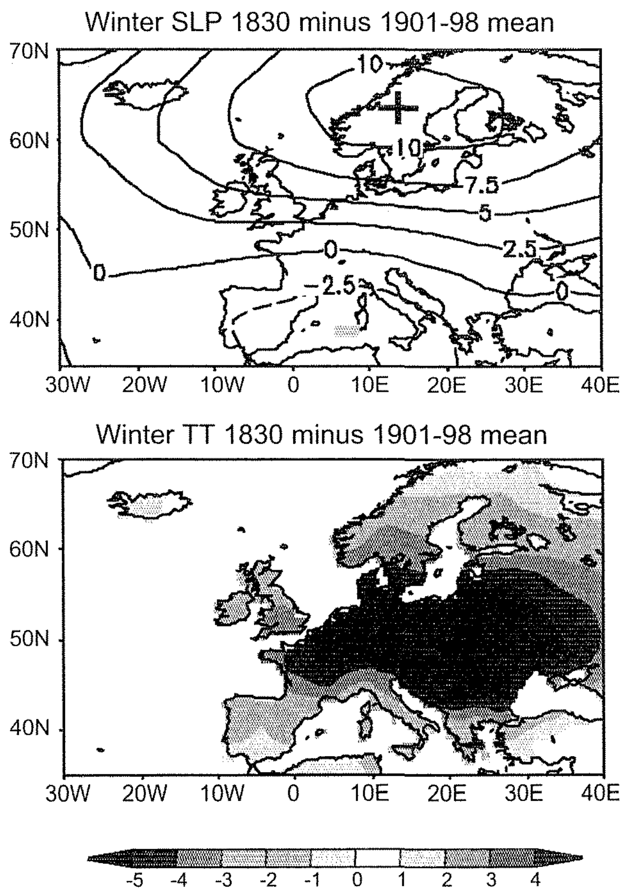
[77] Ibid.



Graph 3-1. Deviations of Surface Air Temperature and Sea Level Pressure in Europe from the Twentieth Century Average (1901–1995) during the Winter 1962/63.[78]

a maximum of the last 500 years. It must be emphasized that the cold air was often limited to the region north of the Alps. Depressions moved through the Mediterranean where rainfall increased as a consequence. When such situations included outbreaks of cold air into the Mediterranean region – usually either in the western or eastern parts of the Mediterranean basin, leaving the other parts unaffected – heavy snow-falls could occur.[79] The worst episode of this kind over the last five hundred years took place in Jan-

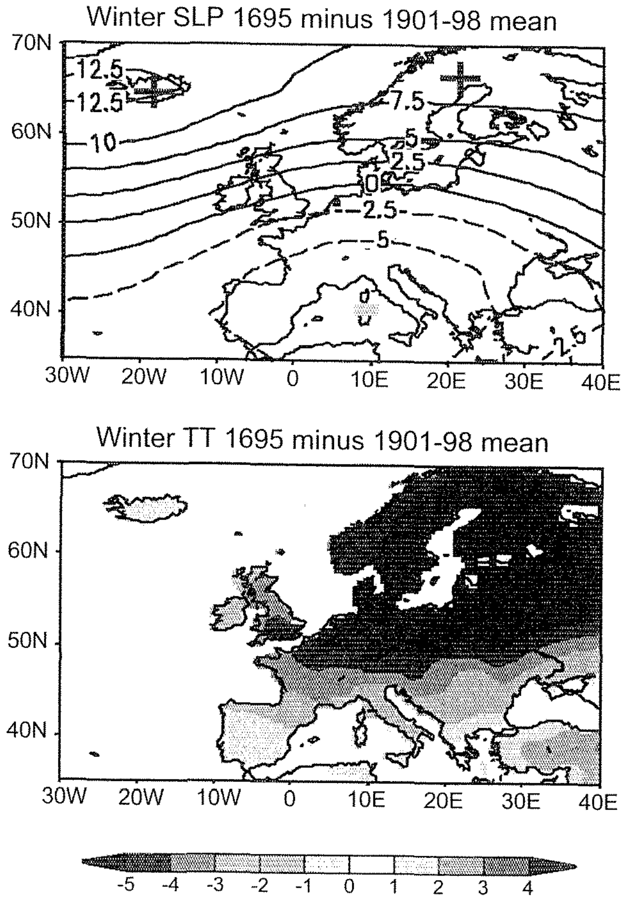
[78] Luterbacher et al., "Reconstructions of Sea-Level Pressure Fields", (see note 42), p. 550.
[79] Xoplaki et al., "Variability of Climate" (see note 40).



Graph 3-2. See 3-1 Deviations in Temperature and Air Pressure at Sea Level in Europe during the Winter 1829/30.

uary of 1709, when a steam-roller of polar air passed directly through the Rhone Valley to the Mediterranean and killed most of the subtropical plants such as citrus, olive and almond trees.[80] Jürg Luterbacher and scientists working with him have recently shown that this winter, with 3.6 °C lower temperature in comparison to 20th-century temperatures, was the coldest in Europe during at least the last 500 years.[81]

[80] Marcel Lachiver, Les années de misère. La famine au temps du Grand Roi 1680–1720 (Paris, 1991), pp. 268–304.
[81] Jürg Luterbacher et al., "European Temperature Variability" (see note 43).



Graph 3-3. See 3-1 Deviations in Temperature and Air Pressure at Sea Level in Europe during the Winter 1694/95.

Severe winters were more frequent and more drastic during the period of the Little Ice Age than during the Medieval Warm Period and the twentieth century. Sometimes the cold air remained until March or even April. The month of April in 1595, for example, was completely dominated by "harsh" northerly to easterly winds, snow and frost. The snow-cover did not melt during the entire month.[82] Cold springs were a recurrent feature. The moan-

[82] Christian Pfister / Rudolf Brázdil / Rüdiger Glaser, "Daily Weather Observations in Sixteenth Century Europe", in Climatic Variability (see note 5), pp. 111–50, here p. 123.

ings of church-goers about the endless duration of winter and their hopes for the beginning of a warm spring are based on experiences people never had in the twentieth century.

Springs in central and eastern Europe were the most severe in the last 500 years between 1687 and 1717.[83] Cold-dry air advection was frequent in March and April, and as a consequence the change from winter to summer circulation was often delayed. Such an observation traces back to the episode of hungry cattle in Einsiedeln, as depicted in the spring of 1688 by Father Joseph Dietrich. Indeed, it may be concluded from the reconstruction of climate that springs prior to 1687 had been extraordinarily warm and sunny. This promoted an expansion of the herds, as earlier observed in the diary entries of Father Dietrich. Obviously, the experience of a first cold spring in 1687 had not lead the peasants to adapt the size of their herds to the changed conditions. It needed a second, more drastic episode to oblige them to do so.[84]

The 1680s and the 1690s, in general, were at the very climax of the so-called "Maunder-Minimum" (1645–1715), which was a period of lower solar activity, numerous volcanic eruptions and world-wide climatic disturbances. This period was the coldest during the last 500 years. Average European temperatures between 1680 and 1699 were around 1 °C lower than the 20th-century mean.[85] The rapid climate change during the "Late Maunder-Minimum" (1675–1715) can be possibly explained by external forcing factors such as solar variability, volcanic impact and internal oscillation in the North Atlantic.[86] However, it needs to be stressed that the cold period at the end of the seventeenth century did not invoke a substantial advance of glaciers. This seems to be connected to the weak, cold and wet signals in summer and to the low precipitation in the winter half-year. This period demonstrates the known fact that glaciers do not react to all important temperature fluctuations, but rather to specific temperature and precipitation patterns.[87]

[83] Christian Pfister, "Spatial Patterns of Climatic Change in Europe, 1675-1715", in Burkhard Frenzel / Id. / Birgit Glaeser, eds., Climatic Trends and Anomalies in Europe, 1675–1715. High Resolution Spatio-Temporal Reconstructions from Direct Meteorological Observations and Proxy Data. Methods and Results. Special Issue. European Palaeoclimate and Man, no. 8. Paläoklimaforschung Band 13 (Mainz, 1994), pp. 287–317, here p. 300.

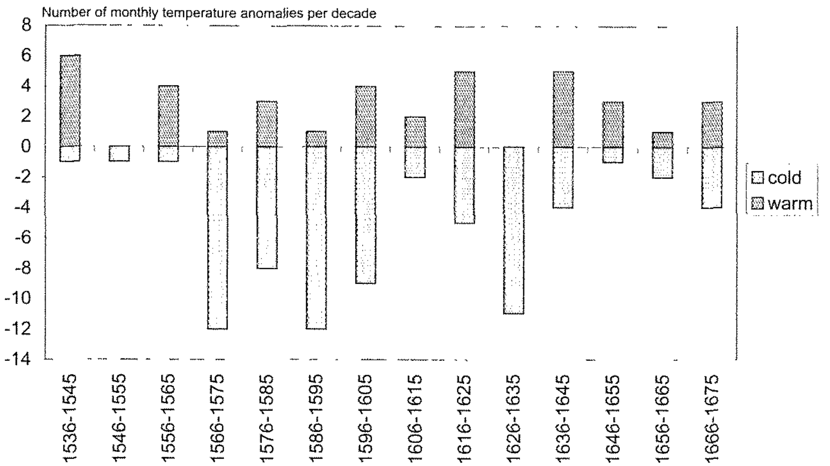
[84] Pfister, Das Klima der Schweiz, II (see note 2), p. 102.

[85] Jürg Luterbacher et al., "European Temperature Variability" (see note 43).

[86] Id. / Ralph Rickli / Eleni Xoplaki / Chantal Tinguely / Christoph Beck / Christian Pfister / Heinz Wanner, "The Late Maunder Minimum, 1675-1715. A Key Period for Studying Decadal Scale Climatic Change in Europe", Climatic Change, 49 (2001), pp. 441–62.

[87] Christian Pfister, "Switzerland. The Time of Icy Winters and Chilly Springs", in Climatic Trends (see note 83), pp. 205–24.

Climatologists usually describe climatic variations and changes in terms of differences in mean temperatures to a selected baseline which is averaged over several decades. According to a recent reconstruction, for example, summer temperatures in central Europe during the last third of the sixteenth century were about 0.4 °C below the 1901–1960 mean.[88] This difference seems slight, almost negligible, and certainly was not noticeable to the inhabitants of agricultural societies. However, it may be argued that changes in long-term averages are not the appropriate measure for grasping the societal link to climatic change. Rather than noting the gradual changes in average conditions, humans and their economy are sensitive to the frequency and severity of extremes. Chroniclers deliberately put a focus on memorable extreme events which disturbed the ordinary rhythm of seasons. If statistics are set up just for the number of extremely cold and warm months per decade, the picture of the second LIATE changes profoundly.



Graph 4. Number of Monthly Temperature Anomalies per Decade in the Summer Half-Year (April to September) in the Swiss Midlands (1536 to 1675).

Graph 4 focuses on the summer half-year (April to September) because this part of the year was of particular importance to agrarian societies. In the mid-sixteenth century, extremely cold months were not more frequent than in the twentieth century. However, during the subsequent three decades the number of extremely cold months increased eleven-fold between the thirty

[88] Id. / Rudolf Brázdil, "Climatic Variability in Sixteenth-Century Europe and its Social Dimension. A Synthesis", in Climatic Variability (see note 5), pp. 5–53, here p. 23.

year periods 1536–1565 and 1566–1595. After a transitional decrease, the icy trend of the late sixteenth century returned for a short period during the late 1620s. Subsequently, the number of cold extremes declined markedly. Detailed narratives on climate anomalies and natural disasters within this time period, month by month, may be found in recent reconstructions of climate in central Europe.[89]

At the conclusion of this chapter, the basic properties of climate during the LIA are briefly recalled:

- The Little Ice Age was the most recent period during which glaciers in most parts of the globe maintained an expanded position, with their fronts oscillating about in advanced positions. In Europe, the LIA began around 1300 and it ended in the late nineteenth century.
- In the Alps, the LIA consists of three "Little Ice Age-type Events" (LIATE). This term designates multi-decennial phases of climate which, on the whole, promote far-reaching glacier advances: the first LIATE occurred from the 1340s to the end of the 1370's, the second one between 1570 and 1630, and the last one from 1810 to about 1860.
- There is no single long-term climatic trend which agrees with the advanced position of glaciers during the LIA. A multitude of interacting seasonal patterns of temperature and precipitation either positively or negatively affected the mass-balance of glaciers.
- However, there is a common climatic denominator for the LIA climate in central Europe: spells of cold advection in the winter half-year were more frequent, more persistent and more severe than in the preceding "Medieval Warm Period" and the subsequent "warm twentieth century". These conditions, however, did not significantly affect the mass balance of glaciers.
- Superposed on this long-term trend of frequent severe cold spells during the winter half-year were incidental clusters of one to three extremely chilly and wet mid-summers. Most, indeed probably all of these clusters resulted from large-scale volcanic explosions in the tropics. The superposition of these two factors resulted in far-reaching glacier advances. At the same time, these elements were the major climatic ingredients of subsistence crises, as will be shown hereafter in the subsequent section.
- Mention should be made that the summer half-year in the LIA included several periods of "near-average" climate, even periods of frequent warm and dry summers such as those between 1718 and 1731. Moreover, some of the hottest and driest summers of the second millennium, e.g., 1473

[89] Pfister, Wetternachhersage (see note 33); Glaser, Klimageschichte Mitteleuropas (see note 34).

and 1540, occurred during the LIA. Warm extremes are even documented during LIATE: the summers of 1590, 1616 and 1623 were among the warmest and driest of the last five centuries but nonetheless occurred during a period of predominantly cold summers.
- The adverse climatic properties of the LIA – the long frosty winters and the occasional occurrence of chilly summers – primarily affected the area of central Europe north of the Alps as well as southern Scandinavia. With the exception of some extreme instances, the Mediterranean and to some extent the western-most part of the continent, were only marginally affected by the LIA climate, if at all.

Historians using the conception of the LIA should be aware of its climatic and spatial limitations.

4. Exploring the Climate Sensitivity of Early Modern Economies[90]

4.1 Preliminary Considerations

When series of continuous, quantitative and quasi-homogeneous climatic indicators are set up for the pre-instrumental period, such series may be used as models which enable the exploration of the impacts of climatic variations upon economies and societies. Whereas the study of future climatic impacts on humankind has developed into a well-funded channel of research, the climatic vulnerability of past societies has only found limited attention, to say the least. There is good reason why many historians are disinclined to consider climate as a potentially significant factor of pre-industrial societies. The effects of climatic fluctuations "on the course of history", for instance, are difficult to demonstrate because most of the factors included many internal mechanisms compensating for adverse climatic effects.[91] It is frequently overlooked that both "climate" and "history" are blanket terms, situated on such a high level of abstraction that relationships between them cannot be investigated in a meaningful way in accordance with the rules of scientific methodology. On a very general level, it could be said that beneficial climatic effects tend to enlarge the scope of human action, whereas climatic shocks

[90] The essence of the following chapter is also contained in: CHRISTIAN PFISTER, "Klimaverlauf und Agrarkonjunktur im weiteren zeitlichen Umfeld des Schweizerischen Bauernkrieges (1550–1670)", in JONAS RÖMER, ed., Bauern, Untertanen und "Rebellen". Zur Geschichte eidgenössischer Landbevölkerungen im Ancien Régime (Zürich, 2004).

[91] BERGER, "Climate History" (see note 22), p. 13.

tend to restrict it. Which sequences of climatic situations mattered depends upon the impacted unit and the environmental, cultural and historical context.[92] However, this statement needs to be restricted in the sense that the term "climatic shock" itself is ambiguous, as it is well known that some of the people and groups involved always take advantage of situations of general distress, both economically and politically.

In order to become more meaningful, "climate and history", as a collective issue, needs to be broken down to lower scales of analysis, e. g., with a specific focus, for example, on the food system, the health system or the energy system, or on specific activities such as transportation, communication, and military or naval operations. Particular focus must also be given to short-term and medium-term events. Moreover, concepts need to be worked out in order to disentangle the severity of climate impacts and the efficiency of measures for coping with them.

The closer that details are investigated, the higher the probability of finding significant coherences.[93] On the other hand, results obtained on lower levels are only valid within these specific contexts. This implies that generalizations need to be made within similar contexts. In the long run, climate impacts are only one factor to be considered with others. Whether and how far climatic factors mattered for individual crises needs to be determined through empirical analyses.

Many historians assume that the productivity of agriculture in the Medieval and Early Modern periods depended just upon the relative scarcity of two prime factors of production: land and labour. The fundamental fact that agricultural output also depends on weather and climate is simply ruled out. Among the few who have really dealt with this issue, Paul Münch needs to be mentioned in addition to Arthur E. Imhof and Hartmut Lehmann.[94] In the previous chapter it was argued that humans chiefly react to challenges in the short and medium term, and in this chapter it is explained how far the effects on these temporal levels really mattered. This is a difficult question and the reader will soon find out that simple answers are not offered.

[92] PFISTER, "Klimawandel in der Geschichte Europas" (see note 31), p. 20.

[93] ELLEN ROY, Environment, Subsistence and System. The Ecology of Small-Scale Social Formations (Cambridge, 1982), p. 7.

[94] MÜNCH, Lebensformen (see note 4), has devoted an entire chapter to this issue: pp. 127–54; Arthur E. Imhof has repeatedly addressed this issue in his numerous books. E.g., ARTHUR E. IMHOF, Die gewonnenen Jahre. Von der Zunahme der Lebensspanne seit dreihundert Jahren. Oder von der Notwendigkeit einer neuen Einstellung zu Leben und Sterben (München, 1981). See also: HARTMUT LEHMANN, "Frömmigkeitsgeschichtliche Auswirkungen der 'Kleinen Eiszeit'", in WOLFGANG SCHIEDER, ed., Volksreligiosität in der modernen Sozialgeschichte (Göttingen, 1986), pp. 31–50.

Whatever the choice of events concerning which impacts are to be studied, an impacted group, activity or area exposed to these events must be selected. In general, the focus is on individuals, populations or activities in the form of livelihoods or regional ecotypes. The most difficult choices of study elements are those of impacts and consequences. After having reconstructed past climate in the area under study, biophysical impact studies may identify the direct effect of climate anomalies on plants, domestic animals and disease vectors through a study of their climatic sensitivity. The social-impact assessment studies then examine how biophysical impacts – i.e., effects of climate anomalies upon biota – are propagated into the social and the political system. Such an integrated approach – including the potential of people to adapt and adjust to climatic stress – reflects historical reality far better than a straight-impact model[95] and it raises more fruitful research questions.[96] Robert W. Kates suggested that such studies should be arranged in the order of propagation (first, second, ...nth order) to events, although these may be arbitrary in the sense that the real time process actually takes place simultaneously or that the sequence is unknown to climatic processes.[97]

First-Order Impacts: Biophysical Impacts on Crops, Energy Availability and Animals (Wild and Domestic)

↓

Second-Order Impacts: Food Prices; Hunger, Malnutrition and Disease; Population Decline

↓

Third-Order Impacts: Economic Disruption and Social Disturbance

↓

Cultural Consequences of First- to Third Order-Impacts

[95] Jan De Vries, "Analysis of Historical Climate-Society Interaction", in Robert W. Kates / Jesse H. Ausubel / Mimi Berberian, eds., Climate Impact Assessment (Chicester, 1985), pp. 273–92, here p. 276. See also: Wolfgang Behringer, "Die Krise von 1570. Ein Beitrag zur Krisengeschichte der Neuzeit", in Manfred Jakubowski-Tiessen / Hartmut Lehmann, eds., Um Himmels Willen. Religion in Katastrophenzeiten (Göttingen, 2003), pp. 51–156.

[96] Robert W. Kates, "The Interaction of Climate and Society", in Climate Impact Assessment (see note 95), pp. 7–14.

[97] Ibid., p. 10.

The more distance from the first level, the less stringent are climate impacts, the broader are the options open to individuals or groups and the more complex is the web of factors masking the climatic effect. In 1980, cliometrician Jan De Vries, postulated that any test of climatic influences on economic life in general should take the form of an econometric model, which in addition to climatic data includes "all the other significant variables".[98] Such a proposition is chimerical. Given the fragmentary nature of relevant sources and their limited potential for quantification, there is little hope of getting enough reliable quantitative data to drive such a model for a given territory, not to mention the several case studies necessary for a generalization. Rather, integrated studies should investigate how individuals or groups perceived, explained and interpreted climatic stress and how they reacted to challenges.

Another approach was chosen by the author of the present paper. In an earlier work he argued that as long as the first order impacts are not well established, the analyses of the climatic vulnerability of early modern societies should focus on biophysical impacts according to the model suggested by Kates. In this context the author developed a climate-impact model tailored to food production within the agrarian economies in the mixed economies of southern central Europe, where grain was the staple crop on the basis of the three-field system in combination with dairy or wine production. In order to solve a specific question, viz. the manner in which climate influenced the everyday life of people, the vulnerability of the main sources of food – i.e., grain, wine and dairy products – to climatic impacts was investigated, using both present and historical knowledge. It turned out that a given set of specific sequences of weather spells over the agricultural year was likely to affect all sources of food, at the same time leaving little margin for substitution. This yielded a model of a worst-case crop failure and, inversely, of a year of plenty.[99] In a subsequent article, the significance of this ideal-type model was tested using empirical high-resolution climate and grain price data for Switzerland. The tuning of the variables was done by comparing the graphic-model output with a Swiss grain price series. The resulting model quite satisfactorily simulated most of the major price peaks, inasmuch as these primarily resulted from climatic shocks. On the other hand, the model was not geared to price surges which were chiefly related to non-climatic factors.[100]

[98] Jan De Vries, "Measuring the Impact of Climate on History. The Search for Appropriate Methodologies", Journal of Interdisciplinary History 10, 4 (1980), pp. 599–630, here p. 608.

[99] Pfister, Das Klima der Schweiz, II (see note 2), pp. 34–64.

[100] Id., "Fluctuations du climat et prix céréaliers en Europe 16ème-20ème siècles", Annales E. S. C. 43, 1 (1988), pp. 25–53.

4.2 The Concept of "Little Ice Age-Type Impacts"

Dieter Groh has convincingly argued in a seminal article that for most members of early modern societies, avoidance was the fundamental strategy for coping with risk.[101] It is true that the known risks - war, dearth and epidemics - were not always present in reality. But these threats were more or less constantly present in people's minds. Thus, the avoidance of worst-case impacts was a lasting concern that impinged on most of the individual and social decisions which had to be made. Regarding food production, the key strategy was a spreading of risk. A broad pattern of resources and a broad horizontal and/or vertical distribution of plots provided a surprisingly good protection against a limited amount of climatic stress. If one crop failed, it could be replaced by another.[102] However, the question must be raised as to whether there were sequences of weather spells which were likely to paralyse such sophisticated systems of risk avoidance. Are there climatic patterns which are likely to affect most or even all resources at the same time? This will be investigated below. The climatic vulnerability of specific resources is considered in a first step. Secondly, the results are included in a model of biophysical climatic impacts simultaneously affecting different crops.

Grain Production

The nutrients contained in the soil, notably nitrogen, are the most critical factors influencing the level of *grain output*. This level depends to some extent on precipitation patterns: too much precipitation, particularly during autumn and winter, reduces the calcium, phosphates and nitrogen in the soil. Sequences of wet years had a cumulative impact.[103] In Britain and elsewhere, there is an inverse relationship between autumn rainfall and the autumn sowing of grains, which is generally reflected in the total annual sowing.[104] For example, the extreme wetness in September and October of 1570 was an important component for the subsequent crisis because it reduced the acreage which could be sown in the available time until winter.[105]

101 Dieter Groh, "The Temptation Conspiracy Theory, or: Why Do Bad Things Happen to Good People", in Carl F. Graumann / Serge Moscovici, eds., Changing Conceptions of Conspiracy (New York, 1986), pp. 1-37, here p. 19.

102 Ibid.

103 Bernhard Hendrik Slicher van Bath, "Agriculture in the Vital Revolution", in Edwin Ernest Rich / Charles Wilson, eds., The Cambridge Economic History of Europe, vol. V (Cambridge, 1977), pp. 42-132, here p. 59; Jean Georgelin, "L'écologie du froment en Europe occidentale", in Joseph Goy / Emmanuel Le Roy Ladurie, eds., Prestations paysannes, dîmes, rente foncière et mouvement de la production agricole à l'époque préindustrielle (Cahiers des Etudes rurales IV, vol. II) (Paris, 1982), pp. 569-82.

104 Martin L. Parry, Climatic Change. Agriculture and Settlement (Dawson, 1978), p. 70. An extreme delay in sowing time seems to be one of the main reasons for the famine of 1693/94 in France (Lachiver, Les années de misère (see note 80), pp. 97-123.)

On the other hand, according to results obtained by agronomists, temperatures are far more involved in mobilizing nitrogen from the soil than was previously believed. The main factors for yield-formation are operative before the end of April. A warm April is beneficial for yield-formation.[106] Since temperature trends are spatially far more uniform than rainfall patterns, this leads to the conclusion that yields tended to react in a similar way within large regions. It is already known from previous studies that a long duration of snow-cover persisting into April promoted the infection of young plants with snow-mold (*Fusarium nivale*) which lead them to rot under the snow.[107] One of the worst impacts of this kind in central Europe was observed in the spring of 1614, which was among the coldest and snowiest in the last 500 years.[108]

Long wet spells during the harvest period lower the flour content of the grain and make it more vulnerable to mold infections and attacks of grain weevil (*Sitophilus granarius*).[109] Huge losses caused by insects and fungi during winter storage lead to surges of grain prices in the subsequent spring.

Dairy Production

Livestock in traditional agriculture not only served the actually exclusive purpose of providing animal protein for human nutrition; rather, their vital role was grounded in their multifunctional use of providing muscular power, manure and milk (meat). They provided a large part of the required labour-input and allowed for active management of plant nutrients.[110]

105 Behringer, "Die Krise von 1570" (see note 95), pp. 51-6, Glaser, Klimageschichte Mitteleuropas (see note 34), p. 120.

106 Herbert Hanus / Oskar Aimiller, Ertragsvorhersage aus Witterungsdaten (Berlin, 1978), pp. 79-81.

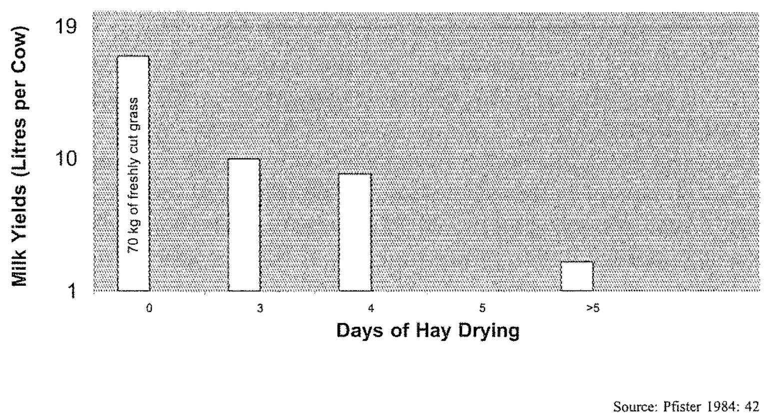
107 http://www.inra.fr/hyp3/pathogene/6fusniv.htm (21 August 2003).

108 Glaser, Klimageschichte Mitteleuropas (see note 34), p. 137; Pfister, Wetternachhersage (see note 33), p. 197.

109 http://www.inspection.gc.ca/english/plaveg/grains/pesorg/coleoptera/prim/sit_-gra_e.pdf; http://entomology.de/addpests/sitophilusgranarius.pdf (21 August 2003). For a discussion of net grain yields, flour content and the multiplying effects, see: Steven Laurence Kaplan, Bread, Politics and Political Economy in the Reign of Louis XV, 2 vols. (The Hague, 1976), vol. I, pp. 253-4. See also: Karl Gunnar Persson, Grain Markets in Europe, 1500-1900. Integration and Deregulation (Cambridge, 1999), pp. 47-64.

110 Fridolin Krausmann, "Milk, Manure and Muscular Power. Livestock and the Transformation of Pre-Industrial Agriculture in Central Europe", Human Ecology (submitted).

The milk yields of cows and goats depended on the size of the daily food ratio available per animal and on its content in nutrients, mainly raw proteins. The size of the feed ration varied according to the duration of winter snow-cover and temperatures in autumn and spring. In a frosty spring, the animals ran out of feed, as seen from the example of Einsiedeln in 1688 (see chapter 1). The longer the starvation lasted, the longer it took for the animals to recover and resume their usual level of milk production.[111]



Graph 5. Milk Production per Animal, Depending on the Duration of Hay-Drying.
If hay remained on the ground for more than five days because of being repeatedly drenched, it's content in nutrients declined substantially and that subsequently affected milk production.

A long wet spell during the hay harvest in July and early August could lower the raw protein content of hay by as much as two-thirds, thus causing the cows to cease producing milk during the subsequent winter (graph 5).

Vine Production

In climatically suitable regions, wine was the most important cash crop. It was either produced by small owners or share-croppers. Large wine estates were divided into small plots which were farmed out to share-croppers. In most cases the vine-dressers sold their share of the production to the land-

[111] PFISTER, Klimageschichte der Schweiz, II (see note 2), pp. 37–47; ID., "Fluctuations du climat" (see note 100).

lord in order to buy bread on the market. The price of wine related to that of grain was crucial for the well-being of this group.[112] The vine is sensitive to late frosts in April or May, particularly when the buds are well developed after an initial warm period. The most critical phase is the period between late June and early August. A long wet spell during and after flowering greatly reduces the size of the harvest. Finally, the sugar content of the grapes (i.e., the sweetness of the wine) chiefly depends on warmth and sunshine in September and early October. In sum, the timing, the amount and the sugar content of the harvest depends on three different sub-periods of the year which are April-May, midsummer and September.[113] A very late harvest, which is at the same time poor and low in sugar content, is a clear indicator for "years without a summer", as seen from the lists compiled for Switzerland: 1529, 1587, 1628, 1675, 1692 and 1816.[114]

Widespread Weather-Related Crop Failures

The results obtained from the consideration of single sources of food are now combined in order to get a model of a widespread weather-related crop failure (table 1).

Table 1. Weather Related Impacts Affecting the Agricultural Production of Traditional Temperate-Climate Agriculture in Europe

Critical Months	Agricultural Products Grain	Dairy Products	Vine
September-October	*Wet*	*Cold*	**Cold and Wet**
March-April	*Cold*	*Cold*	*(Late Frost)*
July-August	**Wet**	*Wet*	*Cold and Wet*

Italics: Weather Conditions Affecting the Volume of Harvests or Animal Production.
Bold: Weather Conditions Affecting the Quality (i.e., the Content in Nutrients or Sugar) of Crops.

Table 1 summarizes the impact of adverse temperature and precipitation patterns on grain, dairy forage and vine production during the critical periods

[112] ID., "Die Fluktuation der Weinmosterträge im schweizerischen Weinland vom 16. bis ins frühen 19. Jahrhundert. Klimatische Ursachen und sozioökonomische Bedeutung", Schweizerische Zeitschrift für Geschichte, 31 (1981), pp. 136–73; ERICH LANDSTEINER, "The Crisis of Wine Production in Late Sixteenth-Century Central Europe. Climatic Causes and Economic Consequences", Climatic Change, 43 (1999), pp. 323–34.
[113] PFISTER, "Die Fluktuation der Weinmosterträge" (see note 112).
[114] ID., Klimageschichte der Schweiz, I (see note 2), p. 84.

of the year. It comprises the following weather patterns: cold periods in March and April, which lower the volumes of the grain harvest and dairy forage production; wet mid-summers, which affect all sources of food production; cold spells in September and October, which lower the sugar content of wine; and wet spells in autumn, which reduce the amount of area sown and lower the nitrogen content of the soil. Most importantly, the simultaneous occurrence of rainy autumns with cold springs and wet mid-summers in subsequent years had a cumulative impact on agricultural production. This same combination of seasonal patterns largely contributed to triggering far-reaching advances of glaciers. Chilly springs and rainy mid-summers were shown to be the most representative elements of climate during the Little Ice Age, even though they are not causally related. This economically adverse combination of climatic patterns is labelled "Little Ice Age-type Impacts" (LIATIMP). Such biophysical impacts need to be understood as ideal-types in the sense of Max Weber. They are constructed from elements and characteristics of the phenomena under investigation, but they are not intended to fully agree with any specific case. Rather, they are heuristic tools against which a given evidence can be compared.[115]

LIATIMP may not be equated with crises. A subsistence crisis is an integrated process in which nature and society interact. Its severity, however measured, depends on one hand on the magnitude of the impact. On the other hand, it also hinges on the preparedness of the people involved and on the efficiency of the measures and strategies that are taken to deal with the crisis. The concept of LIATIMP yields a yardstick to measure the severity of an impact. At the same time it allows considering changes in the vulnerability of the affected group or society. The term of vulnerability stands for a multitude of factors such as social stratification, the availability of substitute foods, the efficiency of provisioning buffers (e.g. private and public grain stores) as well as measures of poor relief. Biophysical climate impacts in terms of duration of cold spells and wetness in particular phases of the year may be relatively similar without being fully identical. Human responses to such impacts on the other hand are often different over time. Such differences may be the starting point for in-depth studies of changing vulnerability.[116]

[115] KALBERG, Max Weber (see note 60), p. 86.
[116] BEHRINGER, "Die Krise von 1570" (see note 95).

4.3 Modelling Little Ice Age Impacts

In order to demonstrate the impact of climate on pre-industrial populations and societies in central Europe, the second Little Ice Age-type Event (LIATE) from about 1570 to 1630 is certainly the most appropriate one. For the first event in the fourteenth century, continuous quantitative evidence on both climate and impacts is lacking. The last event in the nineteenth century already coincides with the early phase of the Industrial Revolution when the cost and the capacity of transport were quite different from those prevailing prior to 1820.

This paragraph outlines the properties of an impact-model which is explained elsewhere in more detail.[117] The analysis involves the relationship between the amount of food staples (grain, dairy products, wine) available for consumption and grain prices. The model has to account for variations in the content of the grain used for flour, the sensitivity of wetness related to the losses in storage, and it has to allow for substitution between different varieties of grain on one hand and dairy products on the other hand. In addition, it has to agree with the fact that such relationships are known to be non-linear, whereas the critical thresholds are not known. The complexity of this bundle of relationships is such that an empirical approach was chosen.

The numerical model which finally corresponds best to the curve of grain prices comprised the following six seasonal impact factors:

1. Autumn Rainfall =	(P-Sep + P-Oct) / 2
2. Autumn Temperature =	(3* T-Sep + T-Oct) / -5
3. Spring Rainfall =	(2* P-Mar + 2* P-Apr + P-May) / 5
4. Spring Temperature =	(P-Mar + P-Apr) / -2
5. Summer Temperature =	(T-May + T-Jun + T-Jul + T-Aug) / -4
6. Summer Rainfall =	(4* P-Jul + P-Aug) / 5
T = Temperature indices	P = Precipitation Indices

Annual aggregate impacts were computed by summing up the seasonal impact factors, including allowance for lag effects. Conditions during a crop-year mattered for prices in the crop-year following the harvest. A rainy autumn could even affect grain prices two calendar-years later. Adapting the model to the grain-price curve included the weighing of temperature and precipitation factors and assessing thresholds for seasonal impacts. A particular weight had to be attributed to the combination of cold springs and wet

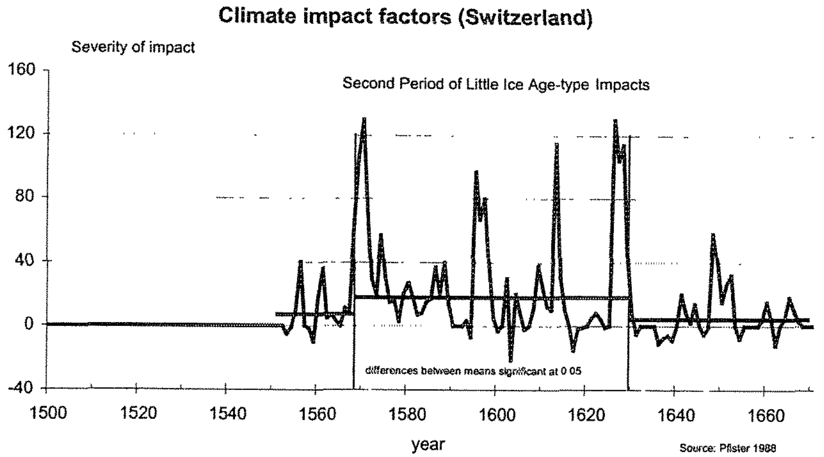
[117] PFISTER, "Fluctuations du climat" (see note 100).

mid-summers.[118] This is due to the fact that such conditions affect both the quality and the quantity (i. e., the content of nutrients) of the major food staples.

5. Climate Impacts and Crises During the Second LIATE (1568–1630)

5.1 The Multi-Decadal Perspective

This paragraph displays the results of the biophysical impact model for the period 1500–1670. The model-output is compared on the one hand with a long series of grain prices in Nuremberg which serves as an indicator of crisis. On the other hand, it is compared with aggregate vine production which stands at the same time for the well-being of vine growers and the *joie de vivre* of vine consumers. The main period of Little Ice Age-type Impacts (1568–1630) is distinguished by vertical lines.



Graph 6. The Level of Little Ice Age-type Impacts (LIATIMP) in South-Central Europe from 1550 to 1670.

Graph 6 displays the output of the climate impact model for the period from 1550 to 1670. The curve indicates how well the interplay of monthly

[118] Ibid.

temperature and precipitation agrees with the ideal-type model of the LIATIMP. The curve peaks at the beginning of the period of Little Ice Age-type crises in 1568–71 and again in its final phase in 1626–28. Somewhat minor impacts are visible in 1614 and in the late 1590s. On a whole, values are above average from 1568 to 1615 except for short phases of lessening around 1590 and 1605. The link to peaks of grain prices, i. e. to subsistence crises, is most obvious for the cluster of impacts in 1568–71 and 1626–28.

The many facets of the crisis in 1570/71 have been ingeniously described by Wolfgang Behringer, including the economic, social and demographic impacts, their consequences on mentalities and religious life, and finally, the strategies of those who profited economically and politically from the public distress.[119]

The crisis of 1626–29 has not yet been the object of a similar in-depth analysis. Thus far, these years of distress have been cited as being side-effects of the Thirty Years' War. However, it seems that the impacts of war were superimposed on a substantial amount of climate stress. Besides the initial and the terminal peak, the permanence of an elevated level of climate impacts between 1585 and 1614 needs to be given consideration. This feature of duration particularly affected vine growing (see graph 7) and cattle breeding.[120]

The statistical analysis of the entire series yielded the important result that the average climate impact level for the period from 1568 to 1630 was significantly higher than for the preceding and subsequent periods.[121] This outcome contradicts the influential statement by Wilhelm Abel, one of the pioneers of German economic history, who inferred from the many unsuccessful attempts to find climatic cycles of any length that the influence of climate on agricultural production was random.[122] Rather, we have to assume that periods of low and high climate impact levels need to be distinguished in the "*durée moyenne*".

Clustering effects were also demonstrated in conjunction with the frequency and severity of natural disasters. For example, periods of low and

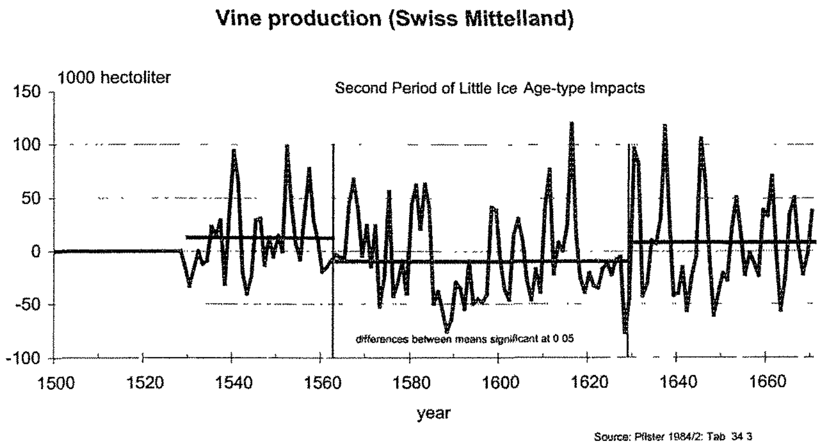
[119] Behringer, "Die Krise von 1570" (see note 95).

[120] Pfister, Bevölkerung, Klima und Agrarmodernisierung 1626–1860. Das Klima der Schweiz, II (see note 2), pp. 83–85.

[121] Previous period to 1629: Climate significant at five percent, April temperatures at five percent and July precipitation at five percent. Period 1568 to 1670: Climate significant at five percent. Significant results were also obtained for the temperature index of April (at five percent) and for the precipitation index for July precipitation at ten percent.

[122] Wilhelm Abel, Massenarmut und Hungerkrisen im vorindustriellen Deutschland (Göttingen, 1972), p. 35.

high flooding frequency were identified for the Rhine, the Danube, the middle section of the Elbe and the Weser over the last five hundred years. Within that period of time a period of high flooding frequency stands out between 1560 and 1590, thus adding to the burden of climate stress with which people were saddled in those years.[123] The occurrence of severe floods, of course, is not necessarily related to the climate during the Little Ice Age, except for those events that are produced by ice-damming which is a consequence of the freezing and thawing of rivers.



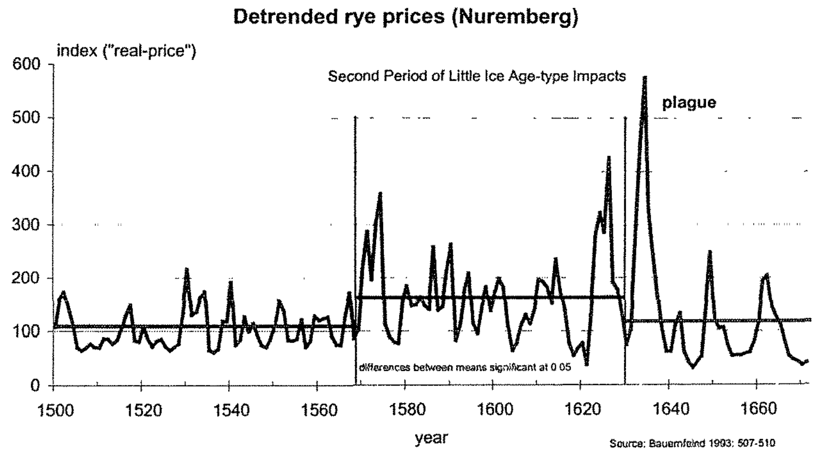
Graph 7. Vine Production (Swiss Midlands). Source: PFISTER, Das Klima der Schweiz (see note 2).

Vine production for Switzerland was estimated from series of receipts paid by share-croppers to the institutions who owned the vineyards, and from series of tithes paid in wine, which were obtained from the authorities' account books. The aggregate series (graph 7) shows residuals, i.e., deviations from a positive long-term trend. Two levels are distinguished between 1530 and 1670: higher levels from 1530 to 1584, and again between 1630 and 1670, and a lower level in the period in between.[124] After 1585, vine production plummeted to very low levels, from which it gradually recovered by the

[123] RUDOLF BRÁZDIL / RÜDIGER GLASER / CHRISTIAN PFISTER / PETR DOBROVOLNÝ / JEAN-MARC ANTOINE / MARIANO BARRIENDOS / DARIO CAMUFFO / MATHIAS DEUTSCH / SILVIA ENZI / EMILIA GUIDOBONI / OLDRYCH KOTYZA / FERNANDO RODRIGO SANCHEZ, "Floods Events of Selected European Rivers in the Sixteenth Century", Climatic Change, 43 (1999), pp. 239–85.; GLASER, Klimageschichte Mitteleuropas (see note 34), p. 197.

[124] Level of significance five percent.

turn of the century. A second drop in production occurred in the 1620s.[125] During the second period of Little Ice Age-type Impacts, vine yields were significantly lower than in the previous and subsequent periods. The slump in vine production after 1585 was a general feature in the vine regions north of the Alps, such as in Württemberg, lower Austria und western Hungary. Slumps in production primarily mattered for the share-croppers, but also mattered for the authorities who suffered a loss of taxes and dues. Wine did not only become rare and expensive. Because autumns were prevailingly cold and rainy, it was generally also sour in most such years. This had an impact on consumption standards. People in the Vienna region, for example, temporarily switched from the traditional "*Heurigen*" wine to beer. In other areas the lower classes had to do without alcohol, which may have caused an increase in the widespread psychic depression.[126]



Graph 8. Detrended Rye Prices in Nuremberg, 1500 to 1670. Source: BAUERNFEIND, Materielle Grundstrukturen (see note 126).

Grain prices belong to the group of second-order impacts. These are only an indirect measure of food production. Intervening variables such as inventory formation, trade and markets have also to be considered. The theory of pre-industrial trade cycles promoted by Ernest Labrousse in the 1970's considers the harvest as being the critical determinant which influences urban income and rural employment levels. A sharp rise in food-prices promoted

[125] PFISTER, "Die Fluktuationen der Weinmosterträge" (see note 112).

[126] LANDSTEINER, "The Crisis of Wine Production" (see note 112).

widespread unemployment, begging and vagrancy, which further propagated infectious diseases and increased crisis mortality.[127] Walter Bauernfeind set up a long series of rye prices from 1339 to 1670, which was used for graph 8. The data have been corrected for changes in the content of the precious metals of the local currency, thereby eliminating the long-term inflationary trend.[128] The results of the statistical analysis of the Nuremberg series (graph 8) show that the differences in the level of rye prices are significant for the periods 1500 to 1567 and 1568 to 1630, but not for the later period.[129] This result suggests that extensive differences in climatic stress also emerged on the level of second-order impacts.

Admittedly, however, this issue is controversial. Jan De Vries concluded from the extrapolation of the Dutch case that "in early modern Europe, the level of economic integration was sufficient [...] to loosen greatly the asserted links between weather and harvests and between harvests and economic life more generally".[130] Most researchers seem to have shared de Vries' assessment, inasmuch as over the last two decades, extensive literature has been published on the importance of economic policy, technological change, and population trends on food prices, while the impact of climatic variation has attracted hardly any attention.[131] Accordingly, market integration – mainly determined by the level of technology and trade policy – became of central interest for the movement of prices. In his attempt to measure the extent of market integration of European grain markets from 1500 to 1900, Karl Gunnar Persson observed that adjustments to supply shocks became quicker while prices in different markets tended to converge to a

[127] John Dexter Post, Food Shortage, Climatic Variability and Epidemic Disease in Pre-Industrial Europe. The Mortality Peak in the Early 1740s (London, 1985).

[128] Walter Bauernfeind, Materielle Grundstrukturen im Spätmittelalter und der Frühen Neuzeit, Preisentwicklung und Agrarkonjunktur am Nürnberger Getreidemarkt von 1339 bis 1670 (Nürnberg, 1993).

[129] Significance level five percent for 1500 to 1629 and ten percent for 1568 to 1670. This is due to the extreme peak of 1534 related to the plague. If this value is not considered, the difference also becomes significant.

[130] De Vries, "Measuring the Impact of Climate" (see note 98), p. 602.

[131] Kevin O'Rourke / Jeffrey G. Williamson, Globalisation in History. The Evolution of a Nineteenth-Century Atlantic Economy (Cambridge/MA, 1999); Mette Ejrnaes / Karl Gunnar Persson, "Grain Storage in Early Modern Europe", Journal of Economic History 59, 3 (1999), pp. 762–72; Karla Hoff / Avishay Braverman / Joseph E. Stiglitz, eds., The Economics of Rural Organisation (Oxford, 1993); John Walter / Roger Schofield, eds., Famine, Disease and Crisis Mortality in Early Modern Society (Cambridge, 1989); Paul Bairoch, "European Trade Policy, 1815–1914", in Peter Mathias / Sidney Pollard, eds., The Cambridge Economic History of Europe, vol. VIII (Cambridge, 1989), pp. 1–160.

stable price ratio. From this he concluded that "in the mid-eighteenth century, there were consistent signs of an emerging integrated European wheat market".[132] However, the evidence from prices which should support the view of early market integration is not a definitive proof regarding the period before 1820, which appears rather murky. Although there are obviously still good reasons to believe that climate was a crucial determinant for price formation in particular, and more generally for the economy prior to the transport revolution of the nineteenth century, quantitative research thus far remains rare. The careful analysis carried out by Walter Bauernfeind for Nuremberg during the period 1339–1670 is a definite exception. Bauernfeind concluded that population and climate were the two most important determinants for price formation.[133] Likewise, Ronald Findlay und Kevin O'Rourke have argued strong doubts on whether a substantial long-distance trade in homogeneous bulk commodities such as grain is documented for the period prior to 1820.[134]

Besides the Baltic,[135] the Mediterranean needs to be mentioned as one potential area of compensation, inasmuch as crop / weather relationships are fundamentally different from those in central Europe. Mediterranean climate is characterised by relatively low and highly variable rainfall, of which the lion's share falls during the winter half-year.[136] The worst climatic effects resulted from extended drought during the winter half-year, which, however, did not affect agriculture in central Europe.[137] However, the issue of grain imports from the Mediterranean or Baltic regions needs to be differentiated according to the geographical location of impacted regions in central Europe, particularly when considering their distance from the sea and their access to cheap water transport. Considering the significance of transportation for economic history, it is surprising that, thus far, no specific research

[132] Karl Gunnar Persson, Grain Markets in Europe (see note 109), p. 100.

[133] Bauernfeind, Materielle Grundstrukturen (see note 128).

[134] Ronald Findlay / Kevin H. O. Rourke, Commodity Market Integration, 1500–2000. Working Paper 8579, National Bureau of Economic Research (Cambridge, 2001); http://papers.nber.org/papers/w8579.pdf (17 September 2003).

[135] Milja van Tielhof, The "Mother of All Trades". The Baltic Grain Trade in Amsterdam from the Late Sixteenth to the Early Nineteenth Century (Leiden, 2002).

[136] Agustín Yoshiyuki Kondo, La Agricultura española del siglo XIX (Madrid, 1990).

[137] Among the most severe episodes of this kind were the droughts of 1565/66 in the western Mediterranean (Javier Martín-Vide / Mariano Barriendos, "The Use of Rogation Ceremony Records in Climatic Reconstruction. A Case Study from Catalonia [Spain]", Climate Change, 30 [1995], pp. 201–21), and of 1712–14 in the Meridional Balkans (Xoplaki et al., "Variability of Climate" [see note 40], pp. 581–615).

has been devoted to the cost and capacities of river transports.[138] Most researchers tend to overlook that inland waterways, at least in sections with a strong current, were in fact one-way streets, thereby causing vast differences in the cost and in the capacity of transportation upstream and downstream.[139] As a consequence, grain could not be imported in sufficient quantities and in adequate time into the major landlocked areas of Europe prior to 1820, not even in periods of subsistence crises, when prices were much higher there than in coastal areas.[140]

5.2 Years Without a Summer. The Gloomy End of the Sixteenth Century

Besides Little Ice Age-type Impacts (LIATIMP), the period between 1568 and 1630 includes a particular kind of impact in the last two decades of the sixteenth century. In order to highlight the outstanding character of this period, the average air pressure at sea-level was reconstructed by Jürg Luterbacher for the period 1585 to 1597,[141] and it is most revealing.

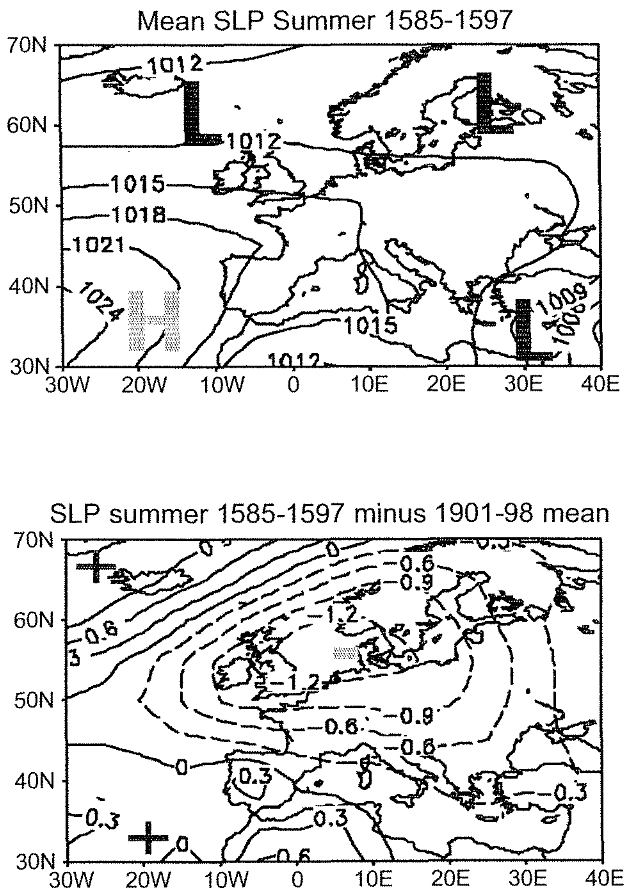
It may be concluded from graph 9 that during this period, summers in central Europe were dominated by recurrent low-pressure systems. This is indicated by the below-normal pressure over large parts of central Europe. This lead to cool and rainy weather related to the passage of frontal systems from the west and northwest. The somewhat higher pressure over Iceland points

[138] The overview provided by ANDREAS KUNZ / JOHN ARMSTRONG, Inland Navigation and Economic Development in Nineteenth-Century Europe (Mainz, 1995), does not contain any substantial contribution on this issue. The article by RUSSELL R. MENRAD, "Transport Cost and Long-Range Trade, 1300–1800. Was There a European 'Transport Revolution' in the Early Modern Era?", in JAMES D. TRACY, The Political Economy of Merchant Empires. Studies in Comparative Early Modern History, 6 vols. (Cambridge, 1991), vol. II, pp. 230–75, deals only with maritime transport.

[139] The MA thesis by ERICH WEBER needs to be mentioned as an exception. WEBER provides a comprehensive synthesis for the history of navigation on the Rhine between 1750 and 1850 which includes quantitative data on the duration and the cost for the carriage of goods both upstream and downstream on different sections of the river according to seasonality and water level. ERICH WEBER, Der Güterverkehr auf dem Rhein 1750 bis 1850. Fahrstrasse, Technik, Organisation, Fahrtdauer, Kosten, Transportmengen und Saisonalität der Rheinschifffahrt, ([Unpublished] Licentiate Thesis, Institute of History, University of Bern, Bern, 2002). This is also the topic of his PhD.

[140] For the crisis of 1570/71, see: ABEL, Massenarmut und Hungerkrisen (see note 122). For the crisis of 1816/17, see the analysis by JOHN D. POST, The Last Great Subsistence Crisis in the Western World (Baltimore, 1977), pp. 54–9, pp. 150–8.

[141] Dr. JÜRG LUTERBACHER from the National Center for Climate Research (NCCR) in Bern is acknowledged for setting up this reconstruction from his data-base.



Graph 9. Average Air Pressure in Europe during the Summer, from 1585 to 1597.[142]

to occasional northerly flows which moved polar air through the eastern Atlantic towards central Europe. Currently, such situations may last for a week, and in some cases even up to a month. However, throughout the years from 1585 to 1597, this situation became the dominant climatic mode in the area north of the Alps, from the Massif Central to Poland (although this period also included an extremely hot summer in 1590). The summers from 1585 to 1597 were on average 0.6 °C cooler than those of the twentieth century. In Catalonia the number of "rogations for rain" was far below the aver-

[142] Source: JÜRG LUTERBACHER, NCCR "Climate", University of Bern.

age for the period from 1588 to 1610. This suggests that droughts in the winter half-year were less frequent during that time. Disastrous floods, on the other hand, were more numerous during the same period.[143]

How did the nature of summer change under such extreme conditions? Fortunately, a few diarists have documented noteworthy changes in considerable detail. David Fabricius (1564–1617) was undoubtedly the most meticulous among them. From 1585 to 1612 he kept a weather diary in Emden (eastern Friesland, Germany). Walter Lenke has assessed the number of days with "frost",[144] as well as the number of rainy, of "hot" and "warm" days from the Fabricius diary in order to compare the "historical" averages with those of the period 1881–1930. The summarized results: late frosts occurred 27 days later on average, whereas early frosts occurred 37 days earlier i.e., the frost-free period was almost two months shorter. The number of "warm" days in the summer half-year (April to September) was 36 percent lower. The largest decline was observed in July. It rained more often in summer, particularly in July, whereas the months in the winter half-year were somewhat drier.[145]

The Danish astronomer Tycho Brahe (1546–1601) left a detailed meteorological diary in Danish for the period 1582 to 1597. His observations were made on the small island of Hven, situated in the Danish Sound. The diary was probably kept by Brahe's assistant Elias Olsen. The entries provide a concise description of the weather, including wind directions during the day and quite often during the night.[146] When considering the changes in summer climate as compared to the conditions in the first half of the twentieth century, the observations of Tycho Brahe agree with those of David Fabricius. The number of days with precipitation was lower in the winter half-year

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143 Mariano Barriendos Vallvé, "El clima histórico de Catalunya (siglos XIV–XIX). Fuentes, métodos y primeros resultados", Revista de Geografía, XXX–XXXI (1996–1997), pp. 69–96.

144 I.e., frozen ground and/or water with negative temperatures.

145 Walter Lenke, "Das Klima Ende des 16. und Anfang des 17. Jahrhunderts nach Beobachtungen von Tycho Brahe auf Hven, Leonhard III Treuttwein in Fürstenfeld und David Fabricius in Ostfriesland", Berichte des Deutschen Wetterdienstes 15, 110 (1968); Pfister et al., "Daily Weather Observations" (see note 82), pp. 143 ff.

146 Victor. E. Thoren, "Tycho Brahe", in René Taton / Curtis Wilson, eds., Planetary Astronomy from the Renaissance to the Rise of Astrophysics. Part A: From Tycho Brahe to Newton (Cambridge, 1989), pp. 3–21; Jan Munzar / Jan Parez, "Tycho Brahe as a Meteorologist", in John Robert Christianson / Alena Hadravova / Petr Hadrava / Martin Solc, eds., Tycho Brahe and Prague. Crossroads of European Science, (Frankfurt a.M., 2002), pp. 360–75.

and somewhat higher in July and August than in the first half of the twentieth century. Likewise, local thunderstorms were less frequent.[147]

The third set of outstanding observations was made in Lucerne by the self-made man, Renward Cysat (1545–1613), who was the son of Italian immigrants. Cysat created a well-known botanical garden near his home in Lucerne, thereby laying the foundation for his scientific reputation. Furthermore, he became one of the most influential Swiss politicians working in favor of the Counter-Reformation. Cysat's weather observations, made over the period from 1570 to 1612, are included in his large collection of miscellaneous information known as the "*Collectanea*".[148]

Before the crisis of 1587, Cysat reported on anomalies in the style of a chronicle. He subsequently changed the style of his observations to quantitative monthly summaries of weather features, such as the number of rainy days. This suggests that Cysat must have kept a detailed weather diary which, however, no longer exists. The tendencies drawn from his observations are in close agreement with those obtained from the diaries kept by Brahe and Fabricius. In central Switzerland winters were drier, whereas June and July were considerably wetter than in the first half of the twentieth century, and Cysat also reports the rare occurrence of thunderstorms as an eye-catching feature of the change in climate. Cysat was accustomed to climbing the mountains near Lucerne – Rigi (1797 m) and Pilatus (2121 m) – during the summer months. On his hikes he used to talk with local herdsmen, who had a good knowledge of their local environment. At that time, such an attitude was quite unusual for a man of his status. Nonetheless, the statesman and scientist seemingly learned in this manner about the astonishing changes of mountain climate and included the acquired knowledge in his accounts. Mountain areas are known to be particularly sensitive to climate changes. The cooling of the summer half-year became manifest through a delay in the snow-melt and, consequently, in the forced postponement of the march with the cattle to the summer alpine meadows. Moreover, long cold spells during the period of alpine grazing lead to frequent snowfalls on the meadows. If

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147 Lenke, "Das Klima Ende des 16. und Anfang des 17. Jahrhunderts" (see note 145); Pfister et al., "Daily Weather Observations" (see note 82), pp. 126 ff.

148 Josef Schmid, ed., Renward Cysat. Collectanea pro Chronica Lucernensi et Helvetiae. Stationes annorum. Witterung, Missjahre, Teuerung, 2 vols. (Lucerne, 1969). The data scattered throughout this publication were compiled by Pfister, Bevölkerung, Klima und Agrarmodernisierung 1525–1860. Das Klima der Schweiz, II (see note 2); Martin Hille, "Mensch und Klima in der frühen Neuzeit. Die Anfänge regelmäßiger Wetterbeobachtung. 'Kleine Eiszeit' und ihre Wahrnehmung bei Renward Cysat (1545-1613)", Archiv für Kulturgeschichte, 83 (2001), pp. 63–92, has mainly drawn on Pfister's, Das Klima der Schweiz (see note 2).

such situations persisted for more than a day or two, the cows had less than sufficient to satisfy their hunger and had to be driven downhill. During the 1590s, Cysat recorded that most of the rainfalls were "cold" and that snow on the "Alps" – i. e., on the Rigi and Pilatus peaks near Lucerne – fell "almost every fortnight". At that time the summit of Pilatus only became snow-free in July, which is almost a month later than in the twentieth century.[149]

In about 1600, Cysat took a retrospective view of the recent past in the foreword to his "*Collectanea*", and maintained that "[...] during recent years the weather and other things have taken such a peculiar and astounding course and undergone such extraordinary alterations" that he

> "was able to do nothing other than record the same as a warning to future generations; for, unfortunately because of our sins, for already some time now the years have shown themselves to be more rigorous and severe than in the earlier past, and deterioration amongst creatures, not only among mankind and the world of animals but also of the earth's crops and produce, have been noticed, in addition to extraordinary alterations of the elements, stars and winds."[150]

Considering the climatic context in which Cysat made his observations, there is no doubt but what the Swiss scientist described a change in climate without, of course, yet knowing the term "climate". He stressed the enduring nature of the alteration and the repetitive sequence of anomalies, as opposed to familiar short-term deviations from "normal". In attempting an explanation, he pointed out changes in the wind system, meteorological causes, as well as considering the stars as possible influencing forces – this latter point may conceal an astro-meteorological belief. Finally, he addressed impacts on vegetation, agricultural production, wild and domestic animals, and even population in ways which may denote apocalyptic beliefs in terms of signs of degeneration pointing to an imminent end of the world. Seemingly many contemporary thinkers shared Cysat's prospects. William Bouwsma identifies a growing concern with personal identity, shifts in the interests of major thinkers, a decline in confidence about the future, and a heightening of anxiety at this time.[151]

On the other hand there is evidence that Cysat's remarks also related to observed changes in the physical world. For example, the cold summers between 1812 and 1817 in the Bernese Oberland caused intensive changes in the vegetation. As may be deduced from the observations then made, this sequence of exceedingly cold summers degraded a number of alpine meadows which remained permanently snow-covered for several successive years.[152] Moreover, clusters of cool summers led to an enhanced pressure from grazing cattle on forests at the upper tree line. When the alpine meadows were covered with fresh snow, cows and goats were driven downhill into the so-called refuge forests where they reportedly fed on shrubs and trees. A simulation of climate impacts on sub-alpine environments suggests that the series of cold summers in the late sixteenth century led to a strong recession of the natural tree-line.

Circumstantial evidence also exists for massive impacts on biota. 1603, the authorities of the Republic of Bern forbade the hunting of snow hares and certain species of birds because the number of both had dwindled alarmingly.[153] This seems to be a consequence of the reduced length of the vegetative period due to frequent severe frost and snow spells which must have drastically reduced biomass availability. The cooling also affected biota in the lowlands. Martin Körner drew up the number of moles that were captured and turned over to the authorities for a fee during the period 1538 to 1643 in the small Republic of Solothurn. The number of animals delivered to the authorities fell drastically after 1565 when the long-term cooling started, even though the incentives to catch these animals in compensation for a small amount of money increased during this period of frequent dearth. Only with the return of summer after 1600 did the number of catches rise, thereby suggesting a gradual recovery of the population.[154]

Other than vine production, the effects of such climatic deterioration on agriculture have not been systematically investigated. Perhaps the best analysis for Germany was attempted for the area of south-western Vogelsberg and based on sixteen qualitative and quantitative indicators drawn from the district accounts and stewards' accounts of the territorial ruler. Vogelsberg is a hilly area north-east of Frankfurt/Main reaching up to 800 m above sea level. During the first half of the sixteenth century, grain yields in the Vogelsberg area were relatively high, especially for rye, corresponding to the favourable climatic conditions. Moreover, years with poorer yields could be always compensated for by the better harvests of the immediately preceding or successive years. However, in the wake of the climatic deterioration, the growing period became shorter. Sources between 1584 and 1622 frequently

[149] Id., "Snow Cover, Snow-Lines and Glaciers in Central Europe since the 16th Century", in Michael J. Tooley / Gillian M. Sheil, eds., The Climatic Scene (London, 1985), pp. 154–74.

[150] Pfister / Brázdil, "Climatic Variability. A Synthesis" (see note 88), p. 44.

[151] William James Bouwsma, The Waning of the Renaissance, 1550–1640 (Yale, 2001).

[152] Messerli et al., "Fluctuations of Climate" (see note 59).

[153] Harald Bugmann / Christian Pfister, "Impacts of Interannual Climate Variability on Past and Future Forest Composition", Regional Environmental Change, 1 (2000), pp. 112–25.

[154] Martin Körner, "Geschichte und Zoologie interdisziplinär. Feld- und Schermäuse in Solothurn 1538–1543", Jahrbuch für Solothurnische Geschichte, 66 (1993), pp. 441–54.

mention snow, excessive cold, late frosts, and unseasonably heavy rainfalls. The average annual yield for rye declined remarkably, especially as a result of frost damage. A massive increase in mould damaged the grain for storage because it had to remain on the stalk longer and be brought in wet (which also reduced the baking quality). The fields could often not be tilled in autumn because of persistent rainfall. As a consequence of the cumulative frequency of bad rye harvests, a growing proportion of the population lived on grain which they borrowed in part from their territorial lord, thereby falling increasingly into debt and poverty. Even territorial lords found it impossible to pay their official overseers the quantities of rye stipulated as part of their salaries, resulting in their having to be content with oats, barley, or buckwheat. It may be assumed that there was a particularly serious decline of dietary protein, thus increasing the population's susceptibility to epidemic diseases.[155]

There is some fragmentary evidence from western Switzerland at the turn of the century which suggests that draught animals such as oxen and cows became rare in some areas of western Switzerland, perhaps as a consequence of (climate related?) epizootics. As a consequence, large plots had to be laid fallow.[156]

Population belongs to the class of second-order impacts where climate is only one amongst the set of various factors. Most victims of crises died from diseases. Connections between nutritional deficiencies, diseases and climate are known to be complex. Some diseases (e.g., cholera) are climate-related, whereas others (e.g., bubonic plague) are probably not.[157]

Susan Scott and Christopher Duncan recently provided a new interpretation of plagues in Europe. It challenges the widely held view that the infective agent of bubonic plague was solely responsible for the most devastating plagues of the last millennium. They argue that a second type of epidemic which they call "haemorrhagic plague" took by far the most lives. In contrast to the bubonic plague, the spread of haemorrhagic plague is promoted by

155 Helmut Hildebrandt / Martin Gudd, "Getreidebau, Missernten und Witterung im südwestlichen Vogelsberg und dem angrenzenden Vorland während des 16. und frühen 17. Jahrhunderts", Archiv für hessische Geschichte und Altertumskunde, NF 49 (1991), pp. 85-146.

156 Pfister, Bevölkerung, Klima und Agrarmodernisierung 1525-1860. Das Klima der Schweiz, II (see note 2), p. 86.

157 Anonymous, "The Relationship of Nutrition, Disease, and Social Conditions. A Graphical Presentation", in Robert I. Rotberg / Theodore K. Rabb, eds., Hunger and History. The Impact of Changing Food Production and Consumption Patterns on Society (Cambridge, 1983), pp. 305-8. Scott and Duncan advocate the view that winter temperatures and the spread of plague are connected. See: Susan Scott / Christopher J. Duncan, Biology of Plagues (Cambridge, 2001).

malnutrition and immunodeficiency. Thus, biophysical climate impacts become essential in their argumentation.[158]

The economic and demographic crises of the late sixteenth century are sufficiently known from published literature. A first book of essays entitled *Crisis in Europe, 1560-1600* appeared in 1965.[159] It received great attention and has inspired a great deal of research. The first two authors, Eric Hobsbawm and Hugh Trevor-Roper, established the fundamental interpretation which, with variations, underlies the remainder of the volume. For Hobsbawm, the fact that the great economic and population boom of the sixteenth century came to an end and was succeeded by the stagnation and frequent recessions of the seventeenth century indicated that there was a "crisis" both in the "old colonial system" and in internal production. Wealth had grown too fast and had been used unproductively, especially by a wasteful aristocracy. Hobsbawm only briefly mentioned population, but a lot of research on which his synthesis is based suggests that demographic stagnation or decline went hand in hand with economic trends.[160]

In most analyses, the causes of this crisis are related to population growth outstripping food production, i.e., a clearly Malthusian situation. It is true that the population grew at a very rapid pace during the relatively warm period between 1520 and 1570.[161] An annual growth rate of 1.4 percent has been attested for the Swiss Cantons of Zurich and Berne, as well as for parts of Thuringia in Germany, a figure not reached again until the nineteenth century; and there are even figures of over three percent per annum attested for the principality of Hohenlohe in the years 1528-1562.[162] Using calculations for German-wide trends in the development of dwellings and settlements made by Fritz Koerner between 1520 and 1600,[163] it has been shown that the increase in the number of dwellings was more than seven percent per annum between 1520 and 1560. Afterwards, the growth rate declined progres-

158 Ibid.

159 Trevor H. Aston, ed., Crisis in Europe (London, 1969^3).

160 Eric Hobsbawm, "The Crisis of the Seventeenth Century", in Crisis in Europe (see note 159), pp. 5-95; Theodore Rabb, The Struggle for Stability in Early Modern Europe (Oxford, 1975), pp. 17-34, summarizes the findings of the Aston volume.

161 Christian Pfister, Bevölkerungsgeschichte und historische Demographie 1500-1800 (Enzyklopädie Deutscher Geschichte, vol. 28) (München, 1994), p. 11.

162 Id., "The Population of Late Medieval and Early Modern Germany", in Sheilagh Ogilvie / Bob Scribner, eds., Germany. A New Social and Economic History, vol. I: 1450-1630 (London, 1996), pp. 33-64.

163 Fritz Koerner, "Die Bevölkerungsverteilung in Thüringen am Ausgang des 16. Jahrhunderts", Wissenschaftliche Veröffentlichungen des Deutschen Instituts für Länderkunde, NF 15/16 (1958), pp. 178-315.

sively until the end of the century. Considering the evidence thus far available, it may not be assumed that food production remained on the same level during the climatic downturn of the late sixteenth century. Rather, the likely situation needs to be conceived in terms of a scissors-effect, in which an increasing demand for food coincided with a decline in production. In the end, this may have throttled down population growth.

Finally, the likely causes for the climatic disturbances in the final decades are addressed. This reference to the global dimension of climatic processes is likely to somewhat counterbalance the usual focus of the humanities on proximate and manageable topics which went along with the post-modernist turnaround.[164] Two causes are provided in scientific literature. Firstly, there is physical evidence pointing to a phase of a low solar activity around 1595.[165] Second, this "solar" cooling effect was superimposed by a phase of enhanced volcanic activity. Five large volcanic explosions in low latitudes are known between 1580 and 1600: Billy Mitchell (Bougainville, Melanesia), exploded in 1580,[166] Kelut (Java) in 1586, Raung (Java) in 1593, Ruiz (Colombia) in 1595, and Huaynaputina (Peru) in 1600.[167] Considering the number and density, this series of explosions seems to be unique within the last millennium.

6. A Period of Crisis or a Period of Crises?

It is open to debate whether the six decades between 1570 and 1630 should be labelled as "a period of crisis" in their entirety. To some extent, this depends on how the blanket-term of "crisis" is understood. Theodore Rabb defines "crisis" as having three criteria. Firstly, it must be short-lived. Secondly, conditions in a crisis need to differ from previous and subsequent ones. Thirdly, the situation in a crisis should be worse than "ordinary conditions", regardless of how such are defined.[168]

The discussion should consider two strands of evidence that are interrelated, namely the reconstruction of biophysical impacts on the one hand and the reconstruction of crises in people's minds on the other. The relationship between the two dimensions should not be understood in terms of basis and superstructure. Rather, the continued exploration of this relationship should

164 RICHARD J. EVANS, In Defense of History (London, 1997).
165 PFISTER / BRÁZDIL, "Climatic Variability. A Synthesis" (see note 88), pp. 33 ff.
166 Or 1579, concluding from the disastrous summer of that year.
167 PALMER ET AL., "High Precision Dating" (see note 65), p. 1953.
168 RABB, The Struggle for Stability (see note 160), pp. 29–30.

become the main objective of historians dealing with cultural consequences of the Little Ice Age.

Based on a broad and consistent body of data from both man-made and natural archives, it is demonstrated here that conditions in the six decades from 1570 to 1630 differed in several ways from those prevailing in the preceding and the subsequent ones. The outstanding character of climate became manifest through far-reaching advances of Alpine glaciers. Their outstanding economic character was demonstrated with the high level of climatic stress in the long term, as expressed by the biophysical impact model, and with the high level of grain prices. Likewise, vine production north of the Alps repeatedly almost collapsed for a few years. Such impacts were felt in most of northwestern and central Europe. However, they usually did not affect the Mediterranean and the territory of present-day Russia. Thus, the term "European" would be misleading.

Crises were more frequent and severe between 1570 and 1630 than in any other period in the last millennium, with the exception of the 1340s. It is true that subsistence crises belonged to the experience of people in the early modern period. But in between the crises, there was usually a considerable number of average or abundant years which enabled a recovery. During the period from 1570 to 1630, however, there was hardly a recurrence to "normal" conditions. Before people had recovered from one shock, they were already confronted with the next one. The sheer absence of summer warmth in the final two decades of the sixteenth century was widely perceived as a feature departing from ordinary experience, as the appraisal by Renward Cysat shows. In this respect the statesman and scientist from Lucerne may have acted as an organ of popular belief. In sum, climatic impacts between 1570 and 1630 concatenated in such a way that to speak of a period of crises seems to be justified.

For a long time, climatic anomalies and natural disasters were considered to be exogenous, short-lived shocks without any long-term consequences for society. As the cliometrician Jan de Vries observed: "A sceptic might feel justified in concluding that short-term climatic crises stand in relation to economic history as bank robberies to the history of banking."[169] This statement mirrors the world view of neoclassical economists who assume that after an exogenous shock, a market economy always returns to its previous equilibrium.

For Peter Borscheid, on the other hand, getting across the volatile, short-winded world of unique events to building bridges toward slow-moving

169 DE VRIES, "Measuring the Impact of Climate" (see note 98), p. 23.

structures is a main challenge of historiography.[170] Crises and (natural) disasters are fundamental in this respect because they create a pressing need for action, at the same time providing occasions and opportunities to communicate attitudes and beliefs with regard to the natural and to the supra-natural world. Processes in the natural world are usually not a topic of public discussion. Sociologist Niklas Luhman has pointed out that such events are only noticed and communicated if and when they interfere with daily routines.[171] If a crisis or a disaster occurs, nature puts itself on the agenda and thus becomes a primary object of discourse. Economic historian Hansjörg Siegenthaler has argued that crises provide(d) incentives to "fundamental learning" as opposed to routine learning. Whereas routine learning aims at acquiring a set of known solutions to given problems, fundamental learning is directed towards finding novel solutions.[172] Siegenthaler's conclusions apply not only to economic and political crises, but also to climatic anomalies and natural disasters.

The crisis of 1570/71 took everybody by surprise. For three generations situations of climatic stress had been relatively rare and of short duration. Thus, no adequate measures were prepared to deal with the disarray in the physical world and in people's minds which resulted from the situation of extreme hardship as it occurred in the early 1570s. During the subsequent six decades crises became a recurrent feature. This chain of events created repeated opportunities for the development of a crisis consciousness, to improve measures taken in the context of former crises or to adapt known measures taken in other areas. Above all, emergency situations provided chances for central authorities to extend their competence at the expense of traditional rights. To which degree such initiatives were already taken during the second period of Little Ice Age-type impacts needs to be further explored.

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170 PETER BORSCHEID / HANS J. TEUTEBERG, Ehe, Liebe, Tod. Zum Wandel der Familie, der Geschlechts- und Generationenbeziehungen in der Neuzeit (Studien zur Geschichte des Alltags) (Münster, 1983), pp. 11–12.

171 NIKLAS LUHMANN, Soziologie des Risikos (Berlin, 1991), pp. 121–2.

172 HANSJÖRG SIEGENTHALER, Regelvertrauen, Prosperität und Krisen. Die Ungleichmäßigkeit wirtschaftlicher und sozialer Entwicklung als Ergebnis individuellen Handelns und sozialen Lernens (Tübingen, 1993).

Zusammenfassung

Dieser Artikel zeigt Wege auf, wie lange, hoch aufgelöste, auf die Bedürfnisse der Geschichtswissenschaft zugeschnittene, aber naturwissenschaftlich dennoch aussagekräftige Zeitreihen über Temperatur und Niederschläge auf der Basis von Wetterbeobachtungen in historischen Dokumenten rekonstruiert werden können. Im Unterschied zu naturwissenschaftlichen Zeitreihen sind die auf Dokumentendaten beruhenden monatlichen und jahreszeitlichen Näherungswerte für Temperatur und Niederschlag (»Indices«) an die Kultur- und Wirtschaftsgeschichte anschlussfähig: Einerseits können sie für Modellierungen von *Impacts* verwendet werden. Andererseits kann über Kommentare zum Witterungsverlauf, in die häufig Deutungen der Ereignisse sowie Reaktionen und Maßnahmen von Betroffenen einfließen, eine Verbindung zwischen Mikro- und Makrogeschichte hergestellt werden. Eine auf diese Bedürfnisse abgestimmte Software (Euro-ClimHist) ist entwickelt worden.

Während der »Kleinen Eiszeit« (ca. 1300–1900) waren die Gletscher zwar weltweit etwas größer als heute. Doch kann diese Periode nicht als einheitliche Kaltzeit bezeichnet werden. Kennzeichnend für das mitteleuropäische Klima waren vielmehr oftmalige kalt-trockene Winter und Frühjahrsperioden, denen sich – ausgelöst durch Vulkanausbrüche in den Tropen – gelegentlich zwei bis drei aufeinanderfolgende kalt-feuchte Hochsommer überlagerten. Die für Gletschervorstöße bedeutsamen Klimaphasen, die Heinz Wanner »Little Ice Age-type Events« (LIATE) nennt, alternierten mit Gruppen von Jahren mit »ruhigem« Klima und solchen mit warm-trockenen Sommern, in denen die Gletscher wieder etwas zurückschmolzen. Zusammenhänge mit den Ergebnissen der Historischen Klimawirkungsforschung sind offensichtlich: Getreide-, Weinbau und Milchwirtschaft litten gleichermaßen unter kalten Frühjahrsperioden (v. a. April) in Verbindung mit wochenlangen Regenperioden im Hochsommer. Die jährliche Klimabelastung der Agrarproduktion ist für die Zeit von 1550 bis 1670 auf der Basis der erwähnten monatlichen *Indices* für Temperatur und Niederschlag anhand eines idealtypischen Modells geschätzt worden. Im zeitlichen Verlauf zeigt die Intensität der Klimabelastung starke Schwankungen. Namentlich treten Gruppen von Jahren mit hohen Belastungswerten auf, die als »kleineiszeitliche Misserntemuster« (»Little Ice Age-type Impacts«) bezeichnet werden. Diese lösten häufig Teuerungen aus (u. a. 1570–1574, 1627–1629), wobei die Intensität des Preisauftriebs durch Kriegsereignisse verschärft, durch Pufferungsstrategien (Kulturwechsel, Vorratshaltung etc.) unter Umständen abgeschwächt wurde. Während der Jahre *1568–1630* lag die *durchschnittliche*

Klimabelastung in Mitteleuropa und Südskandinavien (nicht dagegen im Mittelmeerraum) signifikant *höher* als vorher und nachher, weshalb diese sechs Jahrzehnte als »Second Period of Little Ice Age-type Impacts« (im Anschluss an eine erste Periode erhöhter Klimabelastung im 14. Jahrhundert) bezeichnet werden. Völlig aus den Fugen geriet das Klima in den Jahren 1585 bis 1597. Aufmerksame Beobachter wie der Luzerner Naturforscher Renward Cysat erwähnen diese »unnatürlichen« Veränderungen, ohne schon über den Begriff des Klimas zu verfügen. Es wird postuliert, dass die hohe Dichte von klimainduzierten Krisen zwischen 1570 bis 1630 in Verbindung mit Kriegen für die werdenden Territorialstaaten Voraussetzungen schuf, um unter Berufung auf den wiederholten Notstand ihre Befugnisse zu erweitern.