Documentary evidence as climate proxies

Proxy-specific White Paper produced from the PAGES/CLIVAR workshop, Trieste, 2008
in: PAGES (Past Global Changes), Bern 2009
http://www.pages-igbp.org/cgi-bin/WebObjects/products.woa/wa/product?id=331

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1. Documentary evidence – a broad data field

1. 1. The area of Historical Climatology

The increasingly important area of Historical Climatology is situated at the interface of climatology and (environmental) history, using methods and skills from both disciplines (Brázdil et al. 2005). It deals principally with non-instrumental climate evidence bequeathed by human activity and preserved in documentary archives. In this respect, Historical Climatology needs to be distinguished on the one hand from Palaeoclimatology, which analyses climatic parameters derived from evidence stored in natural archives (for a recent overview see Wanner et al. 2008). The transition to climatology of the Modern Instrumental Period (MIP), in contrast, which deals with meteorological elements systematically measured by standardized instruments has been more gradual. That is to say, early instrumental climatology uses instrumental observations in the manuscript form laid down prior to the establishment of coordinated meteorological networks between the mid 19th and the 20th century and which, importantly, overlap with non-instrumental sources. It is often assumed that each of the three fields – Palaeoclimatology, Historical Climatology and Instrumental Climatology – focuses on a specific time-period window. However, rather than temporally defined, the distinction between them is related to the type of evidence they call upon and is methodological in character.

Documentary data have been proved to be of importance for monthly to seasonal NAO and sea level pressure estimates, determining variations in the occurrence of Atlantic hurricanes (e.g. García-Herrera et al. 2005) and polar front locations as well as regional and large-scale temperature and precipitation field reconstructions **(**Luterbacher et al. 2004**).** Temperature indices derived from documentary evidence are found also to be the most important single proxy for

winter temperature reconstructions in many parts of the European continent (Pauling et al. 2003). Finally, documentary data are the only evidence from which the timing and severity of natural hazards can be assessed for the Pre-Instrumental Period (PIP) (Pfister et al. 1999).

By their very nature, documentary sources will often tend to emphasize extreme events as these are the phenomena that are more likely to have been recorded as a consequence of their socio-economic impact. Most commonly, such events are constituted of hydro-meteorological extremes and severe natural hazards of great destructive power that often jeopardised the success of harvests and the survival of livestock, making them obvious candidates for inclusion in written accounts. Important uses of documentary data are found in the verification of extreme values in natural proxies such as tree rings and varves and in the provision of more comprehensive descriptions of past weather conditions.

1.2. Types of evidence

A climate historical source is a man-made unit of information such as a manuscript, a piece of printed matter, a picture or an artefact (e.g. a flood mark), each of which may contain different kinds of data or evidence. Two forms of documentary data can be distinguished: (Table 1):

Table 1: A survey of data-types suited for reconstructing past climate (Pfister et al. 1999)

Archives: / **Evidence:**	**Natural**			**Man-made**	
DIRECT OBSERVATIONS: of weather and climate and measurement of meteorological parameters			**D o c u m e n t a r y**	***NARRATIVE REPORTS ON:*** • climate anomalies • weather spells • daily weather and wind force • weather induced hazards	***EARLY INSTRUMENTAL MEASUREMENT OF:*** • barometric pressure • temperature • precipitation • water-levels.
INDIRECT (PROXY) DATA: evidence of climate-controlled processes	**ORGANIC:** • tree rings • fossil pollen • animal and plant remains • fossil wood	**NON-ORGANIC** • ice-cores • varves • terrestrial sediments • speleothems • moraines • borehole temperature profiles etc		**ORGANIC:** • plant phenology • animal phenology • distribution of crops • yield of crops; sugar content (vine). **CULTURAL:** • reports on rogations	**NON-ORGANIC:** • water levels • snow- and ice - phenology • first and last frost **PICTORIAL:** • e.g. glacier paintings
				EPIGRAPHIC: • e.g. flood marks	**ARCHEOLOGICAL:** • site remains

- **Direct data:** these principally include narrative accounts on climatic anomalies, weather spells and weather-induced disasters all of which might be found in chronicles, diaries and

newspapers etc. Moreover, daily weather was sometimes systematically noted and investigated using contemporary astro-meteorological knowledge in the hope of developing long-term forecasts. Early instrumental measurements can be found in an equally diverse variety of sources.

- **Indirect (proxy) data:** in a form analogous to the evidence from natural archives, organic and non organic proxies can be distinguished. The former include among other things. observations of plant phenology, crop distribution and plant yields. The latter give, for example, the time of freezing and opening of water-bodies ("ice phenology") or the duration of snow cover ("snow phenology"), the passability of mountain passes as well as the occurrence of first and last frost. Pictorial representations of historic glaciers in the form of drawings, paintings and early photographs may allow reconstructions to be made of the former extension and volume of the ice, sometimes with a time resolution of years. Such evidence ranges from the late 16th century to the onset of continuous glacier-tongue length measurements in the late nineteenth century (Nussbaumer et al. 2007). The most important of the so-called 'epigraphic' sources are flood-marks on houses, bridges or rocks, all of which support the memory of severe floods (Munzar et al. 2006).

Table 2: Documentary evidence according to record keeping agents

Agent	Secular and religious institutions Private households	Individuals / Institutions	Individuals Institutions
Type of evidence	**Accounting:** Dues, tax-, rogation-receipts and expenditures	**Weather data:** *Weather Diaries/ship logbooks*	**Observed Weather Patterns:** *Chronicles, letters* *Reports to authorities*
Content of document	Numeric evidence (proxy data) and/or narrative (climatic) context of entries	Weather, wind direction *wind force*	Extreme events, disasters Impacts, loss perception measures of authorities
Reasons for record-keeping	Control of revenues	Climatic forecasting *safe navigation, record of voyage*	Memory of extreme events, risk management *Status report*
Frequency of record-keeping	Recurrent	Systematic	Sporadic, event-specific *Recurrent*
Time resolution of data	Several months to single days	Daily or sub-daily	Daily, weekly, monthly; seasonal
Continuity of record-keeping	Multi-secular (according to reporting practice)	Life-time of observer *professional life-time of mariner*	Life-time of observer *Up to multi-secular depending on institution*
Form of evidence	**Quantitative /** Descriptive	**Descriptive** suited for quantification	**Descriptive** often including proxy data

Another important distinction in the field of documentary evidence is related to the agents who managed or directed the keeping of the records (Table 2):

- **Sources generated by individuals** usually put an emphasis on describing extreme events such as floods, windstorms, frosts and hailstorms, their socio-economic impact on and the perception by humans. The more extreme an event, the more observations are available and the more detailed they become. Individuals had their personal motivations for committing weather observations to record and developed idiosyncratic means of doing so. But, irrespective of such characteristics, these sources usually contain data gaps of different lengths and they are limited by the life-span of the observer.
- **Sources produced by institutions:** Institutions may be understood as bodies maintaining functions of government or regulating collective fields of action such as religion, law or branches of the economy within existing territorial structures. Historically, religious bodies such as chapters and secular institutions such as municipalities owned and controlled their own sources of income. Book-keeping involved more or less standardized procedures and these often worked in the same way for centuries until they were changed or abolished. In this way, institutional accounting practices often generated very long and quasi-homogenous records (e.g. Leijonhufvud et al. 2009).

In China, the emperors strived for 2200 years to secure reports on current weather events and disasters from the provinces with a view to taking timely measures to forestall the outbreak of famines and riots. Under the Ming Dynasty (1368 to 1644) the central government required provincial authorities to call up local scholars and non-governmental groups, whose duty was to compile the knowledge of past and current geography and to report on natural disasters, population and agricultural resources. Under the Qing Dynasty (1644 to 1911) 273 administrative centres were required to submit detailed records on precipitation (including rain infiltration and snow accumulation depth) and the volume of harvests. Detailed weather diaries were kept from the early 18th century by order of the emperor (Ge *et al*. 2008).

A regular reporting system on extreme events similar to those in China is known from the Venetian colonies in the Adriatic and in the Eastern Mediterranean. Governors had to report on a regular basis to the Venetian authorities, importantly these reports were again prepared in a consistent and standard format thereby ensuring a degree of homogeneity (Grove & Conterio 1994). In most cases, however, institutional bodies in Europe were not interested in documenting climate. Rather, their activities were concerned with the control or the accounting of receipts and expenditures in money or in kind. By-products of such accounting

activities, in particular remarks related to the date of receipts (e.g. beginning of vine harvest) or expenditures (e.g. related to the payment of day laborers for field work or to maintenance operations such as ice cutting on waterways), yield valuable evidence in the form of plant-phenological or ice- phenological proxy data. Most often, the significance of such evidence for climate research is not immediately apparent. Slightly different are the written accounts on the organization of rogations and systems of prayer in the Catholic world, both on the part of the commissioning municipality and the executing ecclesiastical administration. These provide evidence of climatic stress giving rise to processions and other religious rituals to alleviate droughts or spells of extreme weather (Barriendos 2005). The most important institutional source yielding direct observations on wind direction, wind force and weather are ship logbooks. They usually adopt a standardized vocabulary and system of recording. The documents provided the only official record of the voyage and were needed also to assist in safe navigation. Their keeping was an almost universal requirement of the military or merchant undertaking to which the ship belonged and many tens of thousands of logbooks are preserved in European archives, mostly in the UK (Wheeler 2006).

1.3. Spatial and temporal data availability

The geographical range and availability of documentary evidence depends on:

- The permanent presence of literate individuals. This condition excludes therefore oceans, the high altitudes and high latitudes, although attention might be drawn again to ship's logbooks that range widely over the oceans, penetrating even into the high latitudes for whaling and trade.
- An appropriate institutional and cultural framework (e.g. the existence of conventions, of urban elites in towns or of a strong bureaucracy).
- A tradition of keeping the memory of extraordinary events based on eyewitness observations in annals or chronicles.
- The enthusiasm of present-day researchers to identify, validate and promote documentary sources, the insight of experts into the value of this evidence and the readiness of funding agencies to support their analysis and compilation in data-bases.

1.3.1. Spatial availability

Globally, there are three major geographic foci of historical-climatological sources, namely China, Japan and Europe. Research in South America, where such evidence goes back to the beginning of the Spanish colonization, has been initiated and within the past years several document-based climate time series have been prepared, mostly for the closing decades of the 19th

century. Data from North-America and from Australia are far more recent, particularly in comparison with those available from Europe. An annalistic tradition in the Arab world is known to exist, but research has hardly begun (Weintritt 2009). The potential of India and Africa (except Southern Africa) still needs to be explored.

Documentary records in China mainly cover the eastern part of the country and Japanese sources have been recently reviewed in Mikami (2008). Research in Europe is, however, geographically unbalanced. Although some potentially useful documentary evidence exists in most European countries, only a number have been used in systematic historical-climatological investigations, these being in the Czech Republic, Estonia, Germany, Hungary, Italy, the Netherlands, Norway, Poland, Spain, Switzerland and in the U.K.. In these countries studies of Historical Climatology were supported through Research Foundations. Occasional studies from Austria, Belgium, Denmark, Greece, Ireland, Slovakia, Slovenia, Romania, Portugal and Russia are also undertaken. Recently, research was initiated in Sweden and re-launched in France. Promising data from Russia and Ukraine exist, but they still need to be explored. This spatial imbalance is particularly problematic for climate reconstructions on a European scale. On the other hand, ship's logbooks span the world's oceans and seas wherever trade and imperial interests took the ships of the age (Wheeler 2006) and extend the geographic range globally.

1.3.2. Temporal availability

a) China: Systematic historical records were kept beginning in the Qin dynasty (221BC).

b) Europe: Some records from the Byzantine Empire (including the Balkans) and the Carolingian Empire are available prior to AD 1000, otherwise the evidence is characterised in time frames:

- AD 1000 to 1200: individual reports of socio-economically significant anomalies and (weather induced) disasters.
- 1200 to 1500: more or less continuous clusters of individual reports on summer and winter, partly on spring, including reference to "average" conditions (e.g. Glaser 2008). This period is marked by an increasing availability of institutional sources.
- 1500 to 1800: almost full descriptions exist of monthly weather, to some extent also of daily weather. There is an abundance of institutional sources.
- 1650 to 1860: early instrumental measurements made by individuals and organised by scientific and economic societies. Short-lived international instrumental networks (up to 1795) followed by initiatives by the emerging nation states in the 19th century.

c) Latin America

From the Spanish conquest in the early 16th century reports, letters and notes containing information on economically adverse extreme (hydro-) meteorological events were sent to the Crown. The most reliable, continuous and homogenous among them are the weekly "Actas Capitulares" (Local Acts). The warfare and administrative instability connected to the emergence of new independent countries in Latin America in the early 19th century interrupted the flow of climatic information. Early instrumental observations were taken by amateur observers and members of religious orders and some of them were published in newspapers. National Meteorological Offices were founded from the late 19th century (Rosario del Prieto & García Herrera 2008).

d) **(Southern) Africa**: A few published reports providing annual chronologies on relative dry and wet years are known from the early 19th century and chronologies of relative temperatures during the 19th century are currently being prepared. Instrumental records are patchy from the late 19th century and for some sub-regions, they become available only from the mid-20th century!

e) **North and South Atlantic and Indian Oceans:** The temporal coverage of ships logbooks is notable, with the earliest logbooks dating from the mid-17th century (Wheeler et al 2006).

2. Data uncertainties

Documentary data differ notably from the classical natural archives, and the long established uncertainty criteria (sampling, calibration uncertainty) are complemented or replaced by others.

2.1. Uncertainties in data extraction

- **Handwriting** may be difficult to read in manuscripts, and ink may fade or the paper be damaged.
- Records are written in different **languages**: Until the period 1300 to 1500, the *lingua franca* is Latin, with emergent popular languages, often in the form of dialects being found. This situation may involve problems of textual interpretation in addition to which it should not be forgotten that the meaning of terms such as winter, autumn, summer etc. have themselves changed over time (Pfister et al. 1999).
- **Changes in the framework of institutional proxy data**: It is important to assess through a critical evaluation of the institutional framework whether a derived proxy yields the same signal throughout the "life-time" of the institution. A sophisticated statistical analysis of the 19th and 20th century is not sufficient, as is illustrated by the case of grape harvest dates: before 1700 a mixture of grapes was grown and cultivation was directed to gaining the maximum volume in a bad year (risk minimization). Moreover, grapes were sometimes picked before full maturity in case of impending corruption or loss to

plundering armies. Thus, early vintages were not always the result of warm summers. Not until the early 18th century were pure grape varieties grown and cultivation directed to securing a maximum sugar content (Meier at al. 2007).

Reducing uncertainties in the records: Changes in the framework of institutional data need to be investigated besides mastering the problems related to handwriting and languages.

2. 2. Chronological uncertainties

One of the **strengths** of documentary sources lies in the intensive nature of temporal data availability and the fact that they are often continuously **available for the winter season**.

Although documentary evidence are dated, often to the specific day, the dating (mostly **the year)** within individual sources **may be incorrect,** particularly within error prone copies. Most Medieval chronicles begin with the creation consisting of an older, usually non contemporary, and a recent, contemporary component. Chroniclers borrowed the older parts of their work from their predecessors without citing them. Subsequently, they usually added their own observations. Before an event's date is taken for granted, **it needs to be determined whether the observation falls into the life-time of the author of the source**. It is thus often necessary that the biography of the author is established. **The use of documentary evidence without a critical elaboration of sources invites the risk of spurious multiplication of extreme events.** Finally, it should be recalled that prior to 1600 the beginning of the year was different often from one region to another (e.g. beginning at Christmas, 1st of March or "Easter").

Uncertainties regarding the date occur because the Julian style was generally used prior to 1582. The Gregorian calendar was gradually introduced, but in England only in 1752 and in Russia not until 1917!

Reducing chronological uncertainties: Work with contemporary evidence and substantial amounts of data! Establish the spatial distribution of data for specific seasons or months! A spatially-extended coverage in the evidence for a month or season allows the conclusions to be tested in a geographically and meteorologically meaningful way, i. e. in agreement with the physical laws of the atmosphere.

2.3. Uncertainties in the reconstruction

Climate reconstructions can be attempted based on two kinds of proxy data:

- Indices of seasonal and monthly temperature and precipitation: Historical Climatology attempts to secure a systematic reconstruction of temperatures and, under certain circumstances of precipitation, for all months or seasons of the year. The data-field available for a specific month or season including direct narrative and calibrated indirect data can then be assessed to produce an ordinal index comprising seven classes from -3 (extremely cold/dry) through +3 (extremely warm/wet) for the monthly indices with adding of those indices being used to produce seasonal measures (Brázdil et al. 2005).
- Long series of physically based documentary evidence from institutional sources overlapping with instrumental series can be related to climatic parameters through the calibration and verification approach. This approach yields direct estimates of temperature or precipitation, i.e. in degrees or millimetres respectively (e.g. Leijonhufvud et al. 2009) usually involving, however, a loss of time resolution compared to the index approach.

The quantification of the uncertainties within documentary data is currently undertaken within the frame of national and European interdisciplinary projects (Dobrovolný et al. 2008). One promising approach is the use of an overlapping period where instrumental and documentary data are available and can provide an estimate of the underlying errors although this requires an assumption of stationarity in the relationships over time. But problems might still exist and the reconstruction of temperature/precipitation from monthly indices may involve the following challenges:

- Prior to 1500 spatial data density is too low for reliable large-scale reconstructions. Continuing research focuses on smaller sub-regions for which enough data are available.
- Early instrumental series used for calibration are often fragmentary, not homogenized or not available at all (e.g. Frank et al. 2007).
- The period of overlap between (early) instrumental measurements and documentary evidence comprising institutional data and the full spectrum of individual observations (see table 2) is often too short for carrying out a full calibration and verification procedure. This drawback is connected with changes in the style of weather observations around the turn of the 19th century. After this period weather observers usually put a focus on instrumental measurements strictly limiting daily visual observations to specific meteorological parameters such as cloudiness or weather phenomena and omitting other kinds of climate-related observations.

Nevertheless, strong relationships between instrumental and proxy monthly or seasonal temperatures are known to exist and attempts have been made to quantify the combined uncertainties accounting for calibration statistics and changing signal strength back in time. These

quantitative assessments make documentary data useful for constraining climate model simulations of past climate variability, but new questions also arise concerning how best to estimate the full range of reconstruction uncertainties (Moberg *et al*, 2009).

Reducing uncertainties in the reconstruction: The reconstruction of annual, seasonal and monthly indices should be built on documentary information from contemporary sources. The procedure for the definition of indices has to be clearly defined. If possible the time series has to be calibrated and verified based on instrumental measurements including associated uncertainties (error bars). An approach for the post 1500 period is provided by Dobrovolný et al. (2009).

There are **six future challenges for Historical Climatology**. Firstly, research should focus upon those parts of the world which are still unexplored, but for which sufficient documentation might be available. South America and the Islamic world are the most promising in this respect. Secondly, considering well researched areas such as central Europe, new methods need to be developed to cope with the often unsubstantiated data available for the Middle-Ages. Thirdly, evidence from different parts of the globe, particularly from China and Europe, should be consolidated to improve the northern hemispheric analyses of climate for the last millennium. Fourthly, cooperation between historical climatologists and paleoclimatologists should be intensified. Fifthly, comparisons between GCMs/RCMs and local to regional documentary proxies will be of importance for an assessment of the simulated climate sensitivity to changes in external forcing. Finally, studies in well-researched and well-documented periods and areas should take advantage of the abundance of valuable climatic evidence to explore the vulnerability of past societies to climatic stress.

Acknowledgments

Christian Pfister and Jürg Luterbacher are supported by the Oeschger Centre for Climate Change Research at the University of Bern, Switzerland, Pfister is also supported by the EU FW6 project Millennium (contract number 017008-2) Dennis Wheeler's ship's logbook research is currently supported by the EU FW6 project Millennium (contract number 017008-2). Anders Moberg is funded by the Swedish Research Council, VR. Quansheng Ge is supported by the National Natural Science Foundation of China (40625002). Rudolf Brázdil was supported by EU FW6 project Millenium (contract no. 017008). Stefan Grab's current historical newspaper research is supported by the South African National Research Foundation. María del Rosario Prieto is supported by the Consejo Nacional de Investigaciones Científicas y Técnicas de Argentina

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