BIOMONITORING FOR…

PAST CHANGES

FUTURE CHANGES

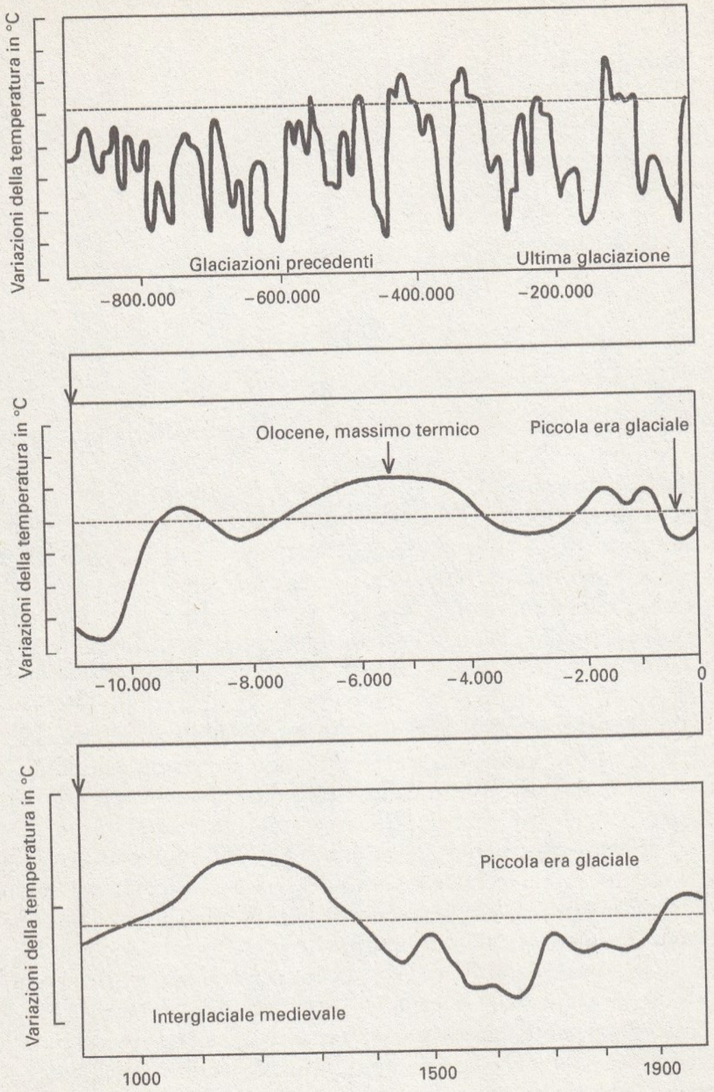


Figura 1
La favola dell'equilibrio climatico è stata smentita già dal primo Rapporto sul clima dell'IPCC, del 1990. Che si consideri l'ultimo milione di anni, gli ultimi 12 000 o gli ultimi 1000, il risultato resta lo stesso: periodi caldi e periodi freddi si alternano costantemente.

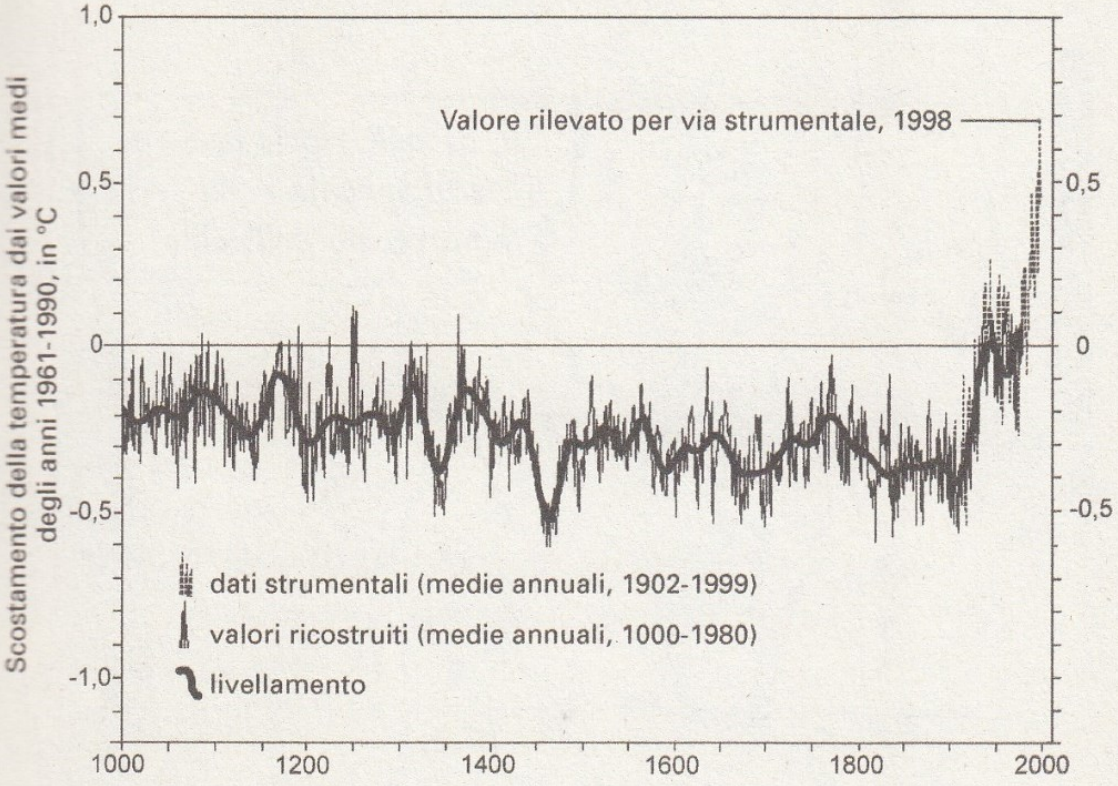


Figura 2
Il clima degli ultimi mille anni come un bastone da hockey. Il Rapporto dell'IPCC del 2001 livellava le oscillazioni della temperatura dei secoli passati, in modo da produrre un effetto di contrasto tra i valori misurati degli ultimi anni, che sono elevati, e quelli relativi ai secoli precedenti, che sono stati ricostruiti per via indiretta.

In order to reconstruct climatic conditions of past centuries or millennia, data are recovered from different resources, basically of physicochemical, cultural or biological nature.

Physicochemical data are obtained for instance by ice cores, sediments, rocks.

Cultural data are obtained by oral or more frequently written sources (diaries, archives, commercial notes ecc.; annotations concerning plant phenology (e.g. harvest of wheat, rye, barley, grapevine).

Biological data are obtained by sediments (entrapped pollen, foraminifera, dinocystes), seeds, trees, corals.

Frequently, biological data are obtained from archaeological sites, and therefore cultural and biological data are mutually interdipendent. But biological data are obtained also from boreholes and ice cores. Therefore, a multisources approach is often applied.

Instrumental recording is of paramount importance for testing the robustness of biological models built up on the basis of rought data. Unfortunately, instrumental recording (now available at planetary level) were introduced relatively late.

The planet is rich of natural archives storing the past climate history

Arctic and Antarctic Ice

Glaciers

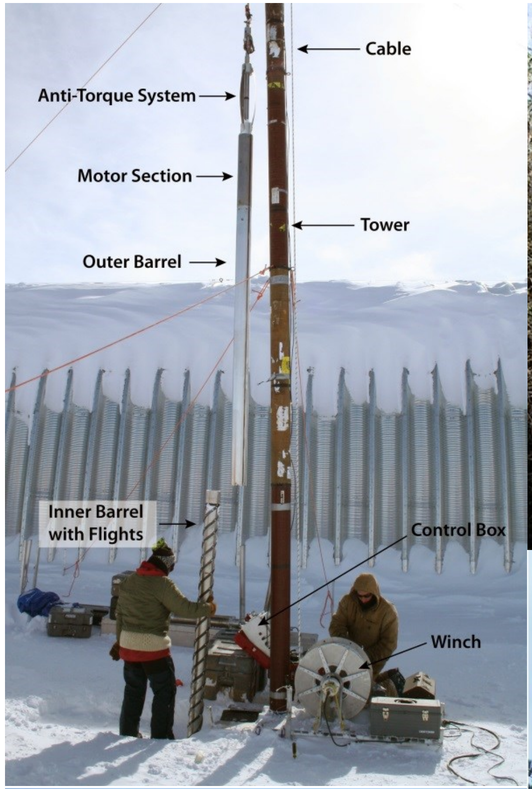
Peat bogs and mires

Marine and freshwater sediments

The analysis of sediments make use of many, integrated techniques to:

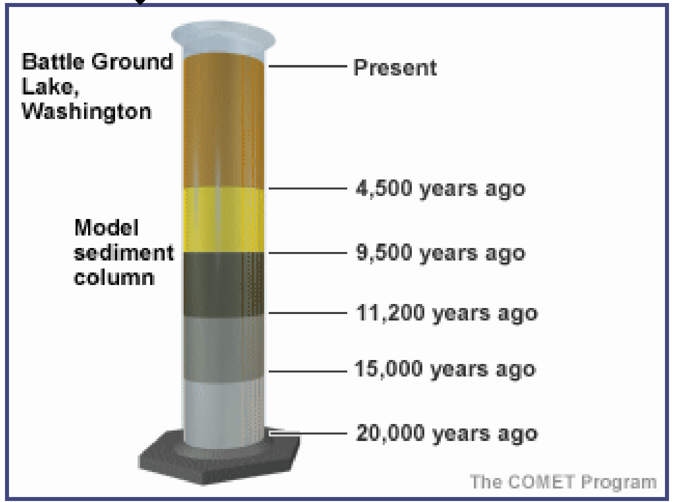
- Date the sediment layers
- Infer temperatures (sea/air) when the layer was deposited
- Date the organic component of the sediments (both plant and animal)
- Infer air composition
- Detect evidence of volcanic activity
- Reconstruct vegetation and its changes
- Estimate precipitations
- other

Cores are made and analysed



Cores

Dating



Analysis of cores

Oxygen isotopes to infer temperature of the water

In 1947, Harold C. Urey, [Nobel in Physics for the discovery of Heavy water (deuterium)], noticed that using the isotopes of oxygen it was possible to calculate the temperature of water in past ages.

Marine water contains two isotopes of oxygen different for their number of neutrons **^{16}O and ^{18}O**

Temperature influences the isotopic ratio between water (H2O) and calcium carbonate (CaCO3)

Urey became convinced that by measuring the isotope ratios in the CaCO3 of the fossils it was possible to reconstruct the temperatures of the water in which these organisms lived.

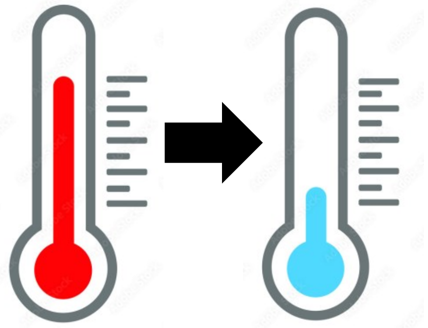
EPSTEIN ET AL. (1951)

Formulated the first paleotemperature equation:

$$T°C = 16.9 - 4.38\,(\delta c - \delta w) + 0.1\,(\delta c - \delta w)^2$$

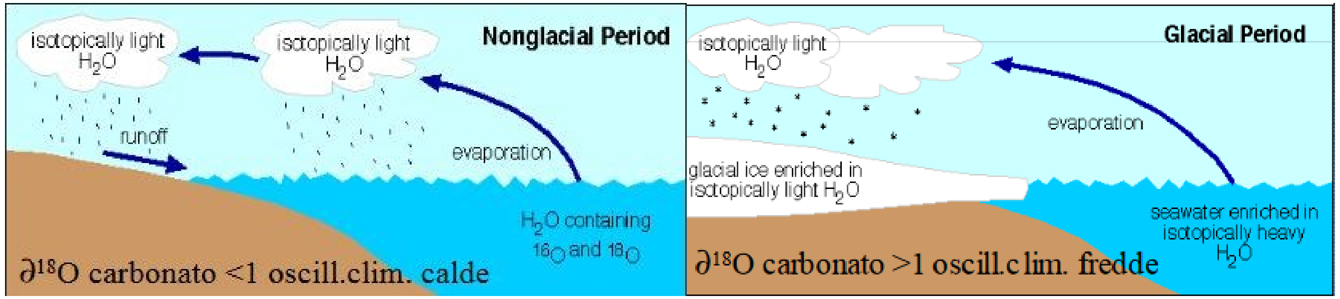
T°C = temperature in °C
δc = isotopic composition of oxygen in $CaCO_3$
δw = isotopic composition of H_2O in which $CaCO_3$ settled

By measuring the isotopic composition of the carbonate, it is possible to determine the temperature at which the carbonate is precipitated.



As the cold increases, the share of heavy isotopes (^{18}O) of oxygen increases compared to normal values (^{16}O)

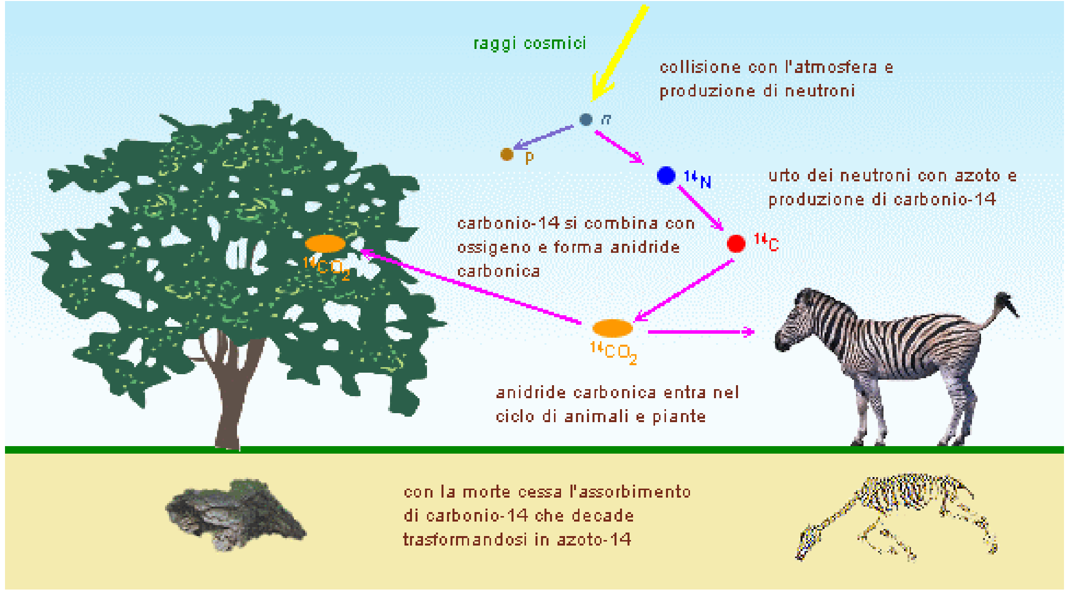
This ratio could also be used as a proxy of glacial and interglacial periods



Analysis of radiocarbon (^{14}C) – Willard Frank Libby (1908 – 1980)

It is used to determine the age of organic rests in sediments.

Due to its long half-life compared to the lifespan of living organisms, ^{14}C remains integrated into every living organic system. After death, the organism stops taking in ^{14}C. The quantity of the isotope present in the organism at the moment of its death will gradually weaken over the years due to radioactive decay.

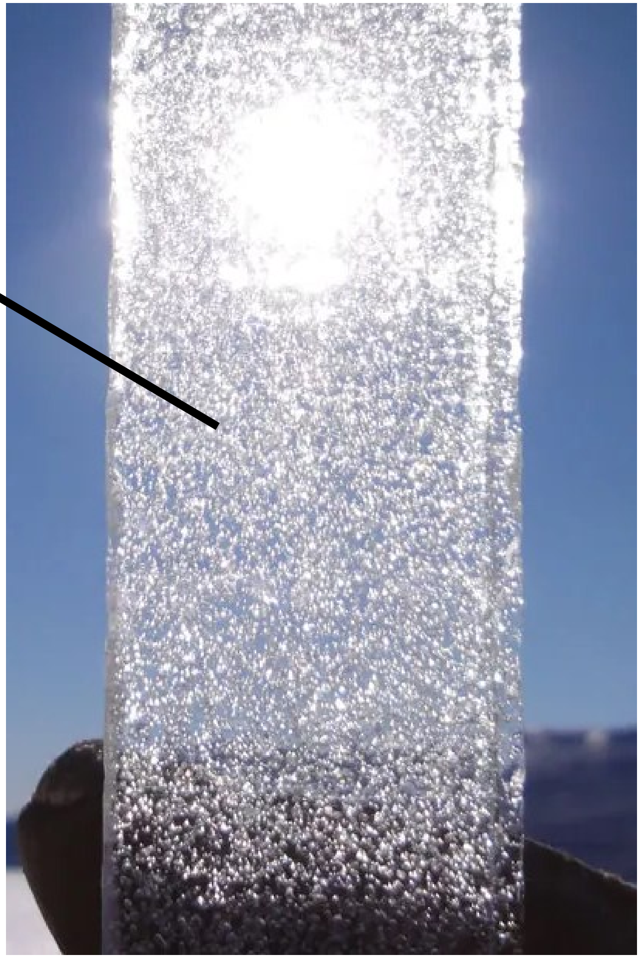


the residual quantity of ^{14}C present in an organic archaeological fossil or wooden structure is measured: knowing the decay curve and the initial quantity of ^{14}C present in the finding when its organic structure was still viable (i.e. an instant before dying), one can easily establish how many years have passed since the death of the organism. In general, it is possible to radio-date only finds dating back up to 40,000-60,000 years ago.

Analysis of Icecores

Other than the analisis of $^{16}O/^{18}O$ **ice cores** allow the analysis of :

- Gas bubbles entrapped in the ice -> **Chemical analysis** of the air allows to infer the composition of air at a determined age (especially SO_2);
- Powders entrapped in ice -> they can be characterized by the **thermoluminescence*** method and allow to identify evidences of volcanic activities in the core. -> knowing the events, they can be used for a more accurate dating.



*method usually adopted by archaelogists to date old ceramics

Data concerning cultivations are particularly rich in information. Changes in the limits of specific plant cultivations describe quite well the fluctuations of thermal isoiets in different periods.

For instance, during the «mild» first two centuries of the Roman Empire (c. 80-200 a.C.) vine was produced in England, to disappear in the following 1,000 years.
Montane villages on the Alps moved at higher altitudes diring the «warm» late Medieval Age, to be abandoned quite soon, c. 2 centuries after, during the small glacial era of the XVI-XVII century.

Italy holds the earliest systematically measured daily series of temperature and precipitation
dating back to 1654 and 1713, respectively.

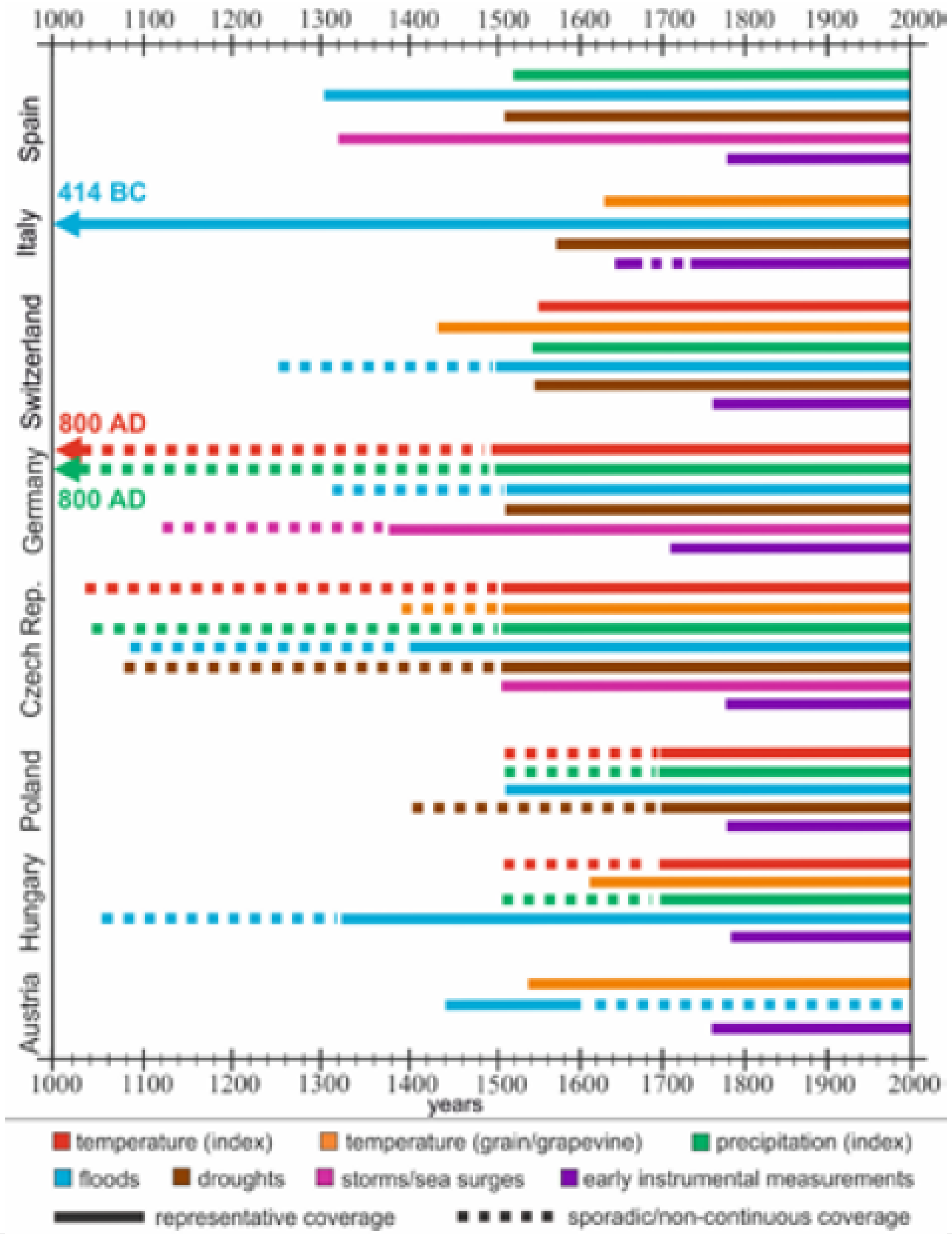


Figure 2: Long-term documentary-based flood, drought, storm, and monthly or seasonal temperature and precipitation reconstructions and grain- or grapevine-based temperature reconstruction series in Central, Southern, and Eastern Europe by country.

Among paleoclimate proxies, the transformation of descriptive qualitative information and documentary evidence to quantitative data has provided the highest resolution information for the reconstruction of temperature, precipitation, and other weather-related extremes over the last 500 years.

Central and Southern Europe hold the largest documentary-based flood and drought collections as well as the most comprehensive and longest (index-based) local-regional temperature and precipitation reconstructions, and have played a key role in investigations.

As for timescale, the temporally densest (often daily) documentation is available from Central and Southern Europe for the last 200–300 years; monthly seasonal data can be gathered for the last 400–500 years. Occasionally, representative data may cover ca. 700–800 years; however, regarding weather-related extreme events, documentary evidence in certain areas of Southern Europe may cover a period over the last two millennia or more (Camuffo and Enzi 1996).

In Southern Europe, the reconstruction of hydroclimatic extremes, i.e. droughts and floods, on a multi-centennial scale is currently a large focus within flood and drought databases, sometimes reaching back two millennia. Major source types applied are narratives (esp. chronicles), church and municipal legal and economic administrative documentation, and, to a lesser extent, private and official correspondence and newspapers. Most research is concentrated on the Iberian Peninsula and Italy.

While in previous decades, long-term temperature and precipitation reconstructions and early instrumental measurements were the main priority, in recent years, individual extremes and the long-term reconstruction of hydroclimatic extremes have received greater attention.

Aside from individual flood and drought reconstruction papers, European and global-scale special issues on historical floods ("Floods and their changes in historical times" in Hydrology and Earth System Sciences: 2015-2016) and droughts ("Droughts over centuries" in Climate of the Past: 2019-2020, "Societal impacts of historical droughts" in Regional Environmental Change: 2019-2020) contain dozens of studies with new, multi-centennial reconstructions, particularly from Central and Southern Europe.

Furthermore, with particular attention paid to Central and Southern Europe, regional and continental-scale online databases have been developed in the last decade(s) and opened for public use in recent years (e.g. **Euro-Climhist, Tambora**).

A research direction that is rapidly growing in importance is climate history that deals with the impacts of weather and weather-related extremes on the human environment, human responses on these impacts and consequent socio-economic processes.

There is currently a strong emphasis on the impacts of weather in anomalous periods of the (late) Middle Ages, the Late Medievalearly modern Period, and the transition from the Medieval Warm Period to the Little Ice Age, with special emphasis on Southern and Central Europe.

Documentary evidence is unevenly distributed in space.

While many series are available for Europe (43%) and Asia (31%), much less evidence stems from other continents: 10% from Africa, 8% from North America, 6% from South America, and only 2% from Australia (Fig. 1).

For Europe and Asia, especially China, documentary series exist for both temperature and precipitation.

For Africa and South America, on the other hand, all the available data provide information on precipitation but not temperature.

All in all, the majority of data series in the inventory are proxies for precipitation (50%) and temperature (36%); very few data are available for other proxies such as wind and cryosphere parameters (e.g. data on glacier movements) (14%).

Case-study: Temperature anomalies after volcanic eruptions

To point out the value of documentary evidence for climate reconstructions, temperature anomalies after the strong volcanic eruption of Mount Serua (Indonesia) in 1693 (Arfeuille et al. 2014) and a further unknown eruption in 1695 (Sigl et al. 2015) are analyzed.

These two eruptions resulted in a noteworthy cooling over the Northern Hemisphere (NH), especially in the summer months of the following years (Sigl et al. 2015).

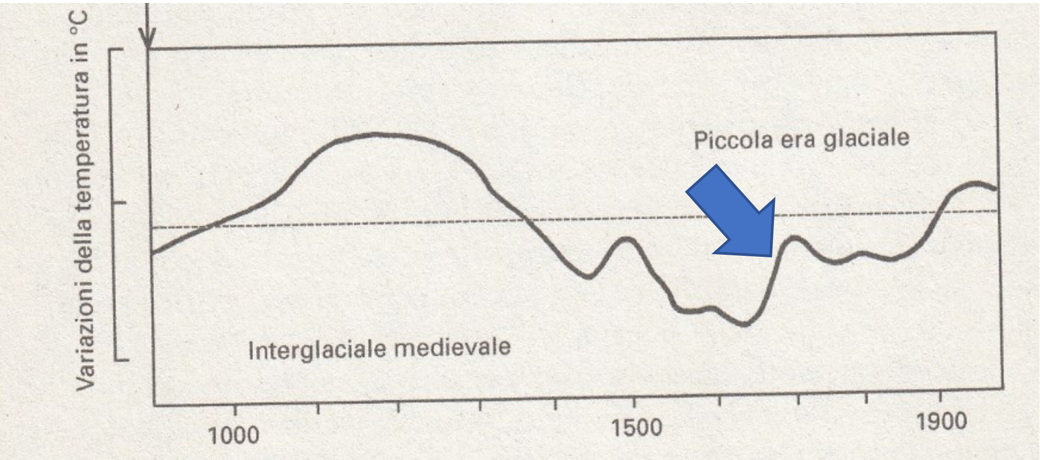


Figura 1
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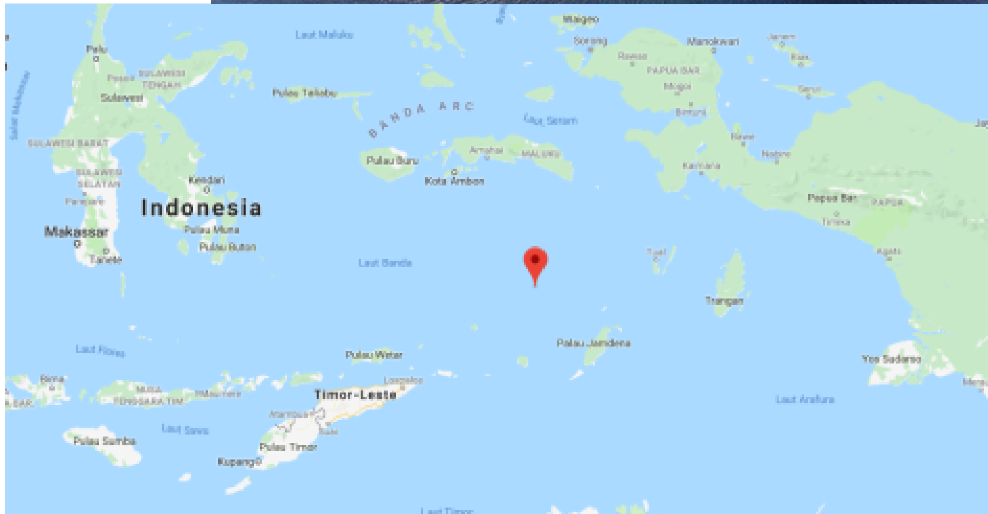


If this cooling is captured by natural proxies such as ice cores, one can assume that it must also have been documented in archives of society.
Especially relevant in this context are records related to harvest, which would have been impacted by cooling during the growing season.

To investigate a potential cooling signal in the NH following the 1693 and 1695 volcanic eruptions, temperature signals from **22 available documentary series** covering this timespan are analyzed. The temperature during the anomalous period 1693–1697 (five years) was expressed relative to the combined average of the 10 years prior (1683–1692) and 10 years after (1698–1707). Each documentary series represents a temperature signal for a particular season or month. To compare these temperature composites, they are grouped into signals for **spring** (March–April), **growing season** (April–August), **fall** (October), **winter** (December–March), as well as an **annual signal**.

They consist of temperature proxies based on various phenological parameters, such as grape and grain harvest dates, freezing of water bodies, duration of snow cover, as well as direct observations of the weather such as reports on temperature-related features such as extreme frost periods.

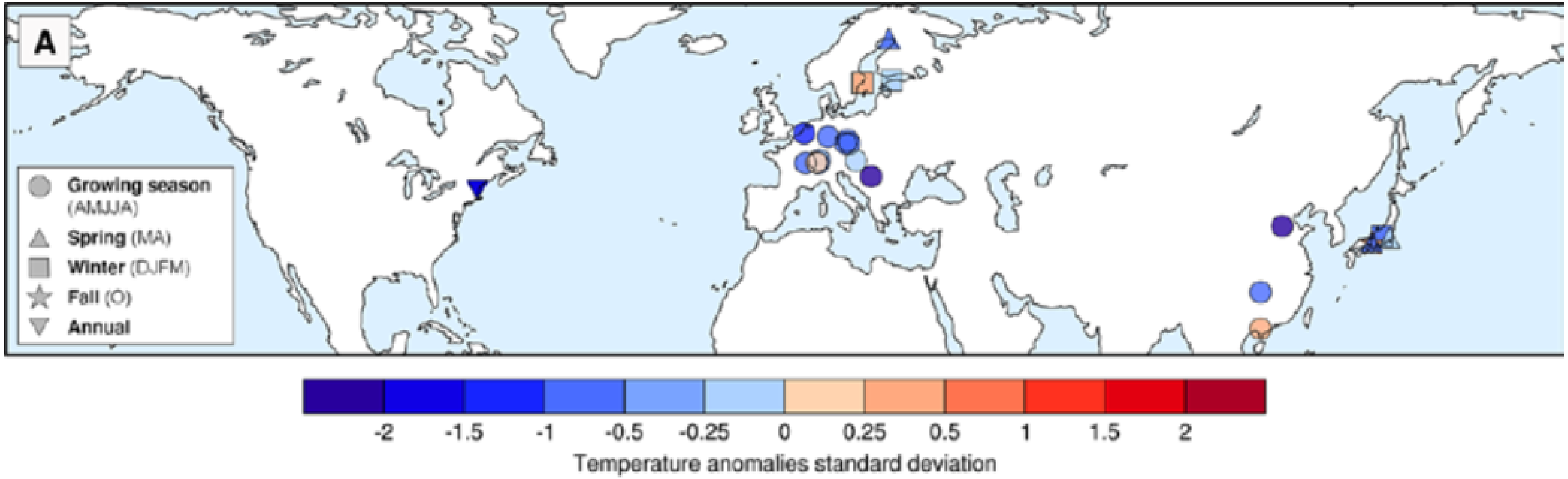


Figure A: Temperature composites from documentary series for the 1693 and 1695 volcanic eruptions. Proxy series are categorized into seasonal groups.

As shown in the above figure A, 16 of the 22 documentary series show negative temperature anomalies for the years after the volcanic eruptions in 1693 and 1695. The signal is especially homogenous over Europe where the growing season during 1693–1697 was notably cooler than during the reference period. All but one of the European growing season proxies exhibit negative anomalies.

These findings based on documentary evidence correspond with the temperature composite from the EKF400v2.0 reconstruction (Franke et al. 2017) for the growing season (April–August; Fig. 2b). The global reconstruction shows very strong negative anomalies over Europe and indicates that the post-volcanic cooling after the 1693 and 1695 eruptions was especially strong over Europe.

The temperature signal over Asia and North America is more ambiguous. This is in good agreement with the signal shown in the documentary evidence

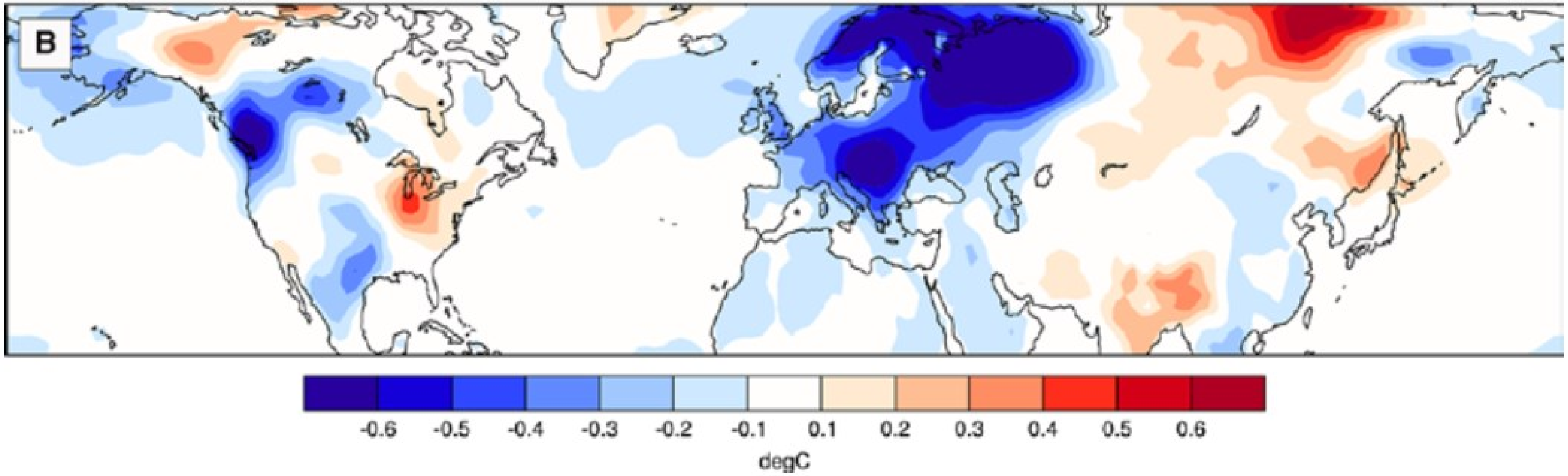


Figure B: Composites of surface air temperature during the growing season (Aopril-August) from the EKF400v2.0 reconstruction.

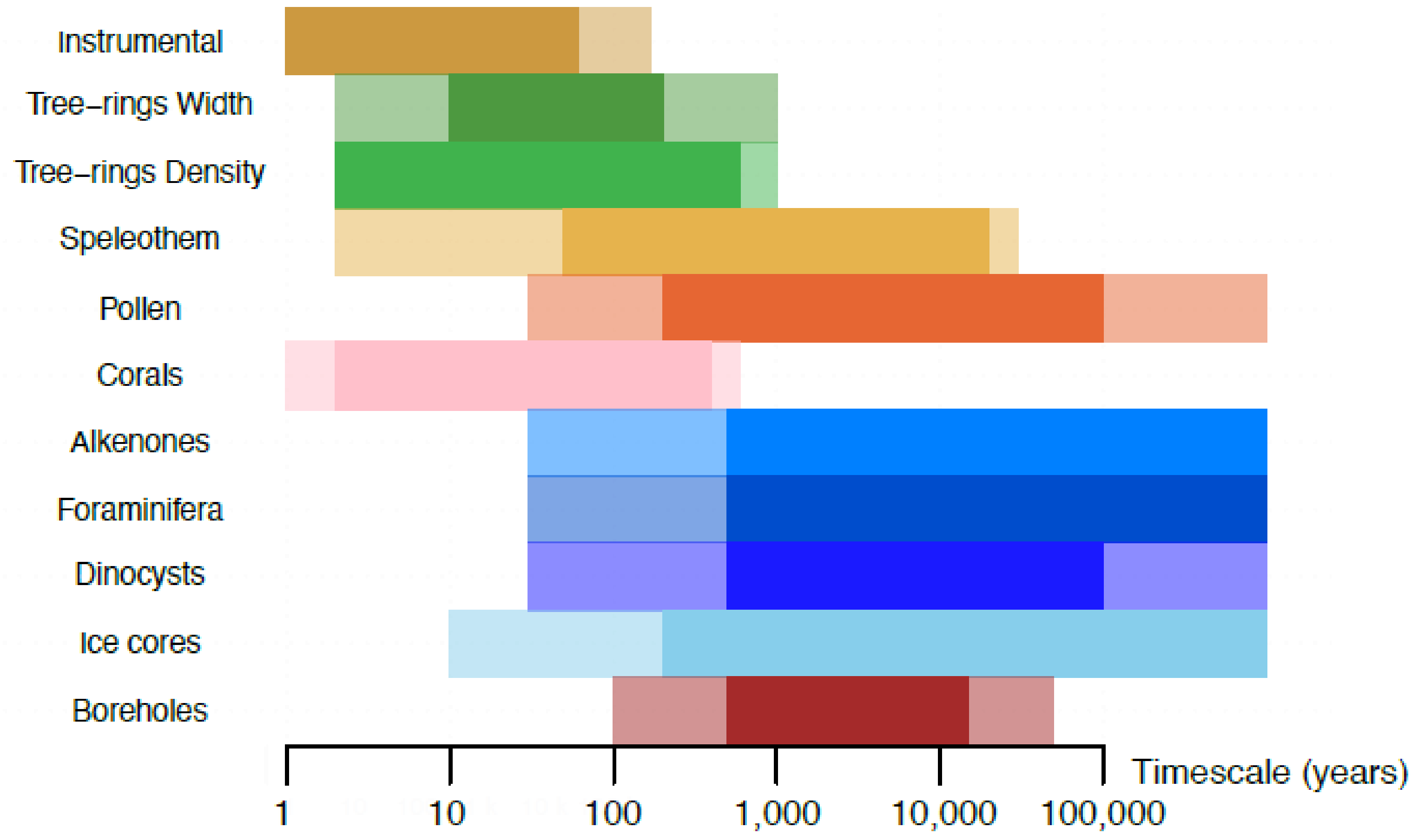
From the analysis of so many data concerning the deep influence of climatic changes on human economy, it became evident that many historical events have been strictly related, if not the direct consequences, of climatic crisis.

Periods of exceptional drought, often associated to deep cold, are now considered at the basis of the Bronze Age crisis (c. 1200 B.C.), the fall of the Western Roman Empire (476 A.C.), the fall of the Yuan dinasty in China (1368). Many factors were obviuously involved, but drastic climatic crises implied riots, violent protests against governments unable to provide foods, movements of peoples from one region towards other territories etc.

Climatic crisis represented also the premises for some pandemic disruptions, as the plague of Emperor Giustiniane or the famous «Black Plague» (the most catastrophic one at world level) of 1346-52 and following years.

These events are so important for the reconstruction of human civilization, that many attemps have been made to give solid explanations of the events underlying them.

By crossing data derived by a variety of sources (physicochemical, biological, cultural ones), it became evident that often some crisis trends were dramatically enhanced by stochastic events such as a big volcanic explosions.



: Shown are the timescales approximately spanned by different climate sensitive proxies. The solid part indicates the most reliable range, whereas the shaded part generally requires proxy system modeling to be interpreted due to effects such as diffusion, bioturbation, biological smoothing, detrending, limited length and availability, lack of modern analogs, changing climatic interpretation, and others.