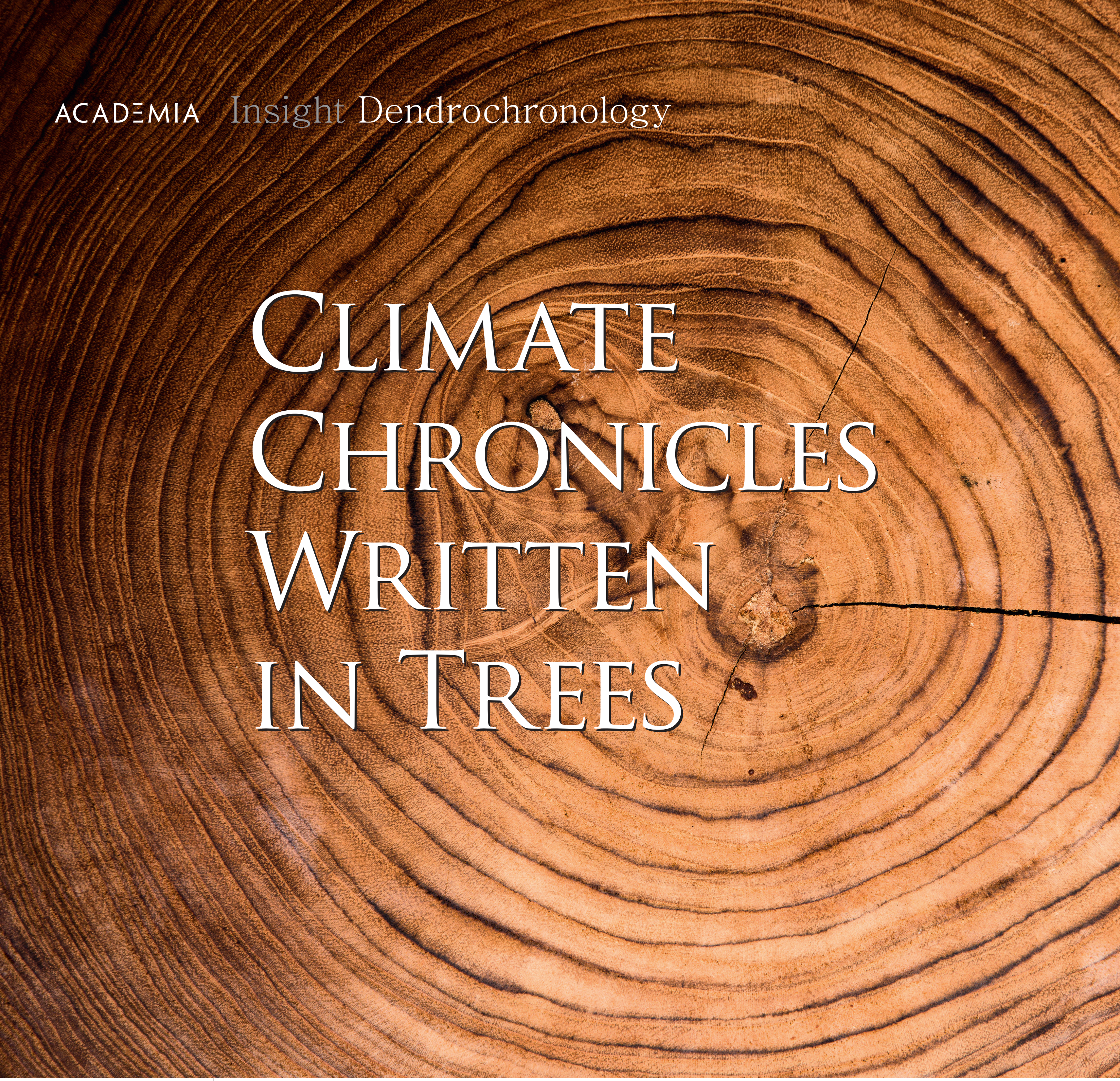

Climate Chronicles Written in Trees

Scholars have been studying tree rings since the eighteenth century. Today, growth-ring patterns provide us with information on climate changes over the last millennium, particularly on variation in temperature and humidity.

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High-resolution satellite images, measurements of carbon dioxide levels and computer modelling all help us understand how climate has been changing over time and the carbon cycle proceeds in forests all over the globe. However, these technologies only allow us to monitor changes dat-

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ing back just three decades or so, which puts a limit on our understanding of long-term change. The earliest traditional meteorological measurements were regularly conducted as early as the mid-seventeenth century at a few individual observation stations in Europe; however, on other continents meteorological observations date back no further than 150 years. The densest global network of automated meteorological stations, operating as part of the World Meteorological Organization (WMO), has been collecting data for a few decades. This means that the main barrier in researching how Earth's climate has been changing over long periods is a lack of early instrumental measurements. And since we cannot travel back in time to learn about past climates, paleoclimatologists have to rely on natural sources of information such as tree rings, ice cores and sediments of lakes and oceans. Such proxy sources help us improve our understanding on weather and climate dating back as far as millions of years ago. Since trees produce new rings every year, dendrochronology dating stands out from other methods in that it is highly accurate.

Dendrochronology

Dendrochronology involves recognizing the particular calendar year that corresponds to each tree-ring on a wood sample. This is done by identifying corresponding annual growth patterns. Cross-dating is used to further extend the chronology, linking up growth sequences corresponding to known time periods. Such chronologies are built up on the basis of long-lived species and, in Europe in particular, by using historic wood samples originating from ancient buildings and archaeological finds of known ages, and also from subfossil tree trunks. Dendroclimatology assumes that alongside location and geomorphological factors, annual growth also records climate signals. Based on the relationship between the thickness of each ring (cambium activity for the given species) and contemporary meteorological data and assuming the principle of geological actualism, we can reconstruct past climate on the basis of the chronology of annual tree growth over the centuries. As well as the most commonly used indicator, which is the width of annual growth, researchers are increasingly applying state-of-the-art analytical methods to determine additional parameters such as wood density, the presence of trace elements, relationships between stable isotopes, and anatomical features of the wood indicating unusual climate conditions at the time.

The recognition that trees produce new rings every year, forming the foundation of modern dendrochronology, was first mentioned by the Greek botanist Theophrastus around 322 BC. The first note observing that their thickness is determined by the conditions under which they grew can be found in Leonardo da Vinci's "Treatise on Painting," written between 1482 and 1498. In the eighteenth century, Carl Linnaeus and other European scholars wrote about using tree rings to determine the age of the tree. Contemporary dendrochronology is based on the methodology developed by the American astronomer A.E. Douglass, who founded the Laboratory of Tree-Ring Research at the University of Arizona in Tucson in 1937. In the laboratory, tree-ring chronologies over eight thousand years long were developed for bristlecone pines from the White Mountains in California. In the Southern Hemisphere, the longest tree-ring record has been created for the kauri in New Zealand (4500 years) and the Patagonian cypress from Chile and Argen-

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tina (3600 years). During research conducted at the turn of the 21st century, data originating from analysis of tree rings gained particular significance in the reconstruction of climate conditions in the temperate zone. In Europe, the longest reconstructions of climate conditions have been developed for the Alpine region (A.D. 755–2004) and around the Torneträsk Lake in northern Sweden (A.D. 500–2004).

Climate

Although the method has been successfully used for many years in studies of past environmental changes, it continues to reveal new research fields and topics. Today, the regions seen as key in dendroclimatology studies are the Asian high mountain region "Hindu Kush – Karakoram – Himalayan," known as the Third Pole, and the Arctic. These regions are particularly affected by contemporary climate change and they experience warming occurring at the highest rate; in recent decades it was double the rate of the global mean.

The results of dendroclimatological research conducted in Central Asia provide a context for the changes and variability of climate conditions over the past several centuries, mainly thanks to ancient trees growing in the region – spruces and junipers – some of which date back 1500 years. Reconstructions of changes in thermal conditions occurring over the centuries reveal that the current warming in this part of the world has exceeded natural temperature variation over the last several thousand years. However, long-term trends of precipitation are far more difficult to assess, since they are highly heterogeneous. In recent years, a team from the University of Silesia has been conducting unique dendroclimatological research in the Pamir-Alay region in Tajikistan (as part of a project of the National Science Centre), which had previously remained a "blank spot" on the map of high-resolution reconstructions of climate change. The region is a crucial link in the attempts to reconstruct climate variability in Asia by connecting Tibet with the vast deserts of Central Asia. Previous reconstructions of Central Asian climate change over the centuries based on dendrochronology mainly focused on the Tibetan Plateau and the Karakorum and Tian Shan mountain ranges. The research conducted by the Polish team was unique since it provided new information on the characteristics of climate change over the last millennium, during the Medieval Warm Period, the Little Ice Age and the MWP/LIA transition. Both periods are relatively well studied in Europe and North America. Based on correlations of juniper tree-ring widths with precipitation, researchers were able to reconstruct series of precipitations from 650 AD in the Pamir region. This allowed them to determine the duration of individual dry and wet periods, which had not been described in this part

A 1200-year-old juniper from the western part of the Pamir-Alay mountain range in Tajikistan. Samples from these trees, collected at elevations of between 2800 and 3200 meters above sea level, were used to reconstruct precipitation conditions over the past millennium

Moss tundra near the Polish Polar Station in Hornsund in Spitsbergen. Individual polar willows, used in dendrochronological research, grown in terrain dominated by mosses

of Asia until then. The results confirmed the influence of wetter and drier climatic conditions on the rise and fall of civilizations (cities) in Central Asia, such as Sogdia, which existed along the Silk Road. By reconstructing past climate dynamics, we are able to interpret social and environmental changes which took place in high mountain regions in Central Asia, which have been poorly understood thus far. The influence of climate change on socio-political changes in the region has been studied by an international team using dendrochronological methods; they recently published their results in an extensive monograph titled "Socio-Environmental Dynamics Along the Historical Silk Road."

Arctic forests

In recent years, there has been an increasing interest in dendroclimatological research in polar and subpolar regions. While there are no trees in the Arctic, the tundra is overgrown with prostrate dwarf shrubs – small, creeping woody plants such as the polar willow, net-leaved willow and dwarf birch; they all form rings which can be used in dendrochronological studies. This research was initiated in 2007 in southwestern Spitsbergen near the Polish Polar Station in Hornsund by a team of geographers from the University of Wrocław. It is now a model region for Arctic dendroclimatological research, mainly due to the station's infrastructure and availability of detailed instrumental climate data. The timescale may seem shorter than data written in tree rings, since the dwarf shrubs live for up to 120 years, but it should be remembered that stationary measurements gathered in polar regions are irregular and only taken in certain places. Studying annual rings of dwarf shrubs makes it possible to reconstruct selected climate elements reaching beyond available instrumental measurements. This is particularly important given the rapid, dramatic climate change occurring in subpolar regions. Studies conducted by the interdisciplinary team from leading Polish universities reveal that dwarf shrubs are an excellent indicator of contemporary climate change, in particular in the context of tundra ecosystems, which should make it possible to predict trends of such changes in the future. While at the beginning of the 21st century dwarf shrubs clearly responded to rising temperatures by creating wide rings, in recent years we have been observing signs of drought stress, presenting as increasingly narrower rings. This means the positive effects of increasing temperatures have come to an end, and the tundra is shifting from greening to browning processes. Ongoing drought conditions in the Arctic are clearly visible in Siberia and the Canadian Arctic, which are experiencing an increasing incidence of fires.

PHOTOGRAPHY BY **PIOTR OWCZAREK**

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