The PAGES 2k Network:
Understanding the climate of the past 2000 years

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Background

The **past 2000 years** (the "**2k**" interval) provide critical context for the recent **anthropogenic** forcing of the climate and baseline information about **natural** climate variability. This period is also key to evaluate the climate **models** used to make future projections.

In 2008 **PAGES** initiated the **2k Network** to coordinate and integrate regional efforts to assemble **proxy** observations and generate climate **reconstructions**. Nine **regional groups** were established during the course of the initiative, spanning **eight continents** and the **global ocean**.

Phase 1 (2008-2013) focused on generating regional **temperature reconstructions** [Figure 1]. During ***Phase 2*** (2014-2016), a number of **trans-regional groups** emerged from amongst the community, focusing on topical challenges such as **method** development, **data-model** comparison, **database** construction and **large-scale climate** [Figures 2-5].

Toward Phase 3 trans-regional projects

The **PAGES 2k initiative** spawned network-wide **projects during Phases 1** and **2** providing the inspiration for **Phase 3** development.

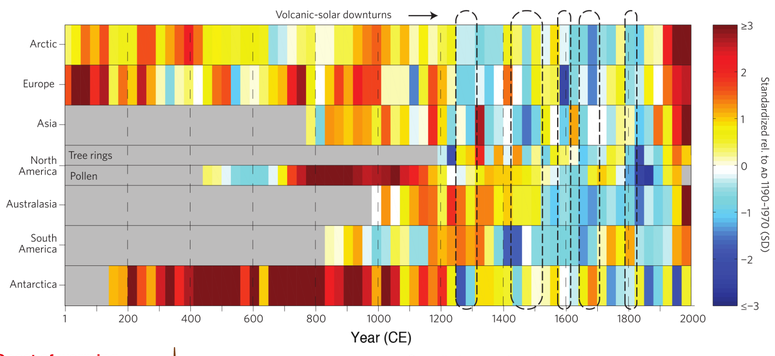
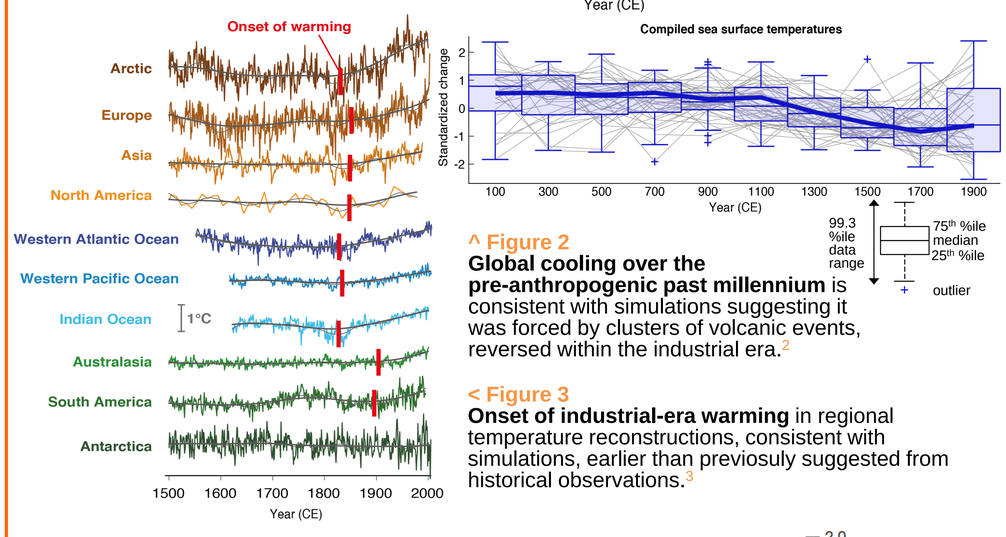
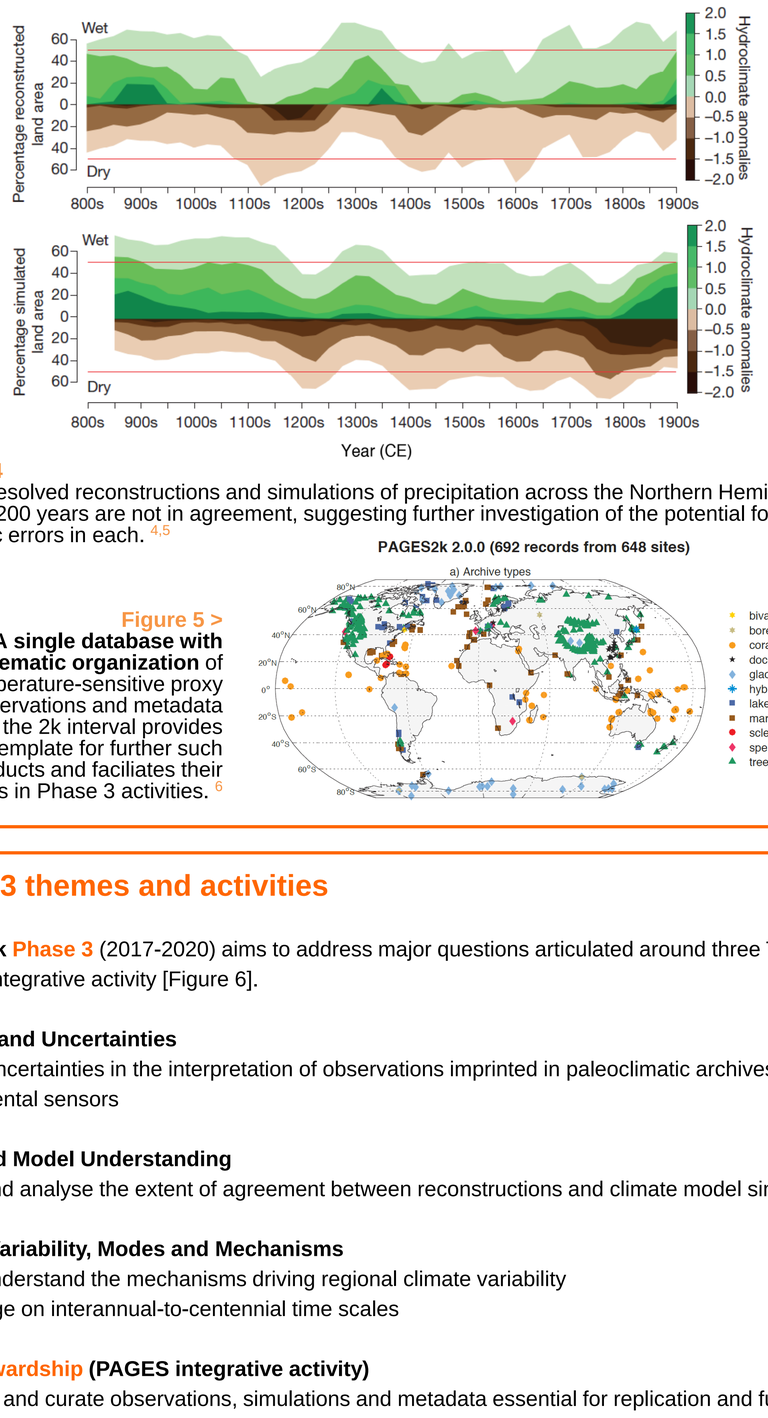


Figure 1 >
The regional nature of the Medieval Warm Period and the Little Ice Age observed in multidecadally averaged standardized temperature anomalies across the seven PAGES 2k Network regions.[1]



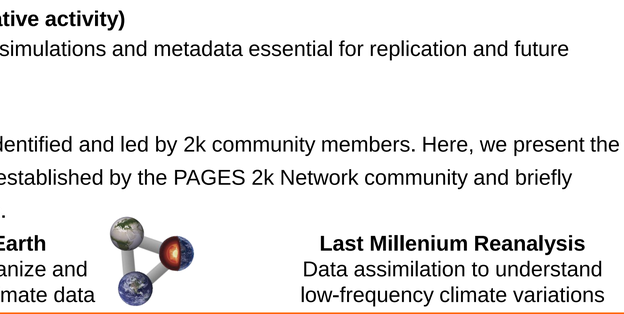
^ Figure 2
Global cooling over the pre-anthropogenic past millennium is consistent with simulations suggesting it was forced by clusters of volcanic events, reversed within the industrial era.[2]

< Figure 3
Onset of industrial-era warming in regional temperature reconstructions, consistent with simulations, earlier than previosuly suggested from historical observations.[3]



^ Figure 4
Spatially resolved reconstructions and simulations of precipitation across the Northern Hemisphere for the past 1200 years are not in agreement, suggesting further investigation of the potential for systematic errors in each. [4,5]

Figure 5 >
A single database with systematic organization of temperature-sensitive proxy observations and metadata covering the 2k interval provides a template for further such products and faciliates their analysis in Phase 3 activities. [6]



Phase 3 themes and activities

PAGES 2k Phase 3 (2017-2020) aims to address major questions articulated around three Themes and one integrative activity [Figure 6].

Methods and Uncertainties
Reduce uncertainties in the interpretation of observations imprinted in paleoclimatic archives by environmental sensors

Proxy and Model Understanding
Identify and analyse the extent of agreement between reconstructions and climate model simulations

Climate Variability, Modes and Mechanisms
Further understand the mechanisms driving regional climate variability and change on interannual-to-centennial time scales

Data Stewardship (PAGES integrative activity)
Assemble and curate observations, simulations and metadata essential for replication and future studies

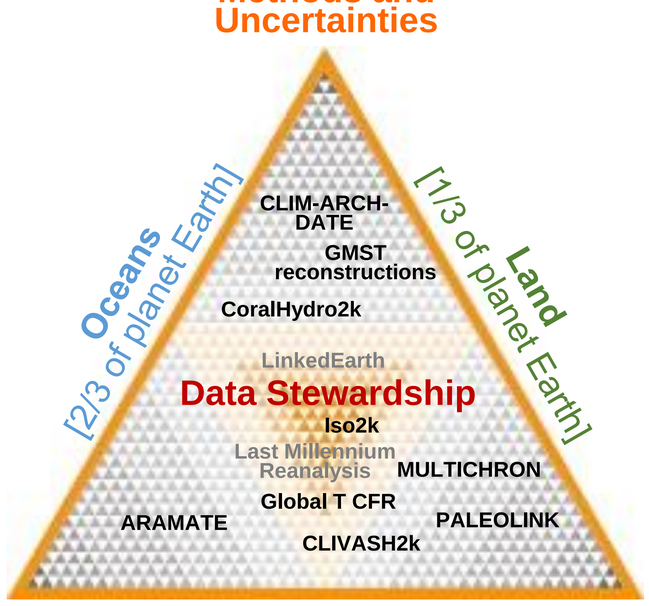
Research is organized in projects, identified and led by 2k community members. Here, we present the ten current projects that have been established by the PAGES 2k Network community and briefly summarize their scientific objectives.

Partner projects

Linked Earth
To better organize and share paleoclimate data

Last Millenium Reanalysis
Data assimilation to understand low-frequency climate variations

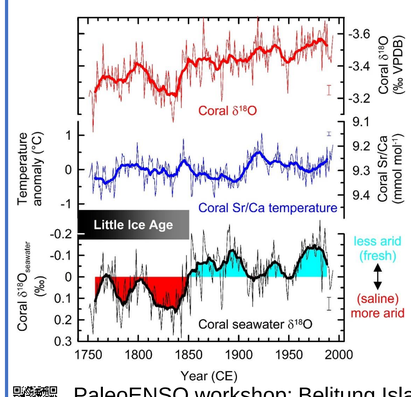
Methods and Uncertainties



Climate Variability, Modes and Mechanisms | **Societies** [Anthopocene] | **Proxy and Model Understanding**

CoralHydro2k

Tropical ocean hydroclimate and temperature from coral archives. Reconstruction of spatiotemporal seawater d18O and temperature changes of the tropical ocean from paired coral **Sr/Ca and d18O** records **back into the Little Ice Age**. Identification of their dynamical drivers on **seasonal, interannual, and decadal to multidecadal** time scales

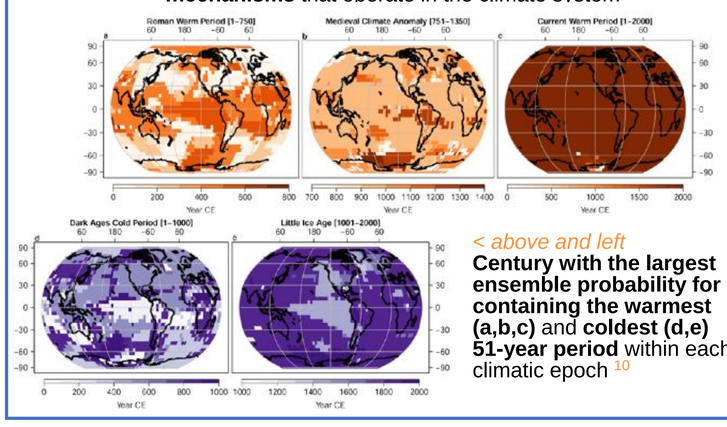


< *left*
Paired coral Sr/Ca and $\delta^{18}O$ record extending back into the Little Ice Age. Current activities include generation and identification of **high-quality paired coral Sr/Ca and $\delta^{18}O$ records**, ranking of records according to specific criteria/tiers (analysed powder, resolution, age model reliability, length, data availability) and **identification of appropriate surface temperature datasets for various coral Sr/Ca calibrations** (seasonal vs. interannual, full vs. detrended, locals vs. regional vs. large-scale). See ref. 7 for details

PaleoENSO workshop: Belitung Island, Indonesia, 26-30 Aug 2019 >
< CoralHydro2k meeting (ICP13): Sydney, Australia, 1 Sep 2019

Global T CFR

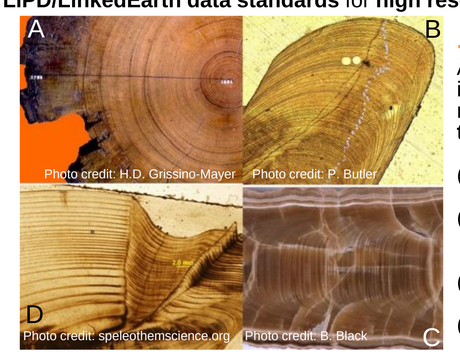
Global gridded temperature reconstruction and method comparisons: dataset of **spatially explicit (5°x5° spatial resolution) temperatures covering the Common Era** to be used for multiple purposes, such as **data-model comparison, detection and attribution, and the analysis of modes and mechanisms** that operate in the climate system



< *above and left*
Century with the largest ensemble probability for containing the warmest (a,b,c) and coldest (d,e) 51-year period within each climatic epoch [10]

ARAMATE

Mechanisms of ecosystem variability in the North Atlantic region using **annually resolved marine and terrestrial climate archives**.
Recently submitted a **Horizon 2020 proposal** based on the relationship between **climate and marine ecosystems**. Also (with **MULTICHRON**) developing **LiPD/LinkedEarth data standards** for **high resolution marine proxies**



< Annually resolved increments in **marine and terrestrial proxies**

(A) Tree rings

(B) Hinge part of a bivalve shell

(C) Speleothem

(D) Fish otolith

Figure 6
The **2k Network** universe **Phase 3**. Key aspects of all **PAGES 2k** projects are **end-to-end workflow transparency**, **open data**, and **knowledge access**.

References

1 **PAGES 2k Consortium**, 2013: Continental-scale temperature variability during the past two millennia. *Nat. Geosci.*, 6, 339-346.
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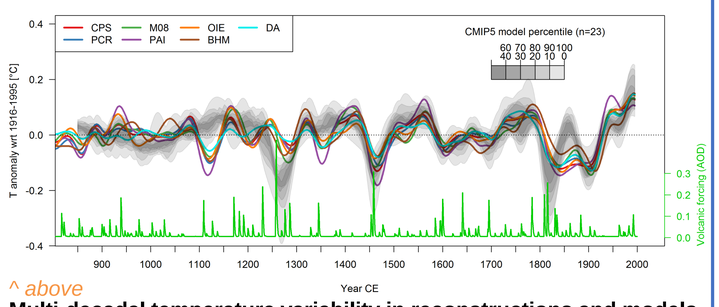
3 **Abram NJ** et al., 2016: Early Onset of Industrial-Era Warming across the Oceans and Continents. *Nature*, 536, 411-18.
4 **PAGES2k-PMIP3 group**, 2015: Continental-Scale Temperature Variability in PMIP3 Simulations and PAGES 2k Regional Temperature Reconstructions over the Past Millennium. *Clim. Past*, 11, 1673-99.
5 **Ljungqvist FC** et al., 2016: Northern Hemisphere Hydroclimate Variability over the Past Twelve Centuries. *Nature*, 532, 94-98.
6 **PAGES 2k Consortium**, 2017: A global multiproxy database for temperature reconstructions of the Common Era. *Scientific Data*, 4, 170088.
7 **Felis T** et al., 2018: Mild and Arid Climate in the Eastern Sahara-Arabian Desert During the Late Little Ice Age. *Geophys. Res. Lett.*, 45, 7112-7119.
8 **Ludwig P** et al., 2018: Perspectives of regional paleoclimate modeling. *Annals of the New York Academy of Sciences*, 1436, 54-69.
9 **PAGES 2k Consortium**, 2019: Consistent multidecadal variability in global temperature reconstructions and simulations over the Common Era. *Nat. Geosci.*, doi:10.1038/s41561-019-0400-0.
10 **Neukom R** et al., 2019: No evidence for globally coherent warm and cold periods over the pre-industrial Common Era. *Nature*, doi:10.1038/s41586-019-1401-2.

GMST reconstructions

Reconstructions of global mean surface temperature (GMST) over the past 2000 years, to compare with **model data** and to identify driving forces



^ above
Multi-decadal temperature variability in reconstructions and models and volcanic forcing over the past millennium.
Colored lines: **Ensemble median reconstruction from seven different reconstruction methods, 30- to 200-year bandpass filtered**.
Gray shading: **model simulation percentiles**.
Green: **volcanic forcing**.[9]

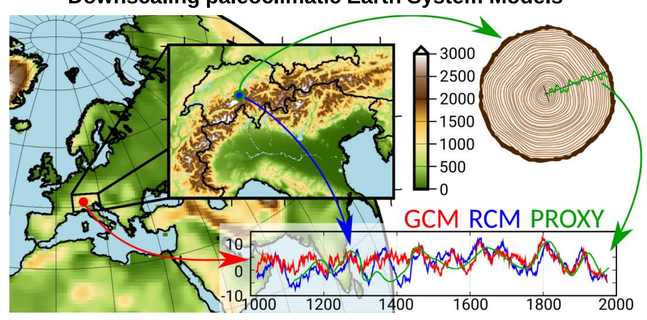
MULTICHRON

Constraining **modelled decadal and multidecadal climate variability in the North Atlantic region** using proxies derived from **marine bivalve shells and coralline algae**

right >
Live- and dead-collected **shells of the long-lived bivalve *Arctica islandica*** collected on the shelf of the Faroe Island. Current activities comprise **improving and extending several bivalve chronologies,** developing **new data based on coralline algae** as well as looking into the sharing of data within LinkedEarth and Linked Paleo Data (LIPD) framework.

PALEOLINK

The missing link in the Past:
Downscaling paleoclimatic Earth System Models



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Typical scale gap between a coarse **Global Earth System Model (GCM)** and the actual topography that induces regional climates leaving a footprint in the **proxy record**. A **Regional Climate Model (RCM)** is able to explicitly resolve such processes, therefore bridging the scale gap. See ref. 8 for details

CLIM-ARCH-DATE

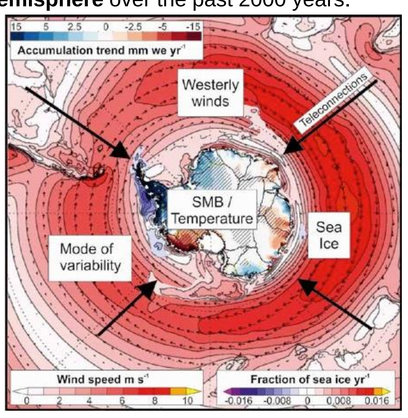
Integrated and precise dating of high resolution marine and terrestrial proxy archives with archaeological and documentary evidence: exploring links between **cultural change** and **environmental change**

< *left*
Remains of the Norse church at Hvalsey, in the Viking Eastern settlement on Greenland. The last written record of this settlement was a wedding recorded in 1408 CE (Photo from Wikipedia under a Creative Commons license)

CLIVASH2k

Understanding the drivers of climate variability in **Antarctica and the Southern Hemisphere** over the past 2000 years.

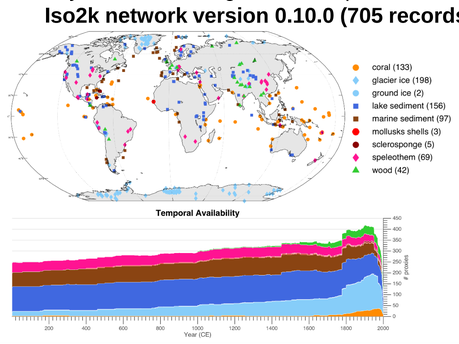
right >
Antarctica and the Southern Hemisphere. **Researchers** working on a range of different paleoclimate archives (**ice cores, marine sediments, lake sediments and peat records**), climate modelers and climatologists are investigating the role of **westerly winds** and **sea ice** in driving **surface temperatures and surface mass balance** over **decadal to centennial timescales**



Iso2k

A global synthesis of Common Era hydroclimate using water isotopes

Iso2k network version 0.10.0 (705 records from 471 sites)



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The **Iso2k database**, a global compilation of $\delta^{18}O$ and δD records, **to investigate spatiotemporal variability and secular trends in global hydroclimate** during the past 2000 years

If you would like to participate in **Phase 3** of the **PAGES 2k Network** or receive updates, please join our mailing list

www.pastglobalchanges.org/2k-network

leave your name and email address on our sign-up list, or speak to a **Coordinating Committee member**

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