

## 2. Project description (<40'000 characters, incl spaces)

### 2.1 Executive summary (<2'000 characters incl spaces)

Past Global Changes (PAGES) facilitates and inspires community-designed activities and global scientific actions beyond the expertise or capacity of individual research groups or disciplines. PAGES' purpose is to document and understand Earth's past global changes with the aim to better understand the long-term dynamics and interdependences between climate, ecosystems, biodiversity and human societies, thereby helping to improve projections of future conditions, as well as informing strategies for sustainability. In the next project phase, PAGES will use proxy-data and modeling approaches to gain new scientific insights into global change processes, risk assessments, and identification of nonlinear or threshold effects in climate, ecosystems, biodiversity and land use, with continued special attention given to the progress of early-career researchers and researchers from low- and middle-income countries (LIMICS). Special efforts will be devoted to the global south, where substantial data and knowledge gaps exist that affect our capacity to address environmental and societal challenges such as climate, land use and biodiversity threats. PAGES will continue to support and coordinate research worldwide, and exchange between local-to-regional-scale reconstruction networks to synthesize global data products, both for the science and stakeholder communities. New findings will contribute to international climate and biodiversity assessments, to the activities of Future Earth and the World Climate Research Program (WCRP), as well as to informing climate scientists. PAGES research will also be distributed to the general public through scientific publications, PAGES magazines, and contributions to other media. Lastly, PAGES will increase its efforts to develop a broader international financial basis for its global activities to complement the SCNAT and the CAS support for the project phase 2023-2027, and beyond.

### 2.2 Keywords

Time, Past and Future, Earth System, Biosphere, Society, Observations, Reconstructions, Simulations, Paleoscience, History, Natural Archives, Societal Archives, Modelling, Dynamics, Responses, Processes, Sensitivities, Resilience, Risks, Adaptations, Mitigations, Global Change, Climate, Climate Change, Environment, Biodiversity, Sustainability, UN SDG, Open Science, Synthesis, Future Earth, Workshops, Community-driven, Bottom-up, Communication, Stakeholders, Management, Planning

### 2.3 Objective(s) of the project

PAGES is a science-driven, international project coordinating paleoscience research. The objectives are addressed by international working groups (WGs) which are genuinely interdisciplinary and transdisciplinary. Topics of particular importance, breadth, or urgency, are further investigated in integrative activities that draw on the expertise of many of the WGs. PAGES objectives typically deliver products and outputs such as observation syntheses, reconstructions, and modeling output of climate, ecosystem, environmental and societal dynamics; the latter is also vital to a better assessment of future conditions. The PAGES strategy enables the creation of new synergies by overcoming boundaries that have historically existed

between different disciplines and resource levels in different regions of the globe. PAGES plays a distinctive role in coordinating, promoting and contributing to paleoscience. The temporal focus is unique and allows PAGES scientists to address long-term mechanisms and assess the risk from processes that have occurred only sporadically, or not at all, within the short instrumental records.

PAGES' objectives for the period of performance are:

1. to foster **international collaborations** and investigations among proxy-data and modeling research groups all over the world, in order to build a more global and inclusive paleoscience community;
2. to improve the understanding of **Earth system variability** and identify **grand challenges**, specifically geo- and biosphere responses, sensitivity and feedbacks, societal resilience and sustainability, with a focus on tipping points and 'early warning signals' under global change conditions;
3. to promote **capacity building** of LIMICS scientists, and early-career scientists across the world;
4. to make paleoscience contributions to global change solutions more **visible** in the broader scientific community;
5. to develop synthesis products which are easily findable, accessible, interoperable, reusable (**FAIR**) and properly curated;
6. to strengthen strategies and **partnerships** to make global and regional paleoclimatic, paleoenvironmental and paleosocietal information **accessible to the public** and decision-makers. This is achieved with educational products, publications, and contributing to our parent organization (Future Earth) through expertise from the working groups and integrative activities.

## 2.4 Project outline

PAGES research focuses on the past, and its relevance for today and the future. The newly developed science structure addresses changes in key components of the Earth system on various timescales: in particular, phenomena and processes that link the atmosphere, hydrosphere (including the oceans), cryosphere, biosphere and anthroposphere (Figure 1). Many of these domains have already experienced extensive change, and hence the paleorecord is crucial to understanding the mechanisms and processes governing Earth system variability.

The long-term evolution of the composition and conditions of the **atmosphere** are an important indicator of climate variability. The reconstruction of these dynamics through time is key to understanding the forcing and response of the Earth system. **Ocean** circulation co-determines the composition of marine and terrestrial ecosystems, and regulates the climate. Marine sediments are an important archive of information about past ocean, climate and environmental states. On **land**, wetlands also act as significant archives of past environmental and ecological variability. The accumulation and destruction of terrestrial and marine **ice** are part of important feedback climate system processes on a large spectrum of timescales. Continental ice records regional and global climate conditions and preserves records of aerosol and greenhouse gas radiative forcing.

The **biosphere** provides the most essential, basic building blocks of societies, including

provisioning and ecosystem services that vary significantly over time, reaching equilibrium or disequilibrium stages with environmental conditions. Finally, **human activities** both build upon, and modify, essential aspects of the atmosphere, ocean, land surface, cryosphere and biosphere. Some of these aspects show legacy effects that can span from centuries to millennia and, thus, can only be fully understood by considering the past. The holistic study of past changes provides a baseline and probability of extreme events that may lead to unexpected societal risks under global change conditions.



**Figure 1:** Overview of PAGES activities and topics of interest (see text).

The ultimate goal of the PAGES research project is to convey global paleoscience evidence to the public, e.g. via scientific publications, the Intergovernmental Panel on Climate Change ([IPCC](#)) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services ([IPBES](#)) reports, to provide the much-needed temporal perspective. PAGES develops and implements focused paleoscience research that is relevant to our parent and partner programs, Future Earth and the World Research Climate Programme (WCRP), in order to explore future pathways that avoid dangerous climate change, in particular to identify risks from low-probability, high-impact events. The PAGES themes also contribute to the United Nations Sustainable Development Goals (UN SDG).

The importance of openly available, quality-controlled data for assuring the integrity and advancement of science (making data [FAIR](#)) underlies the data policies of scientific journals and research funders. PAGES is committed to making data publicly accessible, and will develop and facilitate these best through a dedicated program of data stewardship for data, generated as part of PAGES-related activities.

Of utmost importance to PAGES is the promotion of science and capacity-building in LIMICS countries, and amongst early-career scientists. PAGES supports these communities explicitly through its criteria for financial workshop support, and its fellowship programs of inter-continental collaboration within Africa and South America, to be extended to Asia.

## 2.5 Planned contributions to the project objectives

We anticipate that recently established, community-driven working groups (WGs) and PAGES Scientific Steering Committee (SSC)-identified Integrative Activities (IAs) will pursue the following themes during the period of performance.

### ***Objective 1. International Collaborations***

Since its founding, PAGES has had a long history of collaboration between data production and modeling. Over time, combined proxy data and modeling syntheses progressed, e.g. through the Paleoclimate Modelling Intercomparison Project ([PMIP](#)), an endorsed MIP of the [WCRP](#) Coupled Model Intercomparison Project ([CMIP](#)), with a reciprocal strengthening of the analyses of both proxy data and model results.

In this framework, PAGES' data and modeling communities will work together to better integrate data and model, for example through data assimilation, Bayesian statistics or proxy system modelling. The aim is to improve the reconstruction and process understanding of paleoclimate, paleoenvironment and paleoecology and to answer open question about long-term trajectories, processes and mechanisms. Relevant established, and newly created, WGs using joined data and modeling approaches will take up this challenge. History, archaeology, anthropology and paleoenvironmental science show that civilizations may have reorganized at around the same time as climate and the environment changed. Specifically dedicated WGs will compile high-precision, high-resolution, regional and global synthesis reconstructions and modeling outcomes, and study the resilience and adaptation capacity of past societies, and how the acquired data insights can be used in projections for the future. We anticipate that the foreseen international collaborations will enable major breakthroughs in the accuracy and confidence of environmental reconstructions and projections. PAGES will encourage WGs to annually co-locate workshops on allied topics. This may enable increased workshop attendance and new, potentially transdisciplinary initiatives. Such newly designed co-located Topical Science Meetings (TSMs), with international scientific participation, will create beneficial interaction for the local paleoscience and modeling research communities.

### ***Objective 2. Earth System Variability and Grand Challenges***

The most recent results in terms of data acquisition and interpretation, and modeling and assimilation of paleoclimatic, paleoenvironmental and paleoecological data, complement each other in responding to grand challenges of the Earth System, with a special focus on tipping points and the analysis of 'early warning signals'. Here, some PAGES [working groups](#) (see section 2.13 for recent accomplishments) will assess the patterns and processes by which climate, environment and ecosystems change and vary under radiative forcing scenarios, within warmer

mean states, and across major thresholds, permitting out-of-sample testing of hypotheses put forward by climate projections for the 21st and 22nd century, predicted for large changes in e.g. the frequency and intensity of hot extremes, heavy precipitation, and droughts, and intensified global water cycle ([IPCC 2021](#); Fischer et al. 2018).

Other PAGES WGs will assess the processes that governed past societal responses to climate and environmental variability. These studies will place contemporary human impacts within a longer temporal context to quantify both natural variability and the slow-evolving, low intensity anthropogenic perturbations and improve predictions of future environmental dynamics, to inform strategy for sustainability, and to enable better decision making on pressing environmental issues.

### ***Objective 3. Capacity-Building***

Global change requires a global scientific effort and international collaboration is essential. Accordingly, PAGES will continue to work hard to favor geographic and social diversity. PAGES WGs are required to involve participation from a diverse community and it is a requirement that most of the PAGES support to the workshop is used to fund the participation of early-career researchers, and researchers from LIMICS. Special attention will be paid to the choice of keynote lecturers and plenary speakers to ensure a broad role-model diversity.

PAGES will continue to mentor and promote early-career researcher (ECR)s' development through the PAGES early-career network ([ECN](#)) and provide financial support for attendance of ECRs at meetings and workshops.

PAGES will ensure ways to increasingly involve researchers from Africa, South America and South Asia, specifically through the establishment of new international partnerships with regional institutes or foundations. PAGES will also continue its effort to connect with communities of the global south by making its SSC more diverse. PAGES will encourage the worldwide group of regional representatives within the recently established Early-Career Network (ECN) to serve as liaison with researchers, research institutions and universities in the developing world.

### ***Objective 4. Scientific Visibility***

An eminent possibility of PAGES to promote its visibility in the scientific community is to produce paleo-validated dynamic simulations of past and future earth system stages, from global to local scales (see objectives 1 and 2). Such products, together with novel insights from paleoscience, will contribute to future IPCC and IPBES assessments. PAGES and its partner, WCRP, recognized the convergence and complementarity in their interests and activities, and the existence of substantial mutual collaboration. The WCRP objective is to facilitate analysis and prediction of Earth system variability and change, based on present observation, while PAGES provides the long-term perspective. PAGES will strengthen its ties with WCRP through collaboration within the newly created lighthouse activity (LHA), such as the Safe Landing Climates LHA (in particular for sea-level related topics) and the Digital Earths LHA. PAGES will

continue, improve, or develop collaboration in research efforts, resources sharing, joint publications and/or combined workshops and meetings with other international programs, such as, amongst many other groups, [IODP](#), [IPICS](#), [IPN](#) or [GEOTRACES](#).

### ***Objective 5. FAIR Data***

PAGES is strongly committed to making data availability and information [FAIR](#). The PAGES integrative activity provided guidelines to develop ‘good practices’ for data collection and archiving. PAGES will further develop the recently established [Data Stewardship Scholarship](#) to support WG efforts in safely storing data collected as part of the group's activities. Based on the partnership with NOAA-paleo, PAGES would like to extend this support and to provide training opportunities.

### ***Objective 6. Partnership and Dissemination***

PAGES will continue to actively participate in the co-design of Future Earth Knowledge-Action Networks ([KANs](#)), in particular, Natural Assets, Oceans and Risks and to collaborate with other Future Earth GRNs, such as with AIMES on tipping points. Engagement with Future Earth offers a unique opportunity for PAGES to transfer scientific knowledge to other scientist groups, as well as the public, stakeholders and decision makers. During the next phase, PAGES will encourage the WGs to directly connect with stakeholders. PAGES will expand its social media activity to engage with the public and to disseminate the WG and IA research highlights. PAGES will continue its effort to make paleo-science more accessible to the broader public and in particular the younger generation, through its specifically dedicated novel magazine *Past Global Changes Horizons*. Ultimately, PAGES provides the long-term environmental, ecological and societal perspective, and insists that paleo-science outcomes should be used to improve **future climate and environment** projections, and to inform strategies for **sustainability**.

## **2.6 Current scientific interest and impact of the project**

PAGES fosters international cooperation on past global change through its many international WG activities (Figure 2) that have outstanding scientific impacts and are highly cited both in the media and in the scientific literature (on an average ca. 80 peer-reviewed scientific articles per year over the last 10 years; Figure 3). The PAGES h-index, based on the 1579 PAGES papers available in Web of Science (WoS) since 1999, is 139; on average, PAGES’ papers are cited more than 3750 times per year (total of 90,000 citations). Amongst all the PAGES publications in WoS, 67 papers are in the top 90% of the publications that received most attention (Altmetric) and 49 are in the top 5% of all research outputs (Altmetric, 2019 – 2022).

At the heart of all PAGES communications, and the first point of contact for the community, is the PAGES website: [www.pastglobalchanges.com](http://www.pastglobalchanges.com). The PAGES website was revamped and relaunched in September 2021, and now features a more modern overall look, as well as a more user-friendly experience for the community. The main objective of the website remains to feature relevant news, a searchable people database, working groups contents (current and

former), endorsed and affiliated group webpages, PAGES' publications database, and other services such as a paleo-events calendar and jobs listing page.

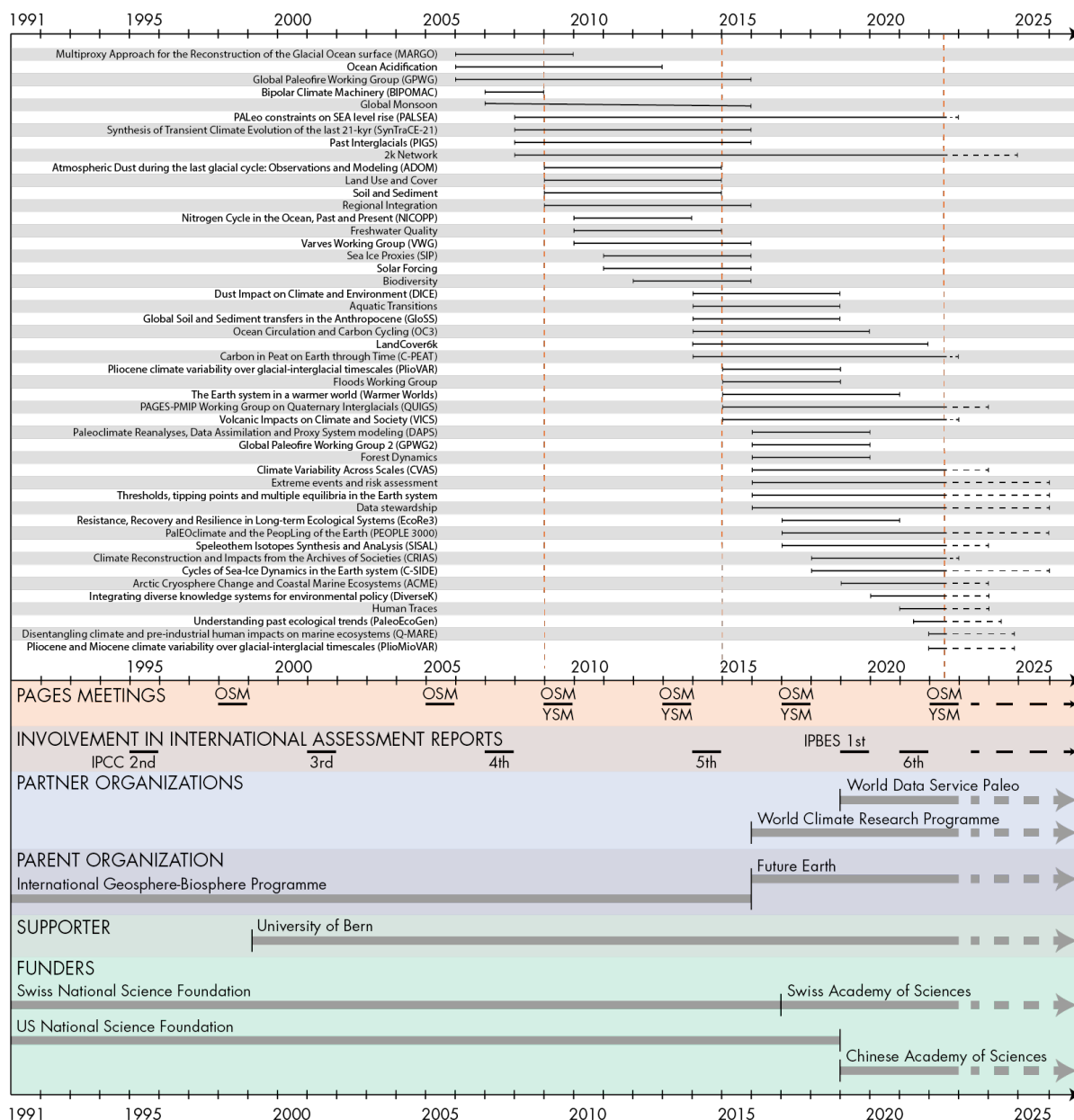
One of the key PAGES products, the [Past Global Changes Magazine](#), a PAGES publication, is downloaded thousands of times each issue. It features a section dealing with a particular topic of past global change and reports on recent workshops. It also constitutes important resources for policymakers, stakeholders and educators. To complement the magazine PAGES launched a new publication, [Past Global Changes Horizons](#) magazine, designed for youth who is interested in learning more about paleoscience, past global changes, and science in general. It can be downloaded for free from the website or a free hardcopy can be ordered. The material published in the magazine can be used, distributed and reproduced in any medium, provided the article authors and all original sources are cited.

PAGES' presence on social media (e.g. Twitter, Facebook, LinkedIn, and YouTube) continues to reach a wider community and keep it informed. Social media followers and subscribers has strongly increased over the last four years (Figure 4).

The PAGES people database currently contains more than 5535 members, of which approximately 3875 people are actively subscribed to the monthly e-news (this number does not remain constant as people unsubscribe, resubscribe and are new). The PAGES monthly e-news contains quick updates on all PAGES activities, e.g. upcoming meetings, deadlines, opportunities, latest products and other relevant news.

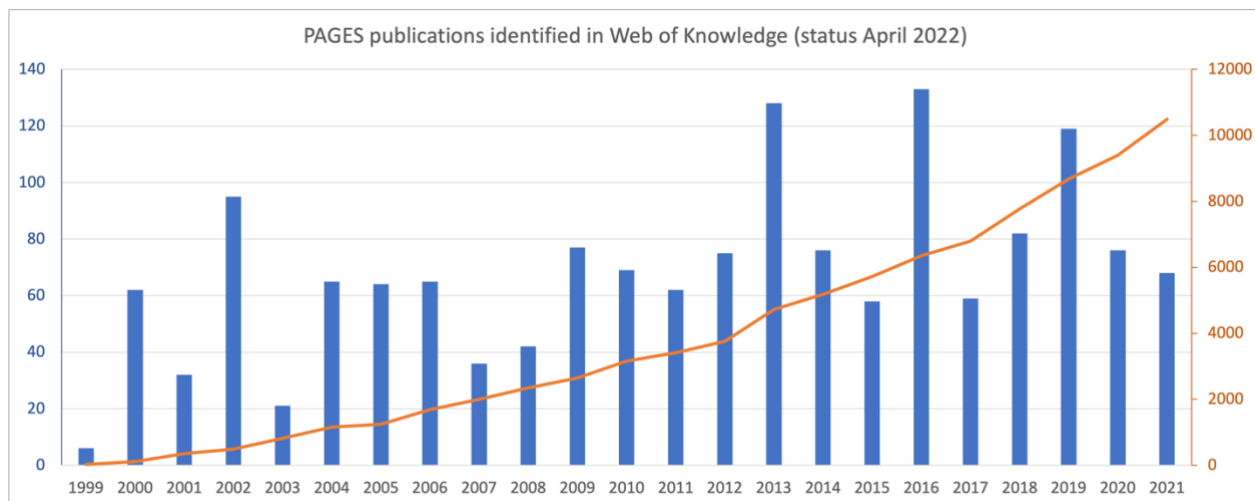
The data stewardship program is a central objective of PAGES. As part of the entire lifecycle of research, it helps to increase the impact of PAGES products, for example by making newly created global data explorations and syntheses available to the broader scientific community and the public. PAGES insists that all the data generated with its support are made FAIR. The data stewardship scholarship program was launched as pilot activity to make the WG data products FAIR, and to help collate and safely store valuable research data. PAGES strongly supports open-access publication and follows the regulations of the home-institutions of the researchers that contribute to the various WG and IA products.



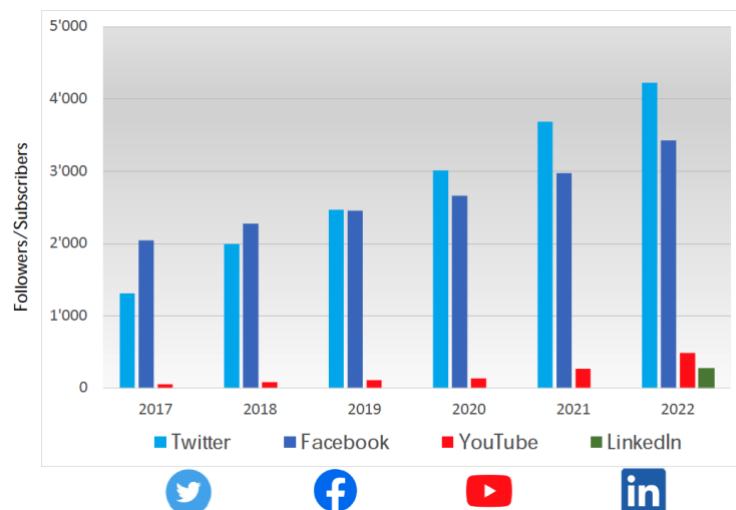


**Figure 2:** Timeline of PAGES' working groups, contributions to other global research activities, and funding. Vertical lines represent structural transitions





**Figure 3:** Annual number of publications (blue) and citations of PAGES papers (red) according to Web of Science (April 2022).



**Figure 4:** Growth of PAGES social media outreach (2017 – 2022)

## 2.7 Suitability and originality of the methods to be used

PAGES WGs (Figures 1 and 2) constitute part of PAGES' contribution to the scientific agendas of Future Earth and WCRP. They have typical durations of 3 years, making PAGES a community-driven, highly dynamic and innovative global research program. During their lifespan they address a particularly timely, sound or urgent topic. Formed via bottom-up initiatives by leading scientists, WGs are competitively created, and provide an innovative platform for discussion, research, innovation, implementation and transformation. Each working phase concludes with a major synthesis. The PAGES SSC regularly assesses the suitability, originality and quality of all WG activities.

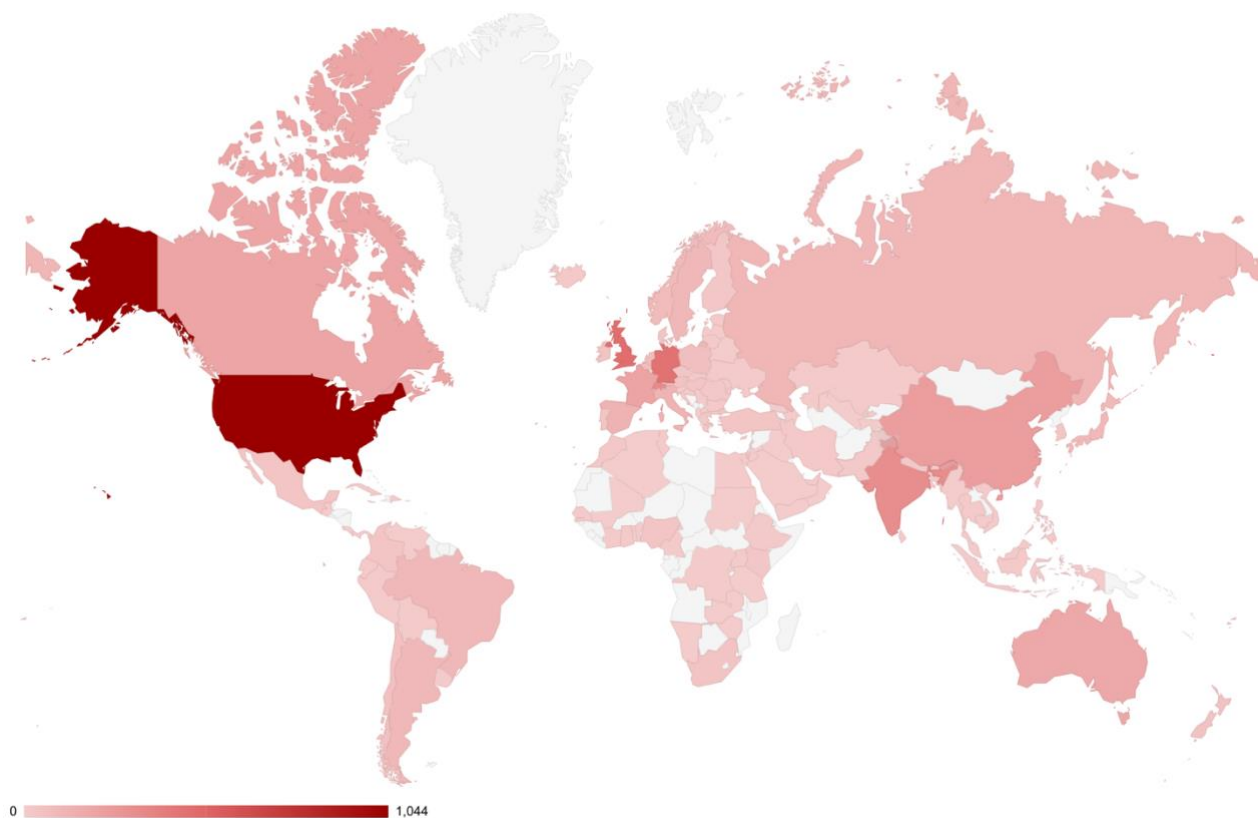
PAGES has ample experience in organizing both the Open Science Meeting (OSM), specifically designed to encourage interaction among worldwide scientists from various disciplines, and the Young Scientists Meeting (YSM), to support and favor capacity-building of young researchers.

PAGES believes the OSM (500 participants in 2022), YSM (60 participants in 2022) and WGs and workshop approaches are extremely successful, as supported by the outstanding quality and quantity of scientific products. Particularly unique is the essential role of PAGES as a conduit between the paleoscience community, its parent organization Future Earth, its scientific partners WCRP, NOAA, IAI, and stakeholders, IPBES and IPCC. PAGES provides the latter information and expertise. PAGES products were used and cited to inform the intergovernmental assessments.

## 2.8 Feasibility of the project

Thanks to the broad support of the scientific community (> 5500 People from 117 countries; Figure 5) PAGES has repeatedly proven, throughout its existence, its ability to coordinate, initiate and deliver many major and significant products and outcomes. PAGES activities are aligned to fit the strategic goals and plans of Future Earth and WCRP, and are interlinked with the major assessments of IPCC and IPBES.

PAGES WGs are committed to delivering a major product (e.g. synthesis, database, or special issue in a scientific journal) at the end of their three-year phase of activity.



**Figure 5:** Distribution around the world of PAGES subscribers (as of May 2022).

PAGES' successful organizational structure relies on the IPO, located and hosted at the University of Bern, to carry out daily operations and serve as the primary communication and

information hub for the global research project, WG leaders, and other global change organizations. Seven staff members (four EFT) are employed under the PAGES project - Executive Director Marie-France Loutre coordinates the PAGES science agenda; Science Officer Sarah Eggleston helps coordinate aspects of PAGES' science agenda, edits the Past Global Changes Magazine and manages data sharing activities; Project/Communications Officers Chené van Rensburg and Leigh Martens Winiger are responsible for all media and public outreach; Finance/Office Manager Ursula Widmer and IT Manager team, Francesco Verde and Manuela Roten, with, occasionally, a student assistant, complete the team. The IPO is supported by the SSC which comprises 15-20 members and is currently chaired by two Scientific Co-Chairs - Prof. Zhimin Jian (China) and Prof. W. Tinner (Switzerland). Together the Co-Chairs, with three other SSC members, elected by the SSC plenary and the Executive Director form the Executive Committee (EXCOM), review and approve expenditures for WGs, workshops, and other initiatives, and oversees and evaluates the IPO. SSC members are assigned to oversee WGs and their activities, and to serve as PAGES spokespeople at scientific meetings.

## 2.9 Sustainability of the project

PAGES' achievements (see section 2.6) owes much to the steady, long term financial support (from Switzerland and the USA, now replaced by China), and to the leveraging of funds by host institutions, participant grant support, and private sources. When the USA concluded financial support, we delivered new support from the Chinese Academy of Sciences. The continued financial support of PAGES over 30 years has kept PAGES in a strong position to attract additional funding from different sources for its activities, and, we are confident, will do so in the years ahead. Historically **every PAGES CHF/\$ has been met with 5 CHF/\$ in matching support**.

PAGES will continue to seek to diversify and internationalize its support base to improve the prospects for long-term support of its scientific goals, so that PAGES community-building efforts will remain sustainable. PAGES successful effort to obtain additional long-term financial support made possible the realization of the previous phase of the project, and strongly improves the prospects for long-term support of its scientific goals. In addition, PAGES encourages the adoption of efficiencies, including teleconferencing, to not only reduce the carbon footprint and cost of project administration, but also to extend the reach of WG activities, enabling more of the PAGES community to share in administration, and to maximize funding of international synthesis science.

### 2.10 Accessibility of project data for researchers during operation and after dissolution

PAGES has developed [guidelines](#) and FAIR practices for open-data sharing and publication, and is linking the paleoscience community to several trusted repositories (e.g. PANGAEA, WDS-paleo, Neotoma). The Data Stewardship Scholarship is specifically designed to implement and facilitate the creation of databases and archiving of datasets and PAGES products in these public repositories.

### 2.11 Experience and past performance of the applicant

PAGES is a highly successful and very-well established global research program, which has been running for more than 30 years (Figures 2, 3, 4 and 5). Since inception, it has played a unique

role in gathering the paleoscience community to collaborate on topics requiring the pooling of human resources, to add value to individual research and to identify knowledge gaps. PAGES is aligned with the goals of Future Earth and WCRP and, by design, is directed by the vision of the vibrant and creative paleoenvironmental science community.

#### 2.12 Specific abilities of the applicants for the proposed project

Willy Tinner is a paleoecologist interested in climate and disturbance impacts through both observation and simulations. He is a faculty member and group leader at University of Bern, with collaborations in Europe, the Americas and Asia, and multiple generations of student and postdoctoral advisees. He was or is the PI of ten (and a co-PI of six) Swiss National Science Foundation (SNF) projects and of a European Research Council (ERC) synergy project. Cantonal and communal archaeological services and forestry agencies (e.g. Bern, Lucerne, Schwyz, Ticino, Valais, Zürich) supported his research. Currently, he is co-Chair of PAGES (since 2017), the Executive Director of the Institute of Plant Sciences, and the Studies Director of the BSc Biology program.

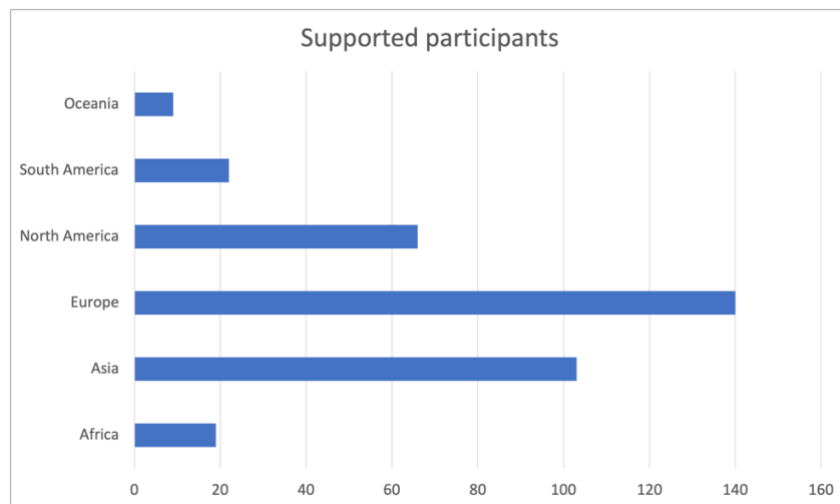
Marie-France Loutre conducted paleoclimate research for 30 years, including modeling and proxy data analysis. As secretary and president of the International Union for Quaternary Research (INQUA) Commission on Palaeoclimate, she re-organized the commission and identified research foci; as president of the Belgian national committee BELQUA (on Quaternary Research), she initiated a series of annual workshops and other coordinating activities. She was treasurer of INQUA for 10 years, and as such she was involved in the daily running of the Union. She has been PAGES' Executive Director since 2015.

### For continuation requests only:

#### 2.13 Current project contributions to the objectives (accomplishments)

- Working groups (WGs), the cornerstone of PAGES, together with the Integrative Activities (IA) and open group activities organize workshops to elaborate scientific topics and products. In 2020 and 2021, because of the pandemic (COVID-19), all the in-person activities were cancelled or postponed. Almost all WGs successfully organized multiple online workshops to keep momentum.
- Three cross-topical IAs were running. The 'Data Stewardship' activity was conducted as a contribution to the Paleoclimate Community reporTing Standards (PaCTS) project and is highlighted in [Khider et al. \(2019\)](#). The AIMES-PAGES workshop on 'Thresholds, tipping points and multiple equilibria in the Earth system' was organized to improve our understanding of the full range of possible abrupt climate, environmental, and societal changes ([Brovkin et al, 2021](#)). A [workshop](#) on 'Extreme events and risk assessment' was organized in February 2019 and aimed to reinforce the coordination between existing research lines on climatological and hydrological extreme events.
- PAGES is involved in Future Earth KANs - Oceans and Risks - and contributes the long-term perspective.

- PAGES collaborates with PMIP to strengthen the comparison of proxy data and reconstructions with simulations.
- In 2018 and 2019, PAGES supported a total of 33 workshops with particular attention to supporting early-career scientists and scientists in LIMICS. In 2018-2019, 358 researchers from South America (22), North America (66), Europe (140), Asia (103), Africa (18), and Australia (9), received support to attend workshops and meetings (Figure 6).
- In **2018 PAGES established a new early-career network** and partnered with INQUA to organize an ECR [workshop](#) on sea-level rise. In 2020 a [virtual workshop](#) for early-career researchers was in preparation for the in-person 'Past Socio-Environmental Systems ([PASES2022](#))' workshop in 2022.
- The International Mobility Research Fellowship Program for Latin American and Caribbean early-career scientists on past global changes, developed in collaboration with the Inter-American Institute for Global Change Research ([IAI](#)), and the Inter-Africa Mobility Research Fellowship Program for African early-career scientists studying past global changes were **newly established in 2021**. Five scholars from Latin America and four from Africa received funding to support inter-continental mobility and collaboration.
- A [Data Stewardship Scholarship](#) program was developed specifically for PAGES WGs to support their efforts in safely storing data collected as part of the group's activities. Eleven groups benefited from this **new scholarship in 2021**.



**Figure 6:** Distribution by continent of PAGES-supported participants who attended workshops (excluding OSM/YSM). Cumulative numbers for 2018 and 2019.

Key recent WG accomplishments include:

- The **PAGES 2k Network** database identified major global and regional features of temperature change over the last 2000 years.
- **C-PEAT** showed that European peatlands have undergone substantial, widespread drying during the last ~300 years, which is concurrent with compound pressures

including climatic drying, warming and direct human impacts on peatlands ([Swindles et al. 2019](#)).

- **CRIAS** used climate reconstructions based on documentary data to identify extreme events (droughts and heatwaves) in Europe over the past centuries and their very strong impacts on environment, economy, and society (e.g. [Camenisch and Salvisberg 2020](#)).
- **C-SIDE** investigated the impact of surface conditions in the Southern Ocean during the Last Glacial Maximum using model simulations and highlighted the importance of convection processes (e.g. [Lhardy et al. 2021](#)).
- **CVAS** has developed analytical tools to disentangle natural from human-caused variability, and to identify the impacts of changes in climate variability under future forcing scenarios.
- **DiverseK** investigated the linkages between climate change, vegetation and diversity in the Qinling Mountains during the Holocene ([Yao Zhang et al. 2021](#)).
- **EcoRe3** studied drivers of resilience in tropical forests and suggested that a faster recovery rates could be associated with regions of higher biodiversity ([Adolf et al. 2020](#)).
- **Floods WG** worked on identifying the most exceptional floods of the past on a regional basis (e.g. [St. George et al. 2020](#)).
- **GPWG2** members released a [Policy Brief](#) to support future decisions on fire policy and biodiversity conservation with evidence from the paleorecord.
- **LandCover6k** estimated land-cover change in quantitative terms for example in China, the Pyrenees and Northern Asia (e.g. [Cao et al. 2019](#)).
- **OC3** used an observationally constrained Earth system model to quantify the ocean carbon components and the role that different processes play in simulated glacial-interglacial CO<sub>2</sub> variations ([Khatiwala et al. 2019](#)).
- **PALSEA** studied sea-level variability during the Quaternary, the Pliocene and the Pleistocene warm periods to improve the accuracy of sea-level projections for the coming centuries to millennia (e.g. [Gilford et al. 2020](#)).
- **PEOPLE 3000** conducted an analysis of the long-term stability or collapse of human societies in North America, in Patagonia and on the Easter Island (e.g. [Lima et al. 2020](#)).
- **QUIGS** used the newly analysis of multi-model ensemble of climate models for the Last Interglacial (LIG) and compared them to new synthesis for surface temperature and precipitation for 127 ka ([Otto-Bliesner et al. 2021](#)).
- **SISAL** used their database ([Atsawawaranunt et al. 2018](#)) to revisit climate reconstructions based on speleothem isotopes for Europe and New Zealand (e.g. [Lorrey et al. 2020](#)).
- **VICS** analyzed volcanic impacts on climate and society, such as the strong hemispheric cooling, the downfall of the Roman Republic and Ptolemaic Kingdom following the eruption of Alaska's Okmok volcano in 43 BCE or the cooling of the Animaqin Mountains on the Tibetan Plateau for two years after a large volcanic eruption (e.g. [Wang et al. 2021](#)).
- **Thresholds, tipping points and multiple equilibria in the Earth system** provided evidence of cascading tipping points and 'early warning signals' after abrupt climate changes. They examined abrupt changes over the last 30,000 years to show how tipping

points, preceded by early warning signals, can help inform our response to the current climate crisis ([Brovkin et al. 2021](#)).

#### 2.14 Max. 10 peer reviewed key publications of the current project

All the bibliography and products are available online on PAGES' website:

<https://pastglobalchanges.org/publications>

- Norström AV et al. (2020) Nature Sustainability, 3, 182–190. DOI: 10.1038/s41893-019-0448-2
- Bellouin N et al. (2019) Reviews of Geophysics, 58, 1. DOI: 10.1029/2019RG000660
- Neukom R et al. (2019) Nature, 571, 7766. DOI: 10.1038/s41586-019-1401-2
- Swindles GT et al. (2019) Nature Geoscience, 12, 11. DOI: 10.1038/s41561-019-0462-z
- Routson CC et al. (2019) Nature, 568, 7750. DOI: 10.1038/s41586-019-1060-3
- Reschke M et al. (2019) Climate of the Past, 15, 521–537. DOI: 10.5194/cp-15-521-2019
- Schulte L et al. (2019) Global and Planetary Change, 180, 66-88. DOI: 10.1016/j.gloplacha.2019.05.011
- Lamentowicz M et al. (2019), Biology Letters, 15(6), 20190358. DOI: 10.1098/rsbl.2019.0358
- Loisel J et al. (2020) Nature Climate Change, 11, 70–77. DOI: 10.1038/s41558-020-00944-0
- Büntgen U et al. (2021) Nature Communications, 2, 3411. DOI: 10.1038/s41467-021-23627-6

#### 2.15 10 most important network activities such as media or workshops of the current project

- The 6th PAGES Open Science Meeting and the 4th PAGES Young Scientists Meeting, online, ' Learning from the past for a sustainable future.', 9-20 May 2022.
- The [PAGES Early-Career Network](#)
- Joint PAGES-INQUA ECR workshop: Past Socio-Environmental Systems (PASES). A virtual workshop ([vPASES2020](#)) for early-career researchers was held from 9-11 November 2020 in preparation for the in-person 'Past Socio-Environmental Systems ([PASES2022](#))' workshop in 2022. Bimonthly **virtual get-together meetings** are also offered to the participants to prepare the workshop.
- Sessions and splinter meetings at large events (e.g. at EGU, AGU)
- Developed strong relations with WCRP, NOAA-paleo, and several Future Earth GRPs.
- [Past Global Changes Magazine](#) communicates paleoscience in an accessible and informative style. [Past Global Changes Horizons](#) magazine is a new publication designed for teenagers and young adults who are interested in learning more about paleoscience, past global changes, and science in general.



- Dissemination of scientific results to the broader public via press releases, blog articles, podcasts, contributions to documentaries and outreach events.
- Communication output including the website, calendar, e-news and social media
- [C-PEAT](#), in collaboration with PAGES and Future Earth, took part in the [United Nations' Framework Convention on Climate Change \(COP26\)](#). The C-PEAT team was presented at the Peatland Pavilion, organized by the Global Peatlands Initiative.
- C-PEAT contributed to a [New York Times series](#) on peatlands.