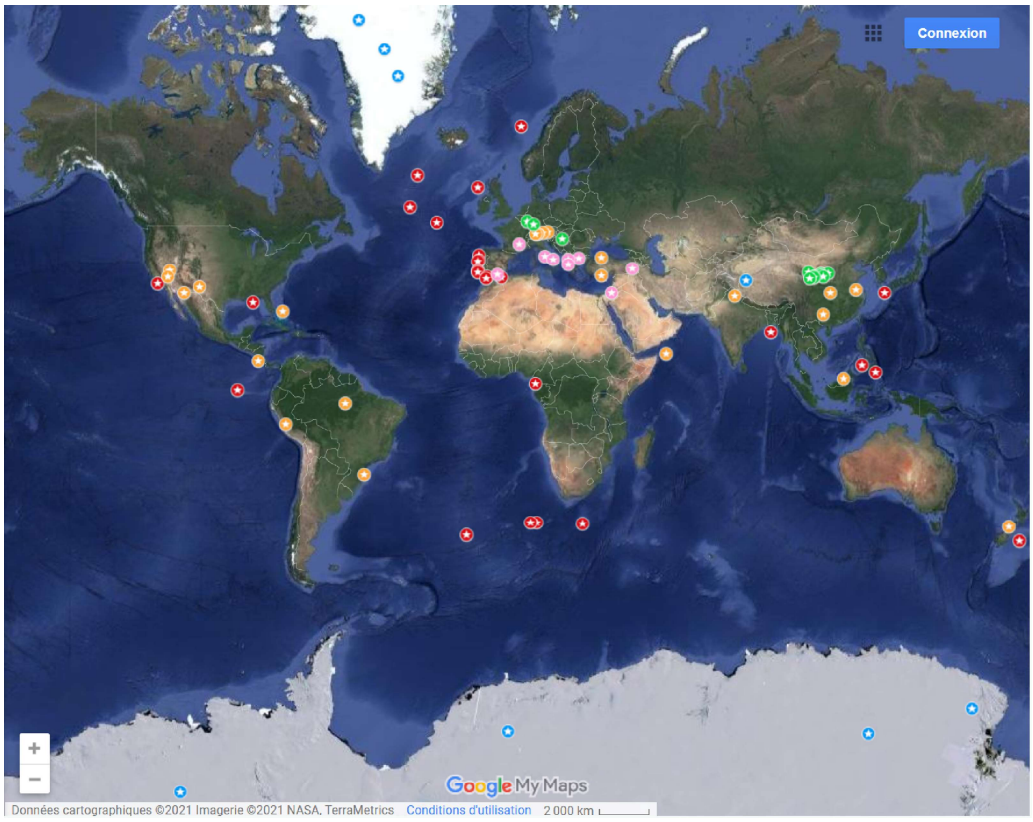
TIPPING POINTS IN THE EARTH SYSTEM

D1.1 Open-access proxy data repository of tipping elements in past climates



Picture: map of proxy records included in the PaleoJump database

TiPES: Tipping Points in the Earth System is *is a Research and Innovation action (RIA) funded by the Horizon 2020 Work programme topics "Addressing knowledge gaps in climate science, in support of IPCC reports" Start date: 1st* September 2019. End date: 31st August 2023.

The TiPES project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 820970.

About this document

Deliverable: D1.1- Open-access proxy data repository of tipping elements in past climates
Work package in charge: WP1: Observation based analysis of Tipping Elements and their interactions
Actual delivery date for this deliverable: Project month 18 -Feb 2021
Dissemination level:
The general public (PU)

Lead author(s)
Name of the partner's institution: Witold Bagniewski, École Normale Supérieure, Laboratoire de Météorologie Dynamique, Paris, France

Other contributing author(s)
Name of the partner's institution: Denis-Didier Rousseau[1,2,3], Michael Ghil[1,4]
[1]École Normale Supérieure, Laboratoire de Météorologie Dynamique, Paris, France
[2]Columbia University, Lamont Doherty Earth Observatory, New York, USA
[3]Université Montpellier, Géosciences, Montpellier, France
[4]University of California at Los Angeles, Department of Atmospheric and Oceanic Science, Los Angeles, USA

Visit us on: www.tipes.dk

Follow us on Twitter: @TiPES_H2020

Access our open access documents in Zenodo:
https://zenodo.org/communities/tipes/

Index

Summary for publication 4
Work carried out 5
Main results achieved 5
Progress beyond the state of the art 6
Impact 6
Lessons learned and Links built 6
Contribution to the top level objectives of TiPES 7
References (Bibliography) 7
Dissemination and exploitation of TiPES results 8
Dissemination activities within this delivery 8
Uptake by the targeted audiences 12

Summary for publication

Paleoclimate records are essential for identifying Tipping points in the Earth's past and to properly understand the climate system's underlying bifurcation mechanisms. Due to their varying quality, resolution, and dating methods, identifying the most relevant paleo-records is, therewith, a daunting task. To address this problem, we created the PaleoJump database, which compiles high-resolution paleoclimate records originating in ice, marine sediments, speleothems, loess, and lake sediments. To allow easy access and navigation, the database has the form of a website, a working version of which is currently online. It includes a map of the paleoclimate records, as well as tables which list supplementary information for each record. As the database is continuously developed and has not yet been peer-reviewed, the link to the website is currently only available on request.

The paleorecords have been carefully selected for their quality, resolution, precision of the time scale, and representation of past climate variability to simplify the process of finding the records that are most relevant for scientists investigating critical transitions and the temporal behavior of tipping elements. While the paleo sites included in the database carry multiple types of proxies, the primary focus is on proxies that may be reliably compared with climate models: oxygen isotopes, which reflect changes in past temperatures, sea level, and precipitation, carbon isotopes, which contain information on past vegetation, and aeolian deposits, which carry signatures of past precipitation and atmospheric transport patterns. The temporal focus is on the Last Glacial Cycle, due to the well-established evidence of past tipping points (Dansgaard-Oeschger events, Heinrich events), with most records also covering Holocene deglaciation. Other records extend further back in time, including Dansgaard-Oeschger-like events during earlier glacial cycles of the Quaternary, and earlier climatic events of the Cenozoic era, such as the Eocene-Oligocene Transition or the Paleocene-Eocene Thermal Maximum. While the database gives a global coverage with records from all continents and ocean basins, spatial distribution is biased towards the North Atlantic region due to greater availability and a strong impact of Dansgaard-Oeschger events.

The PaleoJump database currently includes records from twenty-eight marine sediment, twenty-four speleothems, fourteen loess, nine lake sediment, and nine ice sites, grouped into their corresponding tables. For each site, the data have been analyzed to determine essential information, given in the tables: location, elevation, temporal range, maximum resolution, and available proxies. This information is accompanied with links to the original data and the associated publications.

As paleoclimate records vary in their origin, time spans, and periodicities, an objective, automated methodology is crucial for identifying and comparing Tipping points. Therefore, for every record, a transition detection methodology is applied to identify abrupt transitions. This methodology, based on an augmented Kolmogorov-Smirnov test, has been developed by the TiPES WP1 group at ENS and will be described in an upcoming publication. The results of this analysis are given in the database for selected records, along with temporal plots, and are compared with other transition detection methodologies (e.g. recurrence analysis). The abrupt transitions are detected on different time scales, for example the past 122 thousand years on the NGRIP ice core, the past 3.1 million years in the U1308 marine sediment core, and the past 67 Million years in the CENOGRID marine sediment stack.

By containing proxy records that help study tipping elements in past climates, this open-access online data repository meets the objectives of TiPES Deliverable D1.1.

Work carried out

The work for this deliverable has been conducted jointly by Witold Bagniewski (WB), Denis-Didier Rousseau (DDR), and Michael Ghil (MG), with additional input from Jens Fohlmeister (JF):

- The website hosting the database has been built by WB with input regarding design and content from DDR and MG.
- The records included in the database have been selected by WB, DDR, and JF, with WB responsible for selecting majority of the marine sediment cores, DDR selecting majority of the ice cores, loess records, and lake sediment cores, and JF selecting majority of the speleothem records.
- Selection of the paleorecords was preceded by extensive literature review and an independent analysis of data obtainable from different repositories. Such analysis consisted of determining the temporal coverage and resolution of the datasets as well as assessing their overall quality and applicability for data-model comparison studies. Upon completing the selection, links to the paleorecords, hosted on PANGAEA, NCEI, as well as other data repositories, were added to the PaleoJump database.
- Analyzing and inputting information for each paleorecord into tables, and creating a map of the paleoproxy site locations, have been carried out by WB.
- WB and MG have jointly created a tool to automatically detect abrupt transitions in paleoclimate records. The Kolmogorov-Smirnov (KS) test was selected by MG as the primary method for finding discontinuities in a time series, while supplementary statistical functions aimed at tailoring the KS test to paleoclimate studies were developed and incorporated into an algorithm by WB with additional input from MG and DDR. The diagnostic ability of this methodology has been assessed by WB through the Receiver Operating Characteristic analysis, and has been compared with other transition detection methodologies, e.g. recurrence analysis. A publication describing the augmented KS test is currently in preparation by WB, MG, and DDR.
- Abrupt transitions in the records have been computed and plotted by WB, while spreadsheets listing the transitions in comparison with transitions given in other studies have been made by DDR. For selected records, both the plots and the spreadsheets are available on the PaleoJump database. These results have been discussed by WB, DDR and MG in preparation for an upcoming publication.

Main results achieved

- Establishment of a publicly available online data repository, currently containing paleoclimate records from 84 sites that represent global scale tipping phenomena over the past 67 million years. The database is continuously expanded as more records are being added and information is being updated.
- Development of a methodology for the automatic detection of abrupt transitions in paleoclimate records. This methodology is applicable to multiple types of records, of different origin, time spans, and periodicities.
- Identification of abrupt transitions in selected proxy records, evidencing tipping elements in past climates.

Progress beyond the state of the art

The main advance beyond the state of the art has been the development of the augmented Kolmogorov-Smirnov test, which was applied to various paleorecords, resulting in a robust detection of previously unrecognized transitions at every investigated time scale. These findings allow to advance the discussion beyond the initial description of paleorecords by the original investigators, leading to upcoming papers.

Impact

How has this work contributed to the expected impacts of TiPES?

The carefully selected, high-quality paleoproxy records in the PaleoJump database, with different temporal scales and a global spatial coverage, provide an easily accessible resource for research on the potential tipping elements in the Earth's climate, such as the polar ice sheets, the AMOC, and the tropical rainforests and monsoon systems. This includes model-data comparison studies evaluating the ability of different models to reproduce the observed transitions, as performed in WP2. The newly developed tool for automatic detection of abrupt transitions may be applied to any paleorecord investigated in TiPES, allowing to objectively and robustly characterize known tipping elements, but also to identify previously unrecognized tipping elements in past climates. These latter tipping elements may in turn be further explored with Earth System Models to improve our understanding of the Earth's bifurcation mechanisms and identify possible tipping points for future climates. Furthermore, the broad spatial coverage of the database, including records that vary in nature (ice, land, marine) and temporal scale (length, resolution), will support establishing improved criteria on where and how to collect data for reliable Early Warning Signals.

Lessons learned and Links built

Our results demonstrate that the detection of abrupt transitions in paleorecords could rely on various interpretations of the proxies studied. For example, the threshold of abruptness may have to be changed when investigating different timescales and resolutions, affecting the frequency at which the potential tipping points are identified. However, this still requires a robust and independent way to detect them, as demonstrated by our transition detection methodology.

Throughout this project, links were built with other TiPES deliverables and WPs through regular online discussions and seminars. The database was shared with the TiPES community through an internal newsletter and has been advertised on the TiPES website. Additional meetings with WP1 group members at PIK (Niklas Boers, Jens Fohlmeister and Keno Riechers) were held to facilitate our collaboration and exchange ideas on the creation of the database and automatic transition detection methods. Furthermore, the results of this deliverable were disseminated to the scientific community at EGU and AGU conferences.

The database created for this deliverable will be used further in the TiPES project, in particular by providing the datasets required for evaluating Earth System Models in WP2. We will present the database at an upcoming EGU conference, while the database, the transition detection method, as well as the results of our research on tipping points in past climates, will be discussed in upcoming publications. Both the database and the tool for automatic transition detection will be publicly accessible from the TiPES website in the future, and will thus serve the wider scientific community.

Contribution to the top level objectives of TiPES

Objective 1-Identify tipping elements (TEs) and their interactions in models and data

We built an online repository of high-quality paleoclimate records evidencing abrupt climate transitions in the past, and developed a methodology for automatically detecting these transitions. The data and their identified TEs are highly relevant for climate modelling studies as they further our understanding of the Earth's tipping points and help evaluating the climate models performance in reproducing abrupt transitions observed in the long-term past.

References (Bibliography)

- Ashwin, P., Wieczorek, S., Vitolo, R. and Cox, P. (2012). Tipping points in open systems: bifurcation, noise-induced and rate-dependent examples in the climate system, *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, doi: 10.1098/rsta.2011.0306
- Boers, N., Ghil, M., and Rousseau, D.-D. (2018). Ocean circulation, ice shelf, and sea ice interactions explain Dansgaard-Oeschger cycles, *PNAS*, doi: 10.1073/pnas.1802573115
- Fawcett, T. (2006). An introduction to ROC analysis. *Pattern Recognition Letters*, 27(8):861–874 doi: 10.1016/j.patrec.2005.10.010
- Ghil, M. (2019). A century of nonlinearity in the geosciences. *Earth and Space Science*. doi: 10.1029/2019EA000599
- Kuehn, C. (2011). A mathematical framework for critical transitions: Bifurcations, fast–slow systems and stochastic dynamics, *Physica D: Nonlinear Phenomena*, doi: 10.1016/j.physd.2011.02.012
- Massey Jr, F. J. (1951). The Kolmogorov-Smirnov test for goodness of fit, *Journal of the American Statistical Association*, doi: 10.2307/2280095
- Rasmussen, S. O., et al. (2014). A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy. *Quaternary Science Reviews*, doi: 10.1016/j.quascirev.2014.09.007

The papers related to the different selected paleo records used in the database are listed in the PaleoJump database.

Dissemination and exploitation of TiPES results

Dissemination activities within this delivery

Type of dissemination activity	Name of the scientist (institution), title of the presentation, event	Place and date of the event	Estimated budget	Type of Audience	Estimated number of persons reached	Link to Zenodo upload
Participation to a conference	Denis-Didier Rousseau (CNRS): Abrupt transitions in the Past, TiPES Kick off meeting	Paris (FR), 17-19 October 2019	0	Scientific Community (higher education, Research)	?	https://ext.erda.dk/cert_redirect/TiPES/Meetings/2019_09_Kickoff/Presentations/TiPES_DDR_October2019.pdf
Participation to a conference	Denis-Didier Rousseau (CNRS) & Witold Bagniewski (ENS): Data quality in different paleo archives and covering different time scales: a key issue in studying tipping elements., EGU 'Tipping Points in the Earth System' Session ITS3.1/NP1.2	Online, 6 May 2020	0	Scientific Community (higher education, Research)	400?	https://doi.org/10.5194/egusphere-egu2020-14267
Participation to a conference	Michael Ghil (ENS): Bifurcations, Global Change, Tipping Points and All That, EGU 'Tipping Points in the Earth System' Session ITS3.1/NP1.2	Online, 6 May 2020	0	Scientific Community (Higher education, Research)	400?	https://doi.org/10.5194/egusphere-egu2020-18559
Participation to a conference	Witold Bagniewski (ENS): "Tipping Points in the Climate System: Automatic Detection of Abrupt Transitions in Paleoclimate Records", AGU Paleoceanography and Paleoclimatology iposter session	Online, 9 Dec 2020	0	Scientific Community (Higher education, Research)	?	https://doi.org/10.1002/essoar.10506097.1
Participation to a conference	Witold Bagniewski (ENS): "Automatic detection of abrupt transitions in paleoclimate records using the Kolmogorov-Smirnov test", internal TiPES workshop-	Online, 8th Oct 2020	0	Scientific Community (Higher education, Research)	70	https://ext.erda.dk/cert_redirect/TiPES/Meetings/2020_10_08_paleoworkshop/WitekBagnievski.mp4

	Abrupt Climate and ecosystem transitions in paleoclimate					
Press release	Michael Ghil (ENS): Le climat, matière à recherche pour les physiciens	Paris, France, Online 23 December 2020, ENS-PSL website	0	Scientific Community (Higher education, Research)	?	https://www.ens.psl.eu/actualites/le-climat-matiere-recherche-pour-les-physiciens
Press release	Michael Ghil (ENS): The Complex Variability of Climate	New York, USA, Online 31 July 2020, APS website	0	Scientific Community (Higher education, Research)	10 000	https://physics.aps.org/articles/v13/121
Participation to an event other than a conference or workshop	Michael Ghil (ENS): Les maths, le climat et quelques surprises, at Mathematik und Klima, French Embassy	24 September 2020, Berlin, Germany	?	General public	250–300	https://www.wissenschaft-frankreich.de/materialwissenschaften/mathematik/mathematik-und-klima-von-poincare-zu-lorenz-und-der-klimavorhersage-am-24-september-2020-in-der-franzoesischen-botschaft-in-berlin/
Participation to a conference	Michael Ghil (ENS): Rate-induced tipping points in a simple model of the wind-driven ocean circulation	Online SIAM 2020 Mathematics of Planet Earth, 03–14 August 2020	?	Scientific Community (Higher education, Research)	10 000	https://www.siam.org/conferences/cm/conference/mpe20
Participation to a conference	Michael Ghil (ENS): Transfer operators, climate sensitivity and the topology of random attractors	Online SIAM 2020 Mathematics of Planet Earth, 03–14 August 2020		Scientific Community (Higher education, Research)	10 000	https://www.siam.org/conferences/cm/conference/mpe20
Press release	Witold Bagniewski (ENS): PaleoJump – a TiPES database for research on rapid climate transitions	Online TiPES, 19 Oct 2020	0	Scientific Community (Higher education, Research)	?	https://www.tipes.dk/paleojump-a-tipes-database-for-research-on-

						rapid-climate-transitions/

Peer reviewed articles that relates to this delivery

Title	Authors	Publication	DOI	Is TiPES correctly acknowledged?	How much did you pay for the publication?	Status?	Open Access granted	Comments on embargo time imposed by the publisher	If in Green OA, provide the link where this publication can be found
How dusty was the last glacial maximum over Europe?	Denis-Didier Rousseau, Pierre Antoine, Youbin Sun	Quaternary Science Reviews	10.1016/j.quascirev.2020.106775	YES		Published	No		
Dansgaard–Oeschger-like events of the penultimate climate cycle: the loess point of view	Denis-Didier Rousseau, Pierre Antoine, Niklas Boers, France Lagroix, Michael Ghil, Johanna Lomax, Markus Fuchs, Maxime Debret, Christine Hatté, Olivier Moine, Caroline Gauthier, Diana Jordanova, Neli Jordanova	Climate of the Past	10.5194/cp-16-713-2020	YES		Published	Green		https://cp.copernicus.org/articles/16/713/2020/cp-16-713-2020.html

Arnold Maps with Noise: Differentiability and Non-monotonicity of the Rotation Number	L. Marangio, J. Sedro, S. Galatolo, A. Di Garbo, M. Ghil	Journal of Statistical Physics	10.1007/s10955-019-02421-1	YES		Published	Green		https://link.springer.com/article/10.1007/s10955-019-02421-1
Review article: Hilbert problems for the climate sciences in the 21st century – 20 years later	Michael Ghil	Nonlinear Processes in Geophysics	10.5194/npg-27-429-2020	YES		Published	Green		https://npg.copernicus.org/articles/27/429/2020/
Evaluating the Performance of Climate Models Based on Wasserstein Distance	Gabriele Vissio, Valerio Lembo, Valerio Lucarini, Michael Ghil	Geophysical Research Letters	10.1029/2020gl089385	YES		Published	Green		https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020GL089385
The physics of climate variability and climate change	Michael Ghil, Valerio Lucarini	Reviews of Modern Physics	10.1103/revmodphys.92.035002	YES		Published	Green		https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.92.035002
Geophysical Fluid Dynamics, Nonautonomous Dynamical Systems, and the Climate Sciences	Michael Ghil, Eric Simonnet	Mathematical Approach to Climate Change and its Impacts - MAC2I	doi: 10.1007/978-3-030-38669-6_1	YES		Published	Green		https://link.springer.com/chapter/10.1007/978-3-030-38669-6_1

Uptake by the targeted audiences

As indicated in the Description of the Action, the audience for this deliverable is:

x	The general public (PU) is and is made available to the world via CORDIS.
	The project partners, including the Commission services (PP)
	A group specified by the consortium, including the Commission services (RE)
	This reports is confidential, only for members of the consortium, including the Commission services (CO)

This is how we are going to ensure the uptake of the deliverables by the targeted audiences:

Both the database and the tool for automatic transition detection will be hosted on the TiPES website and publicly accessible. In a first step, we are making the database freely available to the TiPES project members to allow for corrections of potential shortcomings brought up in internal discussions. As a second step, the database will be migrated to the TiPES website before the end of the project, form where it will be widely disseminated to the rest of the scientific community. The database will be presented at an upcoming EGU conference and will be further disseminated through future conferences and press releases. Furthermore, the database, the tool for automatic transition detection, as well as the results of our analysis of paleorecords, will be discussed in upcoming publications.