BioGeoPhylo Workshop Report

2025

Past Records, Current Challenges: Integrating Paleoclimatic and Geographical Controls into Macroevolutionary Models

As phylogenetic, biogeographic, and diversification models become increasingly sophisticated in their computational design, they also achieve greater biological realism. This growing complexity is largely driven—and enriched—by the integration of paleontological, paleogeographic, and paleoclimatic data, which is not only essential for accurate inference but also represents one of the most promising frontiers in macroevolutionary research.

cerege

Funded by the European Union

European Research Council

INTERNATIONAL LITHOSPHERE PROGRAM

Integrating past landmass configurations, climatic shifts, and paleontological evidence offers a more complete framework for understanding lineage divergence and extinction. By including these historical factors, phylogenetic models can more accurately estimate divergence times, infer ancestral ranges, and reveal the ecological and evolutionary forces that shape biodiversity. In turn, these reconstructions shed light on past geological events—such as the emergence of geographic barriers or the timing of major climatic transitions.

The BioGeoPhylo Workshop In Arles (March 26-28th, 2025) brought together 50 biologists, geologists, and paleontologists working at the intersection of Earth and Life Sciences to identify the key challenges in integrating these disciplines. Cutting-edge presentations were followed by discussions and a broad brainstorming session aimed at proposing future research directions and identifying obstacles to overcome and how to incorporate these factors into macroevolutionary models.

5 challenges emerged as focal points for improving this interdisciplinary integration:

1. The Accessibility Challenge

The integration of geological and biological data in phylogenetic reconstructions underscores the urgent need for a shared language between Earth and Life scientists. Differences in methodologies, terminologies, and research priorities have created barriers to collaboration, limiting the potential for truly interdisciplinary insights. Geological data are often inaccessible—both physically and conceptually—to biologists, while the complexity of modern diversification models makes them difficult for Earth scientists to grasp. Several approaches can help bridge this gap:

Improving database accessibility in Earth and Life Sciences by adapting language for broader audiences, increasing visibility beyond specialized professional circles, and sharing relevant information across disciplines. For example, geological papers could include detailed assemblage lists, while paleontological databases could provide geochronological methods and their associated uncertainties.

Standardizing data reporting by adhering to international conventions in taxonomy, geochronology, genetics, and related fields. This would ensure that non-experts can interpret and utilize data effectively.

Fostering interdisciplinary collaboration through regular meetings, dedicated workshops, conferences, and networks—such as the EUROBIG cost network—to encourage dialogue and the development of a common scientific language. These communities remain largely separate today, but increased interaction is key to overcoming communication barriers.

2. The Uncertainty Challenge

All paleogeographic, paleoclimatological, and phylogenetic syntheses in deep time are working hypotheses and inherently somewhat inaccurate, as they rely on multiple assumptions and extrapolations based on limited data.

However, understanding the degree of uncertainty in these syntheses can be challenging for non-experts. Life scientists often struggle to assess the uncertainty in paleogeographic and paleoclimatological reconstructions, while Earth scientists may take diversification curves, phylogenetic trees, or taxonomic identifications at face value.

To address this issue, several approaches can be adopted:

Providing clear uncertainty guidelines for non-experts in current syntheses and explicitly acknowledging uncertainties not accounted for in models. These should be detailed in supplementary materials or within the main text of publications (e.g., uncertainties in fossil ages for phylogenetic trees, in paleoaltitude for paleogeographic reconstructions).

Presenting multiple scenarios (two-end or multi-end) rather than a single synthesis when possible, allowing for alternative hypotheses to be incorporated and tested in models (e.g., multiple paleogeographic models for climate simulations, or different biodiversity curves for comparison with geological data). This provides a mean to evaluate the sensitivity of these models to changes in boundary conditions and/or input data.

Integrating climatic, paleogeographic, and geochronological uncertainties into environment-dependent and age-dependent phylogenetic models to improve their robustness and applicability.

3. The Resolution Challenge

Environment-dependent diversification models require continuous, regionally resolved climatic records spanning long macroevolutionary timescales (>10 Myr). Biogeographic and climatic models depend on high-resolution global paleogeographic maps (~100 km), while phylogenetic trees require multiple fossil taxa with precise chronological constraints (<1 Myr of uncertainty for Cenozoic trees). However, such high-resolution records barely exist, and our understanding of past geography, climate, and fossil biota remains highly fragmentary in deep time.

With few pioneering exceptions, most environment-dependent models rely on global, averaged climate trends (e.g., the Zachos $\delta^{18}O$ curve) or low-resolution paleogeographic maps that lack sufficient detail at the continental scale (e.g., the 55 Ma paleogeography used in deepMIP simulations).

To address this limitation, we propose the following approaches:

Expanding field studies and increasing data acquisition in climatology, paleogeography, and paleontology, as these form the foundation of all reconstructions. Additionally, older (>50 years) paleontological and paleobotanical collections in museums remain underutilized. Re-examining these specimens with modern paleoenvironmental methods and imaging techniques could significantly enhance paleoenvironmental reconstructions and fossil assemblage data at minimal cost. Unfortunately, field geology and taxonomy—both fundamental to paleoclimatic and biogeographic reconstructions—are often undervalued.

Developing and democratizing statistical tools to address data gaps in time and space, such as kriging for time series or downscaling techniques in climate simulations.

Prioritizing regional climatic, paleogeographic, and paleobiological data—even in a smoothed form—over global curves when integrating environmental factors into biogeographic and diversification models.

4. The Trait and Ecology Challenge

Physiological and ecological differences among species play a crucial role in shaping their extinction and dispersal histories. Recent phylogenetic reconstructions have highlighted how pulses of speciation are clade-dependent, reflecting a complex interplay between species traits and environmental pressures. However, biogeographic and diversification models rarely account for these differences due to their computational complexity and the lack of detailed knowledge about the traits and ecological niches of past taxa. Similarly, biotic interactions between species are seldom integrated into these models for the same reasons.

More broadly, researchers often overlook the fact that species traits, ecological preferences, and climatic distributions evolve over time. The persistence of actualism—the assumption that traits remain static over long periods—remains widespread. A clear example of this issue is in paleobotany, where many paleoclimatic inferences rely on the climatic ranges of the nearest living relatives of fossil taxa, even for taxa older than 10 million years.

To address these challenges, we propose the following approaches:

Enhancing and expanding the use of proxies for characterizing past traits and ecological niches in fossil taxa. Although proxies such as dental microwear and isotopic analysis for fossil vertebrates exist, they remain underutilized. Increasing their accessibility and application will provide deeper insights into past ecologies.

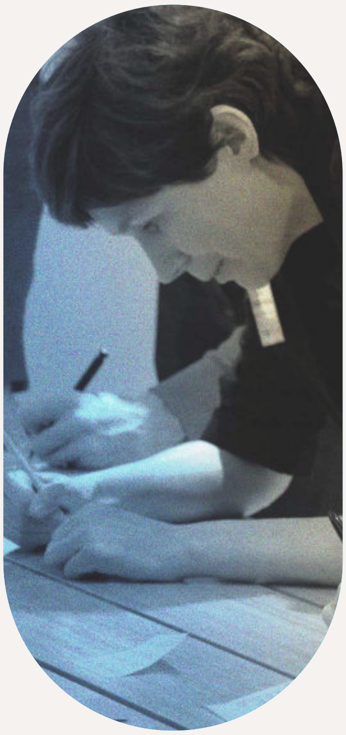
Developing mechanistic models (such as state-dependent speciation and extinction models) that explicitly link species traits and ecological characteristics to dispersal, extinction, and speciation rates.

Broadening trait-dependent approaches in climatic reconstructions based on fossil taxa. Methods like CLAMP (Climate Leaf Analysis Multivariate Program) and Leaf Margin Analysis (LMA) are well established for fossil leaves, but similar approaches should be expanded to other materials, such as pollen, diatoms, and phytoliths, to reduce the reliance on actualism in climate reconstructions.

5. The (in)Dependency Challenge

Reconstructed evolutionary histories and biogeographic patterns are often retrospectively used to infer past geological events—such as the emergence of geographic barriers or the timing of major climatic shifts—and are sometimes incorporated into geological reconstructions themselves. While these inferences can be informative, we highlight the long-term danger of **circular reasoning** when paleogeographic or geological reconstructions rely on biological data that were themselves modeled using those same reconstructions.

Future research must take special care to address this issue **by thoroughly separating biological data from the geological inputs** they inform—whether paleogeographic maps, climate reconstructions, or other datasets.



Conclusion

Integrating geological, climatic, and biological data into phylogenetic, biogeographic, and diversification models presents both immense opportunities and significant challenges. However, these challenges are not insurmountable, as the necessary platforms, tools, and methodologies already exist within our scientific communities. Interdisciplinary coordination and collaboration will be essential to overcoming these challenges and bridging methodological gaps.

The future of this interdisciplinary framework relies on a collective effort to refine existing tools, embrace uncertainties, and push the boundaries of our modeling of deep-time biodiversity and environmental change, ultimately deepening our understanding of the forces that have shaped life on Earth.

Two initiatives are already underway: the drafting of a white paper on the integration of geological data into biodiversity models, and the groundwork for a future European doctoral network, which will be further developed and formalized in the coming years.

Organizing Committee & Funding

Alexis LICHT (CEREGE, Aix-Marseille University) organized the workshop, with the administrative support of Sylvie DE FREITAS, Elodie GAZQUEZ (CEREGE) and the scientific advice of Fabien CONDAMINE (ISEM, Montpellier University) and Thomas COUVREUR (DIADE, IRD).

The workshop was supported by the ERC CoG DISPERSAL (Grant number 101043268) focusing on understanding and modeling past dispersal events, and sponsored by International Lithosphere Program Task Force Biogeodynamics of the Lithosphere. It also benefited from the support of CEREGE. It was hosted by Luma Arles.

List of Participants

Name	Institute	Country
BACON Christine	University of Gothenburg	SWEDEN
BEARD K. Christopher	Kansas University	USA
BETHANY Allen	GFZ Potsdam	GERMANY
BOSCHMAN Lydian	Utrecht University	THE NETHERLANDS
BOTTÉ Paul	CEREGE, Aix-Marseille University	FRANCE
BOUCHARAT Yannick	ISTERRE, Grenoble University	FRANCE
BOUCHER Florian	LEA, Grenoble University	FRANCE
BUFFAN Lucas	ISEM, Montpellier	FRANCE
CASTRO INSUA Adrian	Universidade de Vigo	SPAIN
CONDAMINE Fabien	ISEM, Montpellier University	FRANCE
COSTER Pauline	PNRL	FRANCE
COUVREUR Thomas	DIADE, IRD	FRANCE
DONNADIEU Yannick	CEREGE, Aix-Marseille University	FRANCE
DUPONT-NIVET Guillaume	Potsdam Universitat	GERMANY
FLUTEAU Frédéric	IPGP, Paris	FRANCE
GALVAN Sofia	Universidade de Vigo	SPAIN
GAMBOA Sara	Universidade de Vigo	SPAIN
GAZQUEZ Elodie	CEREGE, Aix-Marseille University	FRANCE
GENTIS Nicolas	MNHN, Paris	FRANCE
GIBERT BRET Corentin	Georgia Tech	USA
GOURBET Loraine	GFZ Potsdam	GERMANY
HOLZMEYER Laura	DIADE, IRD	FRANCE
HOORN Carina	IBED, University of Amsterdam	THE NETHERLANDS
HUSSON Laurent	ISTERRE, Grenoble University	FRANCE

JOURDAN Anne-Lise	CEREGE, Aix-Marseille University	FRANCE
KAYA Mustafa	METU, Ankara	TURKEY
KOEHL Jean Baptiste	University of Oslo	NORWAY
LE MERRER Julie	LEA, Grenoble University	FRANCE
LICHT Alexis	CEREGE, Aix-Marseille University	FRANCE
LORCERY Manon	ISTERRE, Grenoble University	FRANCE
MAFFRE Pierre	CEREGE, Aix-Marseille University	FRANCE
MEIJER Niels	Frankfurt Universitat	GERMANY
METAIS Grégoire	MNHN, Paris	FRANCE
METIVIER Thomas	IPGP, Paris	FRANCE
MONTHEIL Leny	CEREGE, Aix-Marseille University	FRANCE
MORLON Hélène	Ecole Normale Supérieure, Paris	FRANCE
OLSEN Sandi	Kansas University	USA
OTERO Olga	Poitiers University	FRANCE
PINEAU Erwan	CEREGE, Aix-Marseille University	FRANCE
QUINTERO Ignacio	Ecole Normale Supérieure, Paris	FRANCE
RAYNAUD Benjamin	MNHN, Paris	FRANCE
ROBERT Daniel	CEREGE, Aix-Marseille University	FRANCE
ROGGER Julian	ETH Zurich	SWITZERLAND
ROMAN Sabin	Cambridge	UK
SANCHEZ-MESEGUER Andrea	Real Jardín Botanico de Madrid	SPAIN
SANMARTIN Isabel	Real Jardín Botanico de Madrid	SPAIN
SHIPLEY Ben	Oxford	UK
STERNAI Pietro	University of Milano	ITALY
STREIFF Serafin	DIADE, IRD	FRANCE
TOURNIER Raphaël	ISTERRE, Grenoble University	FRANCE
VAES Bram	University of Milano	ITALY
WEPPE Romain	ISEM, Montpellier	FRANCE
WILLETT Sean	ETH Zurich	SWITZERLAND
XU Wei	DIADE, IRD	FRANCE