# Perspectives on Reproducibility and Replication of Results in Climate Science

## *A Paleoclimate Perspective*


https://climate.nasa.gov


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# Paleoclimate Reconstructions

1) Provides an important baseline
*to understand natural variations in the climate system, particularly in the preindustrial era*.

# Paleoclimate Reconstructions

2) Provides a natural laboratory to study climate dynamics
*especially outside of the range of climate conditions that have been experienced in the instrumental/historical period.*

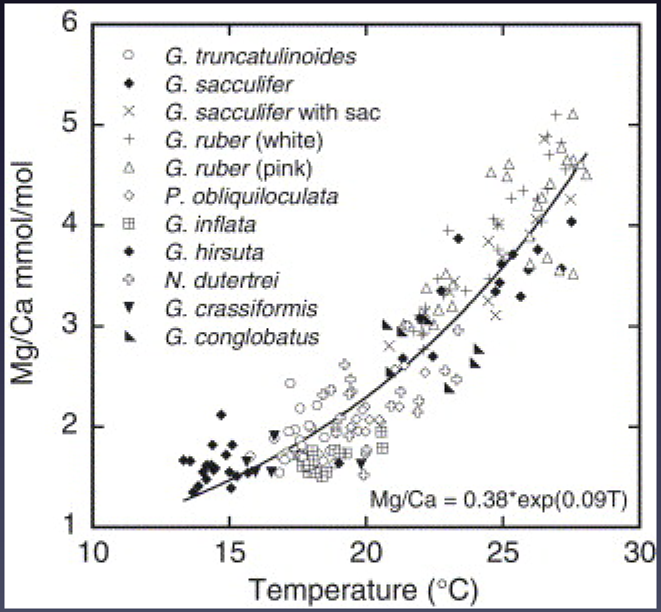
3) Provides important benchmarks
*that can be used to test and calibrate models of climate change, including those that are used to project future changes in climate, sea level, and ice sheets*

# Paleoclimate Reconstructions

**Paleoclimate proxies** are physical, chemical and biological materials preserved within the geologic record (in **paleoclimate** archives) that can be analyzed and correlated with climate or environmental parameters in the modern world.

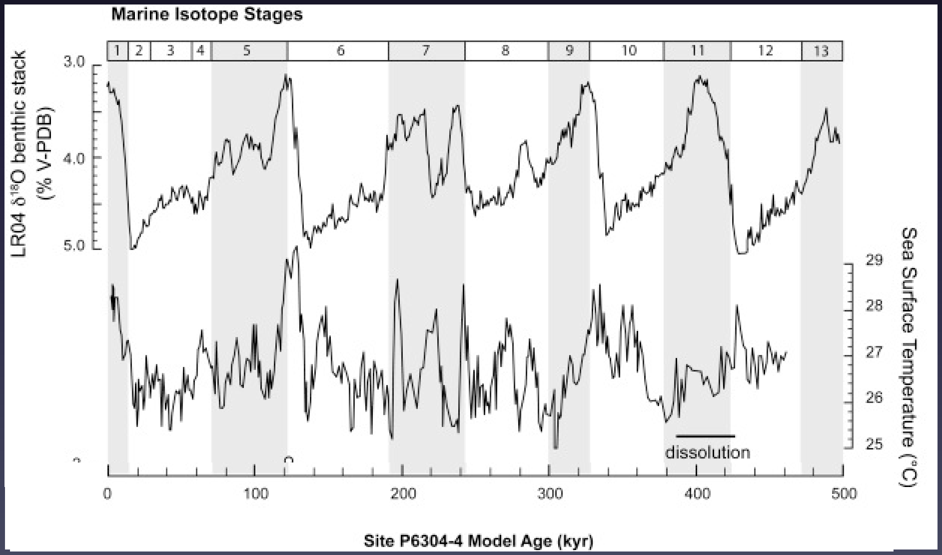
Much of the quantitative paleoclimate data comes from a chemical measurement of a geologic archive (ice/sediment/rock/fossil)

CALIBRATION




Anand et al. (2003) *Paleoceanography*

RECONSTRUCTION




Proxy Data

← Time

# NSF Paleo Perspectives on Climate Change (P2C2 Program)

## Synopsis:

The goal of research funded under the interdisciplinary P2C2 solicitation is to utilize key geological, chemical, atmospheric (gas in ice cores), and biological records of climate system variability to **provide insights into the mechanisms and rate of change** that characterized

- Earth's past climate variability,
- the sensitivity of Earth's climate system to changes in forcing, and
- the response of key components of the Earth system to these changes.

Important scientific objectives of P2C2 are to:

1) provide comprehensive paleoclimate data sets that can serve as **model test data sets** analogous to instrumental observations; and
2) Enable **transformative syntheses of paleoclimate data** and modeling outcomes to understand the response of the longer-term and higher magnitude variability of the climate system that is observed in the geological and cryosphere records.

Program Solicitation
NSF 17-582

# Evolution of Awareness & Understanding

How has the awareness and understanding about reproducibility and replication in climate science evolved over recent years?

**Public scrutiny** has increased awareness of quantifying uncertainties, increasing the transparency of data collection and analysis, increasing the rigor of statistical assessments, and to clearly express the limitations of the data and interpretations.

**Extensive synthetic work**, for example, exercises such as the IPCC, as well international working groups such as those funded by PAGES (Past Global Changes), have clarified consensus views and identified remaining challenges and gaps in our knowledge.

**Online data archiving** has become easier, more prevalent, and in many cases now required by journals and/or funding agencies, which increases the ability to reproduce and compare data.

# Historical & New Approaches to R & R

Highlight historical and potential new approaches to reproducing and replicating climate science research using examples such as paleoclimate data to test models and estimate uncertainties.

- Generally difficult to attract funding to try to reproduce someone's results unless there is a compelling reason to challenge the reconstruction.
- Samples may have been consumed during analysis.
- Field collection of replicate samples may not be feasible due to logistical or financial constraints.

Well-established practices for **reproducing** data:

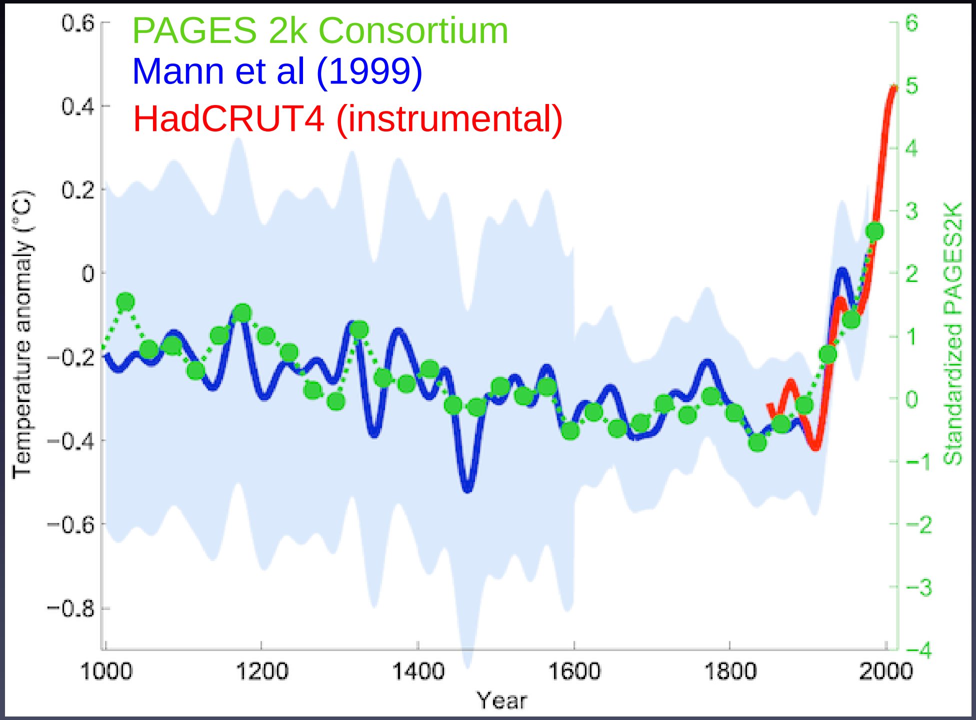
- Assessments of preservation of material
- "Replicate" analyses → repeat analyses of the same material
- Multiple subsamples of one sample to establish reproducibility and internal variability
- Reporting of widely distributed standards to assess inter-laboratory accuracy

# Historical & New Approaches to R & R

Well-established practices for **replicating** data:

Replication efforts typically focus on:

- Including more records (to fill gaps in time and space using more samples, cores, or sites)
- Comparing multiple proxies

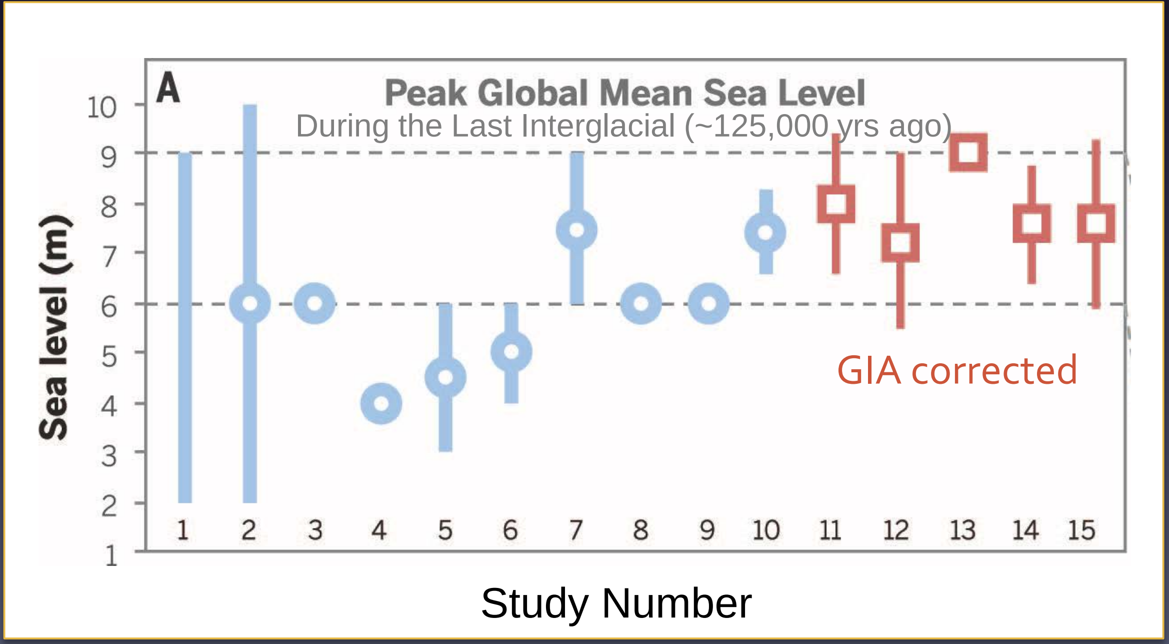



*Graph by K. Bitterman*

# Historical & New Approaches to R & R

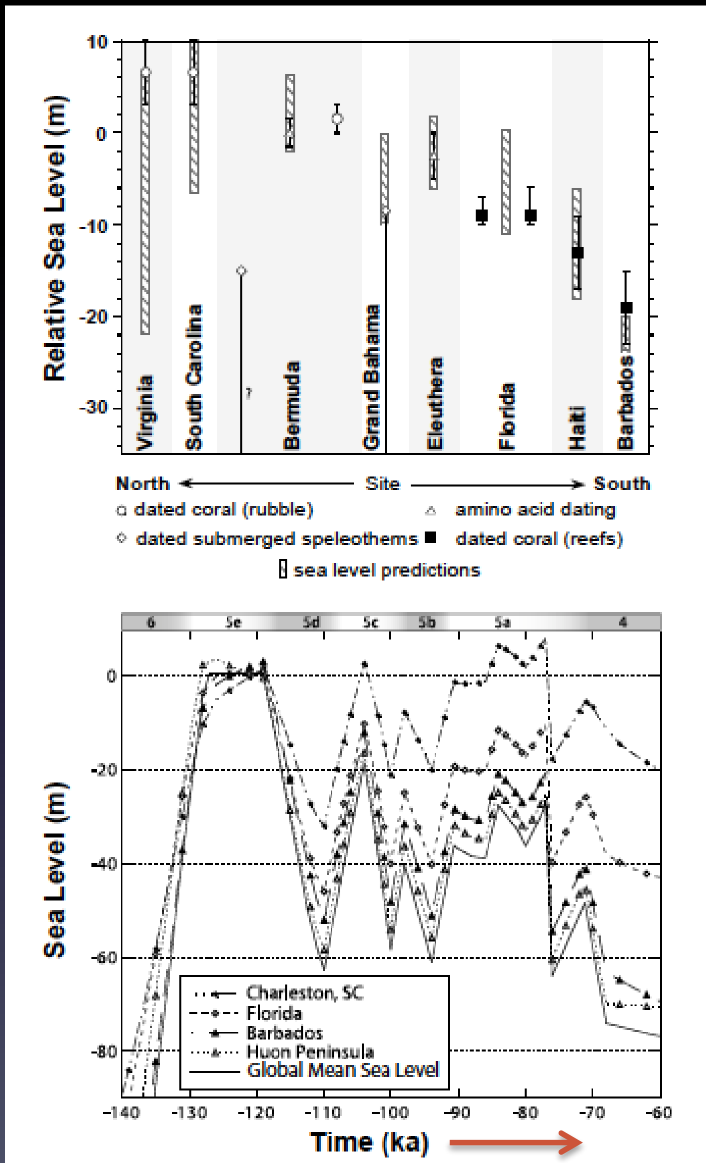
New practices for **replicating and reproducing** data:

- **Availability of data** accessible in open-access online databases facilitates synthetic analyses and comparisons of multiple reconstructions, multiple sites, and multiple proxies
- Continue to develop **new proxies**
- **Interdisciplinary approaches**, such as collaborations between geophysicists and geochemists to resolve discrepancies in reconstructions.  (Example → sea level reconstructions)



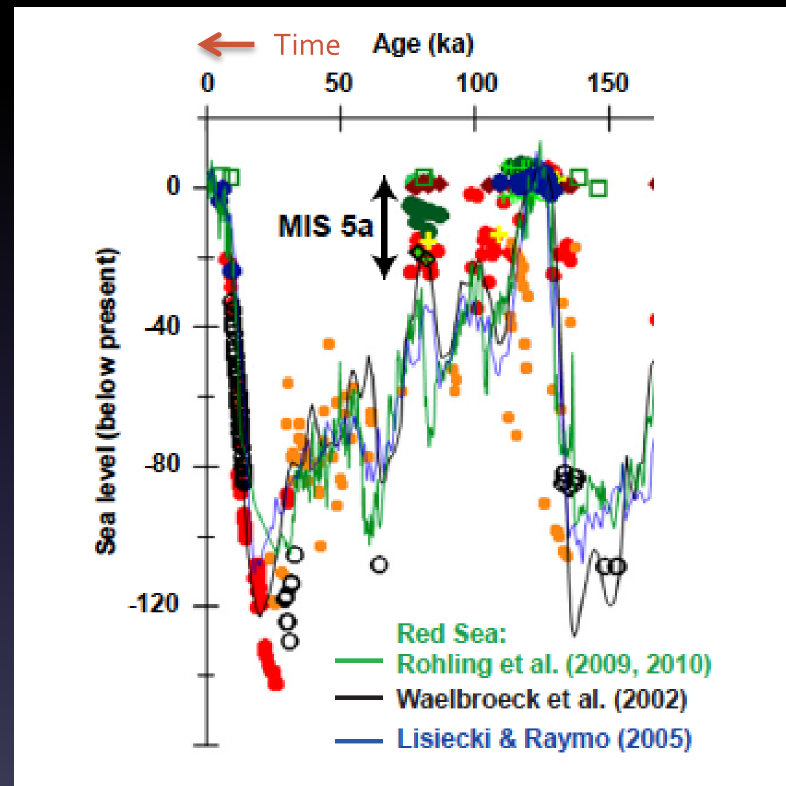

*Modified from* Dutton et al. (2015) *Science*

# Historical & New Approaches to R & R




Potter et al (2004) EPSL

## A new approach to developing a Sea level reconstruction




Medina-Elizade (2012) EPSL

# Challenges

Are there specific challenges regarding reproducibility that you have encountered or are aware of? Identify specific steps that are being taken, either by you or by others, to ameliorate these issues.

- Incomplete reporting or archiving of data or metadata, due to lack of established standards of data-reporting or lack of enforcement in data reporting by editors or funding agencies

Steps being taken:

Quaternary Geochronology 39 (2017) 142–149

Contents lists available at ScienceDirect

Quaternary Geochronology

journal homepage: www.elsevier.com/locate/quageo

ELSEVIER

Research paper

Data reporting standards for publication of U-series data for geochronology and timescale assessment in the earth sciences

A. Dutton [a,*], K. Rubin [b], N. McLean [c], J. Bowring [d], E. Bard [e], R.L. Edwards [f], G.M. Henderson [g], M.R. Reid [h], D.A. Richards [i], K.W.W. Sims [j], J.D. Walker [c], Y. Yokoyama [k]

Discipline standards

IEDA

EarthCube

NSF-DIBBs

Cyberinfrastructure development

Increase in policies & awareness, e.g., must report data within 2 yrs. of collection or upon publication

Enforcement

# Challenges

- If internationally accepted standards do not exist, can be hard to transition to a new practice of introducing a standard that everyone must use.

Steps being taken: Example → U-series (U-Th) dating

- Lacks use of a common standard used between labs,
- Refinement of value (and uncertainty) of decay constant values for the isotopes involved means that ages published with different decay constants cannot be directly compared,
- Inconsistent practices in data-reporting make recalculation (normalization) of ages difficult to impossible

EARTHTIME
ACCELERATING ADVANCES IN GEOCHRONOLOGY SINCE 2003

U-Pb dating & Ar-Ar dating

Prior successes

NSF-DIBBs THPb

IEDA

EarthCube

Cyberinfrastructure development

Funded by NERC

Colleagues in UK

Development & Distribution of Laboratory Standards

# Summary

- Different subdisciplines within the paleoclimate community are at different stages in terms of the calibration of paleoclimate proxies and timescales
- Some of these techniques require continual assessment and oversight by an international group
- Large scale comparative and synthesis work often carried out by international working groups has a challenging funding model
- In general, rigorous practices of replication reproducibility (in sampling and measurement) and interlaboratory calibration are well-established and are expected procedures
- Practices of error propagation and quantification of uncertainty are not always transparent
- Adherence to rigorous data reporting and archiving can still be difficult to achieve and is a challenge for legacy data
- Database development that brings together multiple proxies remains difficult