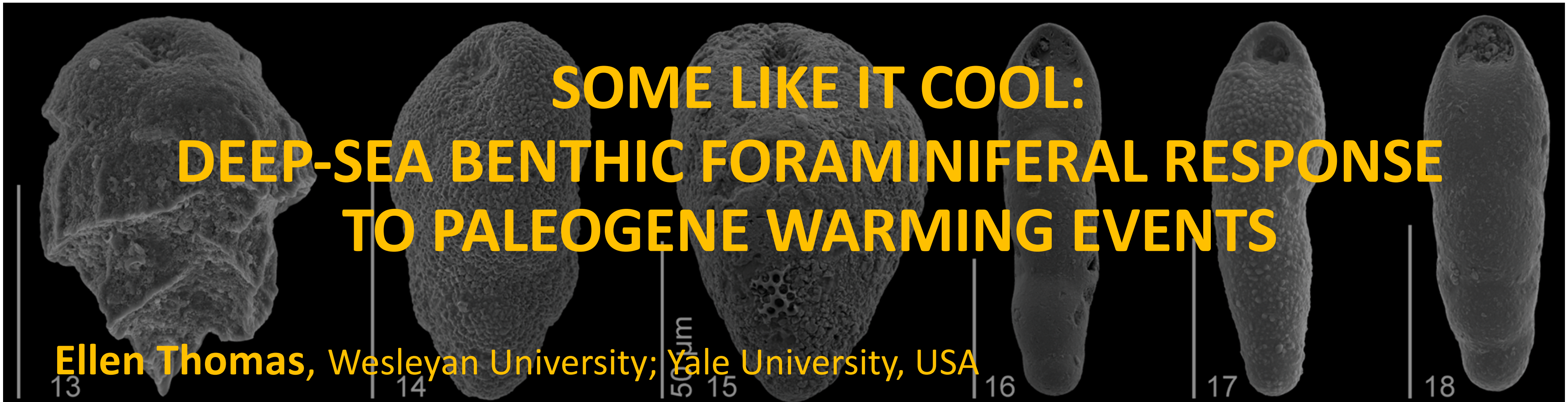


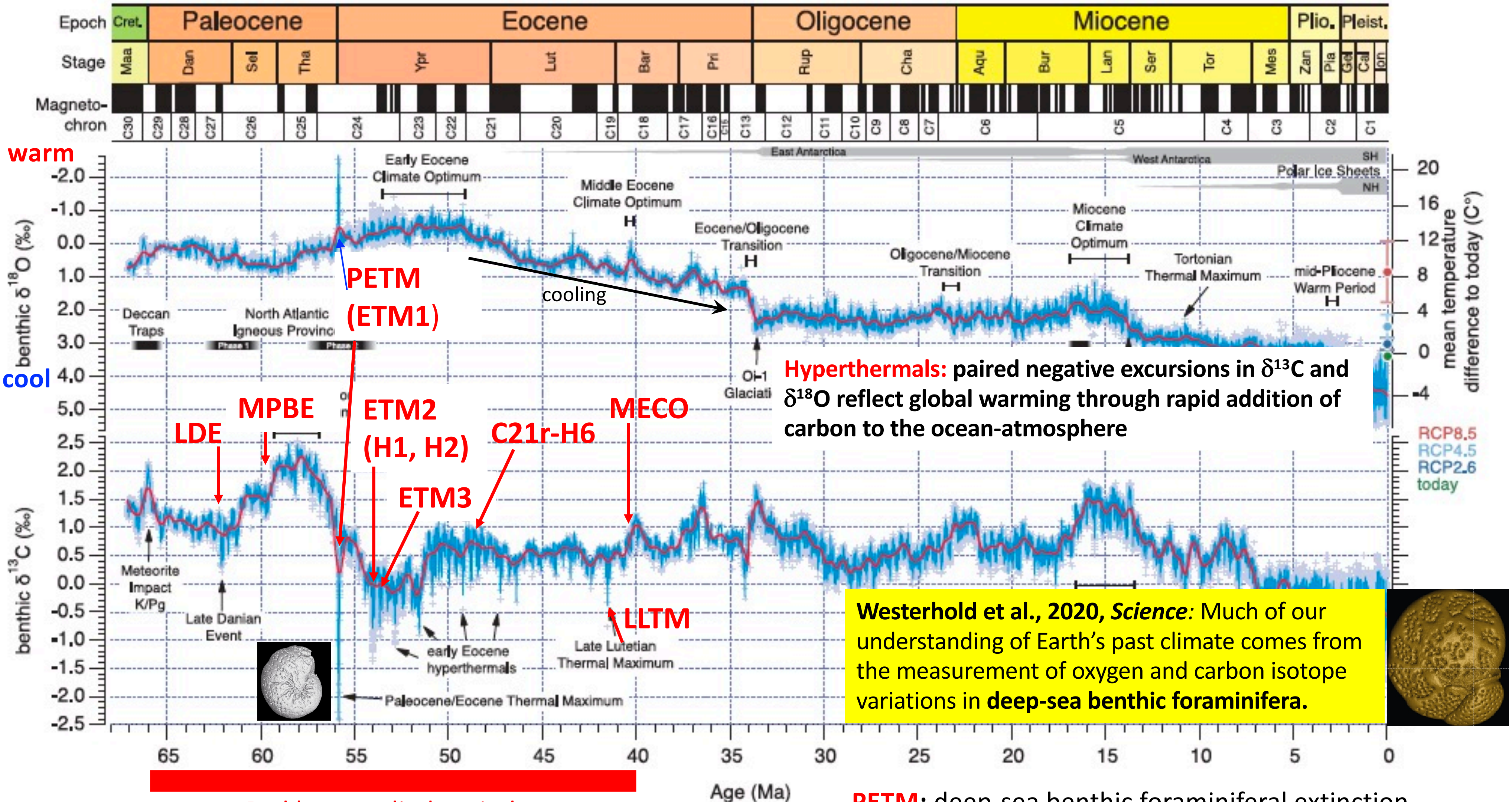
SOME LIKE IT COOL: DEEP-SEA BENTHIC FORAMINIFERAL RESPONSE TO PALEOGENE WARMING EVENTS

Ellen Thomas, Wesleyan University; Yale University, USA

Gabriela Arreguín-Rodríguez, Universidad Autónoma de Baja California, Mexico

Laia Alegret, University of Zaragoza, Spain

Session 174-T80, presentation 6



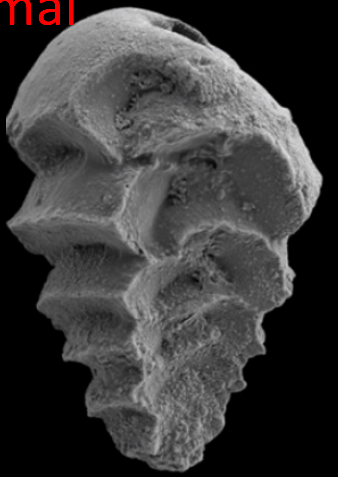
Hyperthermals: paired negative excursions in $\delta^{13}C$ and $\delta^{18}O$ reflect global warming through rapid addition of carbon to the ocean-atmosphere

Westerhold et al., 2020, *Science*: Much of our understanding of Earth's past climate comes from the measurement of oxygen and carbon isotope variations in **deep-sea benthic foraminifera.**

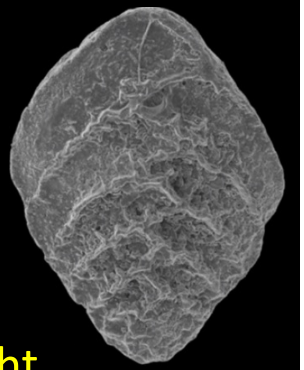
Red bar: studied period

PETM: deep-sea benthic foraminiferal extinction

Typical hyperthermals – similar to anthropogenic global warming: **L**atest **D**anian **E**vent, **M**iddle **P**aleocene **B**iotic **E**vent, **P**aleocene **E**ocene **T**hermal **M**aximum, **E**ocene **T**hermal **M**aximum 2 (H1, H2), **E**ocene **T**hermal **M**aximum 3



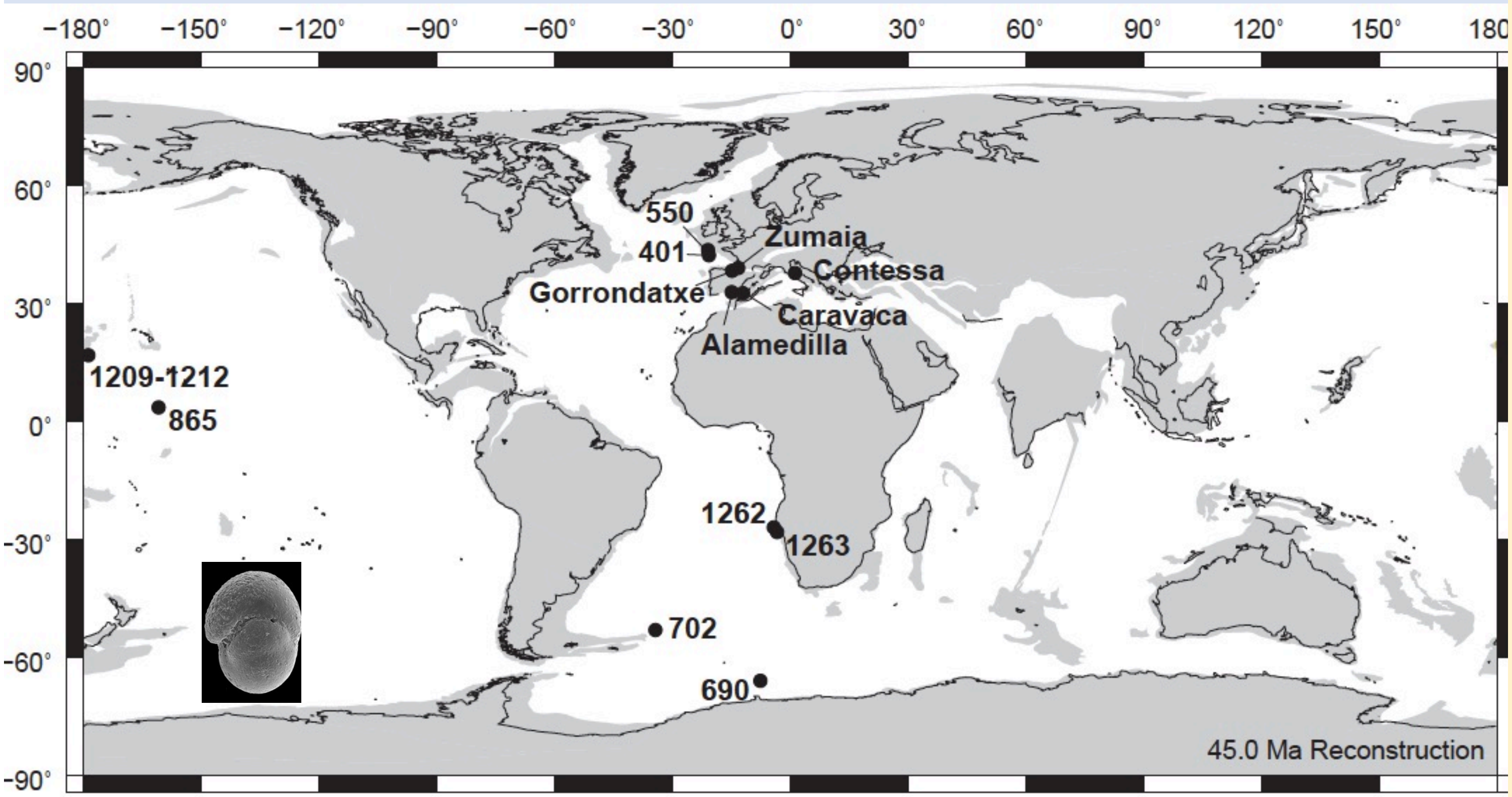
- $\delta^{13}C$ – Carbon Isotope Excursion (lighter values – emission of isotopically light carbon in ocean-atmosphere)
- $\delta^{18}O$ and other temperature proxies: warming – linked to $\delta^{13}C$ CIE
- Evidence of $CaCO_3$ dissolution (rise in Calcium carbonate Compensation Depth)
- Global signals
- Rapid onset, slower recovery
- Orbital cyclicity – maximum in eccentricity



Other Eocene episodes of warming: C21r-H6, **L**ate **L**utetian **T**hermal **M**aximum, **M**iddle **E**ocene **C**limate **O**ptimum

- No clear correlation between $\delta^{18}O$ and $\delta^{13}C$ excursions (warming - isotopically light carbon emission), no clear correlation to carbonate dissolution, signals not global

Benthic foraminiferal (> 63 or 100 μm) published records from 9 'hyperthermal' events at 16 locations (25 case studies), paleodepth ≥1000 m.



- **MECO (1)**: **702** (Rivero-Cuesta et al., 2020)
- **LLTM (1)**: **702** (Rivero-Cuesta et al., 2019)
- **C21r-H6 (1)**: **Gorrondatxe** (Payros et al., 2012)
- **ETM3 (3)**: **865** (Arreguín-Rodríguez et al., 2016); **1262**, **1263** (Arreguín-Rodríguez et al., 2018; Thomas et al., 2018)
- **H2 (1)**: **550** (Arreguín-Rodríguez & Alegret, 2016)
- **ETM2 (4)**: **401** (d'Haenens et al., 2012; Arreguín-Rodríguez et al., 2018); **550** (Arreguín-Rodríguez & Alegret, 2016); **1262**, **1263** (Jennions et al., 2015)
- **PETM (10)**: **690** (Thomas, 1990); **1209**, **1210**, **1211**, **1212** (Takeda & Kaiho, 1207); **Zumaia** (Alegret et al., 2009, 2018); **Alamedilla** (Alegret et al., 2009); **Contessa** (Giusberti et al., 2009); **865** (Arreguín-Rodríguez et al., 2018)
- **MPBE (2)**: **Zumaia** (Bernaola et al., 2016); **1262** (Arreguín-Rodríguez et al., in prep.)
- **LDE (2)**: **Caravaca** (Alegret et al., 2016); **1210** (Deprez et al., 2017)

We compiled published data; **calculated diversity** (Fisher-α); statistically tested differences between time slices (**before**, **during**, **after event,** $\delta^{13}C$ record)

- Fisher-α diversity index, calculated:

$$S = \alpha * ln(1 + (n/\alpha))$$

S = number of taxa; *n* = number of individuals

(Matlab; iterative algorithm for solving non-linear algebraic equations, Newton-Raphson method; e.g., Ypma, 1995).

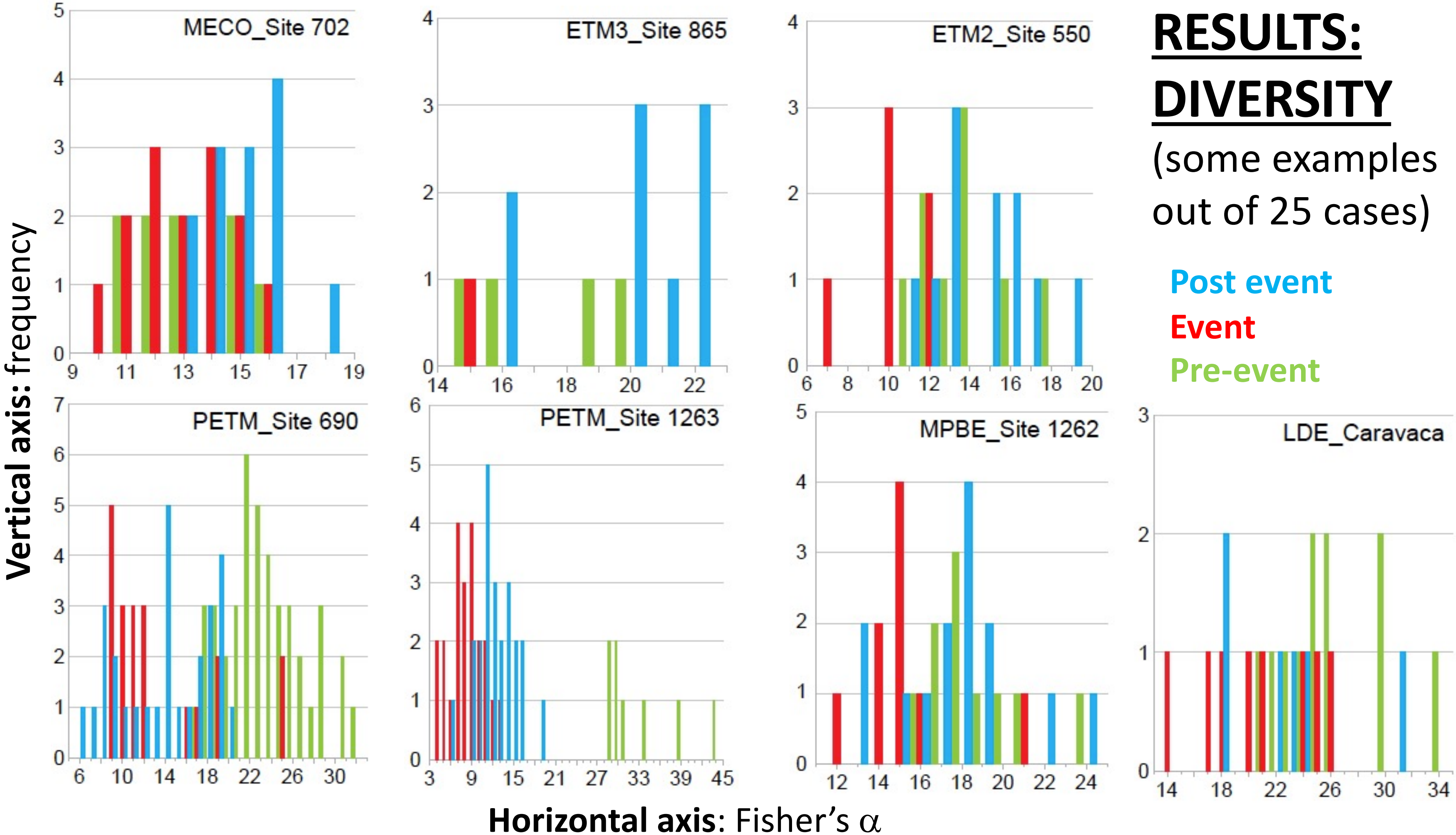
Non-parametric tests:

- Epps-Singleton test (W2, Epps and Singleton, 1986): search for equal distributions (i.e., similar amount of data on specific diversity values)
- Fligner-Killeen test (T, Fligner and Killeen, 1976): comparison of coefficients of variation (i.e., standard deviation/mean value)

PAST software (Hammer et al., 2001)

RESULTS: DIVERSITY

(some examples out of 25 cases)



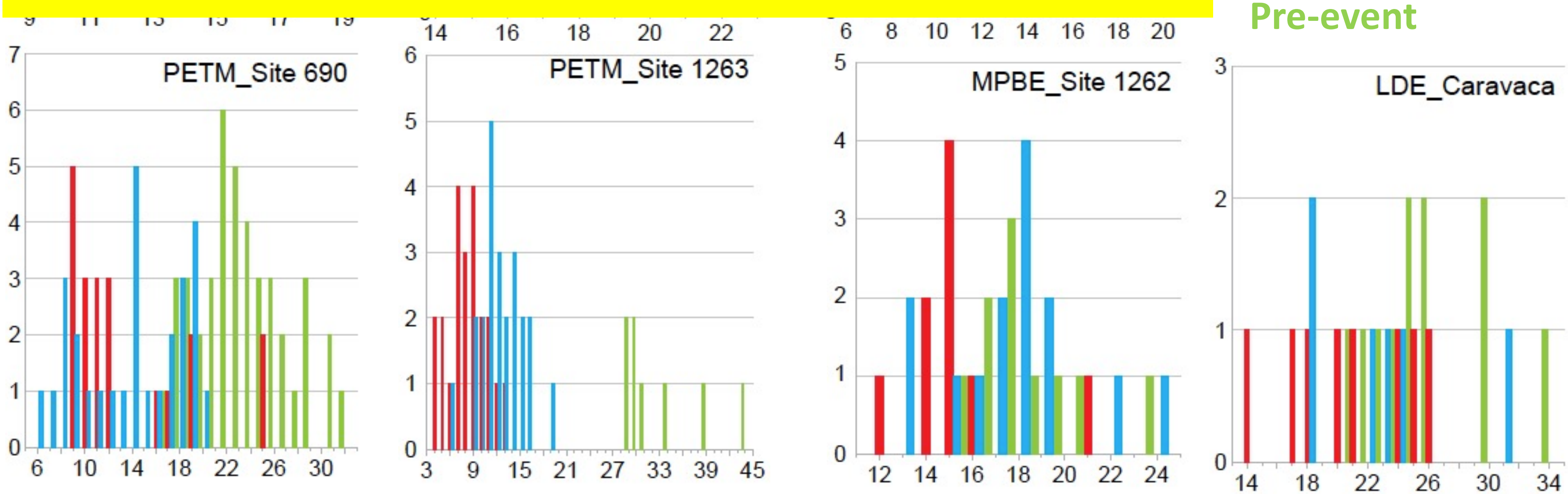
RESULTS: DIVERSITY

(some examples)

MOST (but not all) lower diversity **during event** than **before event** (red bars shifted to left relative to green bars). Significant (p-value < 0.05): almost all PETM (except 1211), all ETM2, 1262 MPBE, 1263 ETM3, Gorrondatxe C21r-H6. **PETM**: no full recovery within studied interval (**pre-event green bars** to right of **post-event blue bars**).

Post event
Event
Pre-event

Vertical axis: frequency

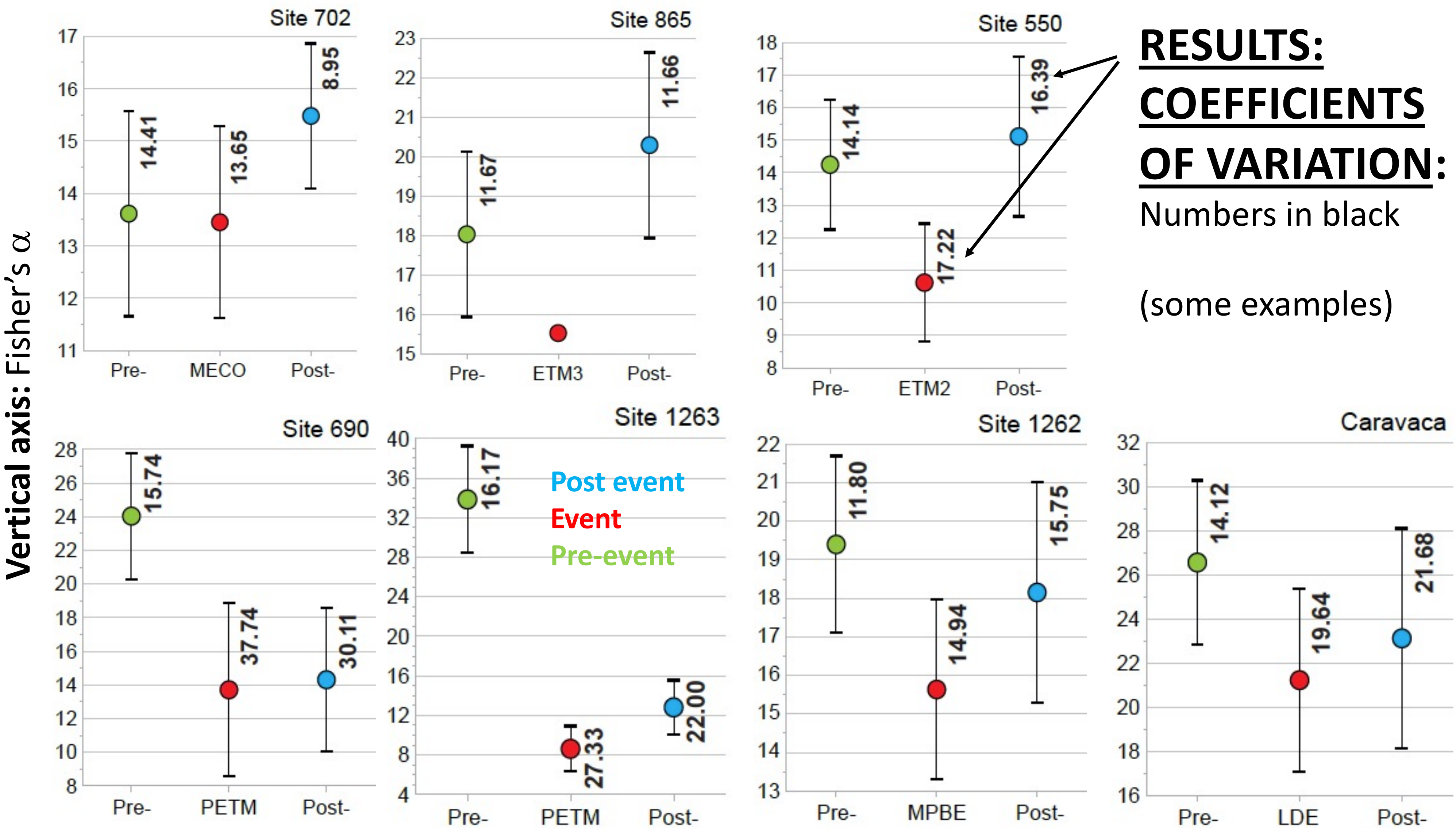


Horizontal axis: Fisher's α

RESULTS: COEFFICIENTS OF VARIATION:

Numbers in black

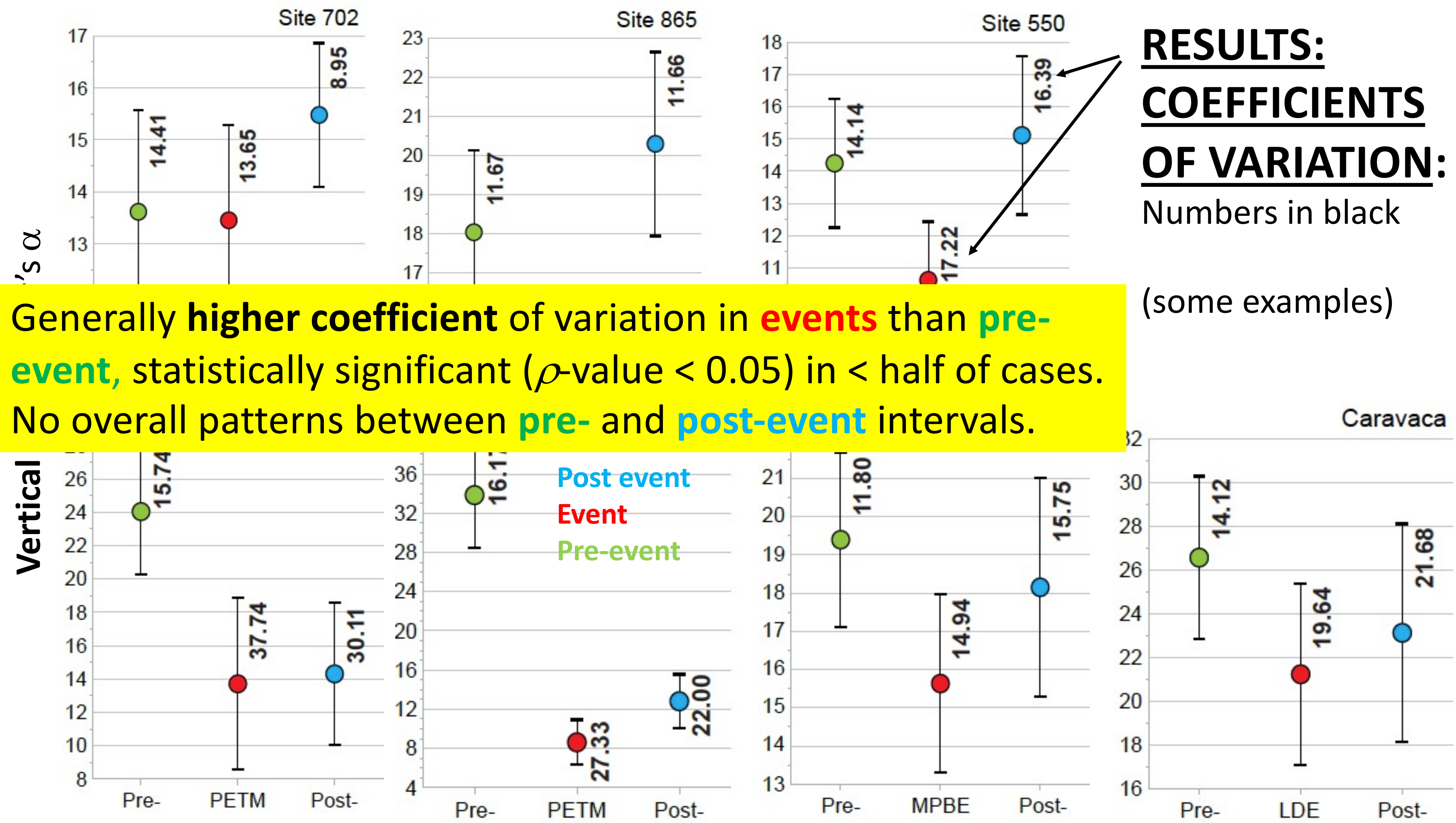
(some examples)



RESULTS: COEFFICIENTS OF VARIATION:

Numbers in black

(some examples)

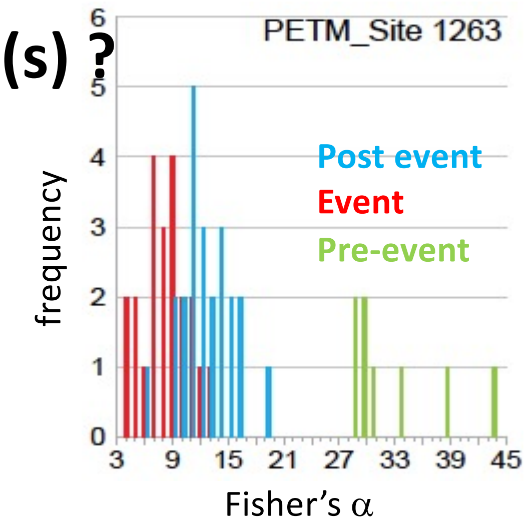


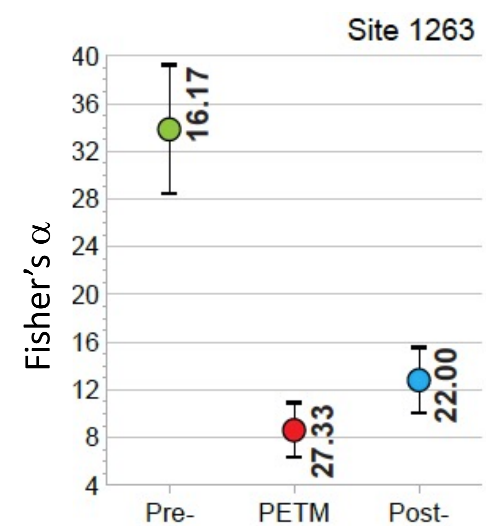
Generally **higher coefficient** of variation in events than pre-event, statistically significant (ρ-value < 0.05) in < half of cases.
No overall patterns between pre- and post-event intervals.

<u>Decreased diversity</u> during hyperthermals: environmental stress, but what kind of stress factor(s) ?

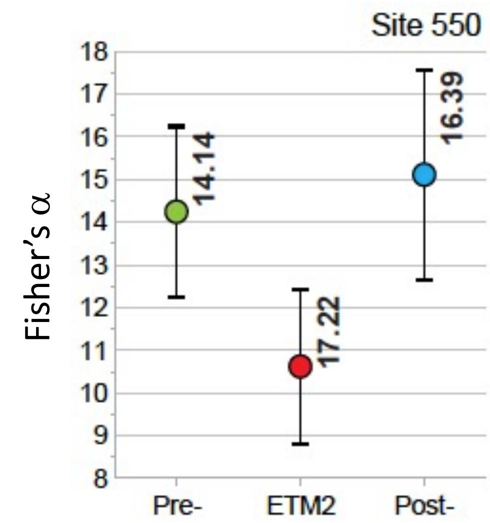
- **Direct effects** on benthic assemblage: **warming** – metabolic rates (higher food demand), rates of remineralization organic matter => starvation.
- **Indirect effects**: ocean acidification; deoxygenation; perturbation hydrological cycle – effects on productivity, lateral transport of organic matter (non-linear)

- **Warming itself** – **common factor in all events**, and **global during PETM:** extinction in benthic foraminifera, efficient dispersers (propagules) in the largest habitat on Earth
- **However**: ~40-50% of the benthic foraminiferal diversity variance at Site 1262 is explained by $\delta^{13}C$ and $\delta^{18}O$ across PETM and ETM2 => other factors may have played a role



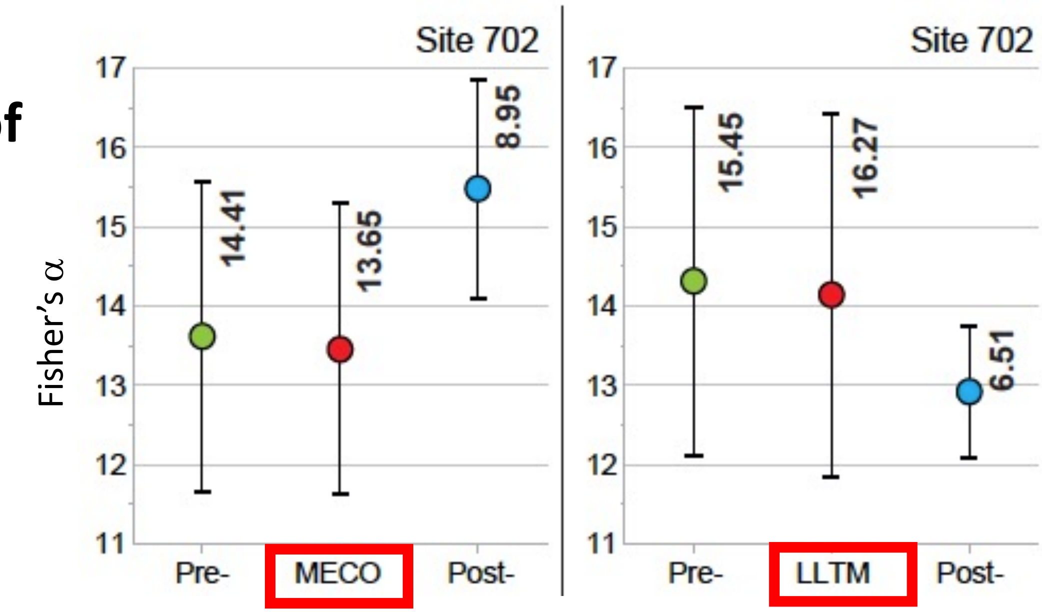


Increased variability in diversity during hyperthermals – ecosystem instability?

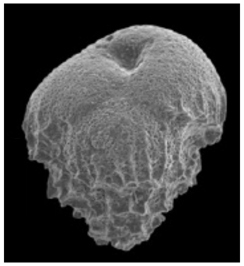


Could instability of the ecosystems have prevented benthic foraminifera from optimally adapting to environmental conditions? E.g. variability in phytoplankton productivity and/or export productivity?

- **Marked increase in stabilization of assemblages** (i.e., decreased coefficients of variation) after **middle Eocene** warming events (LLTM, MECO), i.e., in the cooling world after Early Eocene Climate Optimum.

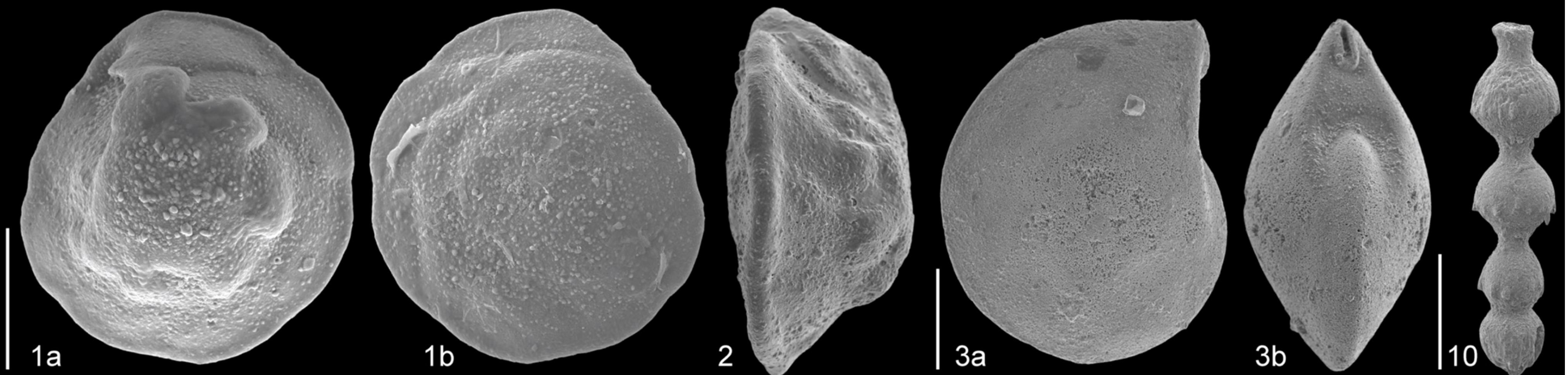


Conclusions



- **Overall,** benthic foraminiferal assemblages **decreased in diversity** (Epps-Singleton test) and/or **increased in variability** of diversity values (Fligner-Killeen test) during most studied warming events; not all statistically significant during lesser events
- Significantly **higher stability in the post-event intervals** in the **cooler middle Eocene,** not in the **warmer Paleocene-early Eocene**: overall cooler conditions were more favorable for recovery of benthic foraminiferal assemblages after episodes of warming (higher temperatures may decrease resilience in recent marine ecosystems)
- **Strongest drop in diversity during more severe events** (extinction only in most severe event, PETM), but no clear correlation between size of event and diversity drop: possibly, ***temperature threshold values*** for benthic foraminifera were not reached during relatively minor warming events and at cooler background temperatures.

Thank you for your attention



Funding by PRODEP, Mexico (UABC-PTC-762-511-6/2019-7930) (GAR), project PID2019-105537RB-I00 (Spanish Ministry of Science and Innovation and FEDER funds (LA), and NSF OCE 1536611 (ET).

Thanks to Roberto Enriquez, Beatriz Atienza and Rafael Hernández