Atmospheric CO_2 during the Mid-Piacenzian Warm Period and the M2 glaciation

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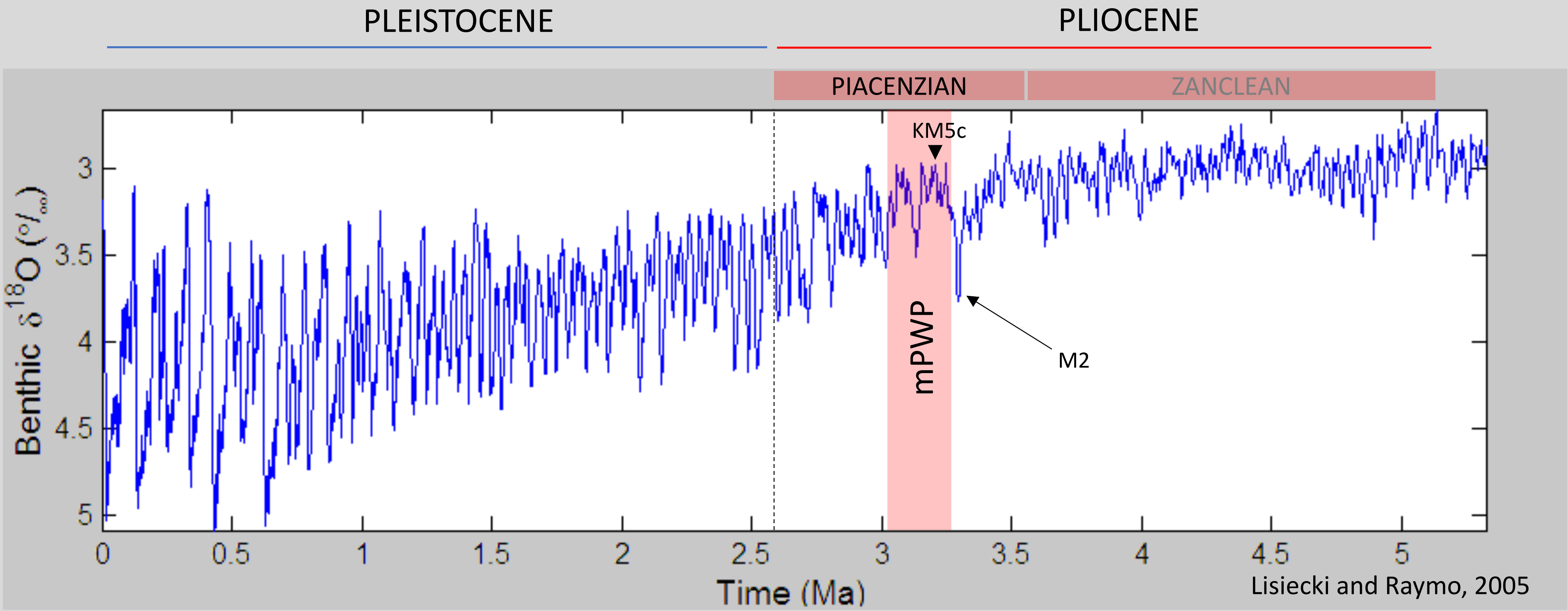
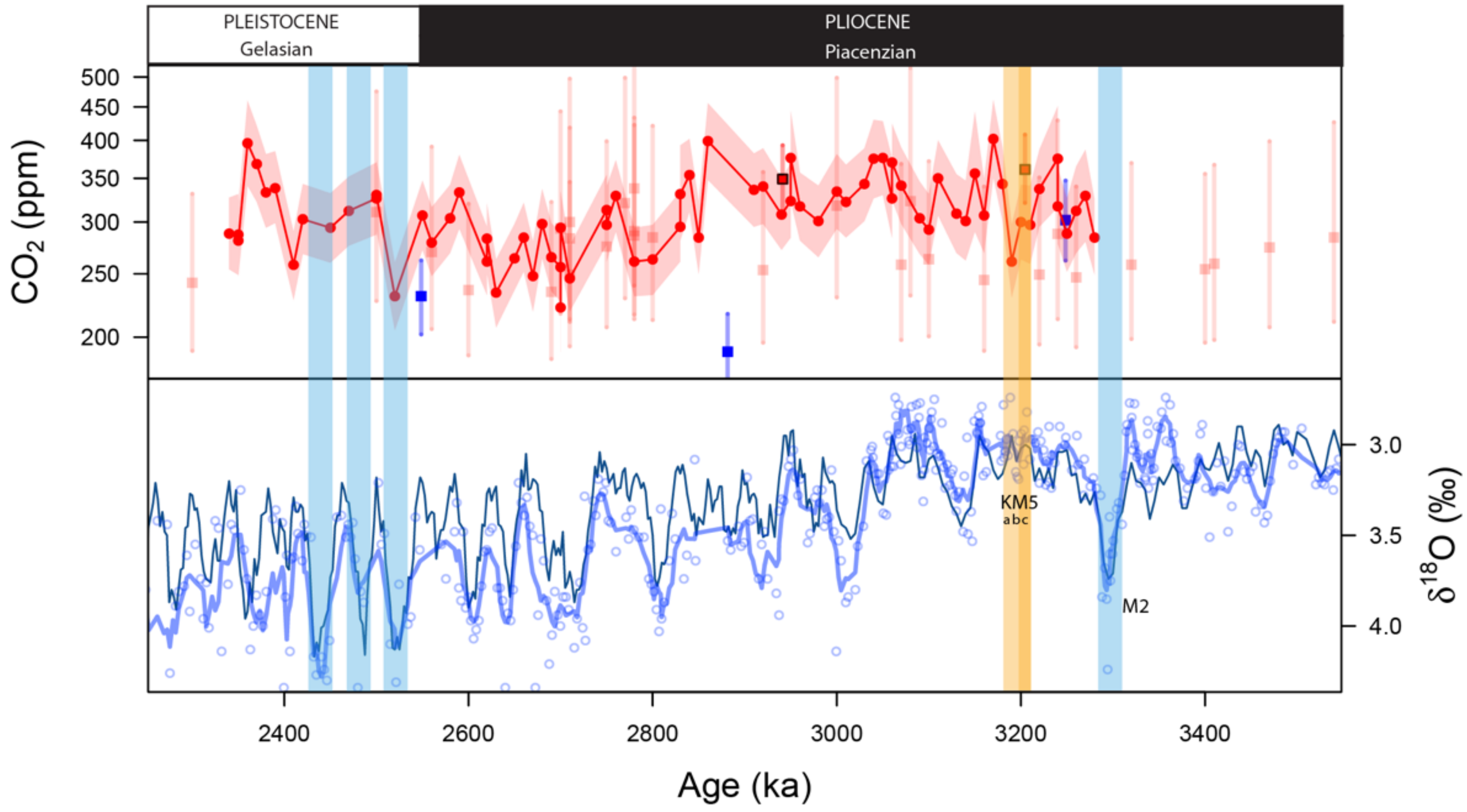
Why Study the mid-Piacenzian warm period (mPWP)?

- The mPWP is a warm interval where CO_2 is thought to be comparable to modern values (based on current CO_2 reconstructions), it includes MIS KM5c and is preceded by MIS M2.



Why Study the mid-Piacenzian warm period (mPWP)?

- Current CO_2 data sets are low in resolution to capture the variations in these intervals and some disagreement between records exist.



Published $\delta^{11}B$-CO_2 records and methods of measurement.

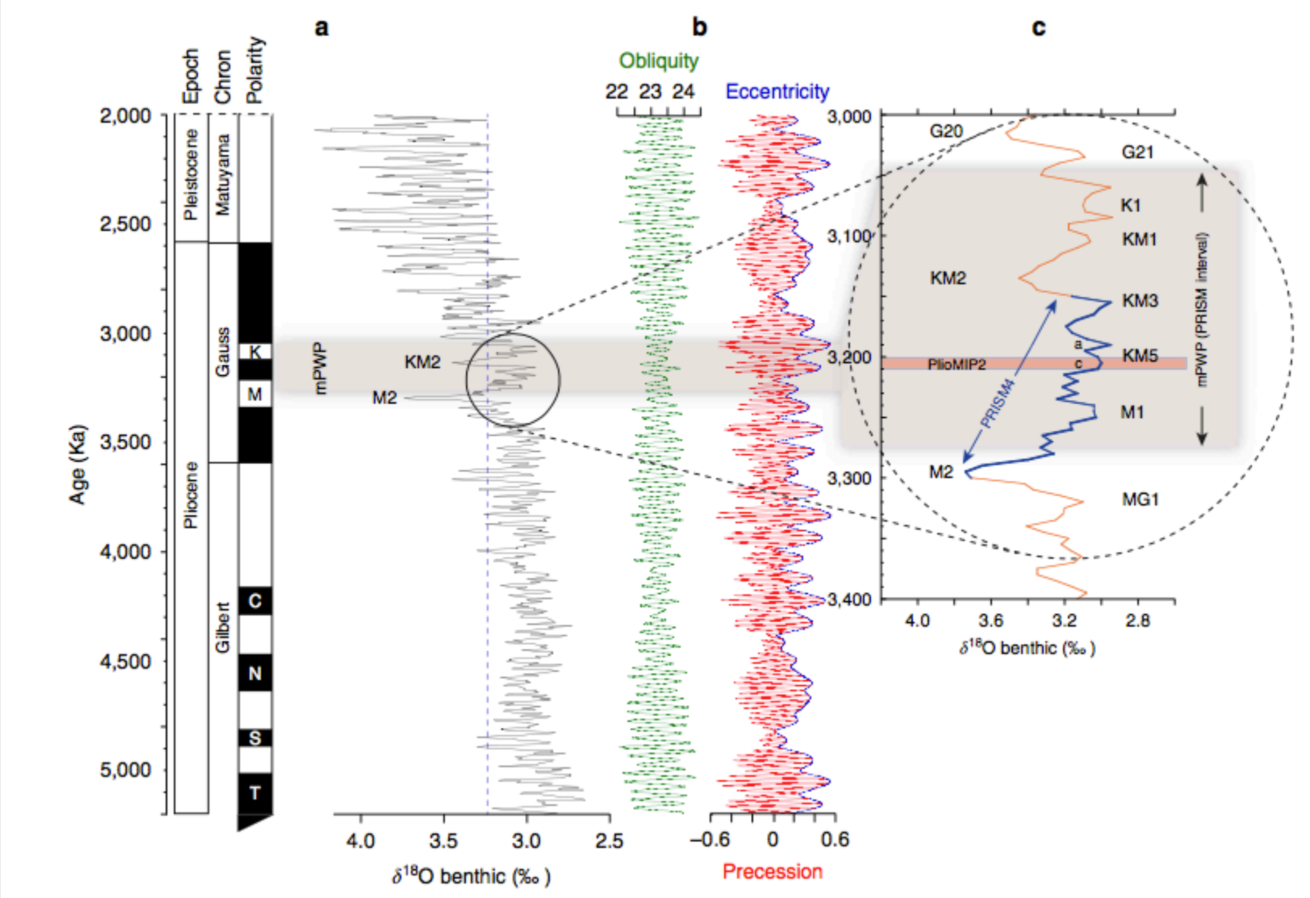
- Site 999 $\delta^{11}B$ from *G. ruber* (Martinez-Botí et al., 2015). MC-ICPMS
- Site 999 $\delta^{11}B$ from *T. sacculifer* (Seki et al., 2015). MC-ICPMS
- Site 999 $\delta^{11}B$ from *T. sacculifer* (Bartoli et al., 2011). NTIMS
- Site 926 $\delta^{11}B$ from *T. sacculifer* (Sosdian et al., 2018). MC-ICPMS

Why Study the mid-Piacenzian warm period (mPWP)?

1. The KM5c interval

KM5c is established as a key interval for CO_2 reconstructions.

- Similar orbital configuration than today.
- Near modern boundary conditions.
- Range of CO_2 comparable to today based on existing proxy evidence.
- Ideal period to test the response of the climate system (e.g. temperature, sea-level) to elevated/similar levels of CO_2 from today.



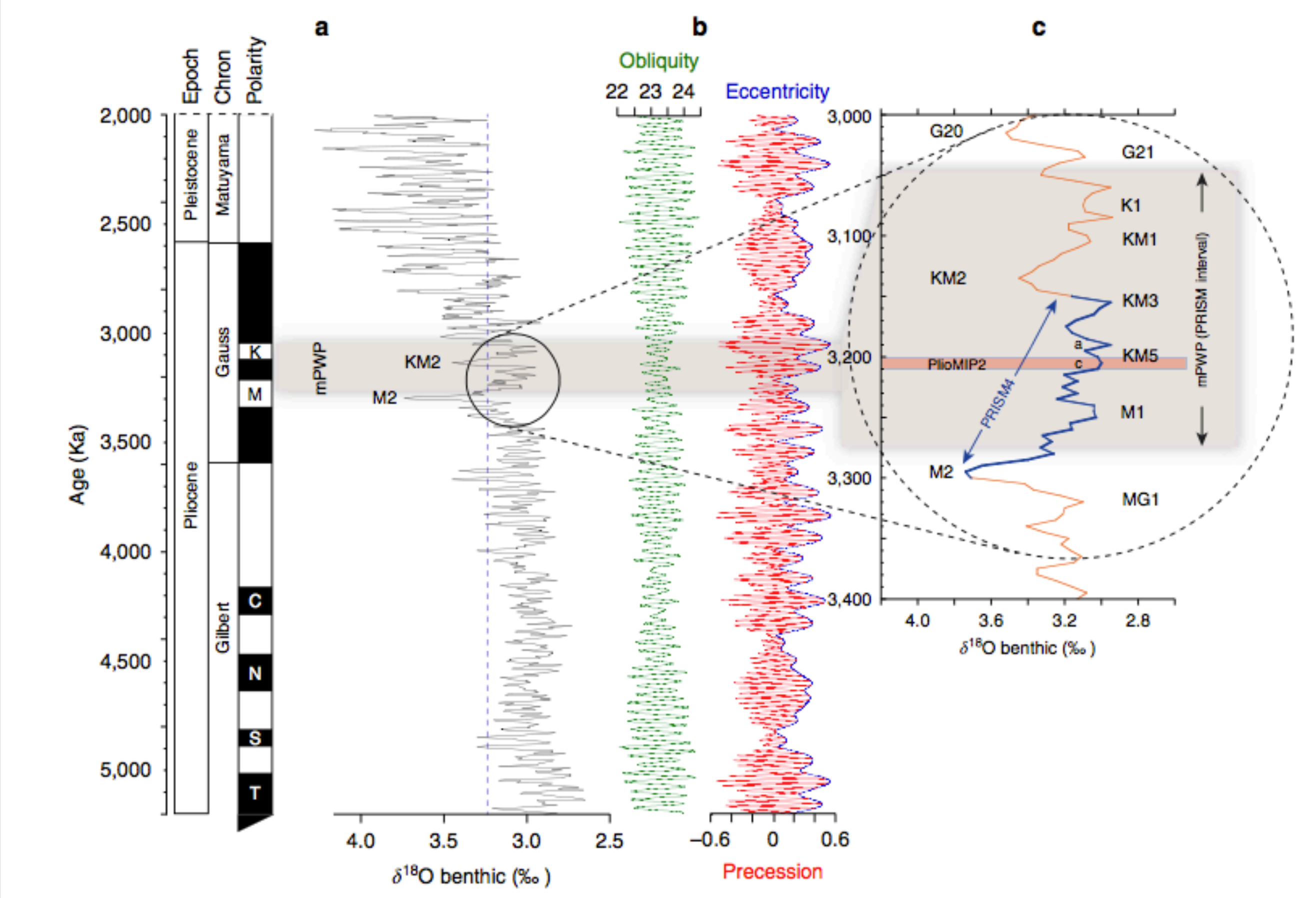
Haywood et al., (2016)

Why Study the mid-Piacenzian warm period (mPWP)?

2. The M2 glaciation

M2 is an period of marked glaciation within a warm period where no apparent orbital forcing seem present to trigger such a large glaciation.

- Knowing CO_2 during the M2 interval will enable us to determine the role of CO_2 in this enigmatic event and underlying mechanisms and radiative forcing.



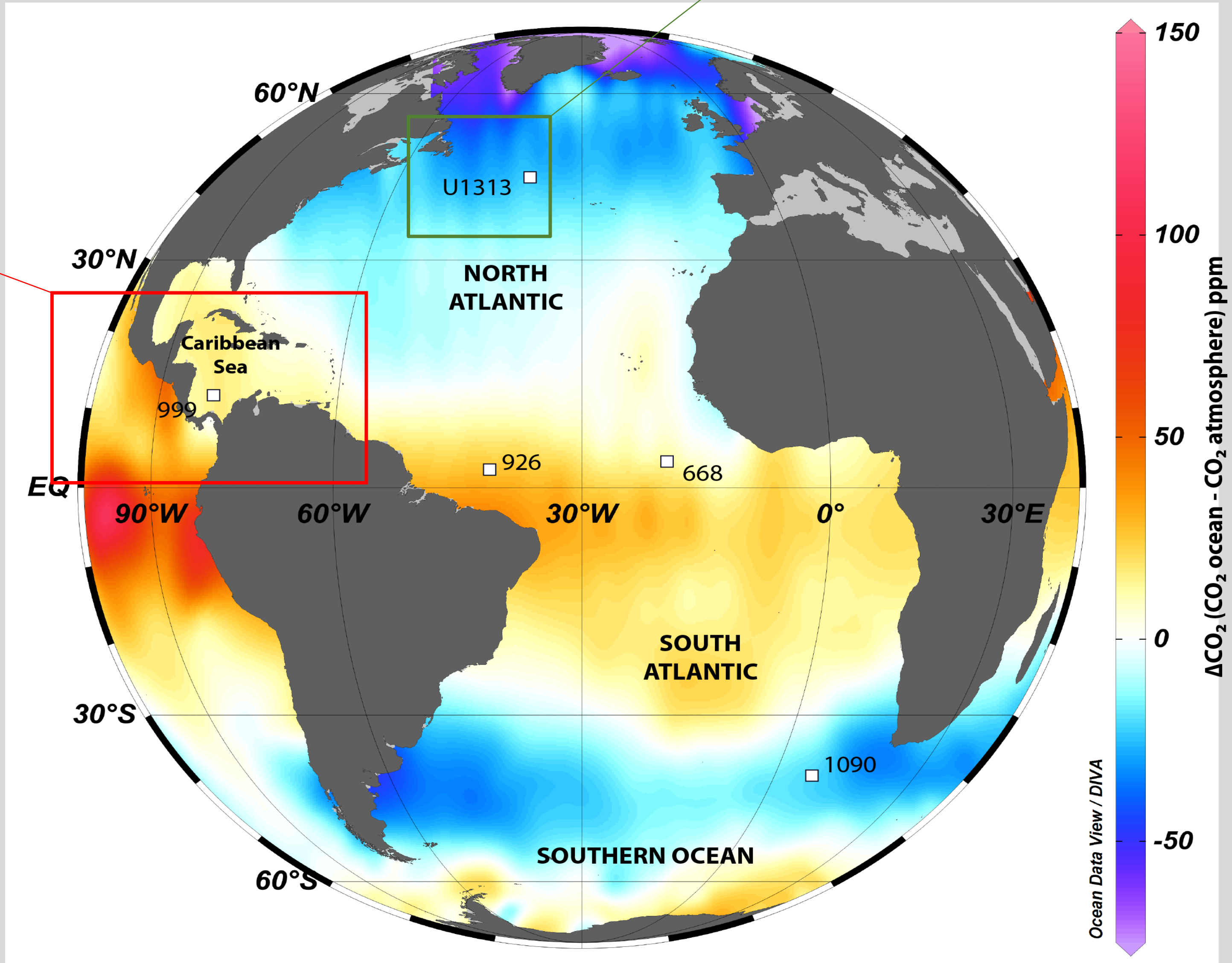
Haywood et al., (2016)

Study location

U1313 for Nd data and water mass changes (Lang et al., 2016)

ODP site 999

- New $\delta^{11}B$-derived CO_2 reconstructions.
-western Caribbean
- Minor source of CO_2 to the atmosphere : + 20 ppm



Input parameters for the $\delta^{11}B$-pH proxy

Material *Globigerinoides ruber (sensu stricto) white*

pH Calculation. Input parameters:

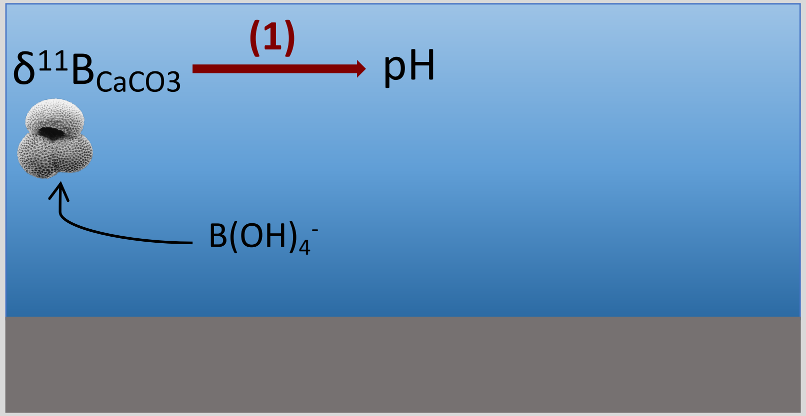
$\delta^{11}B_{sw}$=39.61‰ (modern value)

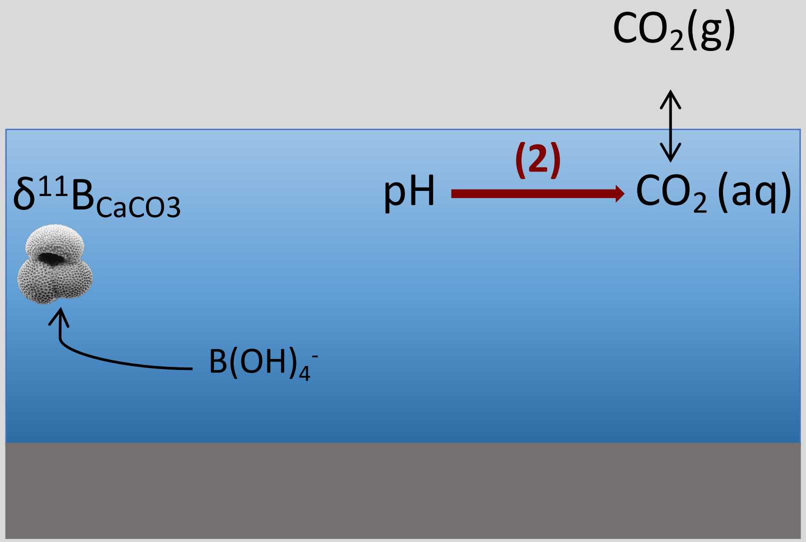
$$pH = pK_B^* - log\left(\frac{\delta^{11}B_{B(OH)_4^-} - \delta^{11}B_{sw}}{\delta^{11}B_{sw} - {}^{11-10}K_B * \delta^{11}B_{B(OH)_4^-} - 1000 * ({}^{11-10}K_B - 1)}\right)$$

Function of:
-Temperature : Mg/Ca derived corrected for Mg/Ca of seawater
-Salinity: modern value used

Species-specific $\delta^{11}B$ $B(OH)_4^-$/foram relation from calibration by Henehan et al. (2013)

$^{11-10}K_B$=1.0272 (Klochko *et al.*, 2006)
Isotopic fractionation factor

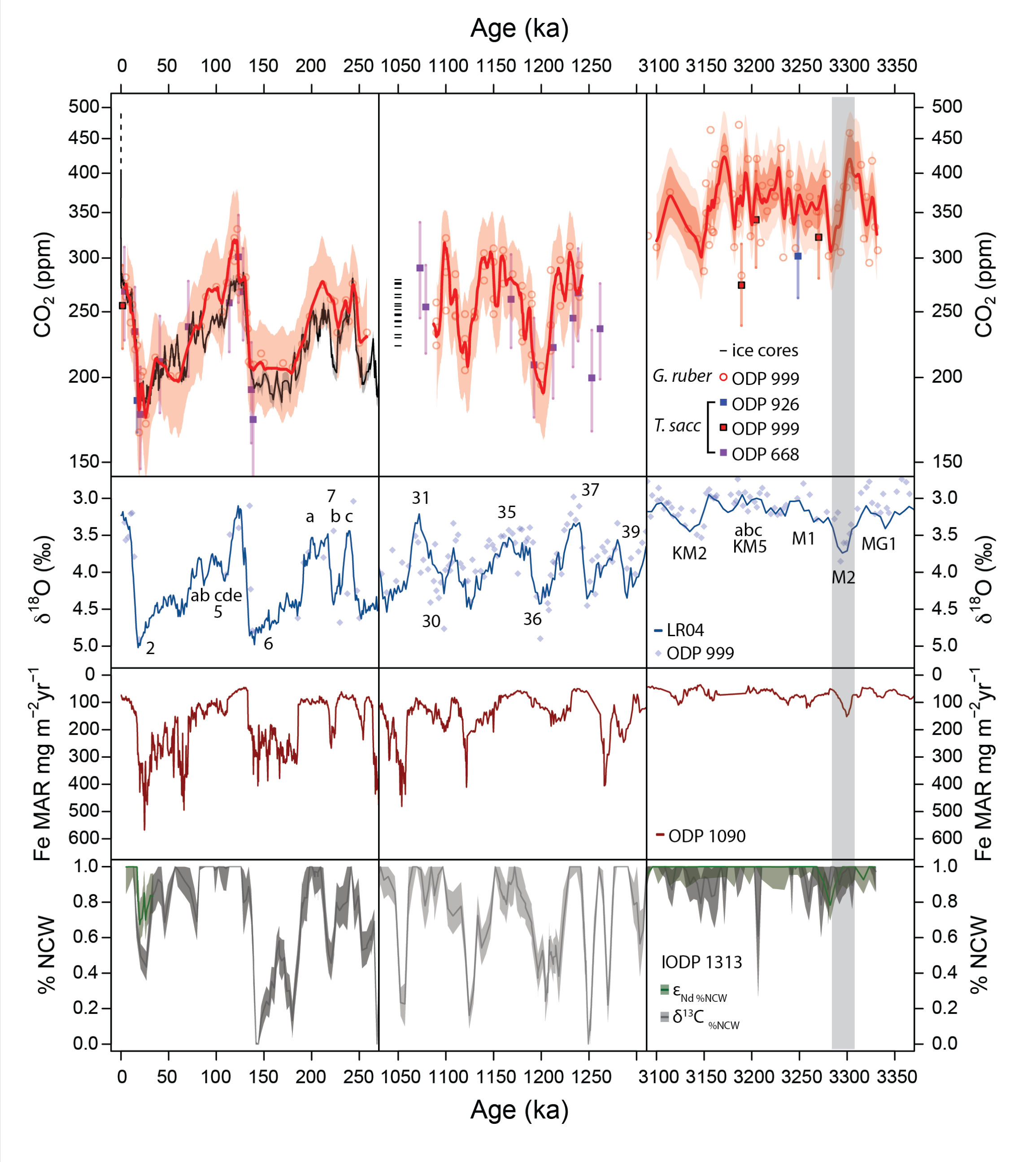




CO_2 Calculation. Second carbonate parameter used:
Dissolved inorganic carbon (DIC) from Sosdian et al., 2018

CO_2 cycles during the mPWP

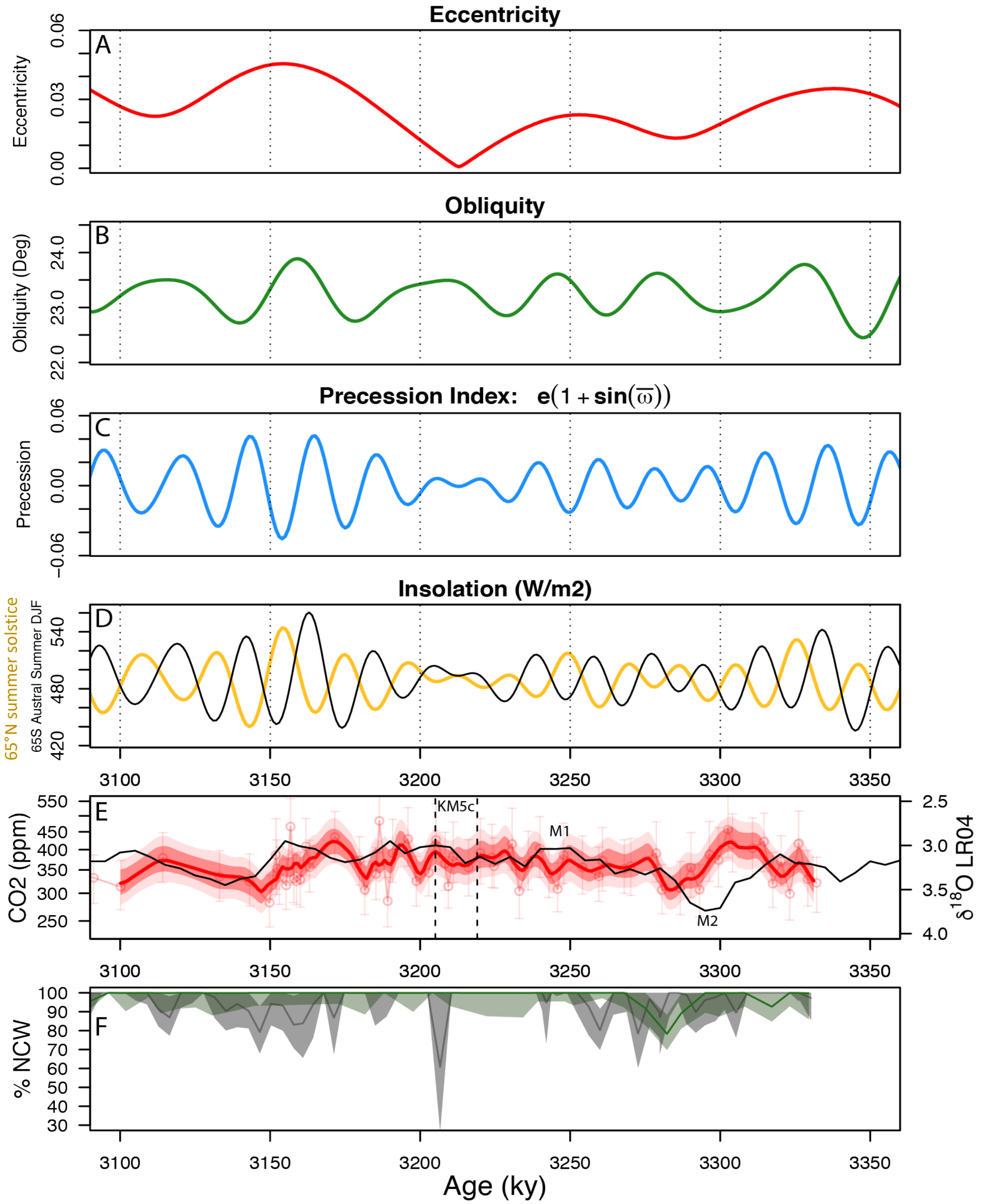
New δ^{11}B-derived CO_2 reconstructions



Key observations during the mPWP

- CO_2 range during mPWP including M2 =331-389 ppm based on lower and upper quartile of the data. (This range is similar regardless of M2 included or not)
- CO_2 during KM5c (3212 ky) = 371^{+32}_{-29} ppm based on the average of five δ^{11}B points at 3212 $\pm$ 7 ky.
- CO_2 during M2 lags δ^{18}O by ~ 10ky
- CO_2 correlates with change in water masses (ε_{Nd}) to a first order.
- Small variations in Fe mass accumulation rate (subantarctic Southern Ocean site 1090) during the mPWP relative to mid- and late- Pleistocene. Likely plays a minor role in CO_2 cycles of the mPWP.

de la Vega et al. (in review), Lang et al., 2016; Martinez-Garcia et al., 2011



CO_2 and orbital parameters

- KM5c occurs during eccentricity minimum (similar to modern).

- The tail of the CO_2 decrease after M2 maximum is:
  - -out of phase with Northern summer insolation minima (yellow).
  - - in phase with Southern summer insolation minima (black).

- ε_{Nd} proxy of water mass change at U1313 (N Atlantic) is in phase with CO_2 during M2.

de la Vega et al. (in review), Lang et al., 2016; Laskar et al., 2004

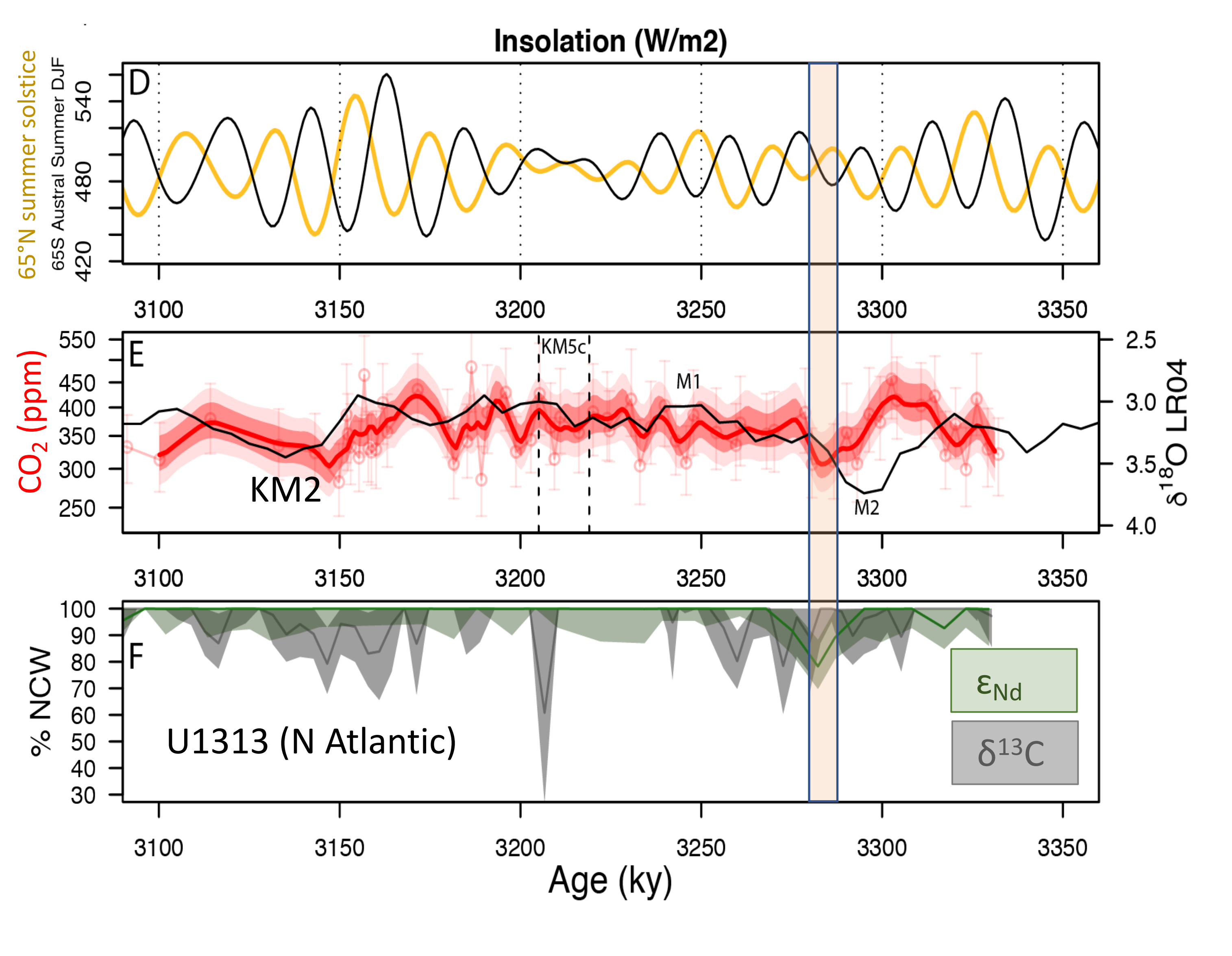
What are the possible causes of M2 glaciation **trigger**?

Possible causes of M2 glaciations trigger

● M2 maximum not in phase with CO_2 minimum (lag of ~ 10ky)

● Similar CO_2 during KM2 which is weaker glaciation.
--> Secondary role of CO_2 during M2

● Suggests a control of orbital configuration in triggering the M2 glaciation.

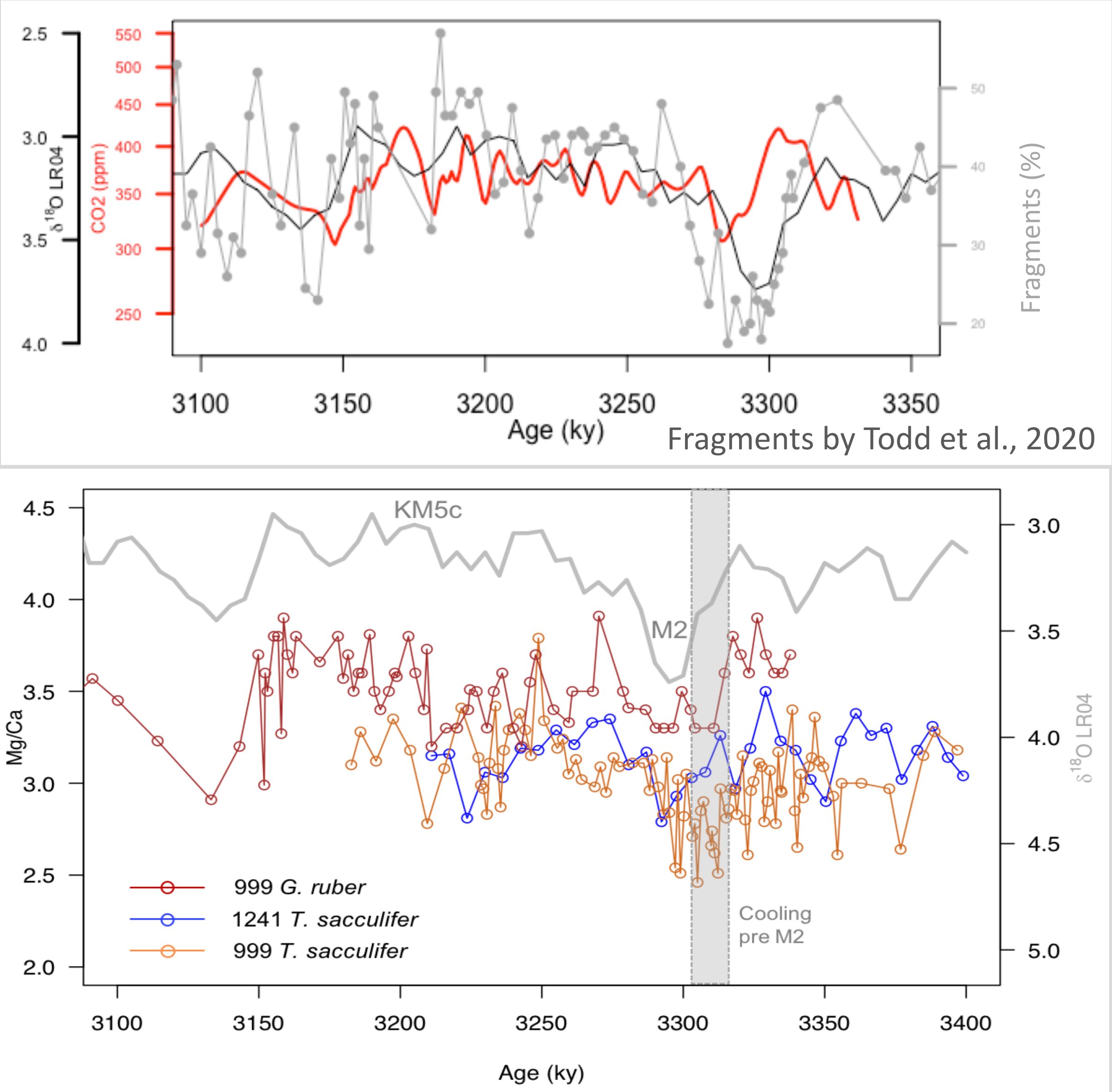


de la Vega et al. (in review), Lang et al., 2016; Laskar et al., 2004

What are the possible causes of **CO_2 lag** during the M2 glaciation ?

Possible causes of CO_2 lag during M2

- Effect of foraminifera preservation?
  - Unlikely, preservation is improved during the M2 interval (Todd et al., 2020).
- Change in local disequilibrium?
  - Mg/Ca decreases pre M2 maximum at ODP 999.
  - Possibly associated with local upwelling or temporary connection through the central American seaway (CAS) bringing carbon-rich waters to Site 999.
  - Abundance of *G. ruber* is however still high during M2 at 999 suggesting waters remained oligotrophic.

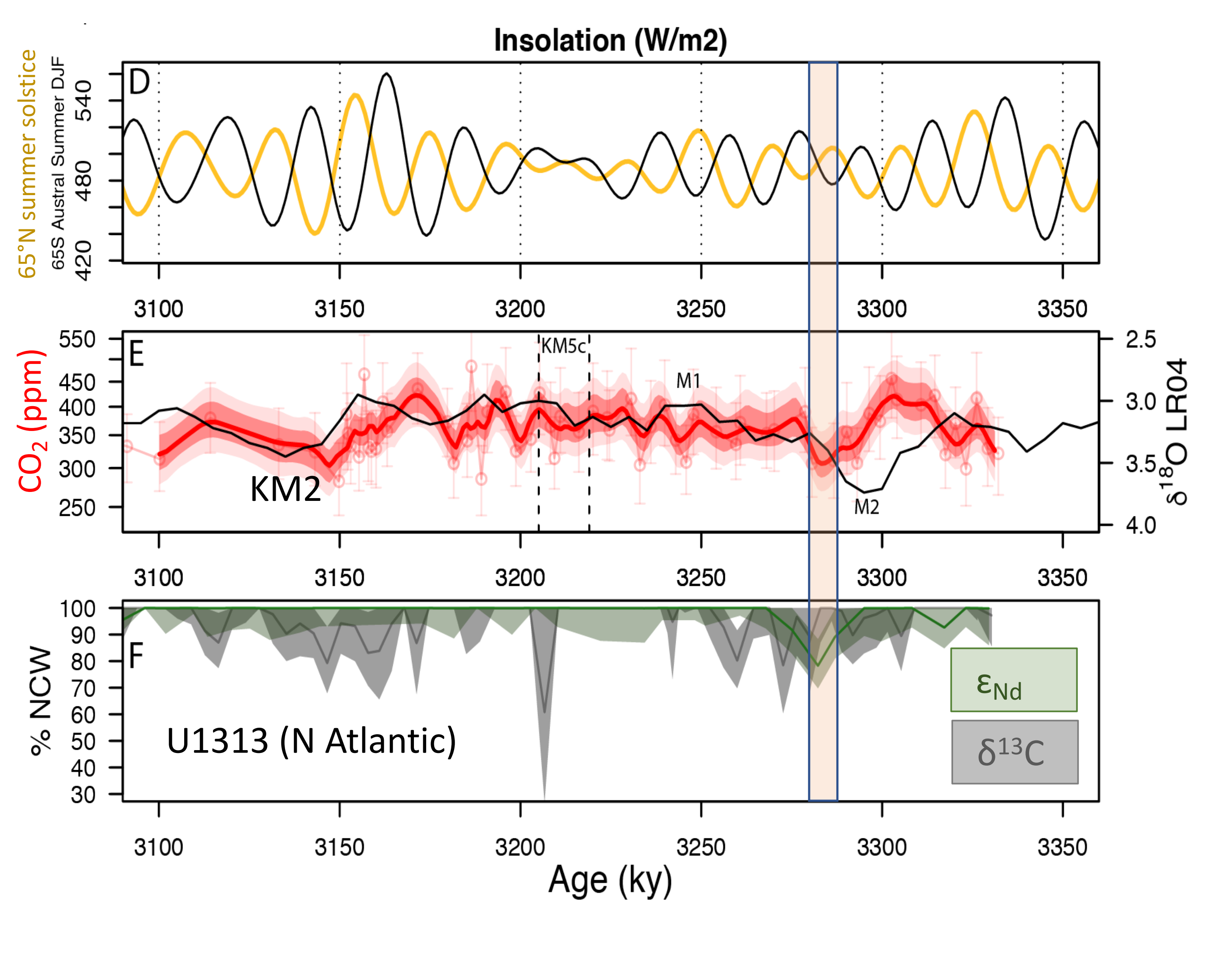


de la Vega et al. (in review), De Schepper et al. (2013); Groeneveld and Tiedemann (2005)

Possible causes of CO_2 lag during M2

- Control by change in water masses as indicated by ε_{Nd} similarly lagging $\delta^{18}O$.

- Implied control by southern hemisphere changes as observed with the phasing of austral summer insolation with the tail of CO_2 decrease (at ~3280 ky).



de la Vega et al. (in review), Lang et al., 2016; Laskar et al., 2004

Mid Piacenzian warm period versus Pleistocene.

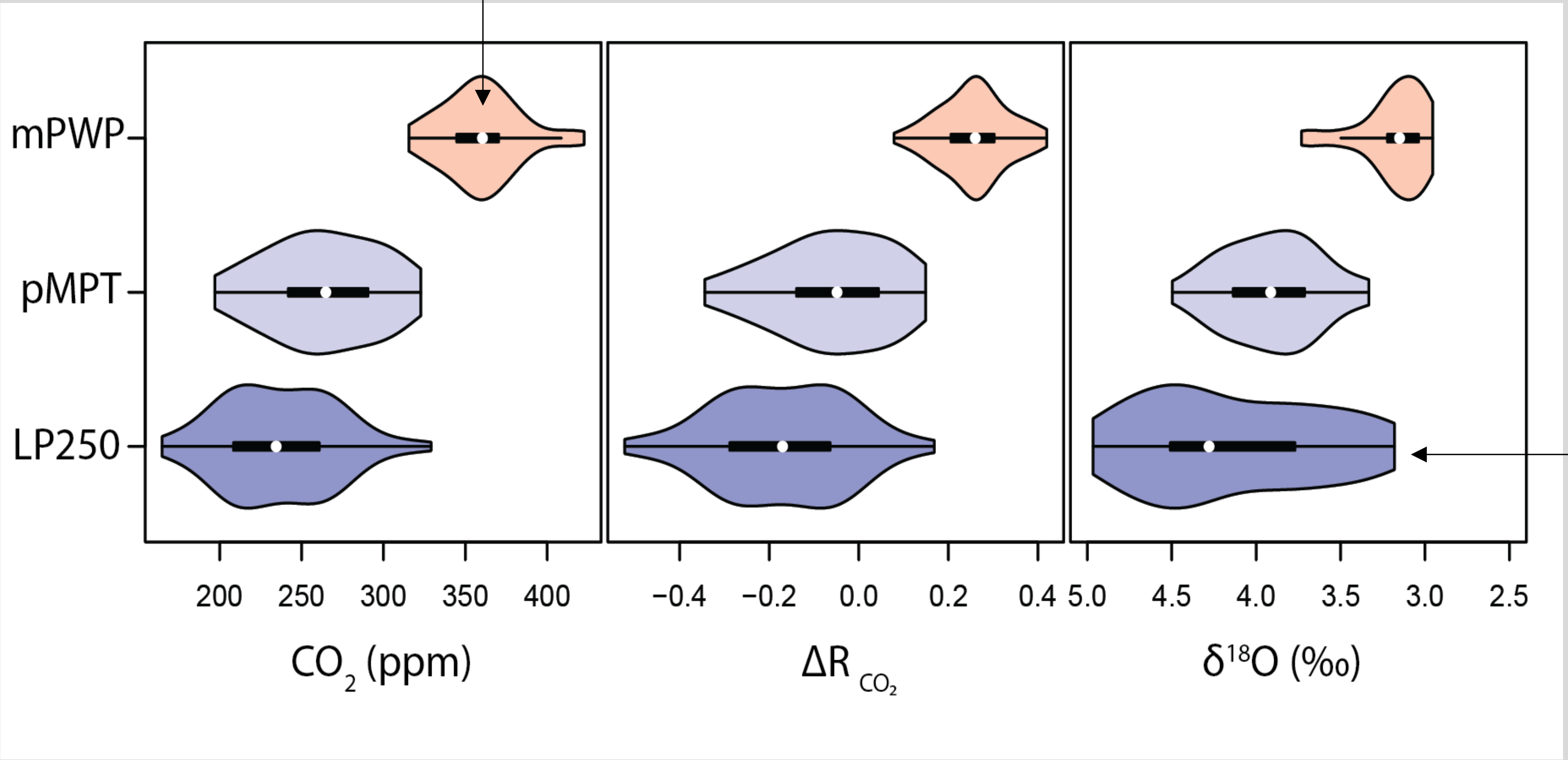
mPWP vs. the Pleistocene: CO_2 and $\delta^{18}O$ response

CO_2 range during mPWP similar (yet smaller) than Pleistocene values

Mid-Piacenzian warm period

Pre Mid-Pleistocene transition

Late Pleistocene 0-250 ky



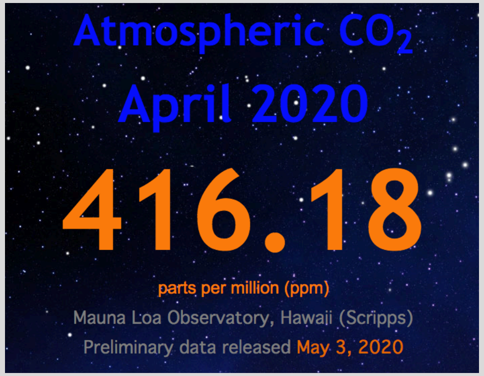
Larger response of $\delta^{18}O$ during the LP relative to the mPWP

→ Larger ice sheet response following intensification of Northen hemisphere glaciation with lower absolute CO_2 levels.

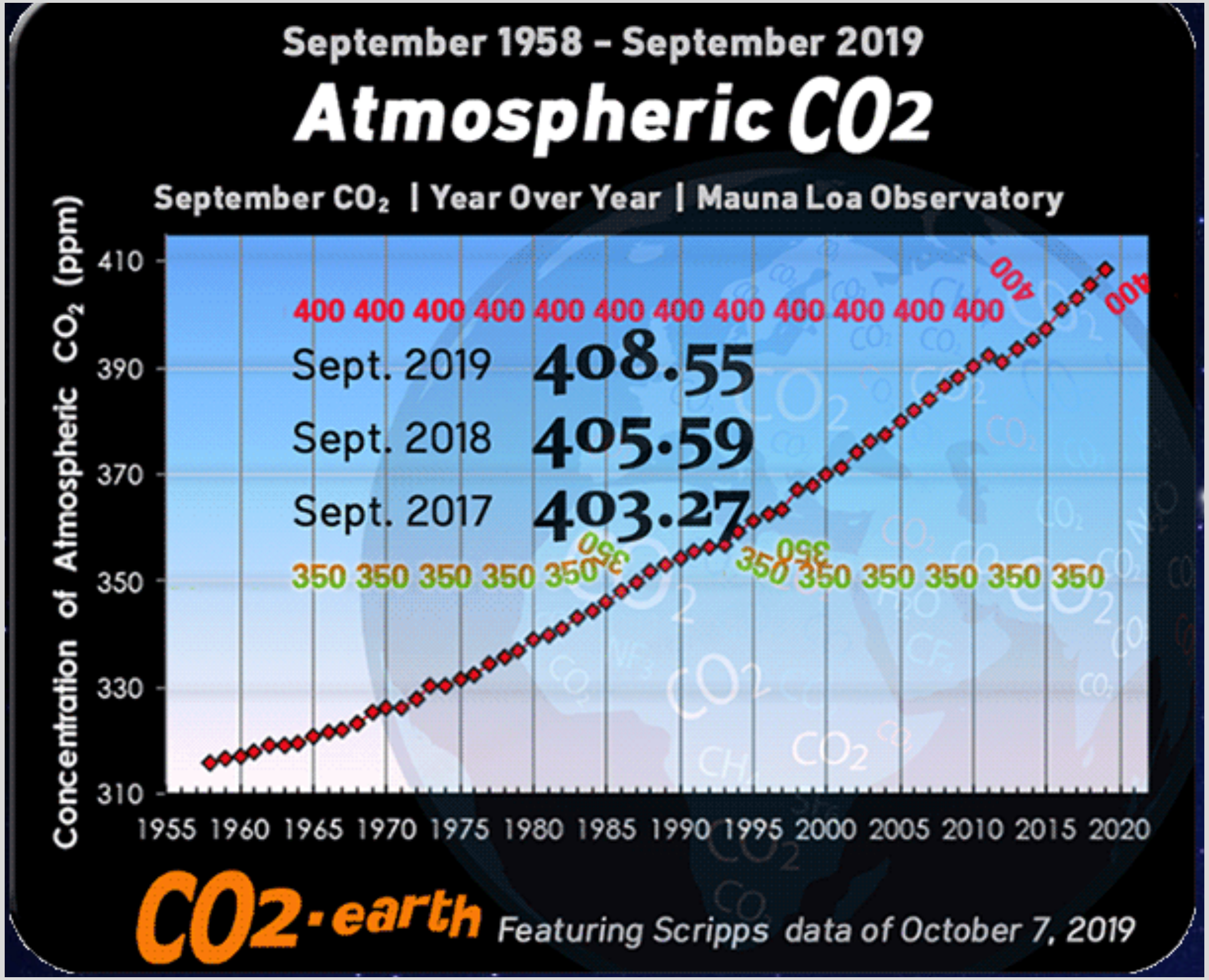
May. 1, 2020	418.03 ppm
May. 1, 2019	414.88 ppm
1 Year Change	3.15 ppm (0.76%)

Last CO2 Earth update: 2:35:04 AM on May. 2, 2020, Hawaii local time (UTC -10)

CO_2 range during the mPWP and the modern



CO2.earth



Upper range of the mPWP= 389^{+38}_{-8} ppm.

Maximum CO_2 = 427 ppm (upper uncertainty).

At current rate of CO_2 increase (~ 2.5 ppm/year), the highest level of the mPWP will be reached in ~2025.

Conclusion

- CO_2 during the mPWP ranges between 331 and 389 ppm (~60 ppm), similar absolute range as the late Pleistocene (~90 ppm) where full bihemispheric G-IG cycles occur.

- CO_2 during KM5c is determined for the first time at 371^{+32}_{-29} ppm, a key value to enable models to be tested and evaluate the response of the climate system (e.g. temperature, ice sheet, sea-level) to current CO_2 values.

- CO_2 during M2 lags $\delta^{18}O$ by 10 ky possibly caused by Southern hemisphere forcing (insolation).
- The response of ice sheet is amplified during the late Pleistocene despite a similar **range** of CO_2. Lower absolute value (<280 ppm) of CO_2 are an important aspect to trigger large ice sheet response due to logarithmic nature of forcing.