Limited Role of Export Production in Glacial-Interglacial CO_2 Cycles?

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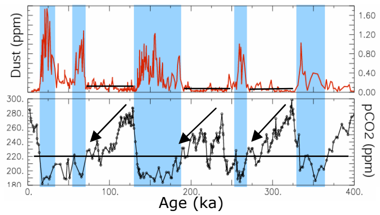
1. Motivation

Observations from Vostok ice core[1]:

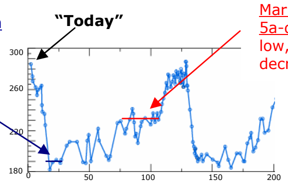
- High dust associated with peak glacial periods
- High dust ONLY occurs AFTER atmospheric CO_2 drops below 220 ppm
- Initial ~50 ppm drawdown occurs at LOW dust levels



What is the impact of marine carbon export and iron fertilization on CO_2 at different dust input levels?

We examine marine export production proxies from three time periods:

Last Glacial Maximum (LGM, 19-23 cal. ka): Physical, chemical & biological changes at maximum intensity



Marine Isotope Stage 5a-d: atmospheric dust low, but CO_2 already decreased by 50 ppm.

2. Data

Paleo-export data compiled for 145 deep-sea cores[2]:

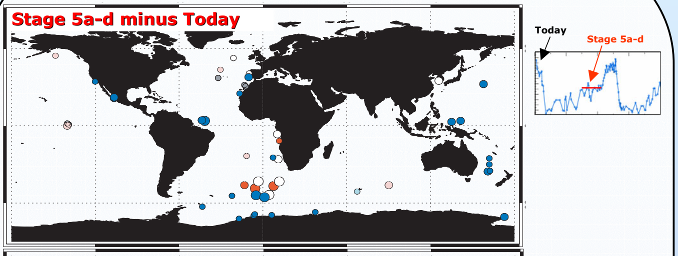
Ten paleo-export proxies used to assess relative changes in export production:

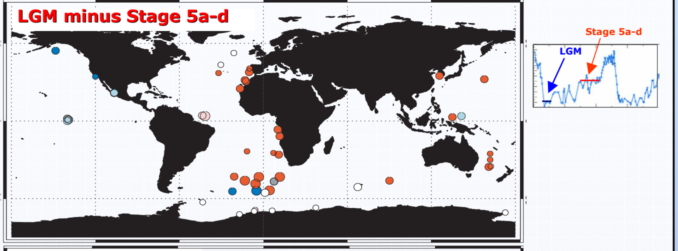
- Opal (SiO_2)
- Calcium Carbonate ($CaCO_3$)
- Organic Carbon
- Biomarkers (C37 Alkenones)
- ^{10}Be
- ^{231}Pa
- Barite
- Authigenic Uranium
- Authigenic Cadmium
- Benthic Foraminiferal Fluxes

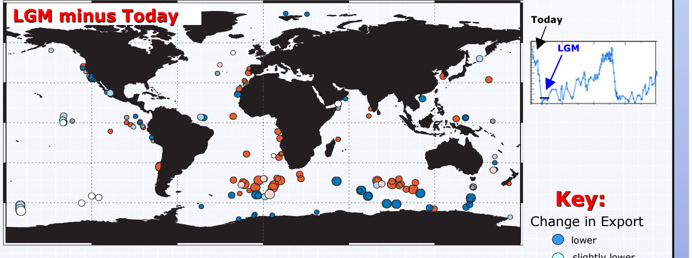
Confidence in data ranked for each core, based on (from highest to lowest for each category):

- **Age Model Type:**
  - Radiocarbon dating (AMS)
  - Oxygen Isotope Stratigraphy
  - Lithogenic Correlation
- **Type of Flux Measurement:**
  - Constant Flux Normalization (230Th)
  - Mass Accumulation Rates
  - Sediment Concentration
- **Nunber and % agreement of proxies in core**

3. Results







Key:

Change in Export
- lower
- slightly lower
- no change
- slightly higher
- higher
- ambiguous

Data Confidence
- high
- medium
- low

The first 50 ppm of atm CO_2 drawdown not caused by an increase in export production.

- W. Pacific and S. Ocean (S. of 50°S) show uniformly lower export at Stage 5a-d compared with today (top), suggesting that if anything export was reduced 80-100,000 years ago.
- Export was for the most part enhanced at the LGM compared with Stage 5a-d (middle) and today (bottom). The major exception is south of 50°S, where export had already reached minimum levels by Stage 5a-d.

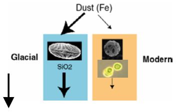
4. Discussion

Simulated contribution of dust to atmospheric CO_2 changes:

An ocean biogeochemistry model[3] was forced with LGM-Modern changes in temperature, sea ice, circulation, and dust[4]. Results were compared with paleodata (right).

PISCES + OPA Model

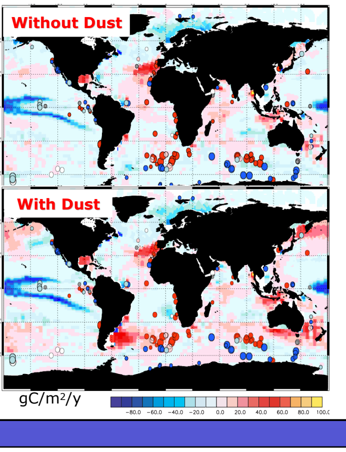
- Si, P, Fe limitation
- 2 Phytoplankton Groups



Modeled LGM – Modern: Δ Carbon Export (and ΔpCO_2)

Paleo Export Production Data

LGM-Modern Changes in Carbon Export



Conclusions:

- **Dust fertilization is required to reproduce export production patterns, particularly in the Southern Ocean.**
- **Combining temperature, sea ice, circulation and dust changes only results in a 30 ppm drawdown of atmospheric CO2, 15 ppm of which is attributed to the dust effect.**
- **This result is in line with results from other simulations[5,6], and is reasonable giving the timing of increased dust concentrations relative to CO2 in the Vostok ice core.**
- **The small role of ocean biology suggests that other physical or chemical processes must be responsible for the first 50 ppm drawdown of atmospheric CO2.**

5. References

1.Petit, J. R. et al. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* **399**, 439-436 (1999). **2**.Kohfeld, K. E. & Le Quéré, C. Limited role of marine biological export in glacial-interglacial CO2 cycles. (in prep, 2003). **3**.Aumont, O., Maier Reimer, E., Blain, S. & Monfray, P. An ecosystem model of the global ocean including Fe, Si, P co-limitations. *Global Biogeochemical Cycles* (in press). **4.** Bopp, L., Kohfeld, K. E., Le Quéré, C. & Aumont, O. Dust impact on marine biota and atmospheric CO2 during glacial periods. *Paleoceanography* (revised). **5.**Archer, D., Winguth, A., Lea, D. & Mahowald, N. What caused the glacial/interglacial atmospheric pCO2 cycles? *Reviews of Geophysics* **38**, 159-189 (2000). **6.**Watson, A. J., Bakker, D. C. E., Ridgwell, A. J., Boyd, P. W. & Law, C. S. Effect of iron supply on Southern Ocean CO2 uptake and implications for glacial atmospheric CO2. *Nature* **407**, 730-734 (2000).

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