Ecosystem effects of CO_2 concentration: a paper review on how C_3 & C_4 plants interact with CO_2 concentration in paleodata

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The paper

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Climate of the Past

Ecosystem effects of CO_2 concentration: evidence from past climates

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Three types of Photosynthesis: C_3, C_4, and CAM

1. **C_3**
   - Most plants are C_3. Photosynthesis takes place throughout the leaf.
   - More efficient than C_4 or CAM in moist, cool conditions because photosynthesis requires less machinery.
   - Atmospheric CO_2 is the limiting factor for photosynthesis even for today's elevated levels.
   - **Examples:** wheat, barley, potatoes and sugar beet.

Three types of Photosynthesis: C_3, C_4, and CAM

2 C_4

- Photosynthesis takes place in inner cells.
- Photosynthesises faster than C_3
- Adapted for low atmospheric CO_2.
- **Examples:** fourwing saltbush, corn, many of summer annual plants.

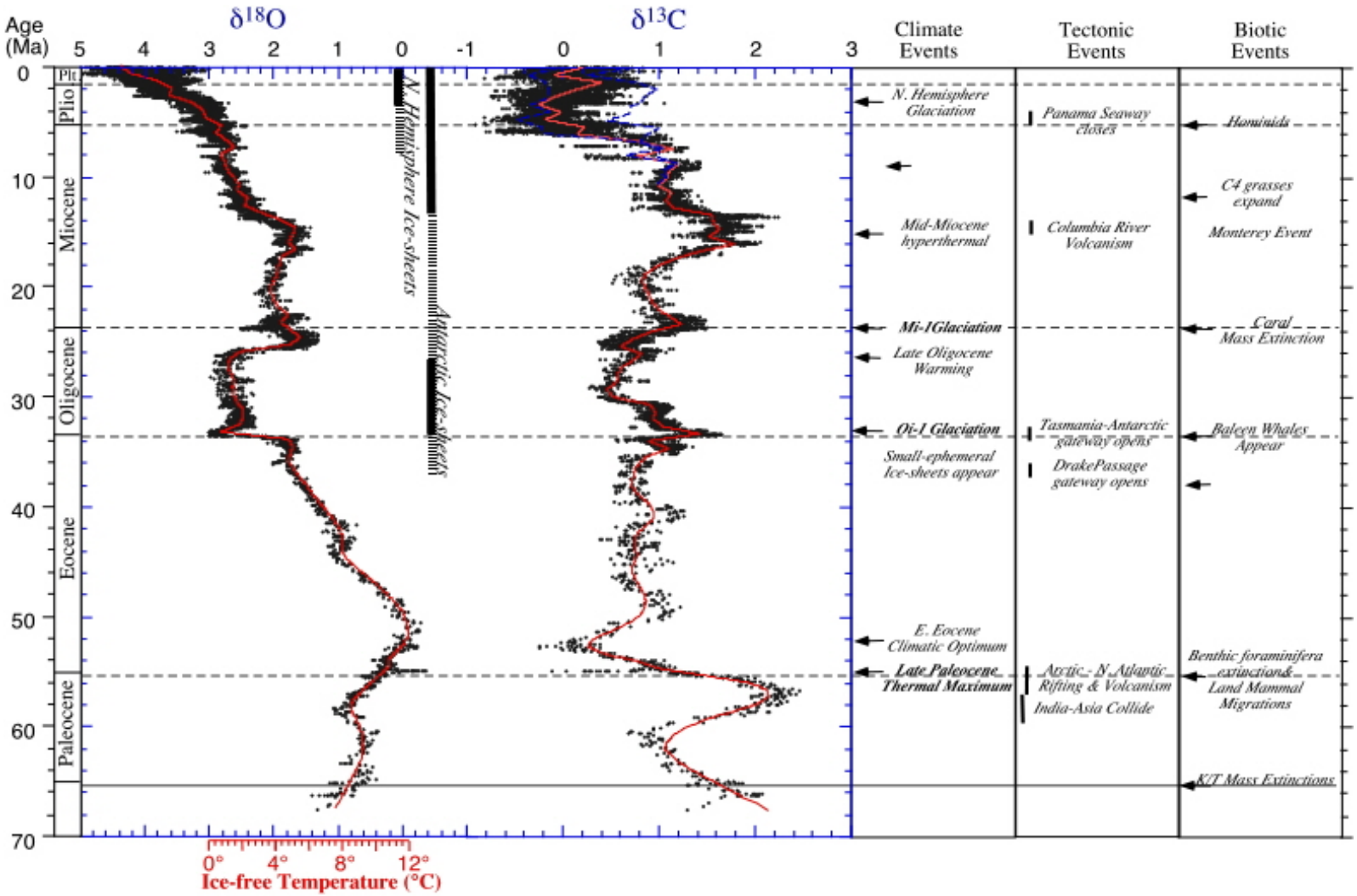
Three types of Photosynthesis: C_3, C_4, and CAM

3 CAM

- Photosynthesis has diurnal cycle.
- Adapted for very arid environments.
- **Examples:** cactuses, some orchids and bromeliads

http://legacy.earlham.edu/ vandeel/notes.htm

Affecting Paleoclimate Data



Affecting Paleoclimate Data

Atmospheric CO_2 concentration, c_a, affects C_3 photosynthesis and therefore will effect competition between C_3 and C_4 plants.

One example of this could be between C_3 trees and C_4 grasses in a tropical savannah. This could affect pollen assemblages!

http://ephsfoleybiomes.pbworks.com/w/page/9552179/Tropical

Affecting Paleoclimate Data

"If these variations in c_a have caused changes that are detectable in compositional data, such as pollen assemblages, then conventional approaches to reconstructing past climate using statisical or analogue methods - if applied to period with c_a different from that of the late Holocene- are certain to yield incorrect results."

Affecting Paleoclimate Data

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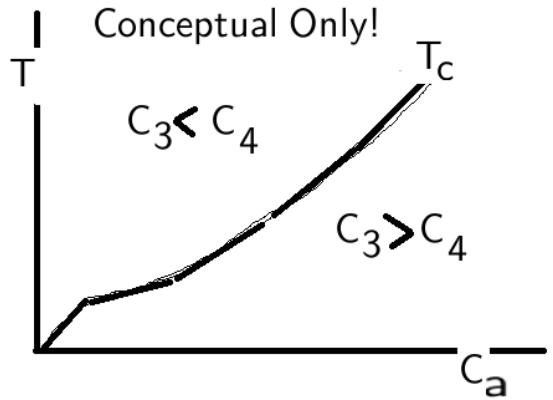
I think this means that if we assume the same ratio of C_3 to C_4 plants as we have today when we do pollen reconstruction, then we'll get the wrong answer.

C_3 vs C_4 Carbon fixing

- There exists a crossover temperature T_c above which C_4 plants can fix CO_2 much faster than C_3 plants.
- T_c increases as c_a increases.
- $T < T_c \Rightarrow$ that C_4 is fixing carbon much slower. Thus C_4 is more competitive at low c_a.
- $\therefore$ today we should expect C_3 plants to be dominanting.



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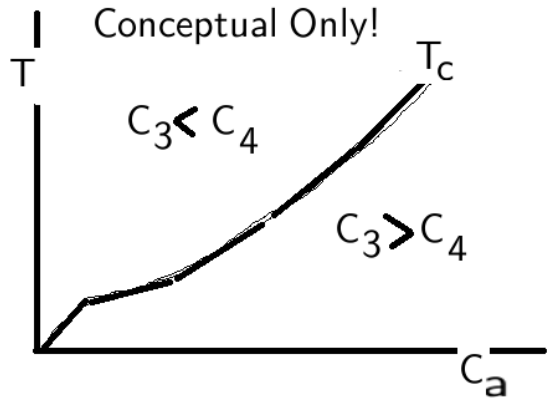

A widespread trend towards an increase of (C_3) tree cover at the expense of (C_4) grasses has indeed been observed in tropical savannahs.

Understanding Glacial Terrestrial Carbon Storage Decrease

- In 1977, Shackleton notes that subfossil benthic forminifera from LGM were light in ^{13}C.
- This suggests a change in the stable isotope composition in the ocean.
- Relative to the Holocene, $\partial^{13}C$ was offset by -0.7 per mille at LGM
- Shackleton's hypothesis is that this change is caused by a balance between terrestrial and ocean carbon reservoirs because it is only terrestrial organic carbon which is observed to be depleted in ^{13}C.
- A simple mass balance says organic carbon storage was greatly reduced during glacial times.

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Can we put a number on "greatly"?
He wasn't quite correct. The cannonical estimate is -0.32 per mille offset in $\partial^{13}C$ from benthic data.

Estimates of Terrestrial Carbon Storage Reduction for LGM

$310 - 550 PgC$	Bird et al(1994, 1996)
$300 - 700 PgC$	Bird et al(1996)
$430 - 665 PgC$	Strecet − Perrott et al(1998)
$550 - 680 PgC$	Beerling(1999)
$630 PgC$	Ikeda and Tajika(2003)
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Two interesting comments Prentice et al makes:
(1) Reduced carbon storage is **not** accounted for by the presense of continential ice sheets becuase the area of exposed continential shelf (in the tropics) roughly balances that occupied by ice!

(2) Peatland **cannot** account for "net postglacial carbon accumulation" becuase there is evidence of tropic peatlands which sequester on the order of 200 PgC.

Physiological Effects

Physiological Effects (physical plant mechanism differences) can reduce carbon storage on land during a glacial maximum.

C_4 plants fix carbon much slower than C_3. C_4 plants are more dominant in a glacial maximum. Therefore less carbon is being sequestered per unit of time.

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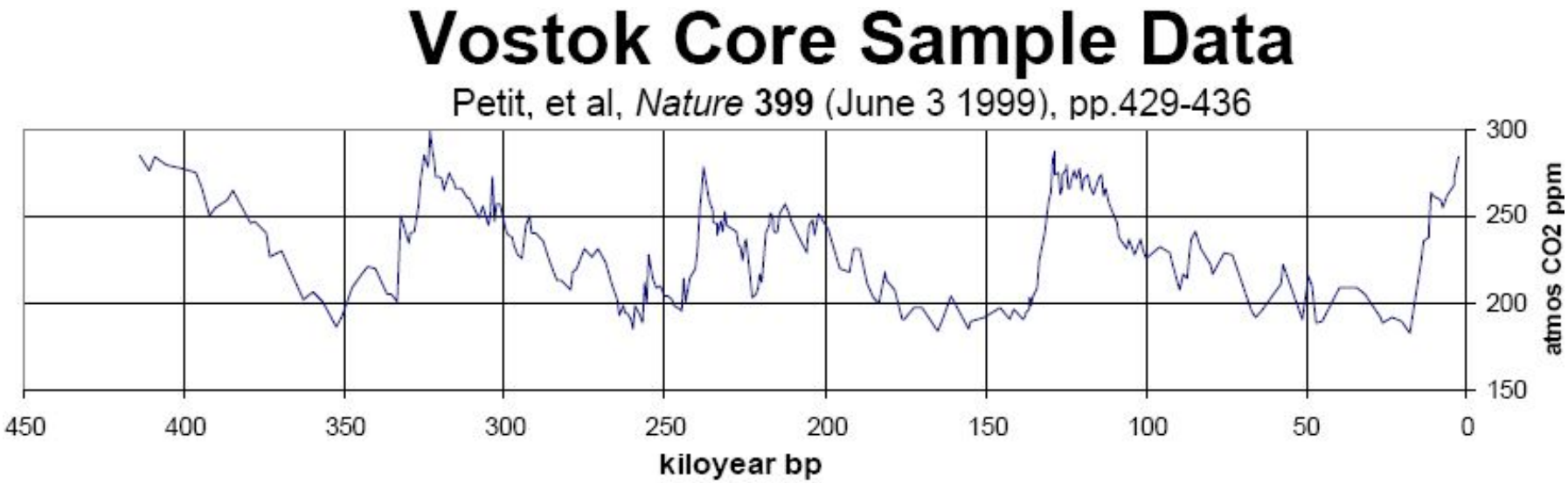
However, there is a opposing mechanism. Carbon stays in the soil much longer at low temperatures because decomposition happens much slower. (hence all the really good soil is in Boreal regions).

> *One model suggests that global cooling to LGM levels would have a minor impact on total terrestrial carbon storage, wherea the CO_2 changes would reduce terrestrial carbon storage substantially.*

The Claim

Paleodata combines with process based modelling that includes physiological effects can correctly reproduce

1. The 100ppm increase in c_a from LGM to Holocene.
2. The approx. magnitude of carbon storage change.



Determining Magnitude of Carbon Storage

- View pollen and plant macro-fossil records from terrestrial sedients with an eye for change in c_a.
- Many papers have shown that CO_2 changes with change plant types, biomes etc but haven't added it to the model before.
- There exists evidence that tropical lowland regions shift towards C_4 plants during glacial times.

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Question: How do we determine if Physiological Effects are important?
Answer: Run some really big models with and without the code that determines physiological effects.

A typical result is that the terrestrial carbon storage reduction is:

160 PgC without physiological effects.
610 PgC with physiological effects.

Conclusion

Physiological effects are essential to correctly modeling terrestrial carbon storage changes.

Additionally, if one wants to model previous climates, then one must consider the compitition between C_3 and C_4 plant to determine the CO_2 fixing values and other plant type parameters.