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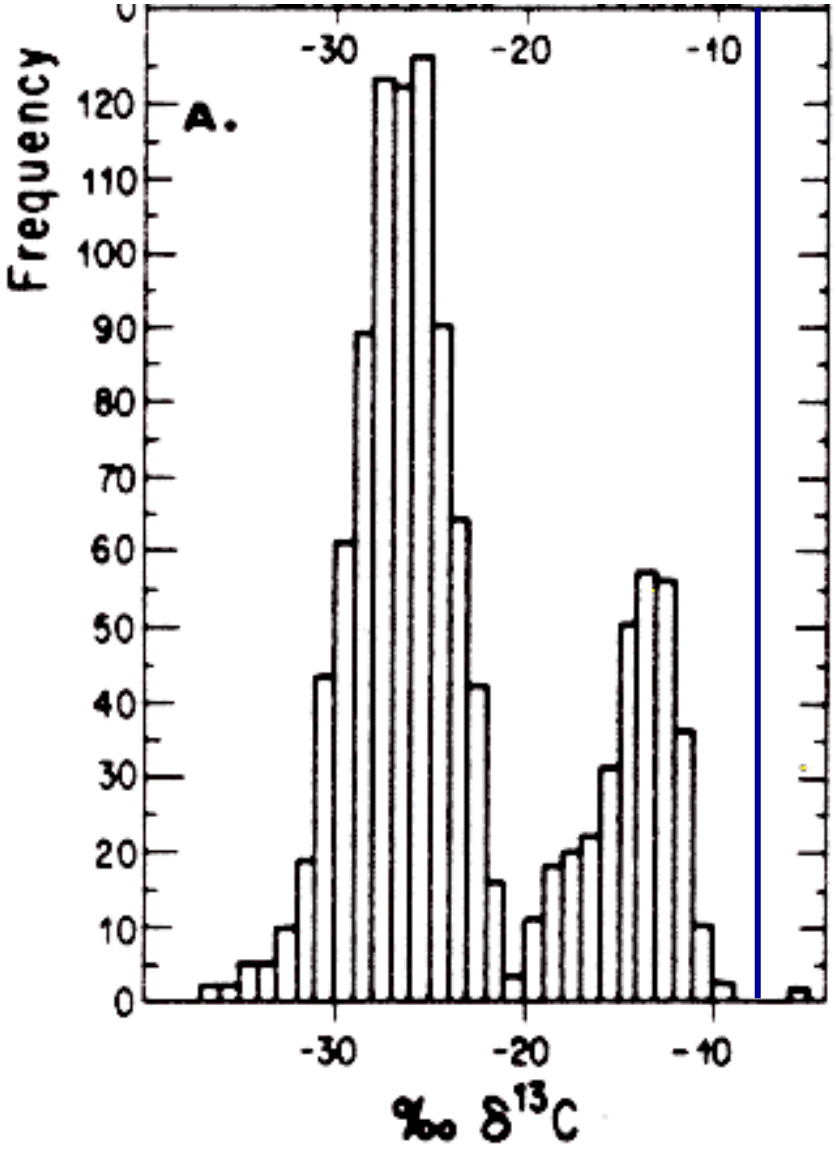
Photosynthesis & Stable Carbon Isotopes

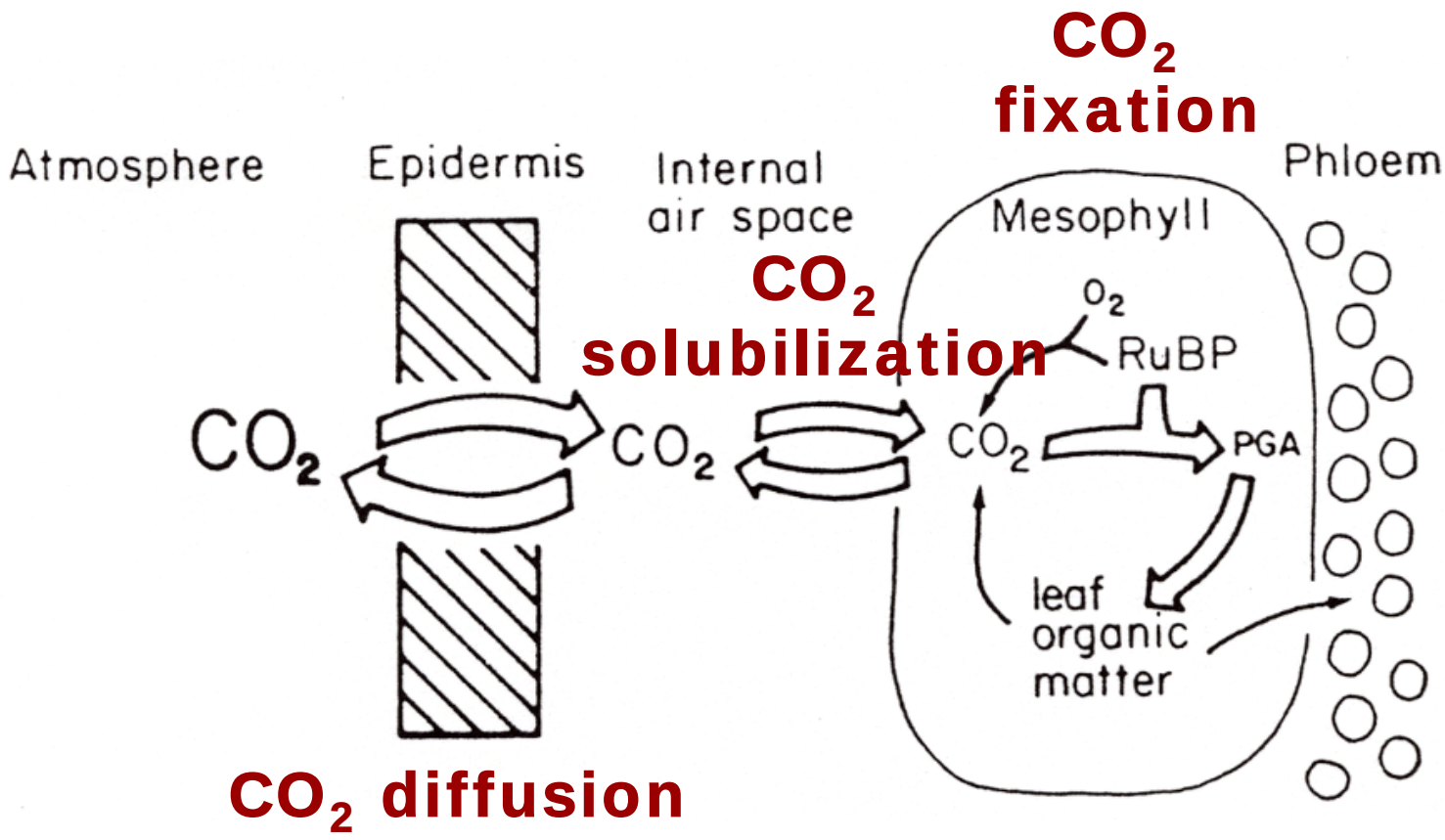
Stable C Isotopes in Plants



Terrestrial Plants:

+ different from $\delta^{13}C$-value of the atmosphere
+ unequal distribution of $\delta^{13}C$ values

Photosynthesis



Which processes are discriminating against ^{13}C?

Photosynthetic Fractionation

$$\Delta = a + (b-a) * (c_i/c_a)$$

a, diffusion in air [+4.4 ‰ , α=1.0044] kinetic

b, carboxylation [+29 ‰ , α=1.029] kinetic

incl. CO_2 dissolution [+1.1 ‰ , α=1.0011] equilibrium

CO_2 aqueous diff. [+1.1 ‰ , α=1.0011] kinetic

C_i, internal CO_2

C_a, ambient CO_2

Net Fractionation of Photosynthesis

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$$\delta^{13}C_{plant} = \delta^{13}C_{air} - [a + (b-a) * (c_i/c_a)]$$

$$\delta^{13}C_{plant} = (-8) - (4.4) - (31.1-4.4) * (c_i/c_a)$$

If $c_i = c_a$: $\delta^{13}C_{plant} \sim -39$ ‰

i.e., diffusion does not play a role!

If $c_i << c_a$: $\delta^{13}C_{plant} \sim -12.4$ ‰

i.e., discrimination by RubisCO does not play a role!

Effect of internal CO_2 concentration

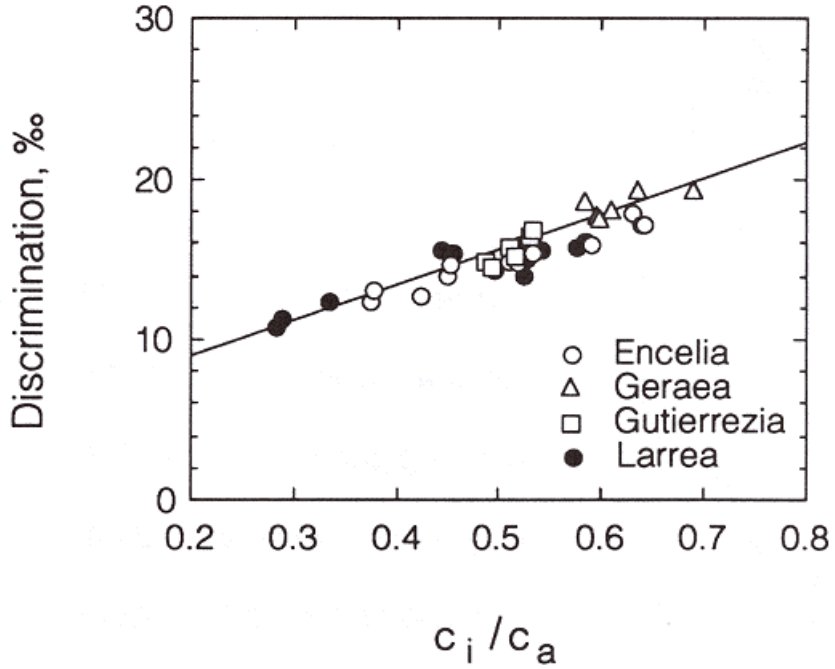
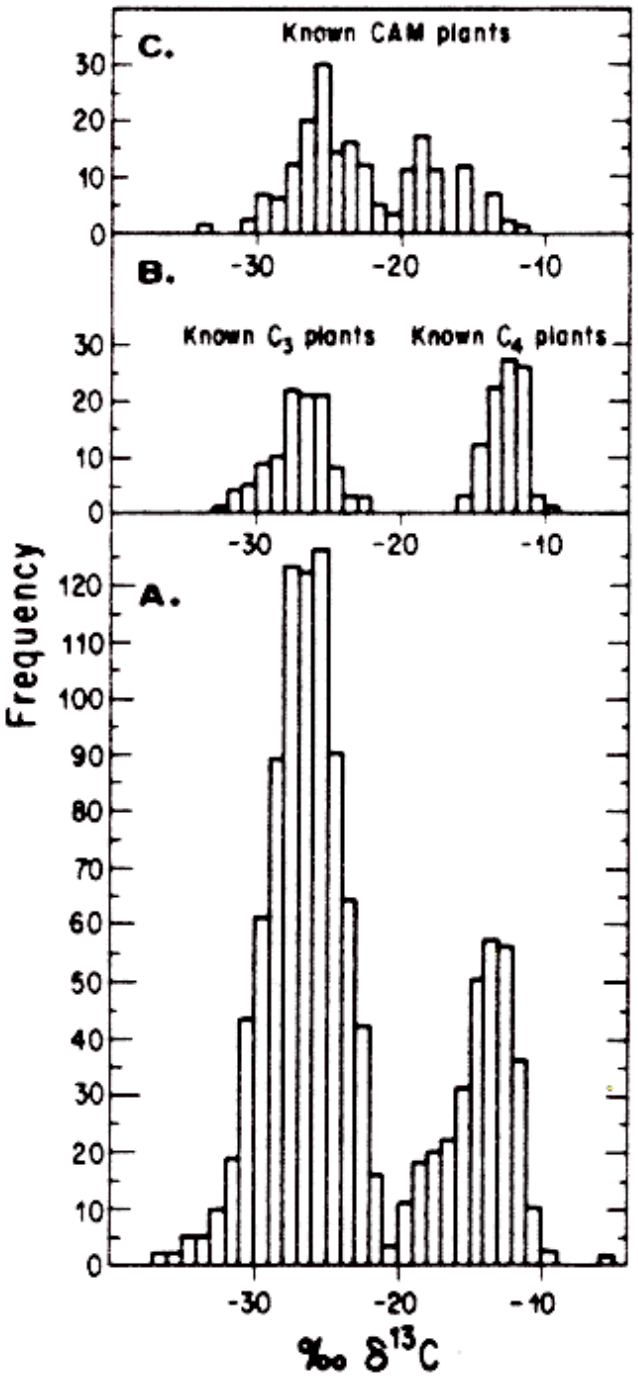


Figure 3. Observed carbon isotope discrimination values from on-line gas exchange measurements as a function of the simultaneously measured ratio of intercellular to ambient CO_2 concentrations for *Encelia farinosa* (drought-deciduous shrub), *Geraea canescens* (annual), *Gutierrezia sarothrae* (winter-deciduous shrub), and *Larrea tridentata* (evergreen shrub). Line through the data represents the C_3 carbon isotope discrimination model, $\Delta = a + (b - a)\, c_i/c_a$, where a is 4.4‰ and b is 27‰. From Ehleringer *et al.* (1992).

Plants C Isotopes



Terrestrial Plants:
Different photosynthetic pathways
C3, C4 and CAM

Terrestrial Plants:
Why bimodal distribution?

Photosynthetic types

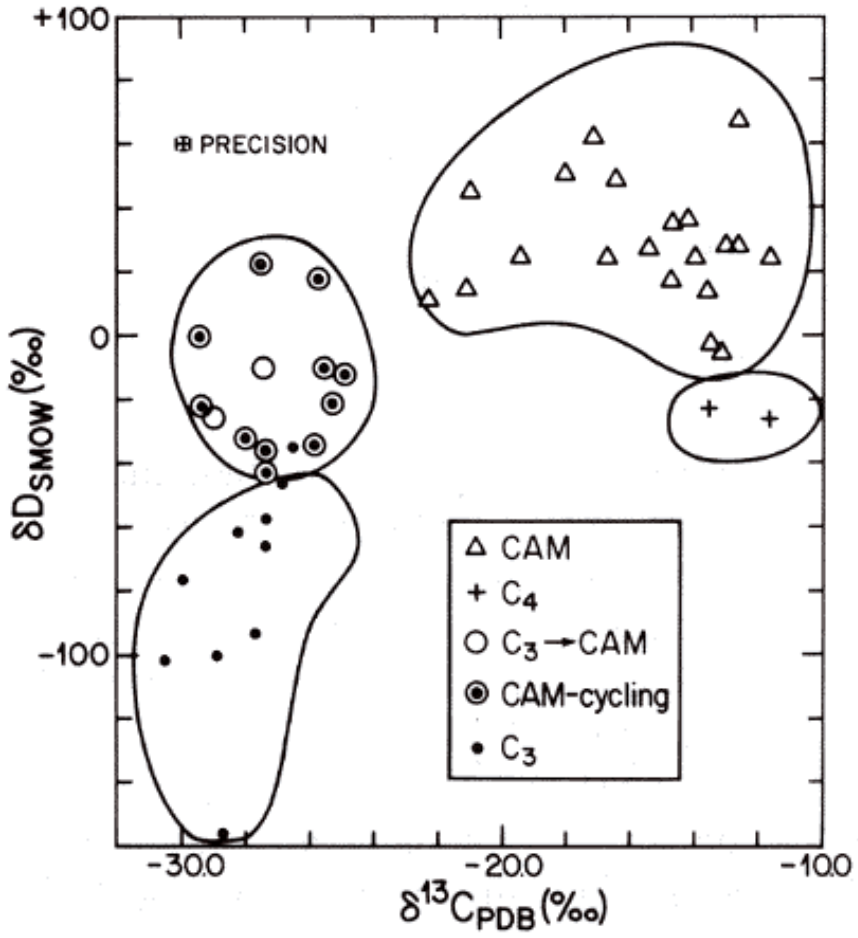
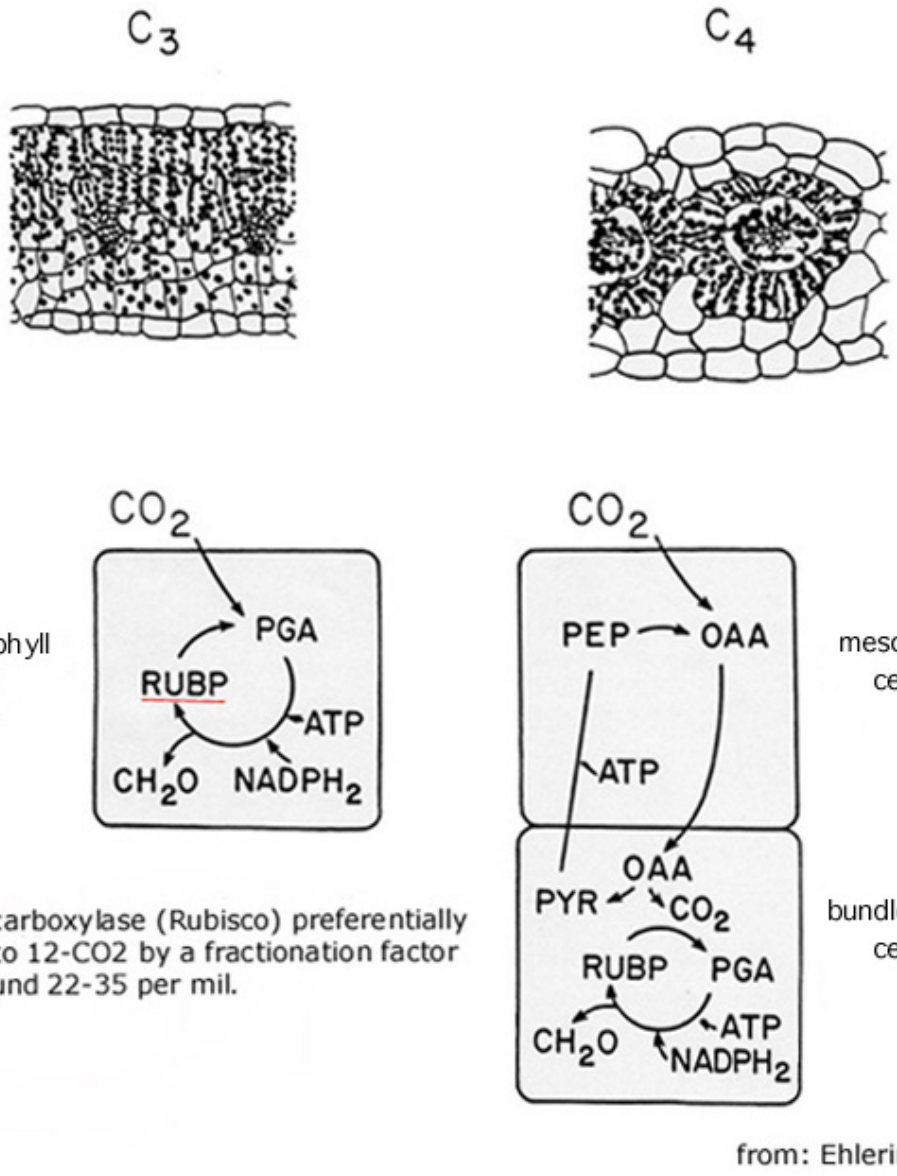


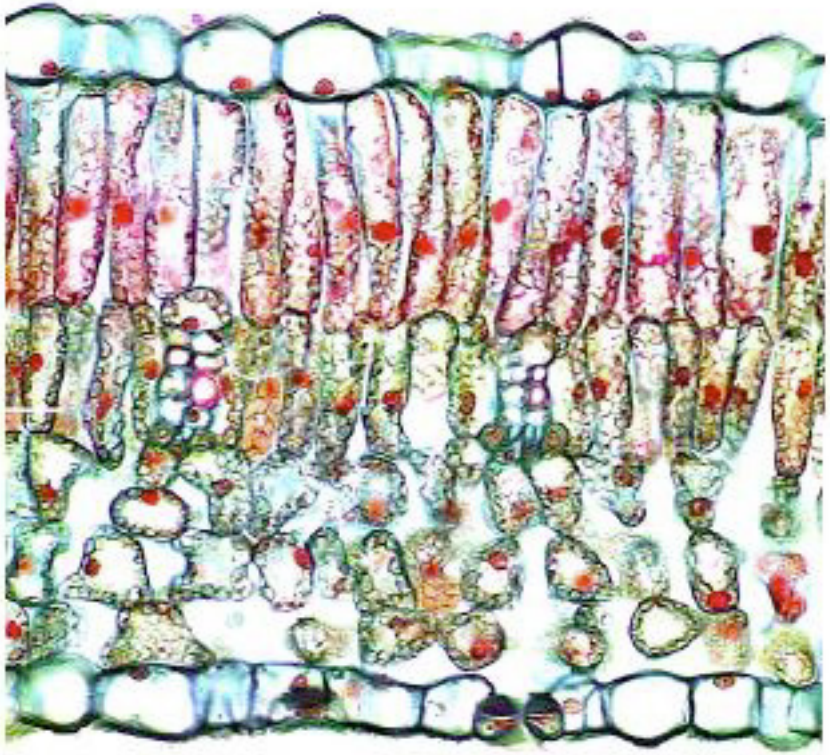
Figure 9.7. Hydrogen isotope ratios versus carbon isotope ratios of cellulose nitrate from greenhouse-grown plants having different photosynthetic modes. From Sternberg et al. (1984c).

C3 vs C4

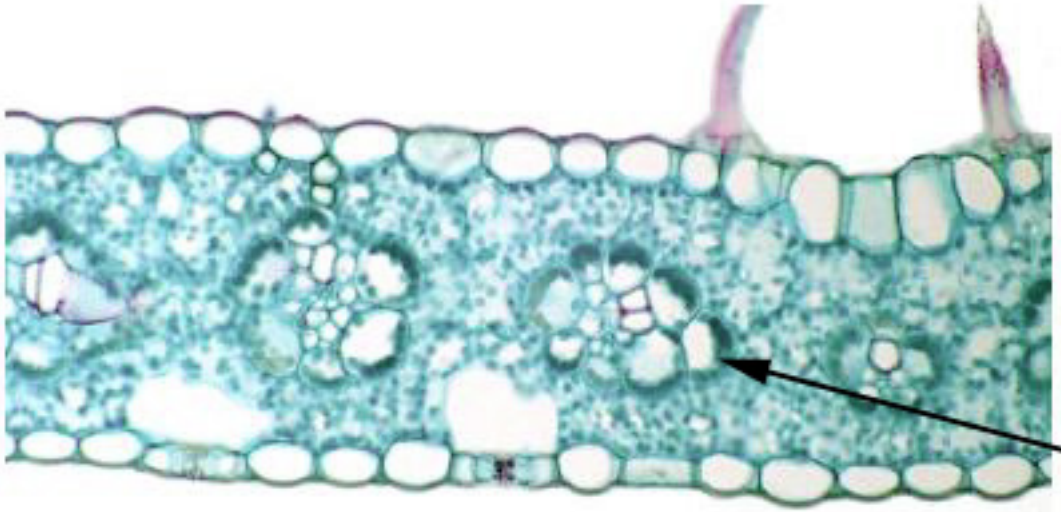


PEP Carboxylase

$\alpha = 1.002$ (2 ‰)



C_3



C_4

Crassulacean acid metabolims and succulence

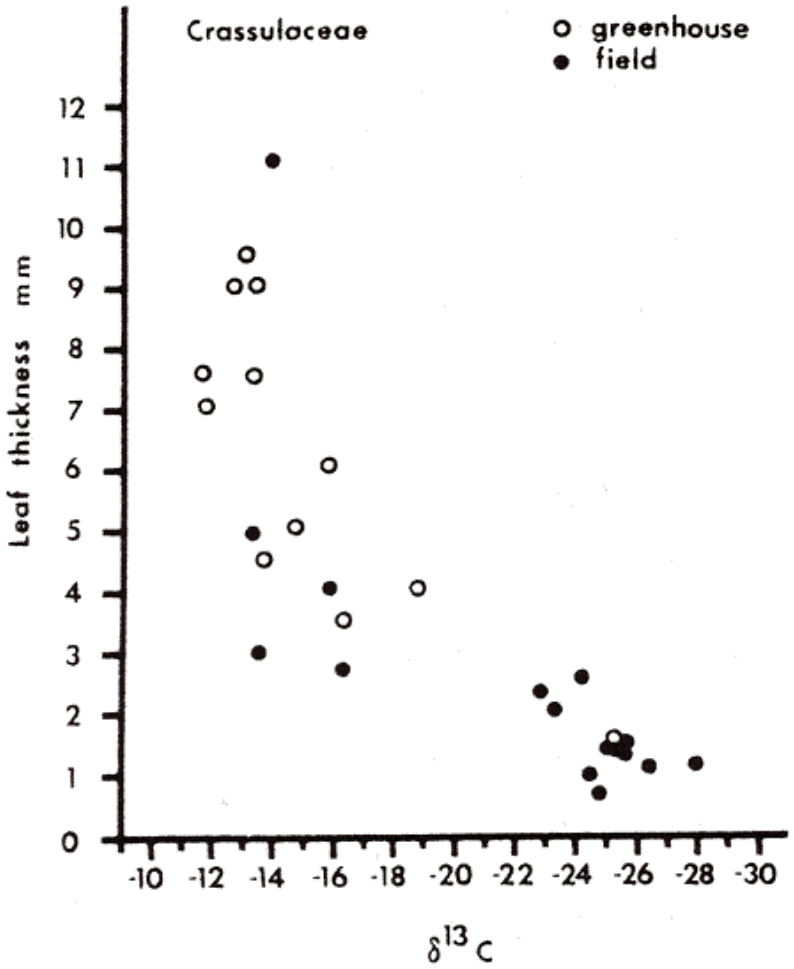


Fig. 1. The relationship between leaf thickness and $\delta^{13}C$ value of the twenty species and three intergeneric hybrids of the Crassulaceae reported in Tables 1 and 2

Photosynthesis

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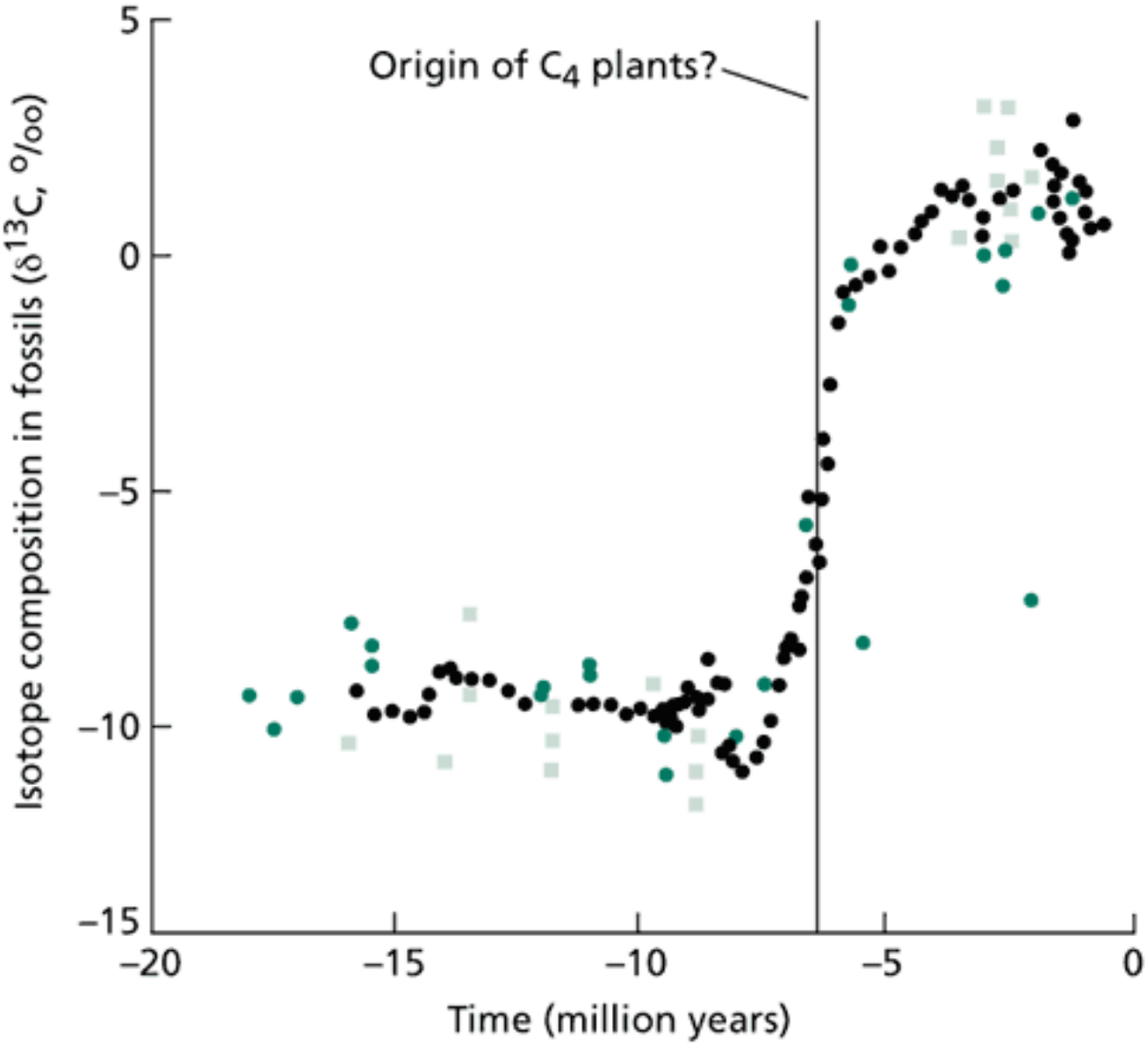


Effect of internal CO_2 concentration

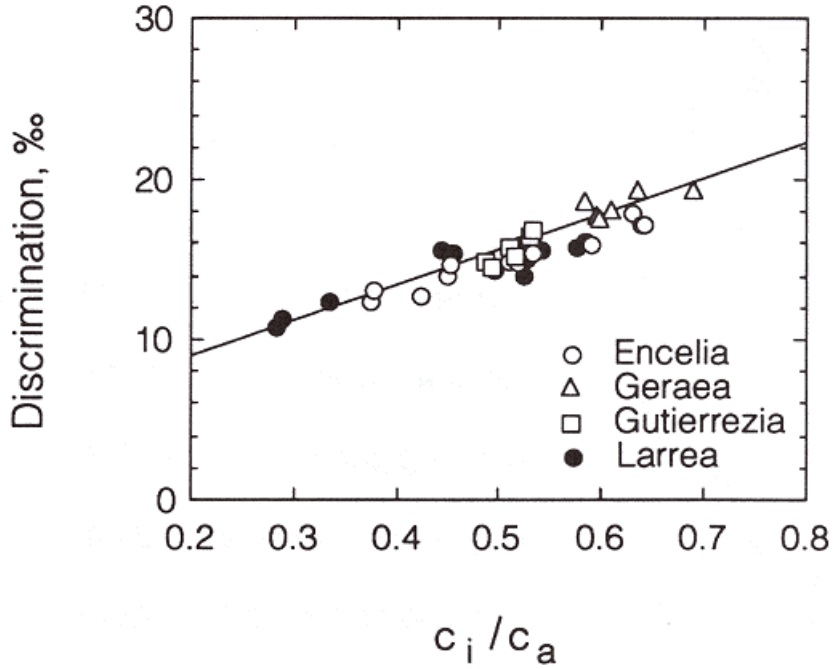
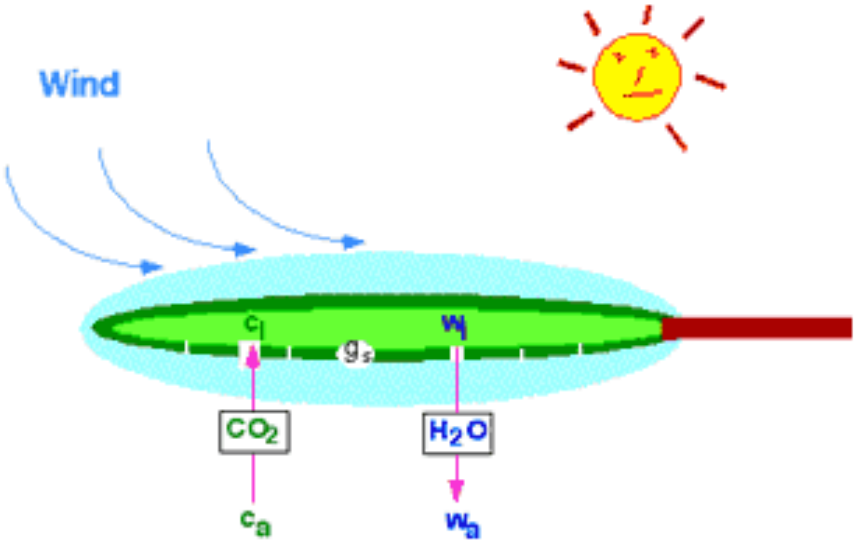


Figure 3. Observed carbon isotope discrimination values from on-line gas exchange measurements as a function of the simultaneously measured ratio of intercellular to ambient CO_2 concentrations for *Encelia farinosa* (drought-deciduous shrub), *Geraea canescens* (annual), *Gutierrezia sarothrae* (winter-deciduous shrub), and *Larrea tridentata* (evergreen shrub). Line through the data represents the C_3 carbon isotope discrimination model, $\Delta = a + (b - a)\, c_i/c_a$, where a is 4.4‰ and b is 27‰. From Ehleringer *et al.* (1992).

Water Use Efficiency



Photosynthesis: $A = \frac{g}{1.6}(c_a - c_i)$

Transpiration: $E = g(w_i - w_a)$

$$WUE = \frac{A}{E} = \frac{c_a - c_i}{1.6(w_a - w_i)}$$

$$\Delta = a + (b - a)\frac{c_i}{c_a} \qquad WUE = \frac{c_a(b - \Delta)}{1.6(w_i - w_a)(b - a)}$$

WUE

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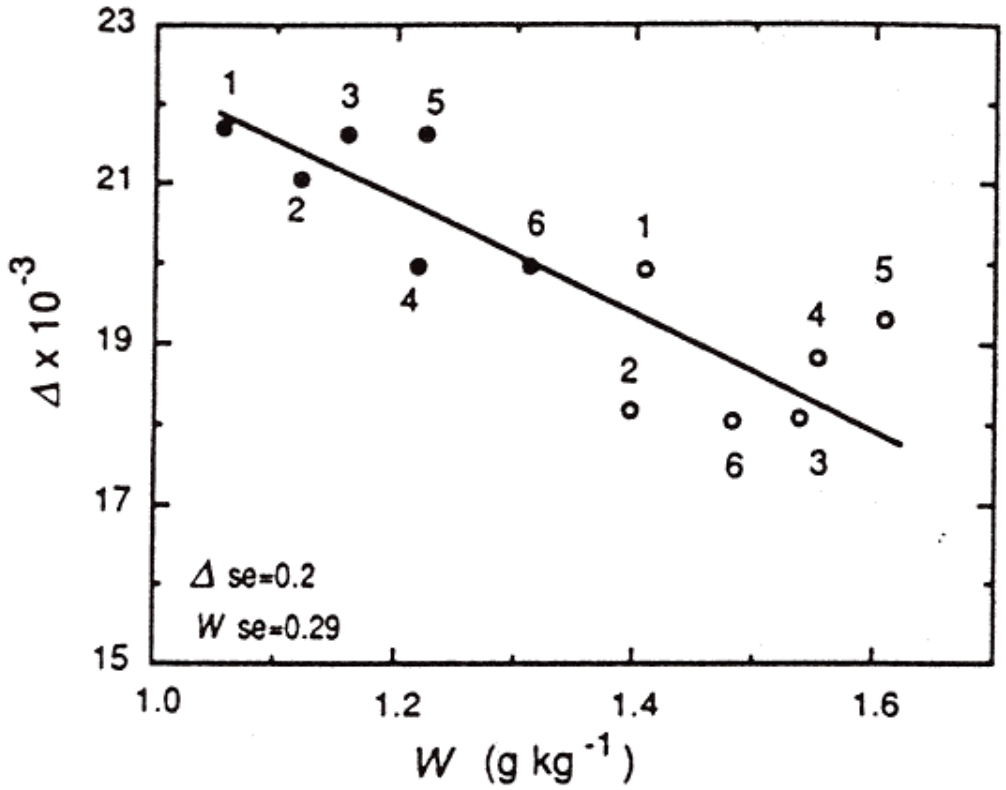

Figure 3. Water-use efficiency (W) (grams dry matter per kilogram water used) versus carbon isotope discrimination ($\Delta \times 10^{-3}$) for all species at the final harvest. Open symbols, dryland plants; closed symbols, irrigated plants; se, standard error of the mean. Numbers on the figure are species: (1) Polish canola; (2) pea; (3) Argentine canola; (4) durum wheat; (5) mustard; (6) soft wheat. Regression equation: $Y = 28{\cdot}4 - 6{\cdot}4X$, $r^2 = 0{\cdot}71$. The regression is significant at $P < 0{\cdot}001$.

Valid for different cultivars and different species

Salinity and Drought Stress

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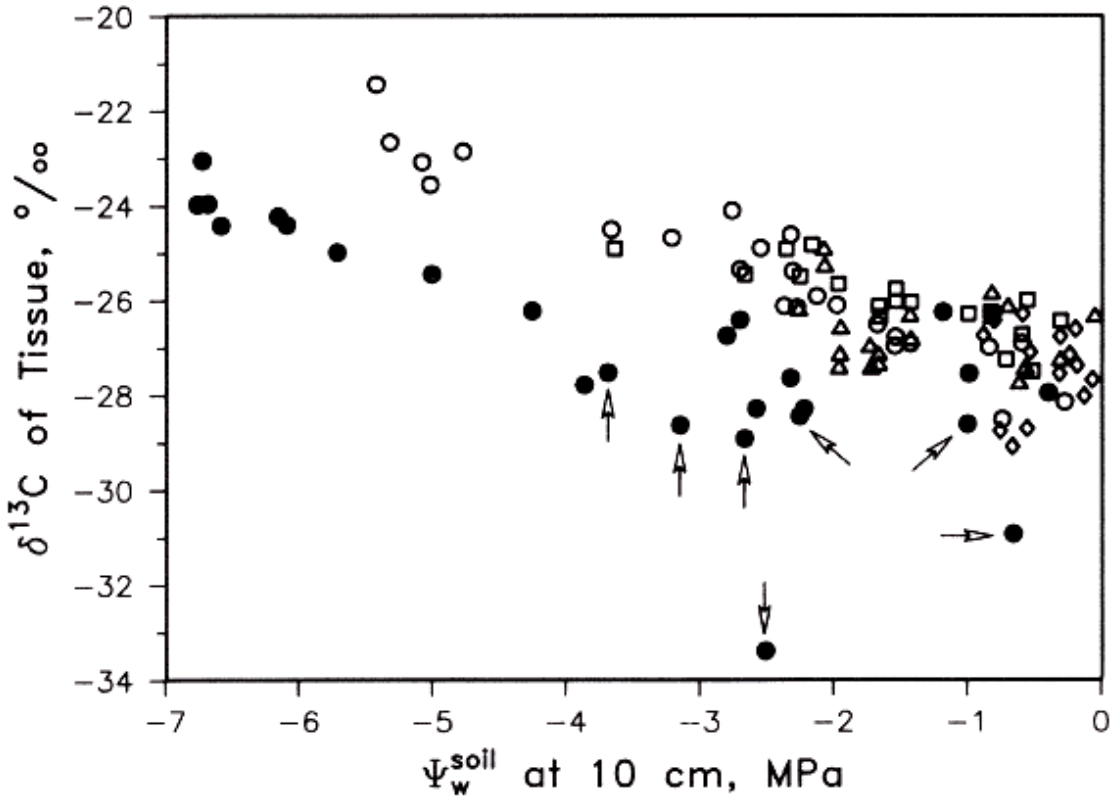
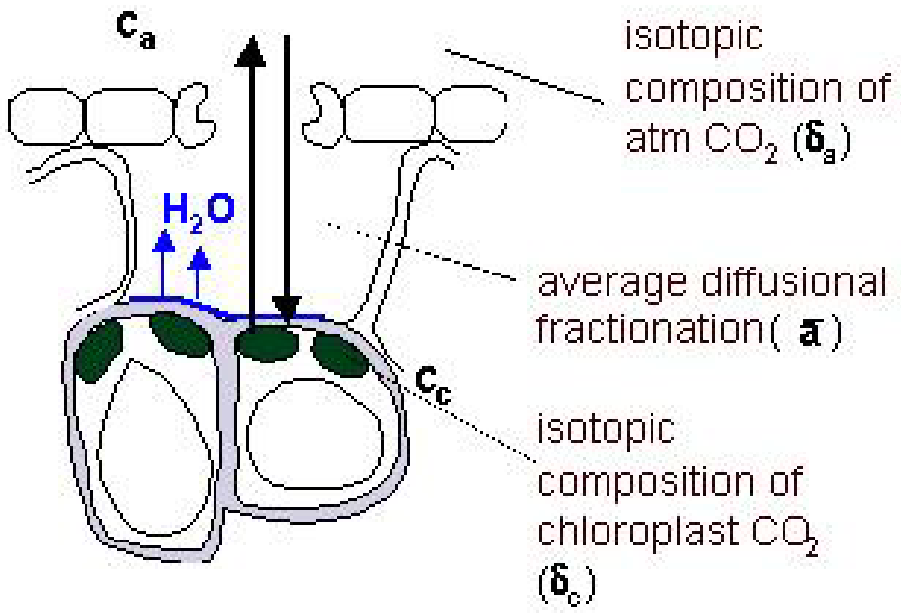


Figure 4.11. Total tissue $\delta^{13}C$ values of field-collected "leaf" material representing five major species of inland halophytes and plotted according to the soil water potential at a depth of 10 cm. A total of 102 data points are depicted including 19 for *Hordeum jubatum* (□), 25 for *Puccinellia nuttalliana* (○), 25 for *Salicornia europaea* (●), 14 for *Sonchus arvensis* (◇), and 19 for *Triglochin maritima* (△). All collections were between early July and mid-August (1978/1979). Arrows indicate *S. europaea* specimens associated with a high percent cover by other species. Replotted from Guy et al. (1986b).

^{18}O - Discrimination

c_c = chloroplast $[CO_2]$

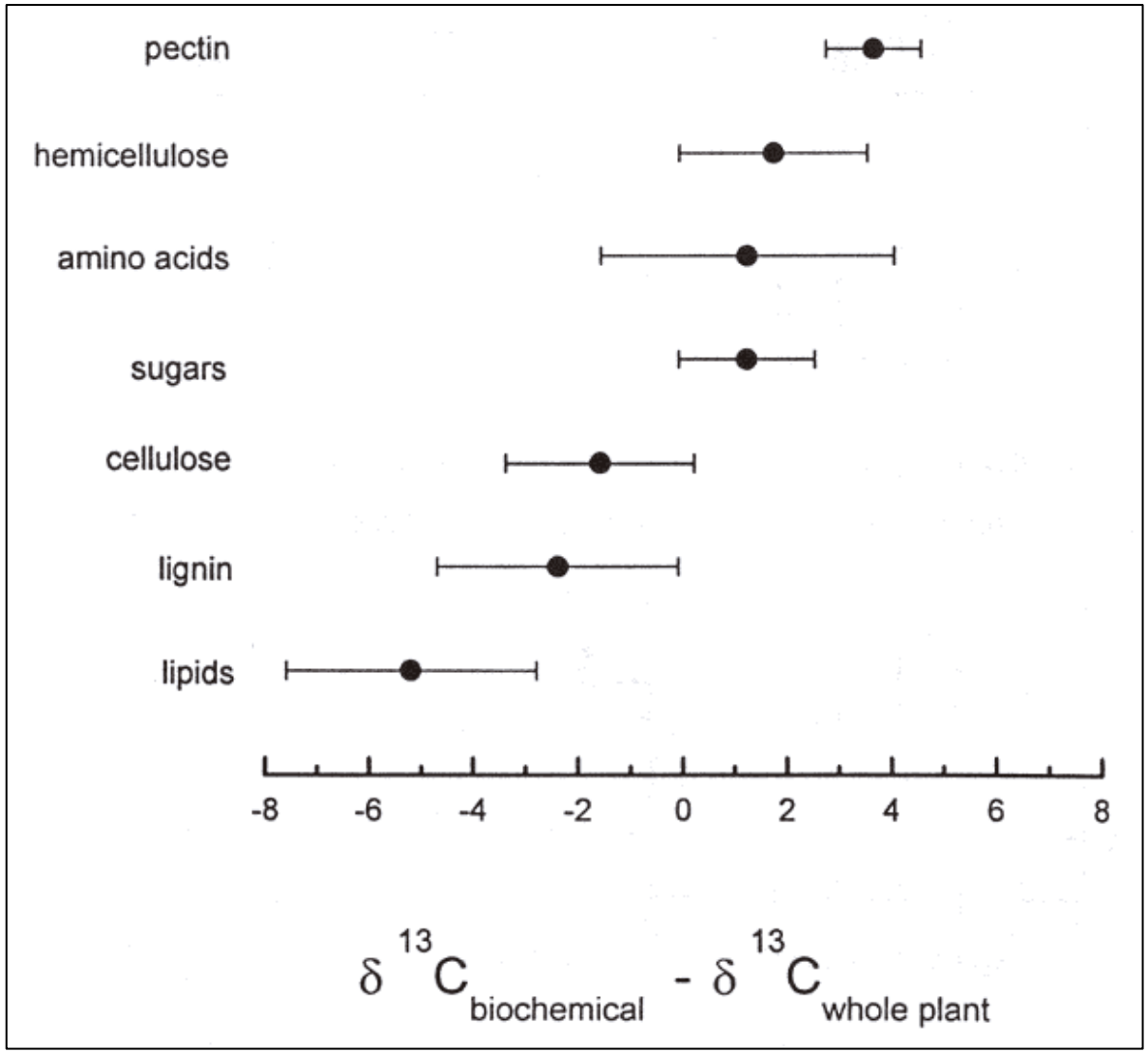
$$^{18}\Delta = \bar{a} + c_c(\delta_c - \delta_a)/(c_a - c_c)$$



The enzym „carbonic anhydrase“ catalyses the exchange of O_2 between CO_2 and leaf water.

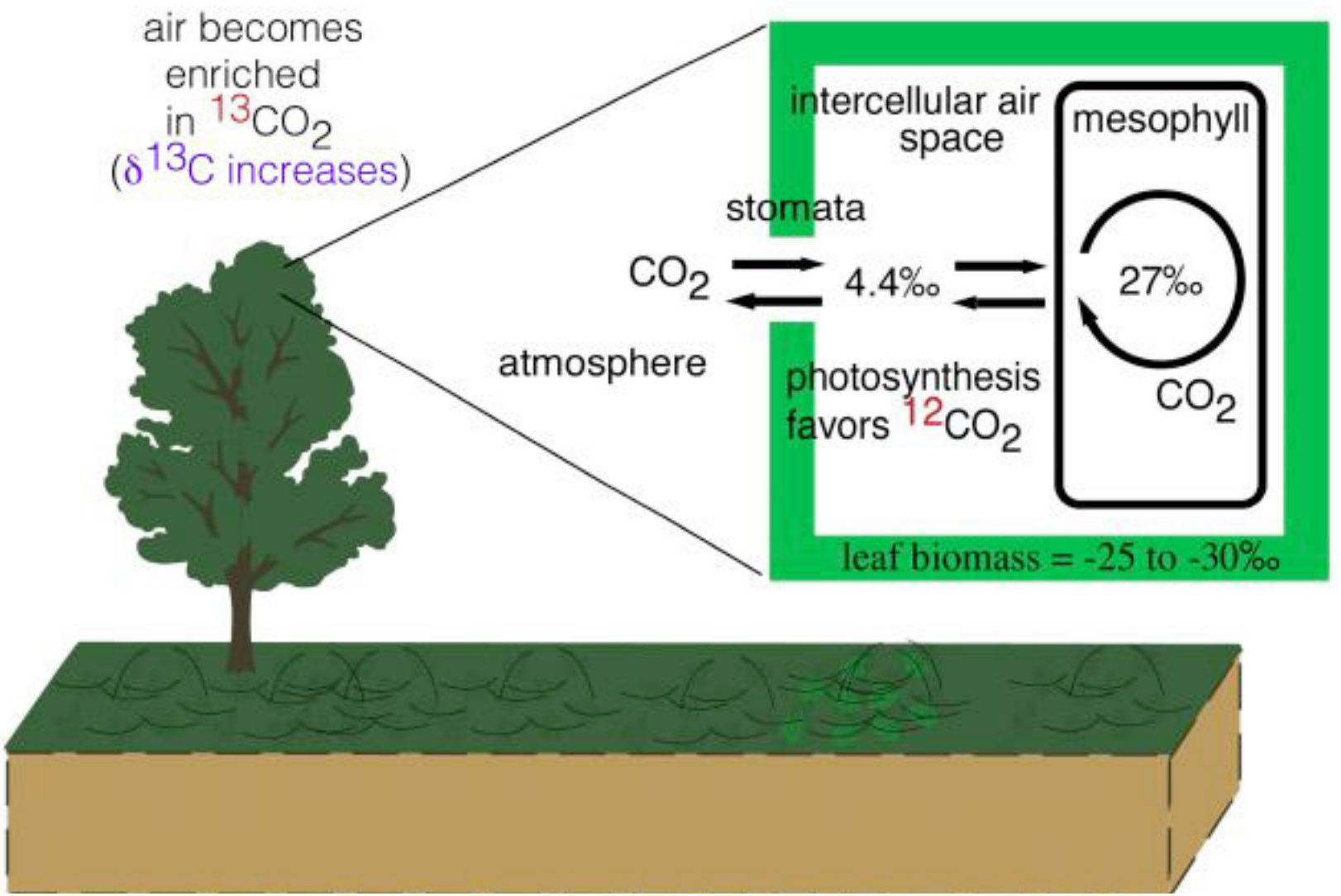
Organic material caries two „lables“ –
^{13}C and ^{18}O – which allow for different conclusions!

Intramolecular C Isotope Distribution



Fractionation in metabolism!

Ecosystem CO_2-Exchange



Global CO_2-Concentration

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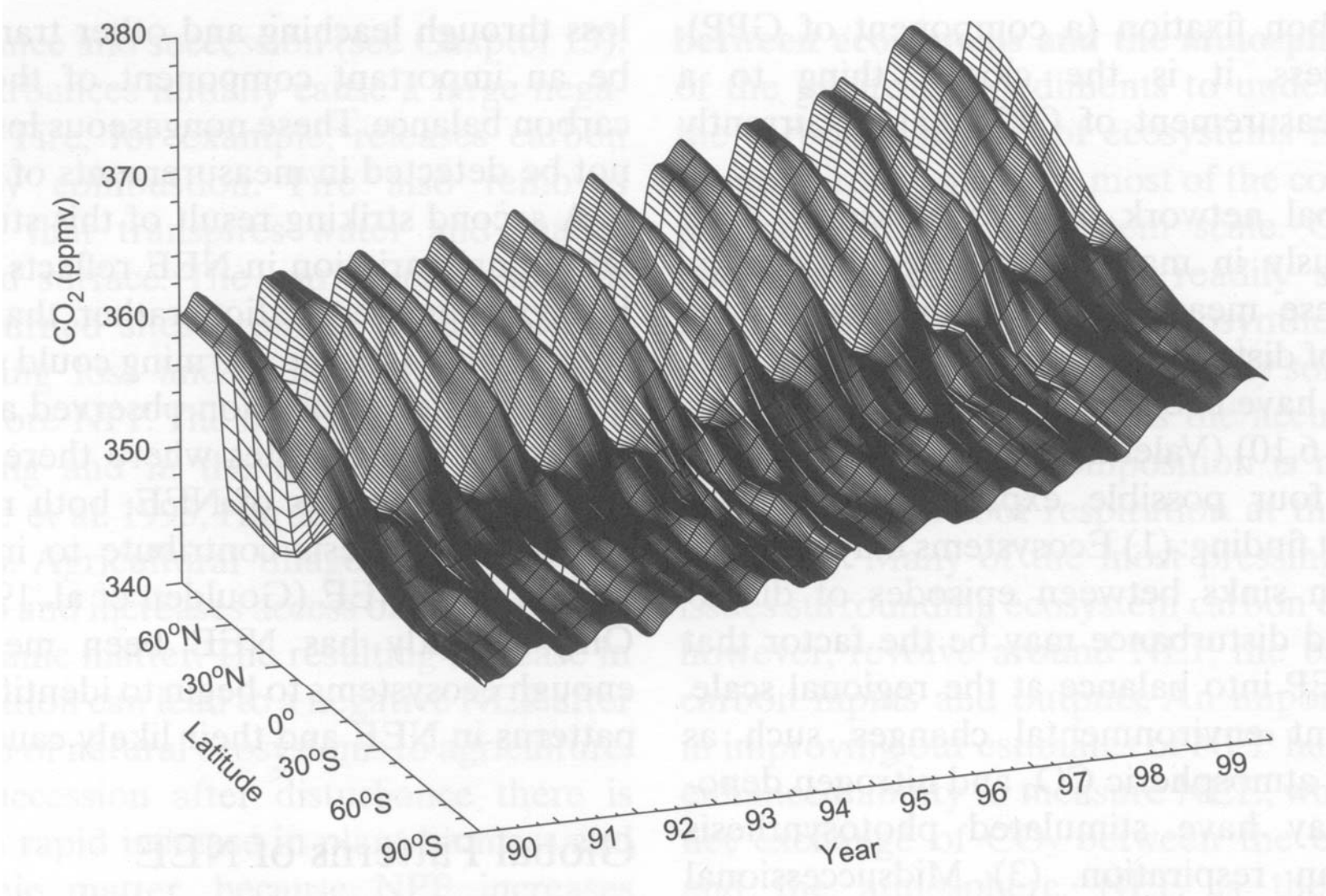
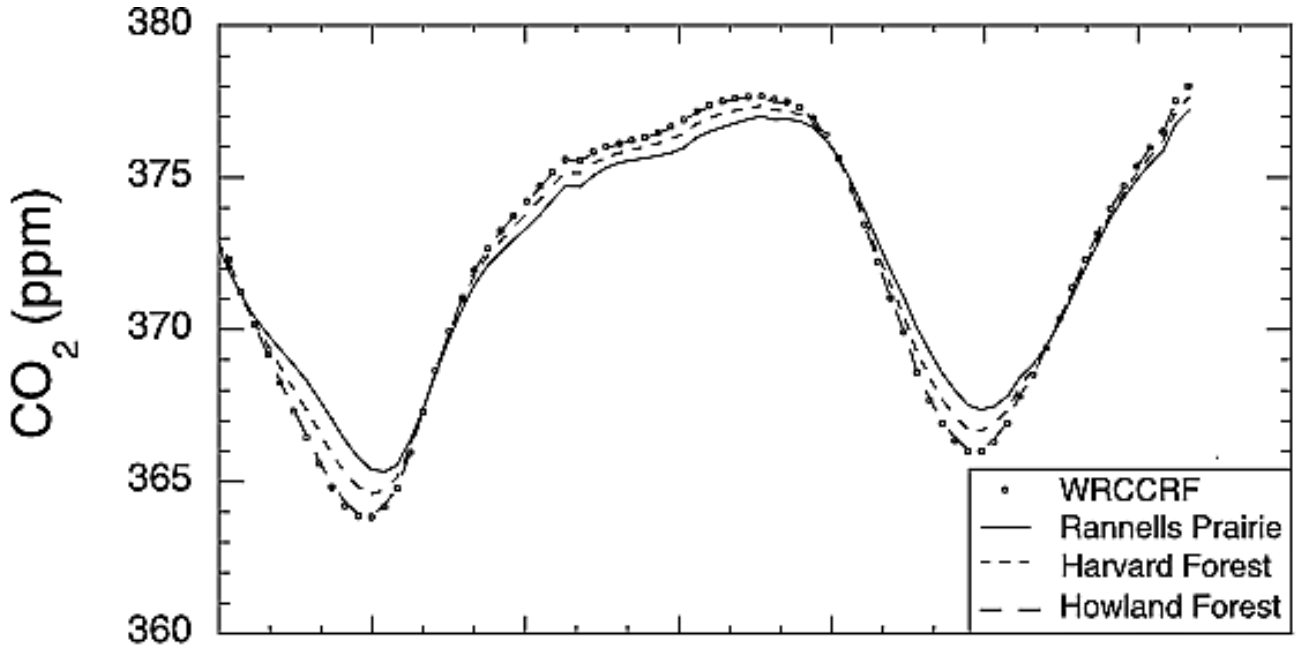
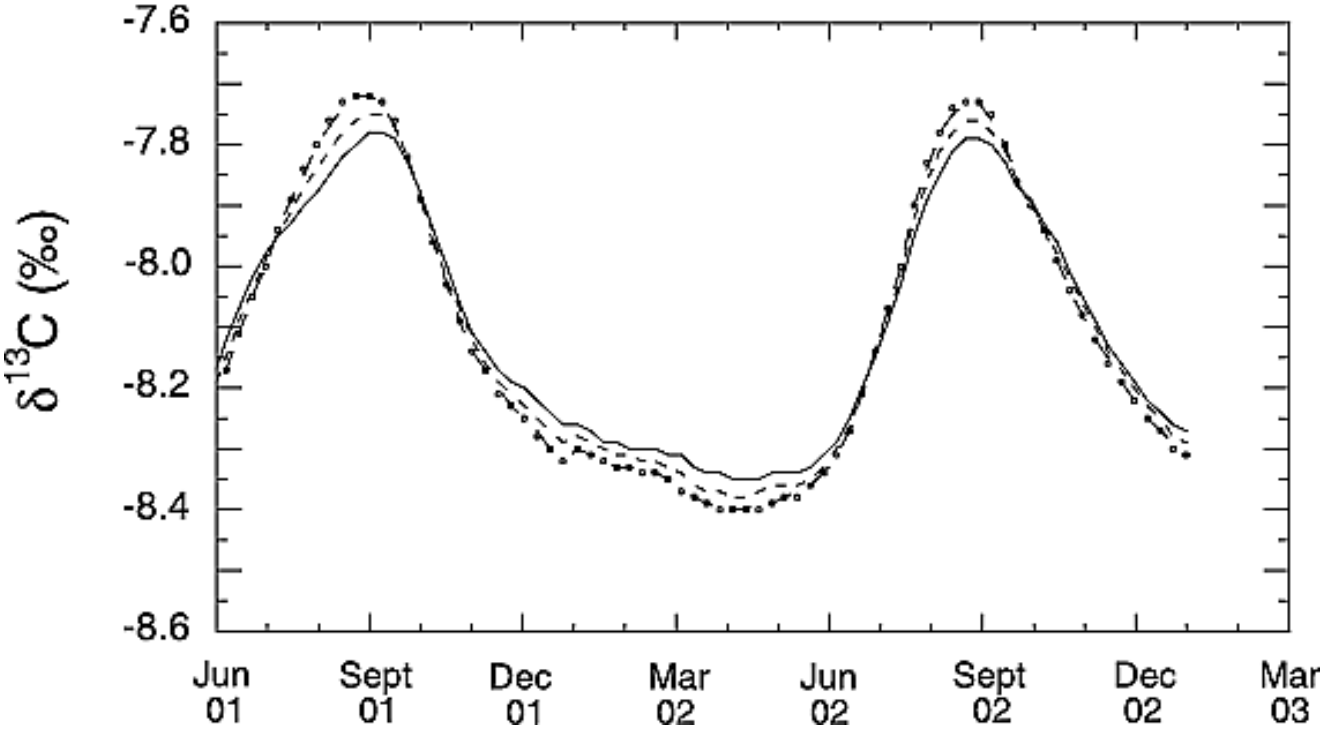
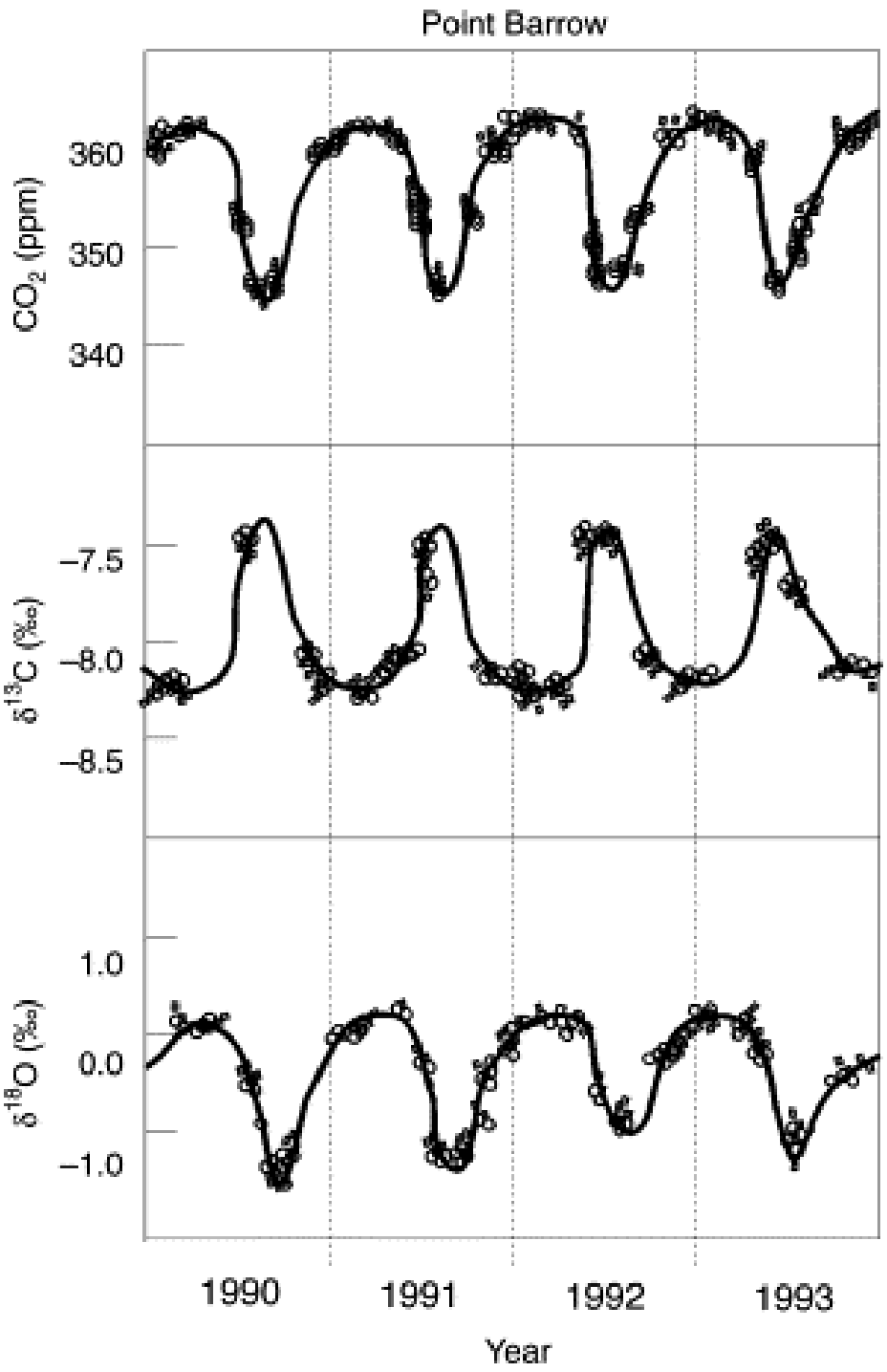


Chapin, Matson, Mooney (2002)


380
375
370
365
360
CO_2 (ppm)
WRCCRF
Rannells Prairie
Harvard Forest
Howland Forest


-7.6
-7.8
-8.0
-8.2
-8.4
-8.6
$\delta^{13}C$ (‰)
Jun 01
Sept 01
Dec 01
Mar 02
Jun 02
Sept 02
Dec 02
Mar 03

Seasonal Changes



High Photosynthesis:
enrichment in ^{13}C of the atmospheric CO_2 (preferential use of $^{12}CO_2$)

Oxygen exchange:
enrichment of ^{18}O during exchange in leaves; depletion during exchange in soils

(M. Trolier *et al.*, 1996)

Latitudinal Discrimination

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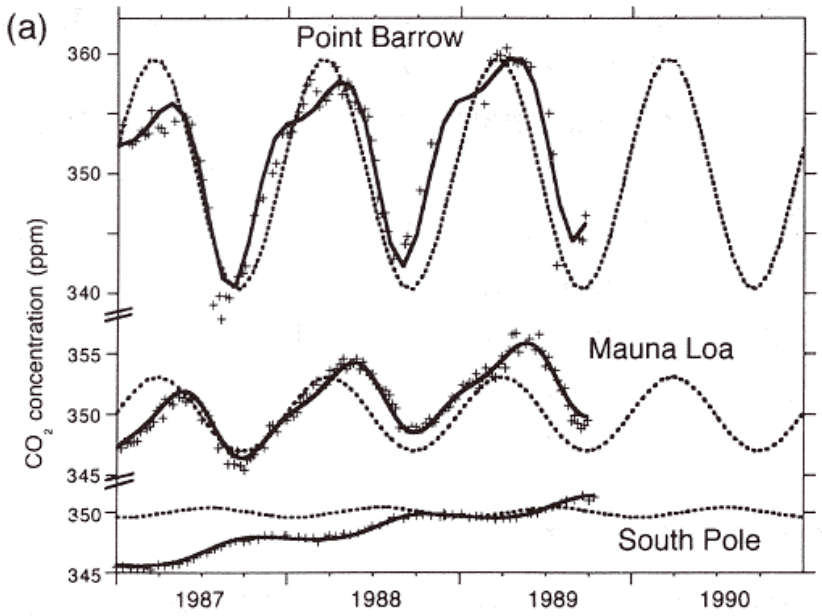
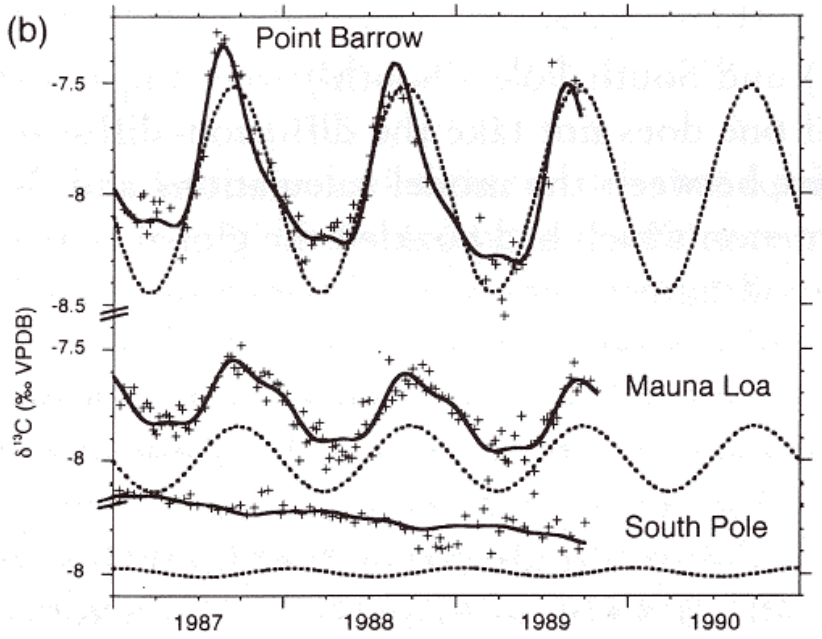
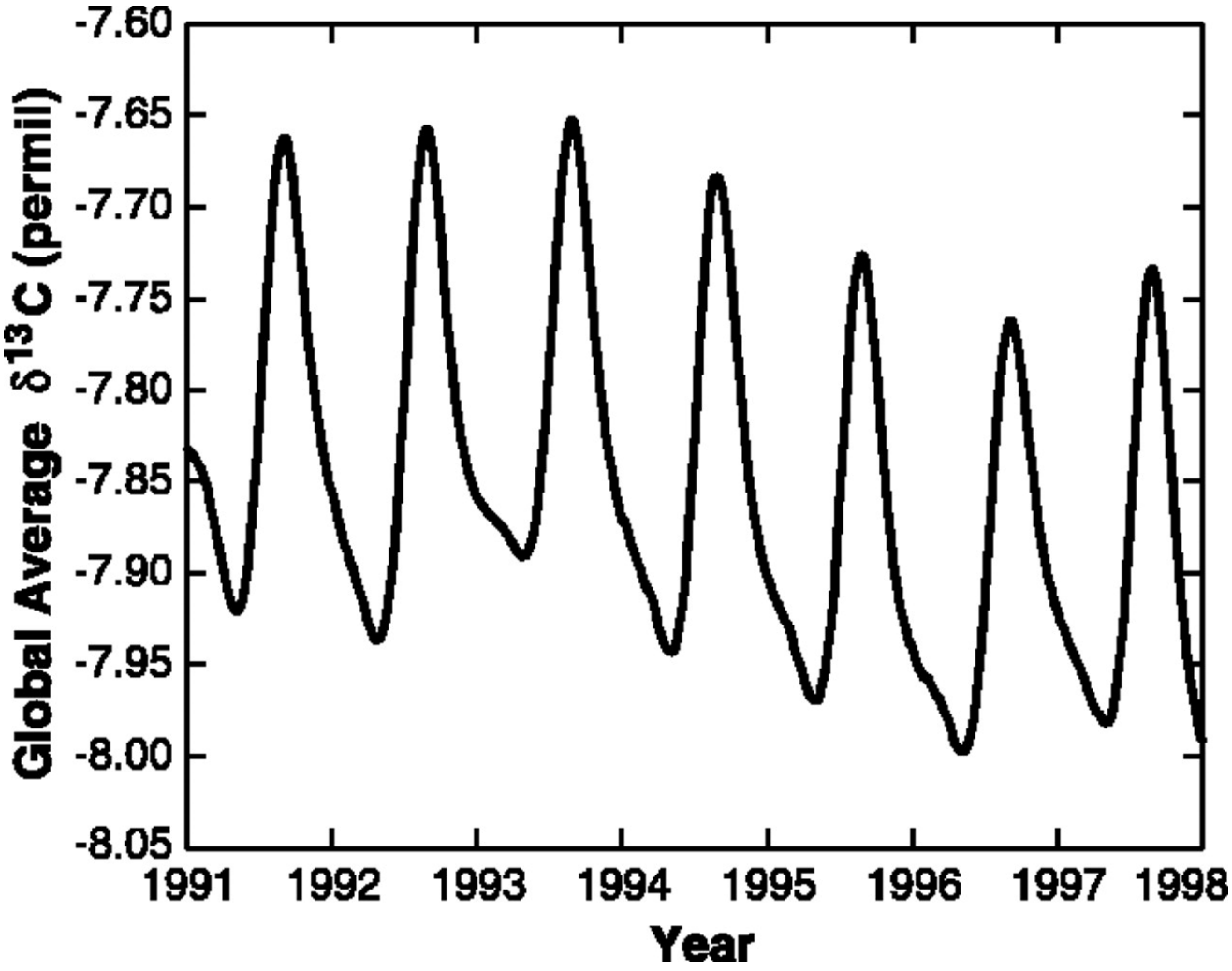




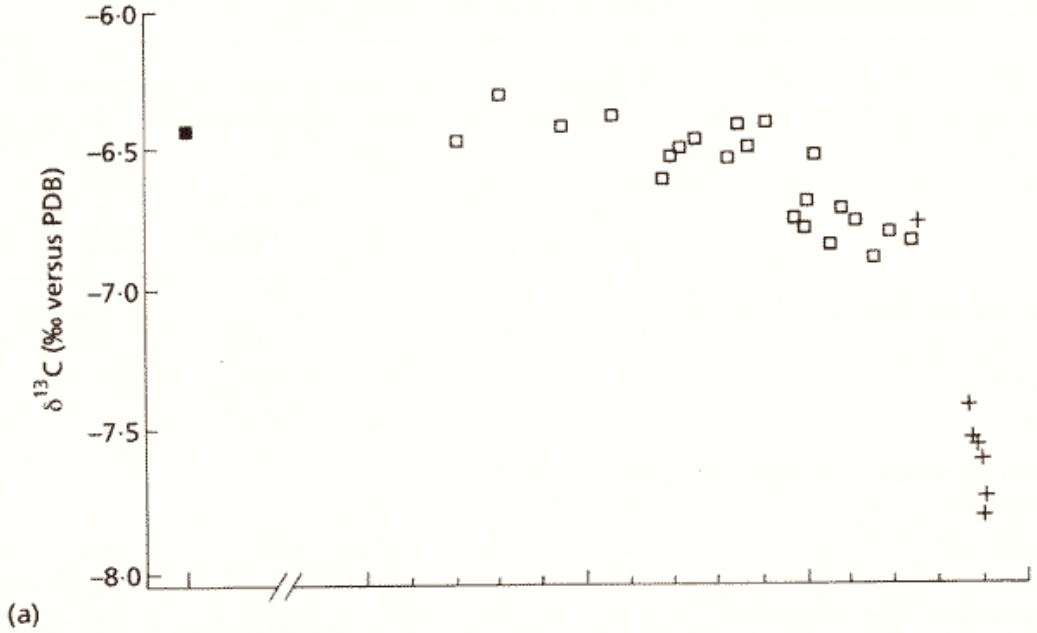
Effected by vegetation and land mass distribution

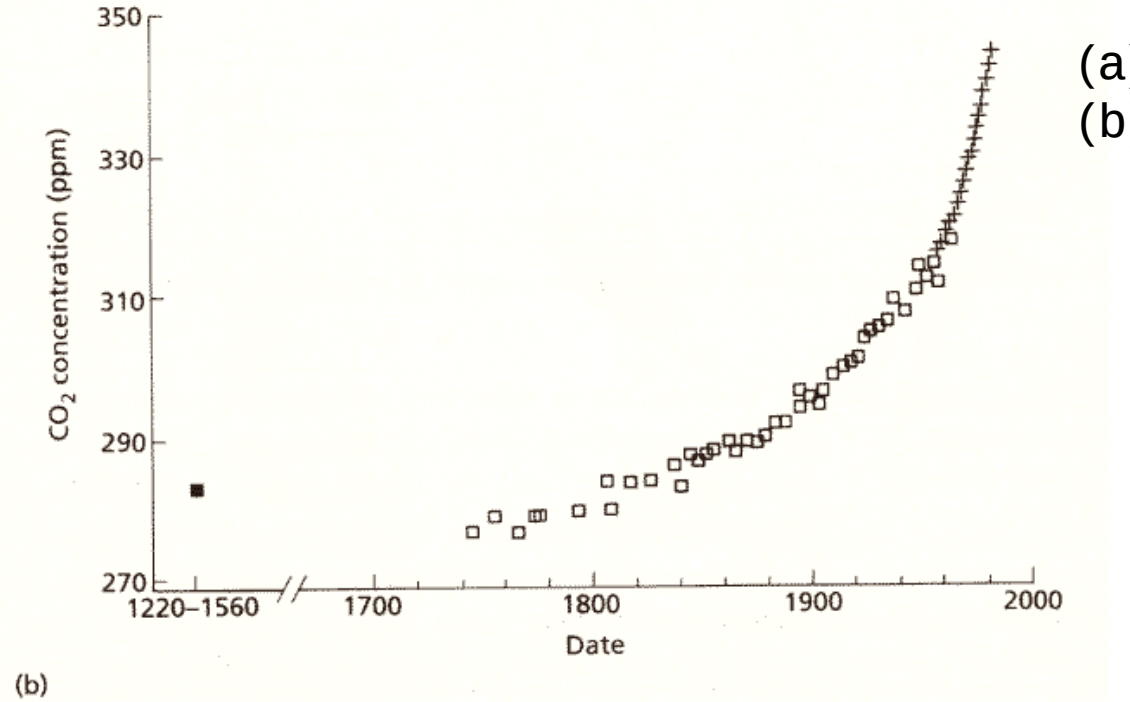
(Chapin, Matson, Mooney, 2002)

Global $\delta^{13}CO_2$-Value



Battle et al. (Science, 2000)





Atmospheric CO_2

Fossil fuel burning

(a) decreases $\delta^{13}C$ of CO_2
(b) increases in CO_2 concentration

Balesdent & Mariotti (1998)