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Intégration d'un module de détoxification métabolisme-dépendant dans un modèle d'évaluation des risques encourus par les arbres soumis à l'ozone

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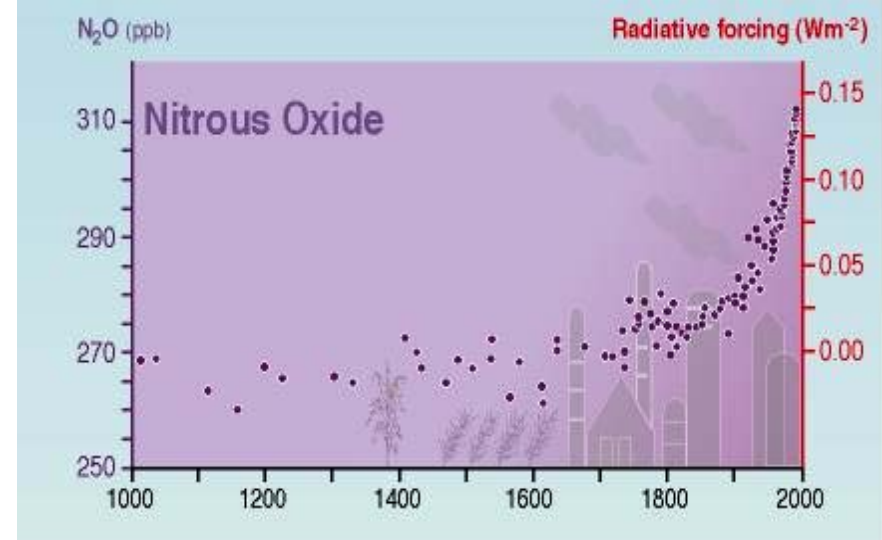
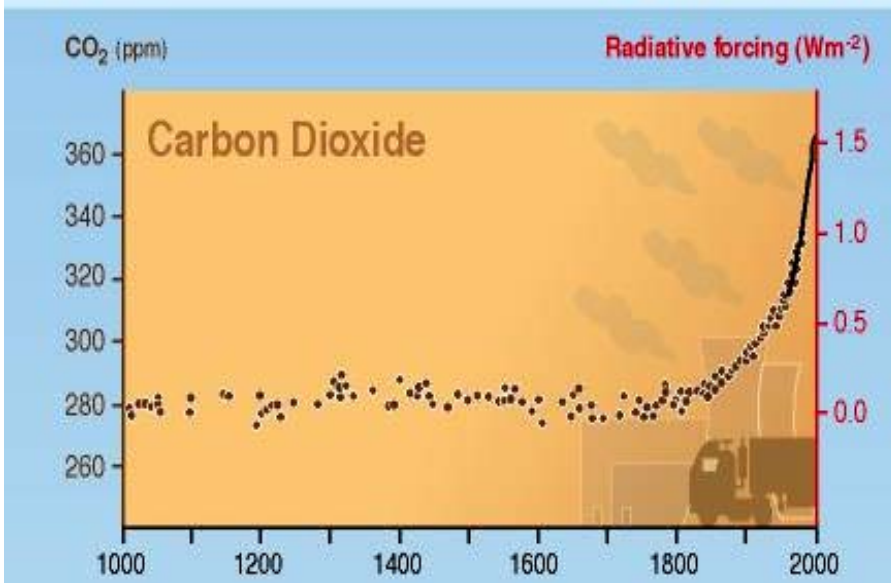
Wood fuel is the only source of fuel for one third of the world's population

Wood demand will double in next 50 years

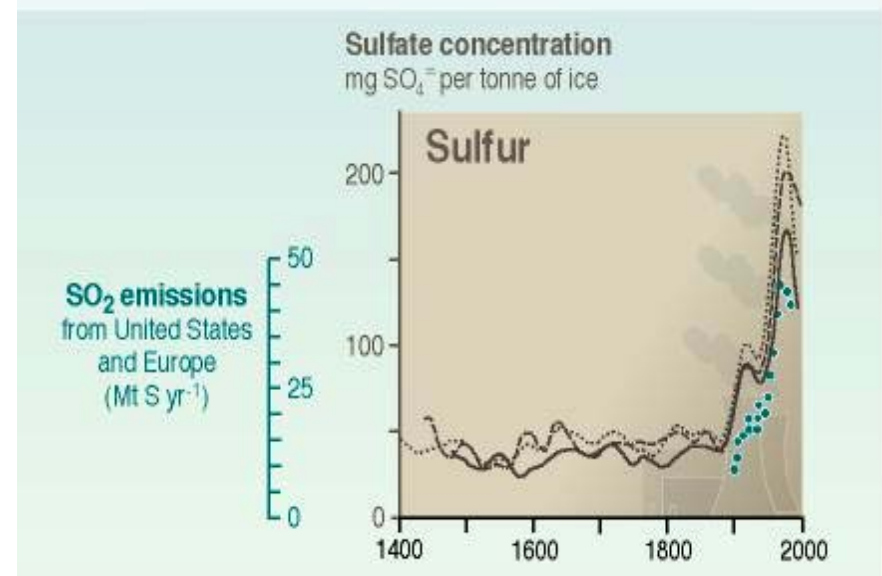
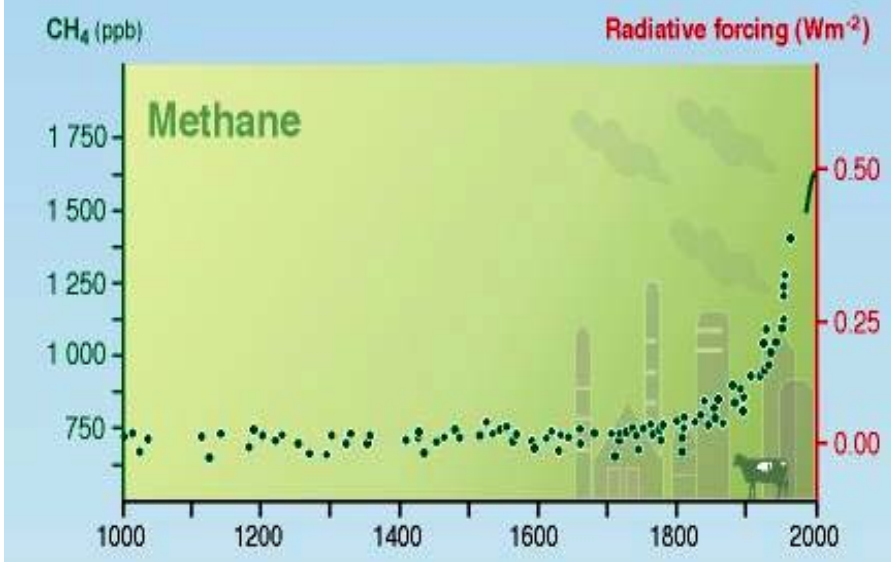
Climate change is projected to increase forest productivity, but forest management will become more difficult, due to an increase in pests and fires



Human activities have changed the composition of the atmosphere since the pre-industrial era

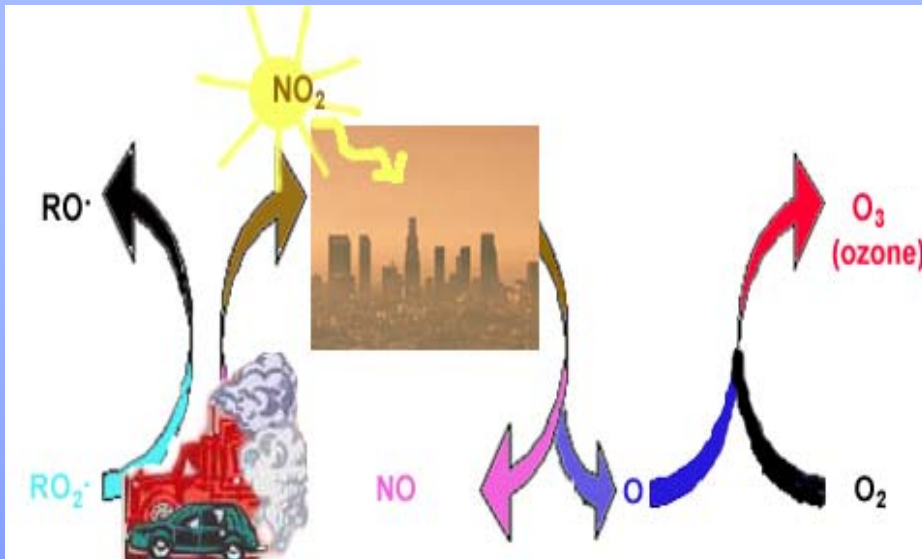


Sulfate aerosols deposited in Greenland ice



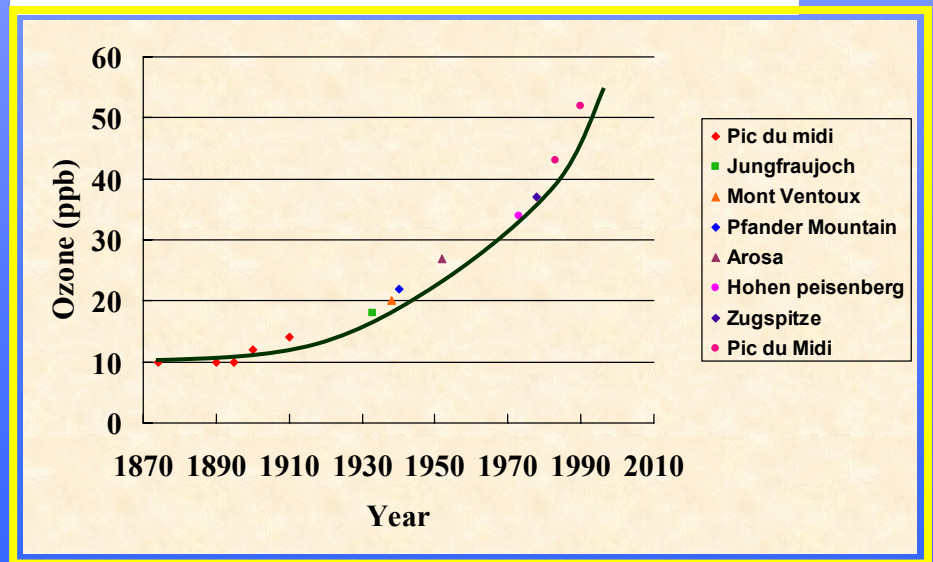
Ozone formation

Evolution of ozone level



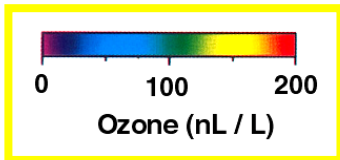
(C. Herman & R. Frey, St-Louis, USA, 2001)

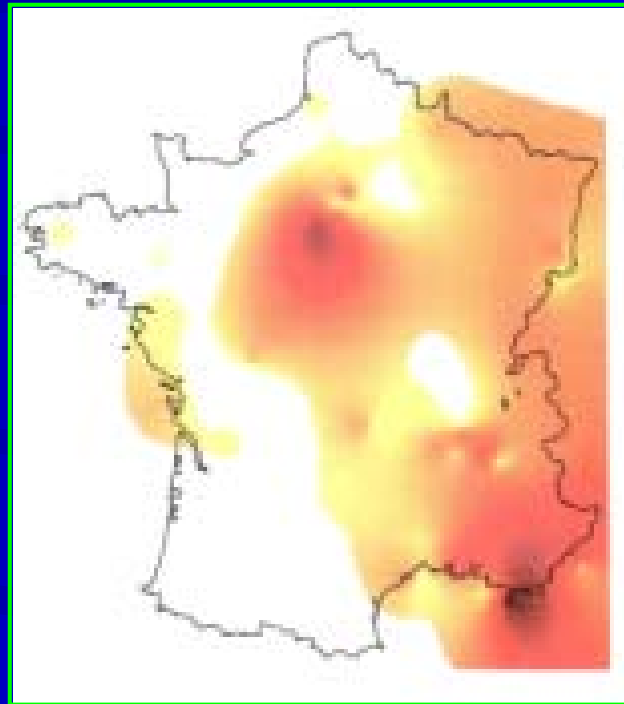
Ozone concentrations 1870-2000



Pollution climate at L.A :

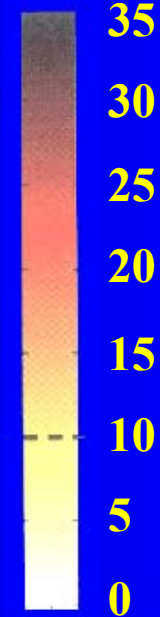
August 27, 1987





Année 1997

ppm.h⁻¹



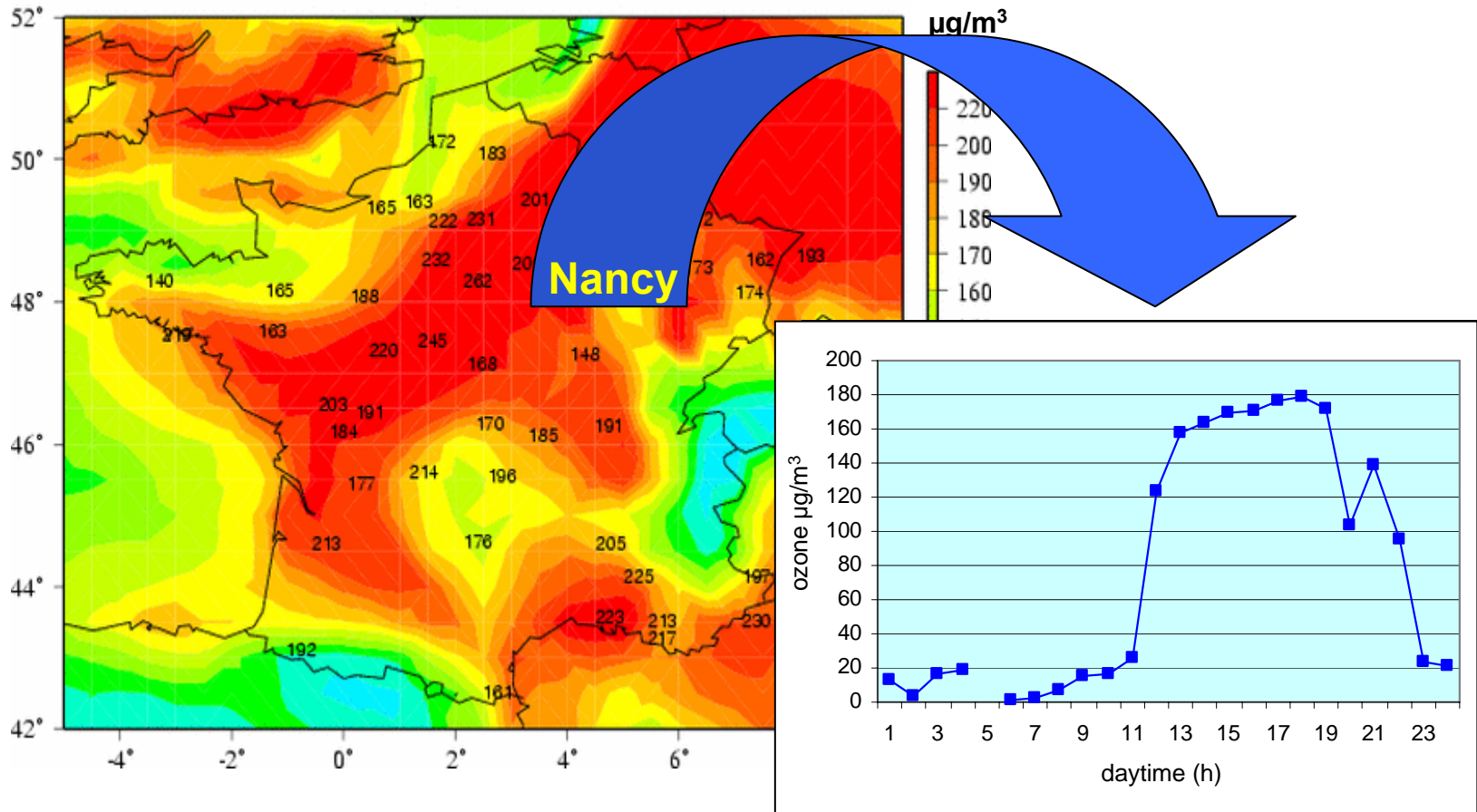
10 seuil critique

Pour les plantes, un seuil critique (AOT 40) de 10 ppm.h⁻¹ (6 mois) est fréquemment dépassé dans les pays industrialisés

(Source : Cahiers du Département de la Santé des Forêts, 1999)

Ozone level in France

August 8, 2003



↘ Peaks up to 180 $\mu\text{g}/\text{m}^3$ 100 ppb

Smog over :

Los Angeles



Athens

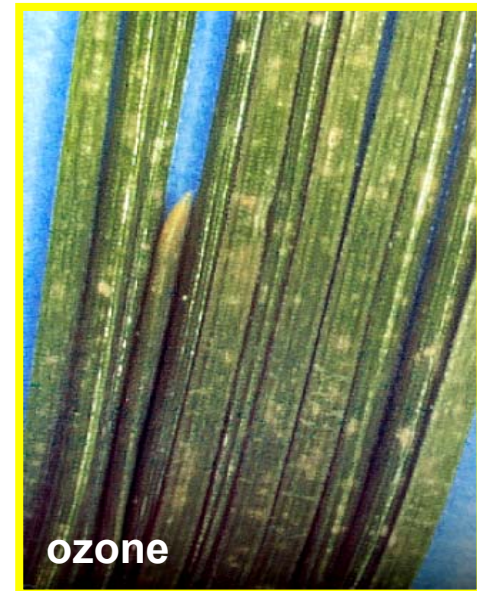


control



ozone

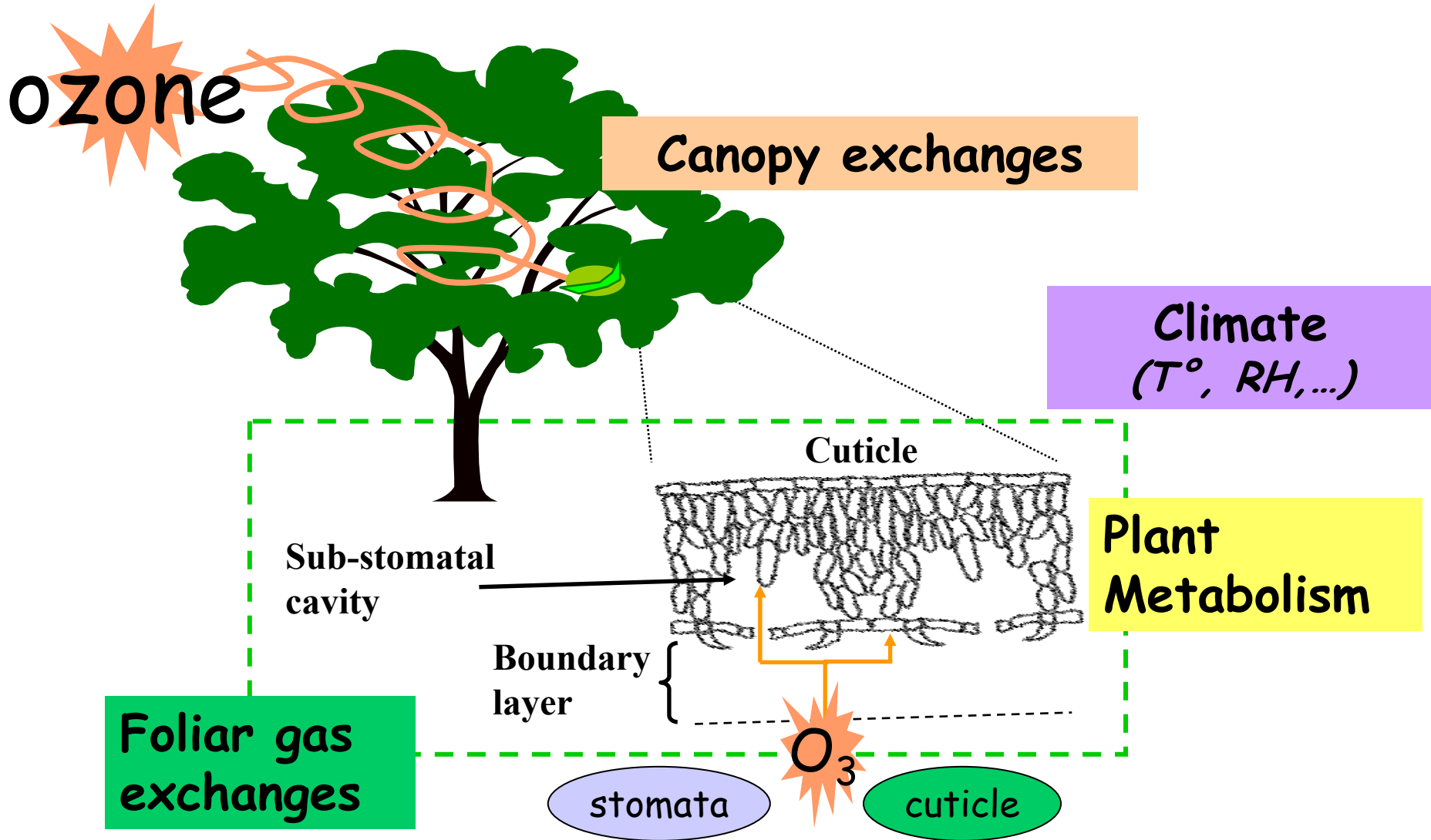
Ponderosa pine



ozone

Aleppo pine

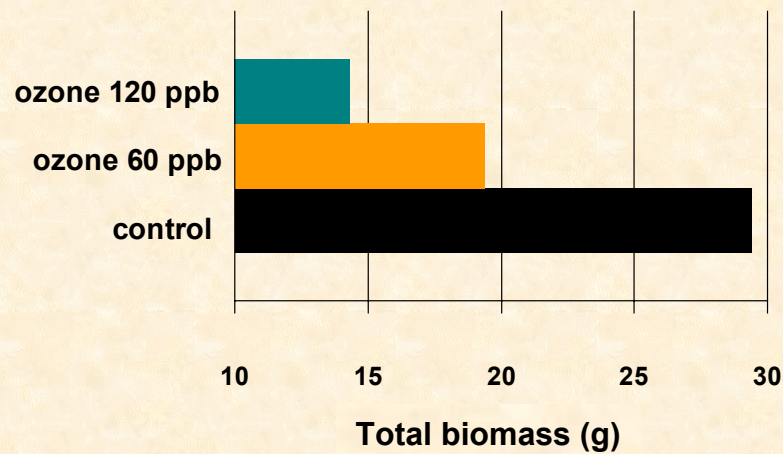
Exchanges of ozone with vegetation



Effect of ozone on growth of poplar

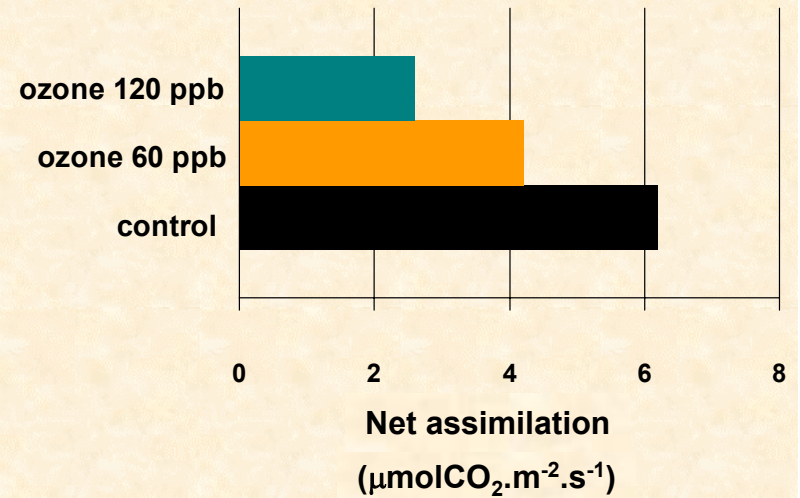
Biomass

Fumigation : 34 days



Photosynthesis

Fumigation : 34 days



➡ **Parallel decrease
of biomass and
photosynthesis**

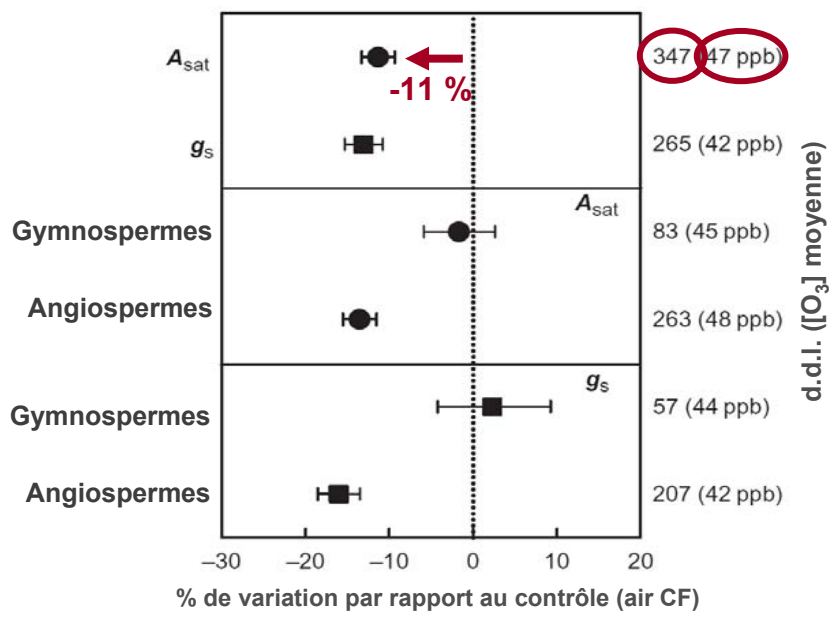
Impact de l'ozone sur les arbres forestiers

Assimilation de CO₂ et conductance stomatique

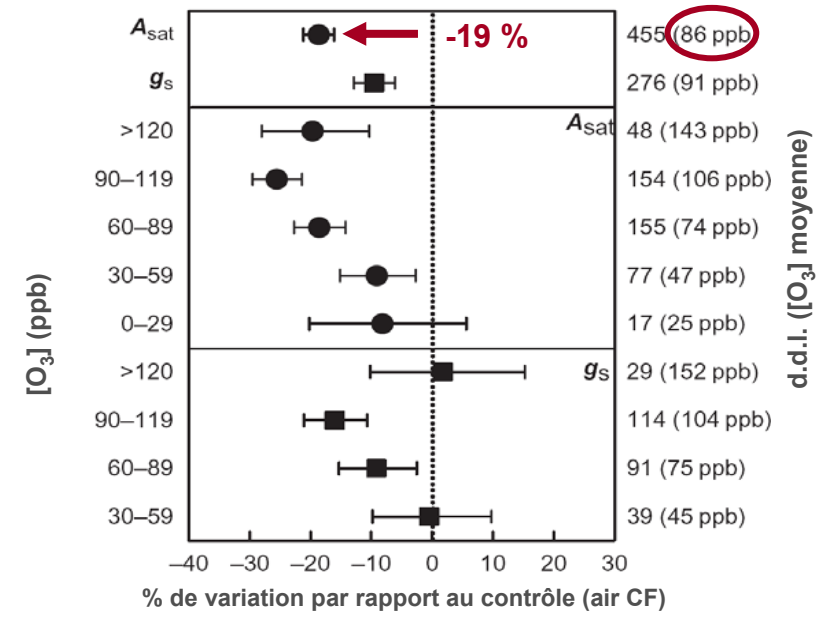
Méta-analyse de 61 (A_{sat}) et 55 (g_s) études publiées

Wittig *et al.* (2007) *Plant, Cell and Environment*, 30 (9) : 1150-1162.

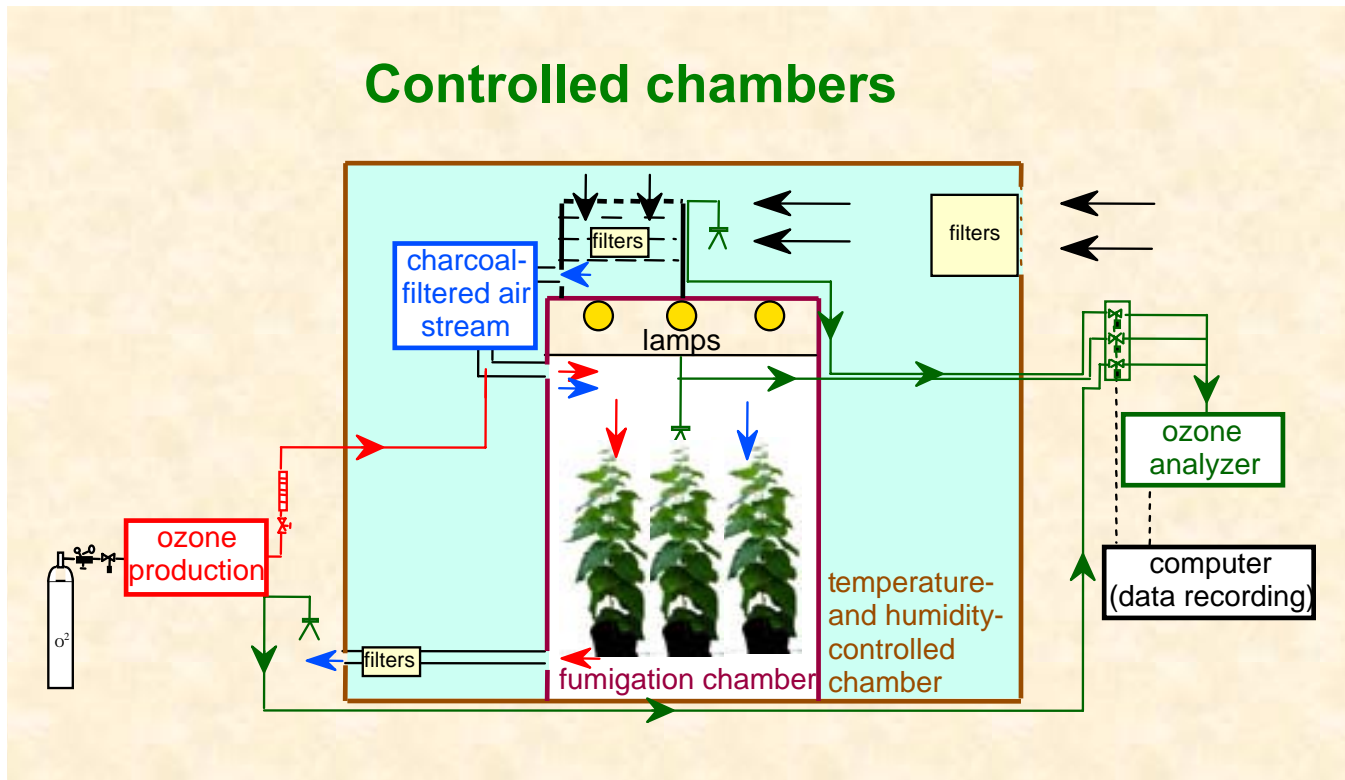
Concentration ambiante en O₃



Concentration élevée en O₃



Experimental design at Nancy



ozone 60-200 ppb
light 200-300 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$
temperature 22/18°C (day/night)
humidity 75/85 % (day/night)

Symptômes foliaires observés

Mûrier blanc



Peuplier noir



Air filtré

Ozone



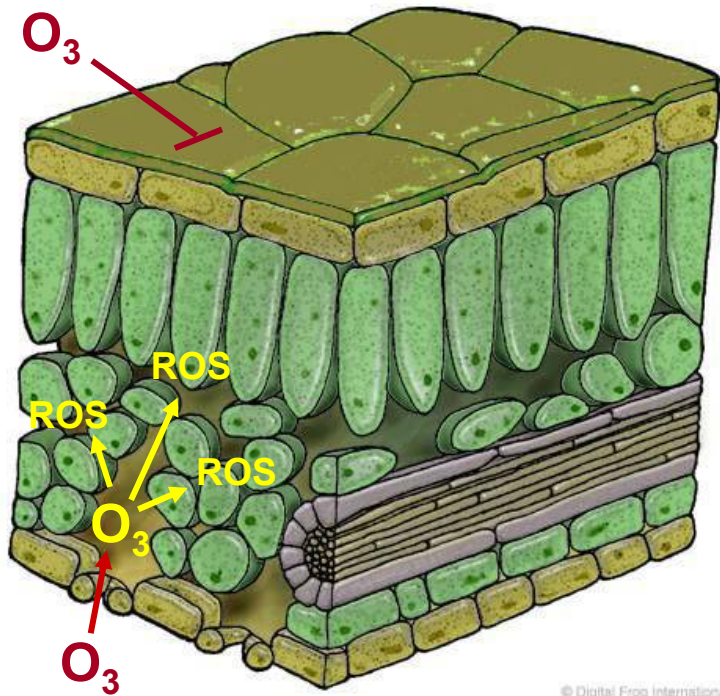
Populus tremula x alba
Chambres phytotroniques
35 jours, ozone 120 ppb



Source : Field Exercise of the 4th UN/ECE ICP-Forests Ozone Training Course.
Italie/Suisse, 25-27 août 2003.

<http://www.wsl.ch/ozone>

Action de l'ozone sur les végétaux



- ▶ **Pénétration par les stomates**
- ▶ **Décomposition rapide**
- ▶ **Génération de ROS**
(espèces oxygénées réactives)
 O_2^- ; HO^{\cdot} ; H_2O_2 ; etc.
- ▶ **Stress oxydant**

Exposition chronique

Concentration en ozone modérée

→ Perturbation du métabolisme

Photosynthèse réduite

Coûts de détoxification et de réparation

→ Réduction de croissance.

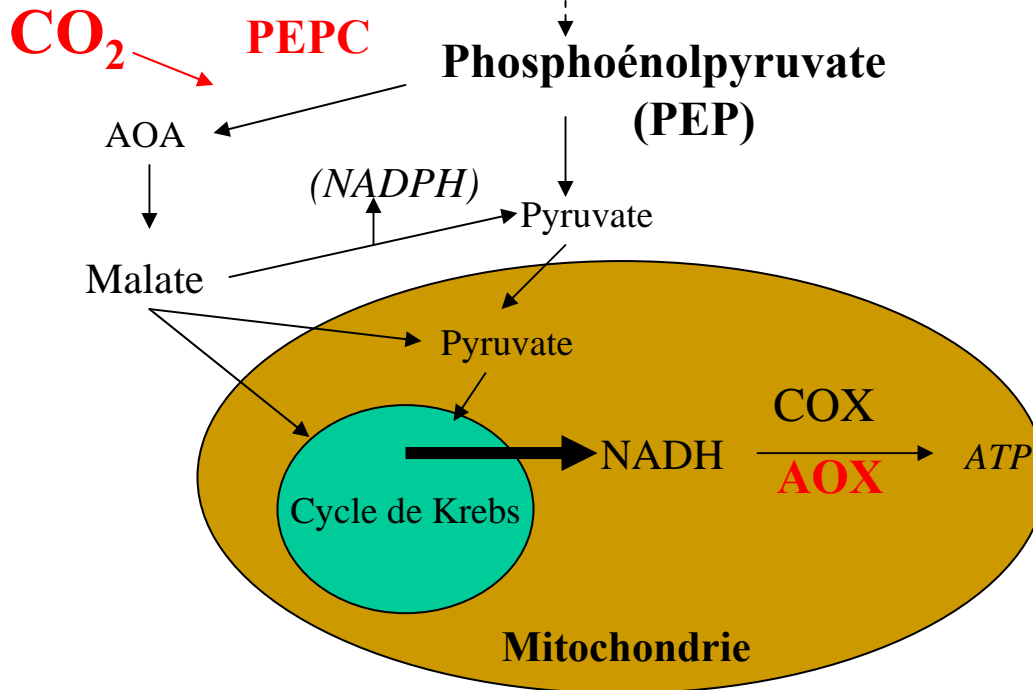
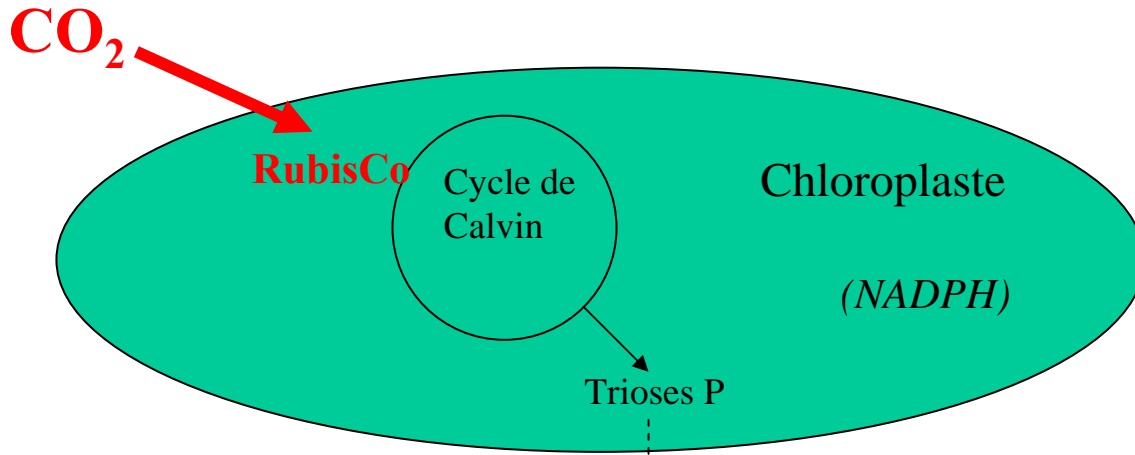
→ Sénescence accélérée.

Exposition ponctuelle

Pics de concentration en ozone

→ Symptômes foliaires

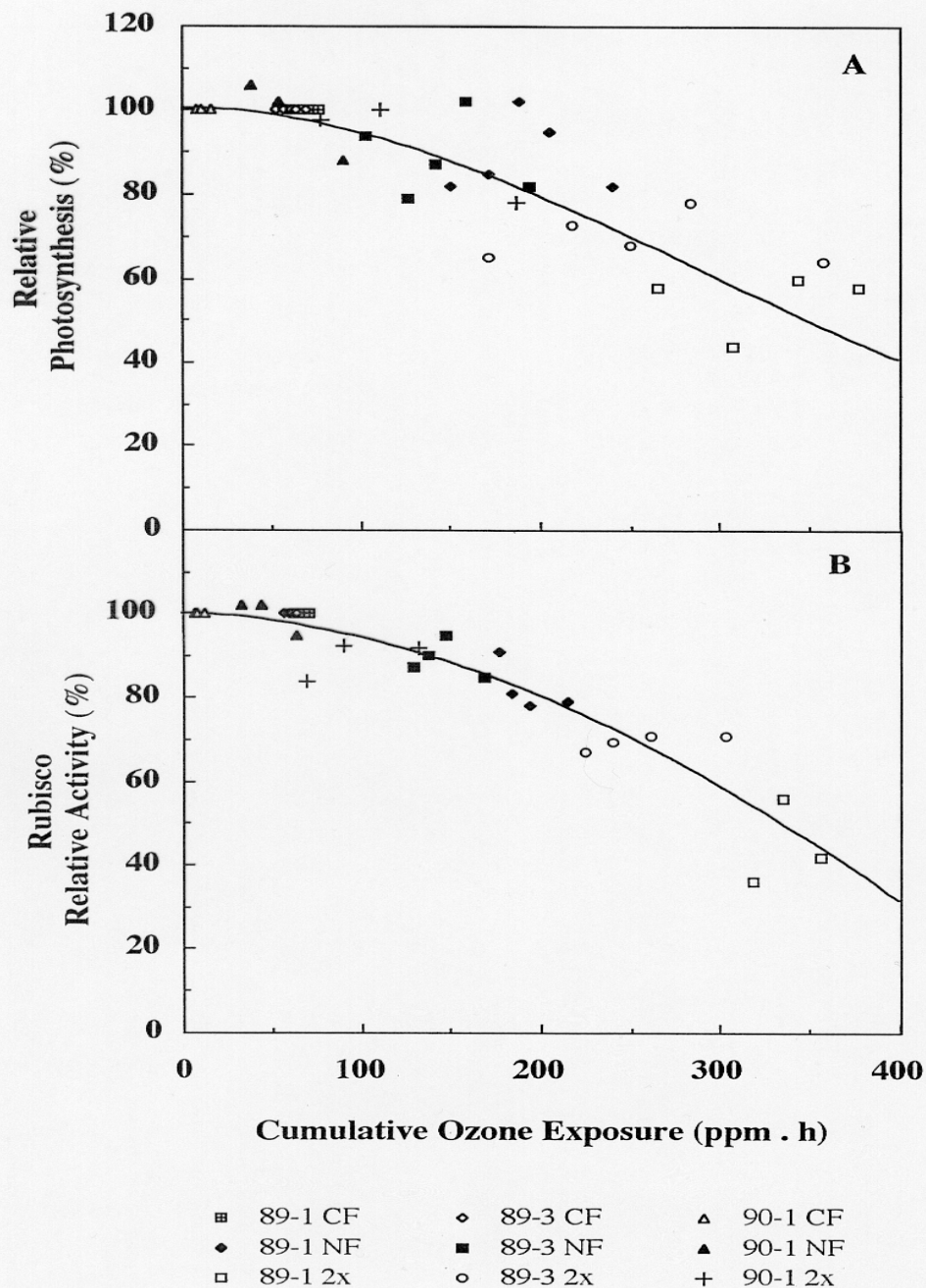
(chlorose, brunissement, nécrose)



Comparaison de l'effet de l'ozone
sur
la Photosynthèse (A)
et
l'activité RubisCO (B)

d'aiguilles de Pin loblolly
(*Pinus taeda*) âgés de 3 ans

Dizengremel et al., 1994

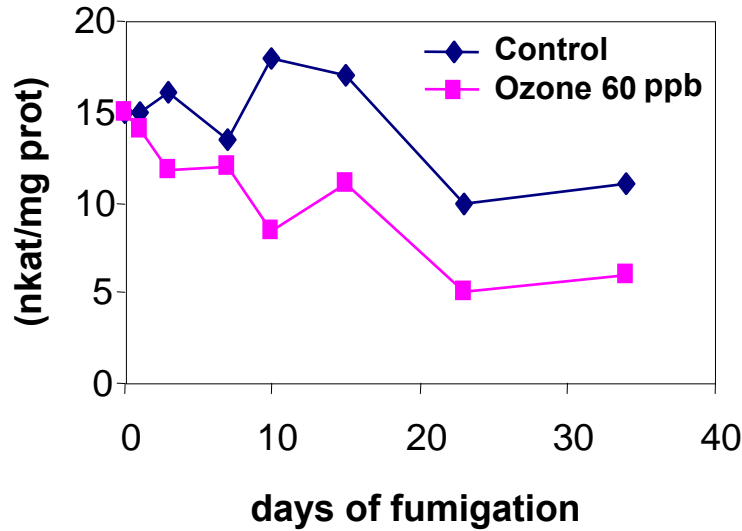


Effect of ozone on carboxylation:

Rubisco & Peps

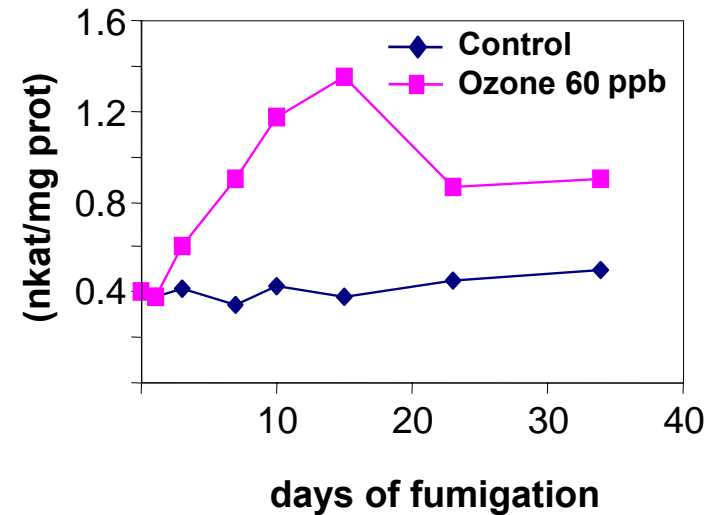
Poplar, 60 ppb O₃

Rubisco



➡ In ozone-treated plants :
inhibition of Rubisco activity

PEPc



➡ and huge stimulation of
Pepc activity

Indices of ozone exposure

$$AOT40 = \sum_i^j ([O_3]_h - 40)$$

AOT40 (accumulated exposure over a threshold of 40 ppb)

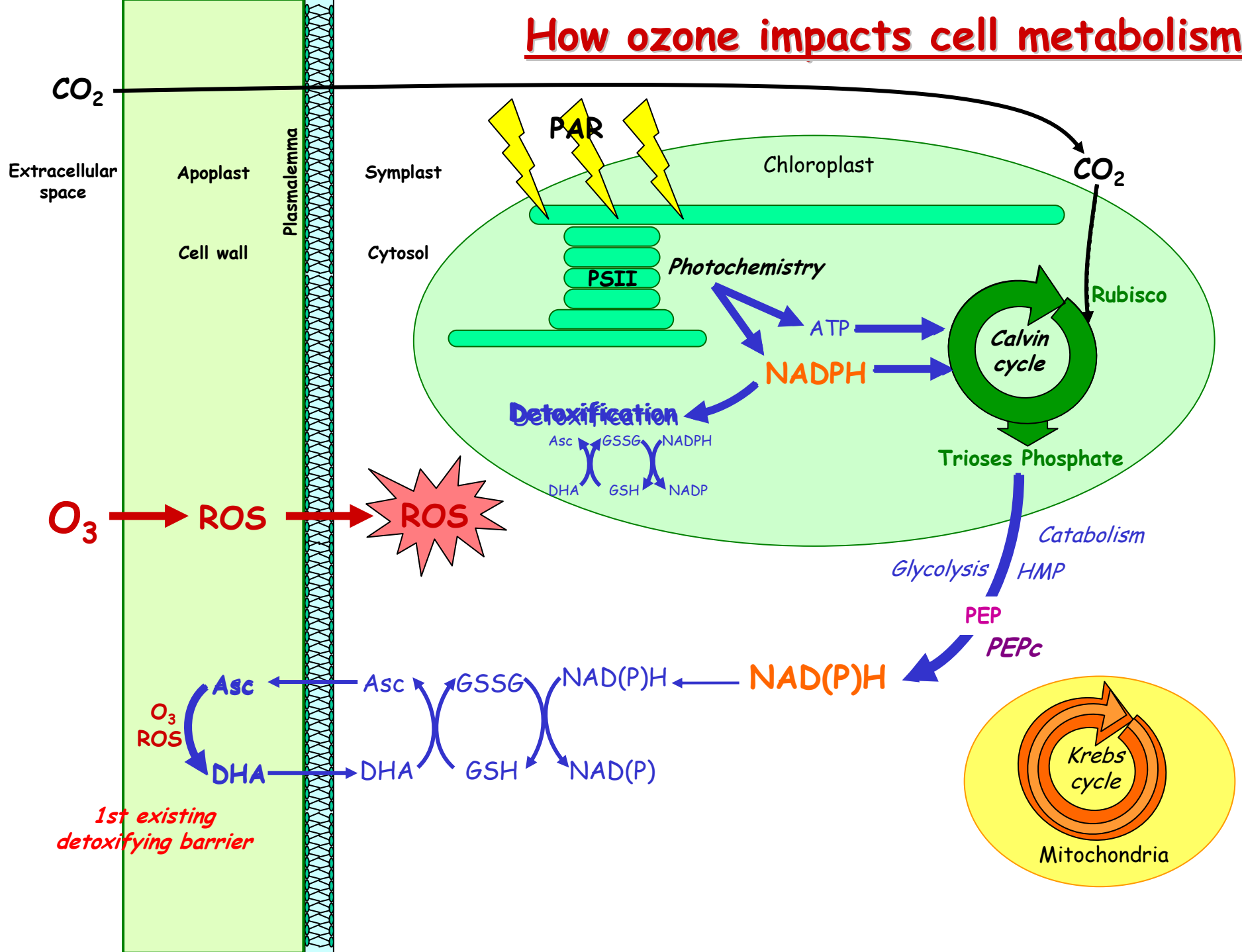
$$CUO = \sum_i^j (FO_3)_h$$

Karlsson *et al.* (2007)
Pleijel *et al.* (2007)

CUO (cumulative uptake ozone)

- Differences exist according to species, climate, etc...
- Effective ozone flux
- Detoxification/Metabolism

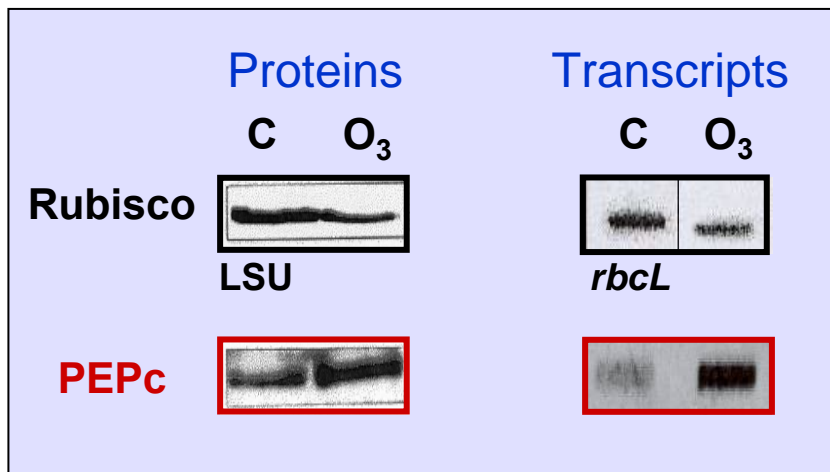
How ozone impacts cell metabolism



Effect of ozone on carboxylation

Rubisco & PEPc

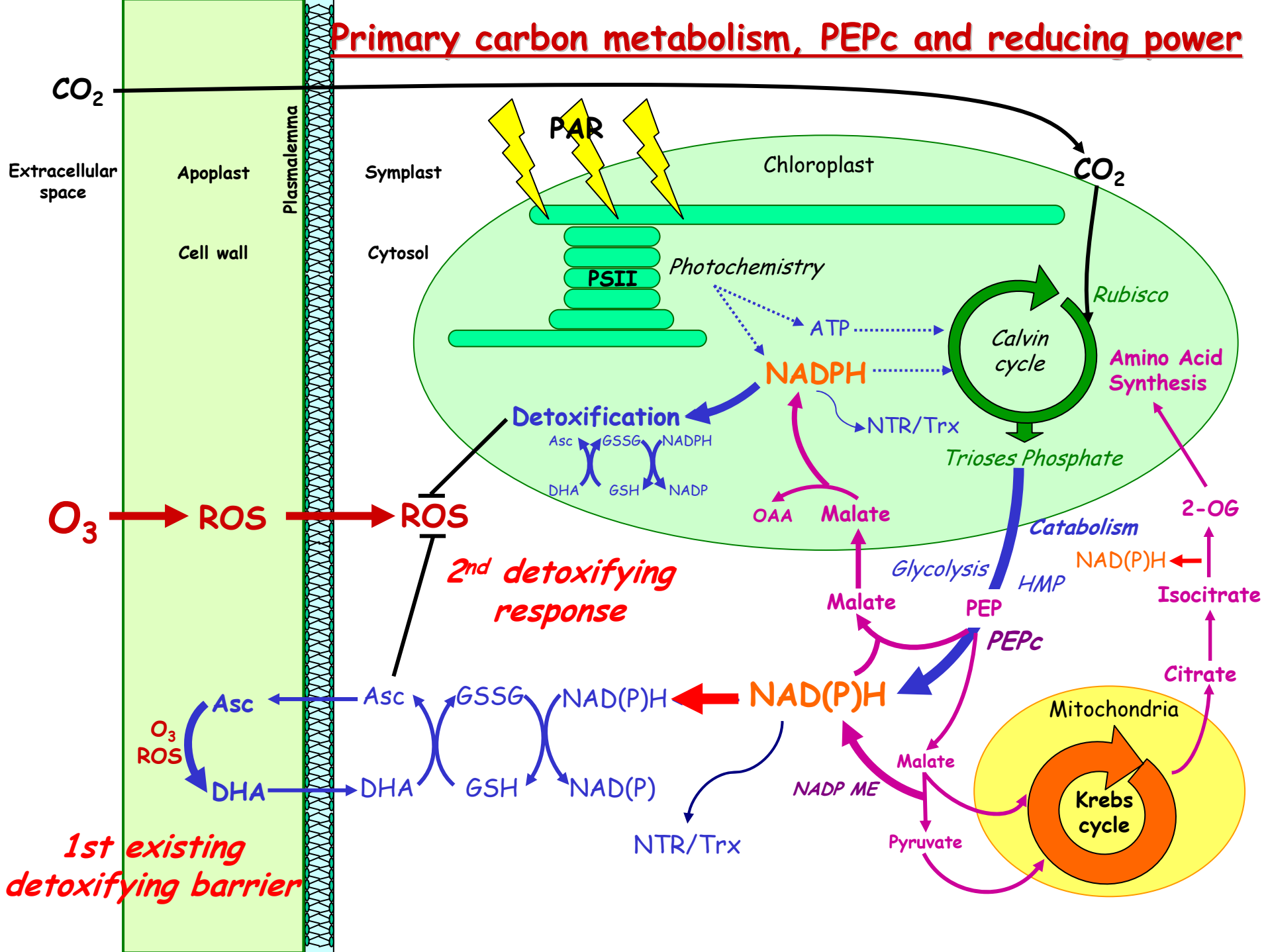
Specific activity (nkat.mg _{prot} ⁻¹)	Rubisco		PEPc		Rubisco / PEPc ratio	
	C	O ₃	C	O ₃	C	O ₃
Poplar 60 ppb O ₃ , 2 weeks	17.0	9.1	0.36	1.35	47.2	6.74
Norway spruce 200 ppb O ₃ , 12 weeks	13.2	6.2	0.45	2.55	29.3	2.43
Aleppo pine 200 ppb O ₃ , 5 weeks	13.6	7.5	0.55	1.96	24.7	3.82



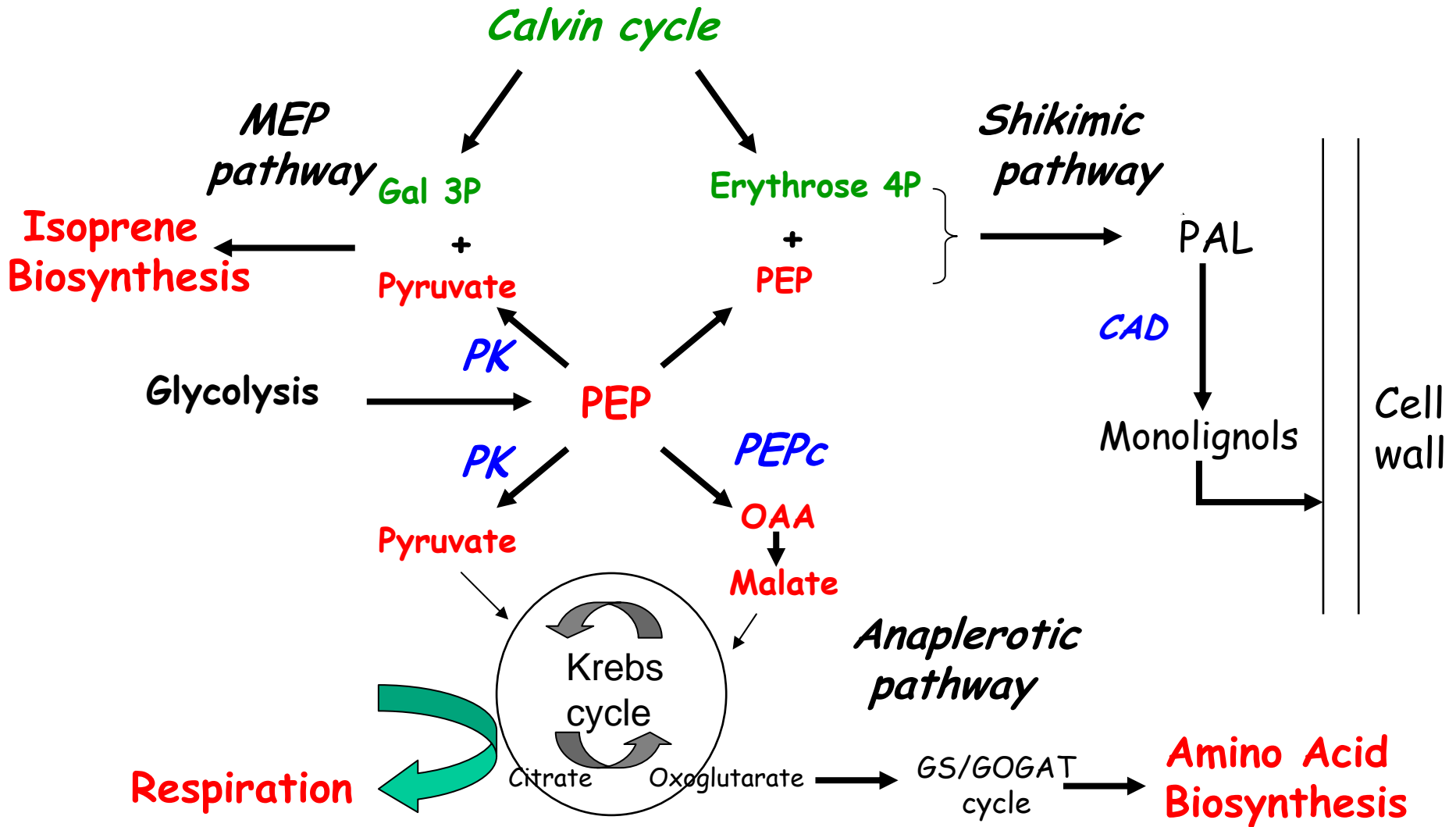
↪ In ozone-treated plants :
higher contribution of PEPc
to carboxylation activity

↪ putative transcriptional
regulation of Rubisco and
Pepc corresponding genes

Primary carbon metabolism, PEPc and reducing power



PEP as a key metabolite at crossroads for many purposes?



Which links could exist between PEPc increase, discrimination against $^{13}\text{CO}_2$ and WUE

$$\text{WUE} = A / g_s \quad (1)$$

From (1), (2) and (3):

$$\text{WUE} = (C_a - C_i) / 1.6 \quad (4)$$

According to Farquhar *et al.* (1982) :

$$\Delta = a + (b - a) (C_i / C_a) \quad (5)$$

From (4) and (5) :

$$\text{WUE} = C_a / 1.6 \times (b - \Delta / b - a) \quad (6)$$

According to Farquhar & Richards (1984) :

$$b = \beta \cdot b_1 + (1 - \beta) b_2$$

$$\beta = \text{PEPc activity} / (\text{PEPc activity} + \text{Rubisco activity})$$

b_1 = isotopic discrimination due to PEPc

b_2 = isotopic discrimination due to Rubisco

WUE = Water Use Efficiency

A = CO_2 assimilation = $g_{\text{CO}_2} (C_a - C_i)$ (2)

g_s = stomatal conductance to water = $1.6 \cdot g_{\text{CO}_2}$ (3)

C_a = atmospheric $[\text{CO}_2]$

C_i = internal $[\text{CO}_2]$

Δ = discrimination between ^{12}C and ^{13}C isotopes

a = stomatal diffusion

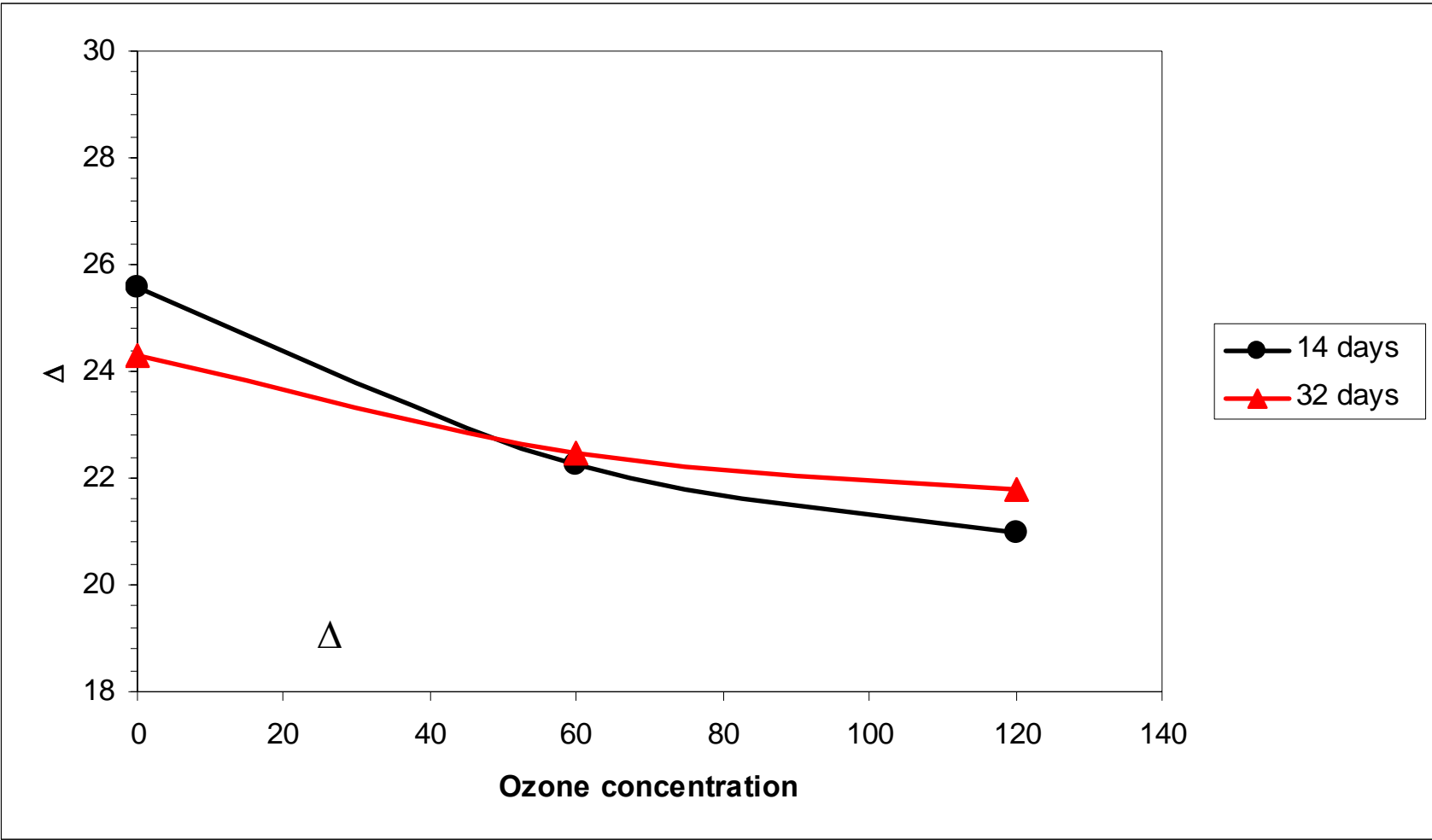
b = isotopic discrimination due to carboxylation

As ozone induces an increase in the PEPc/Rubisco ratio,

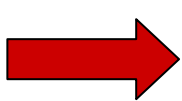
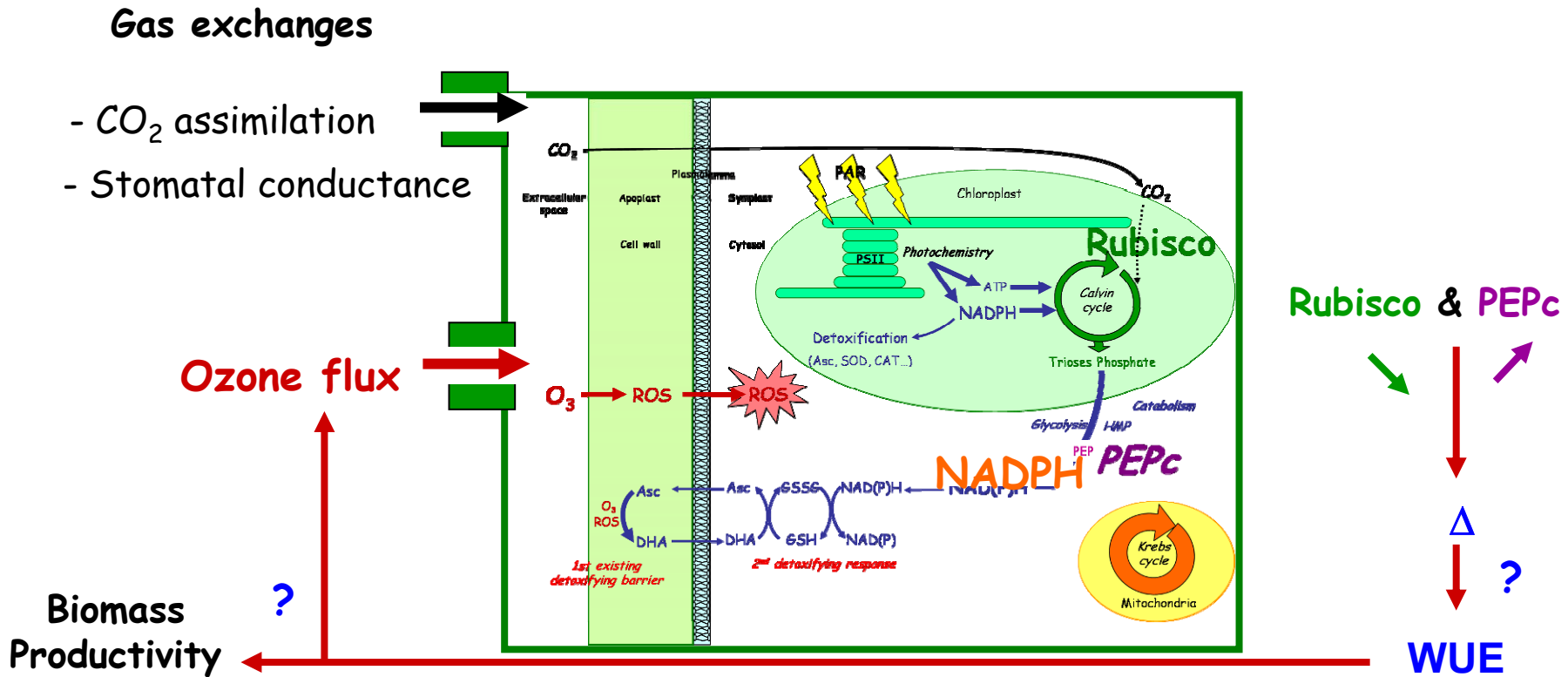
- β and b increase,

-and consequently Δ and WUE should be modified.

Δ (calculated) changes in poplar leaves submitted to two external ozone concentrations



Possible links between ozone flux, PEPc increase, isotopic discrimination against $^{13}\text{CO}_2$ and WUE

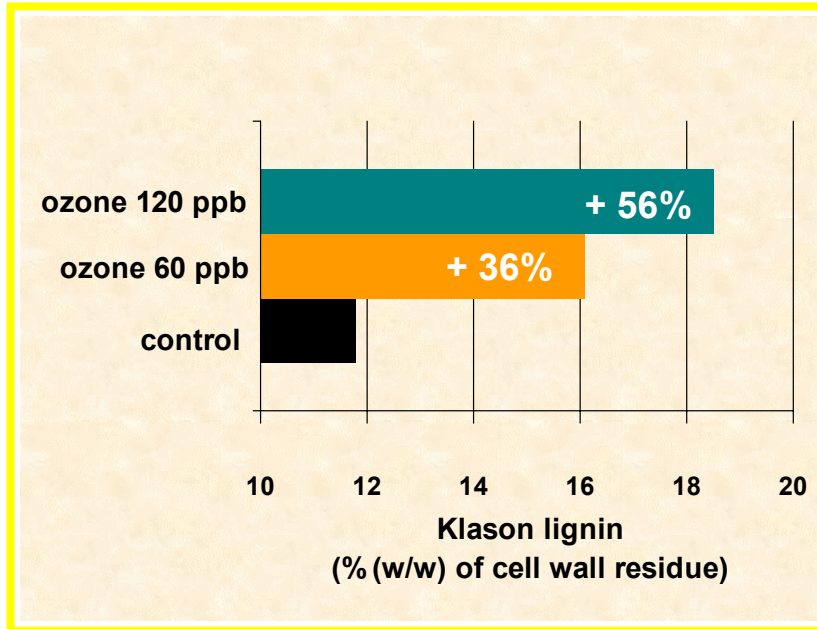


Is there any feedback impact on WUE and/or stomatal conductance ?

(Dizengremel et al., 2008)

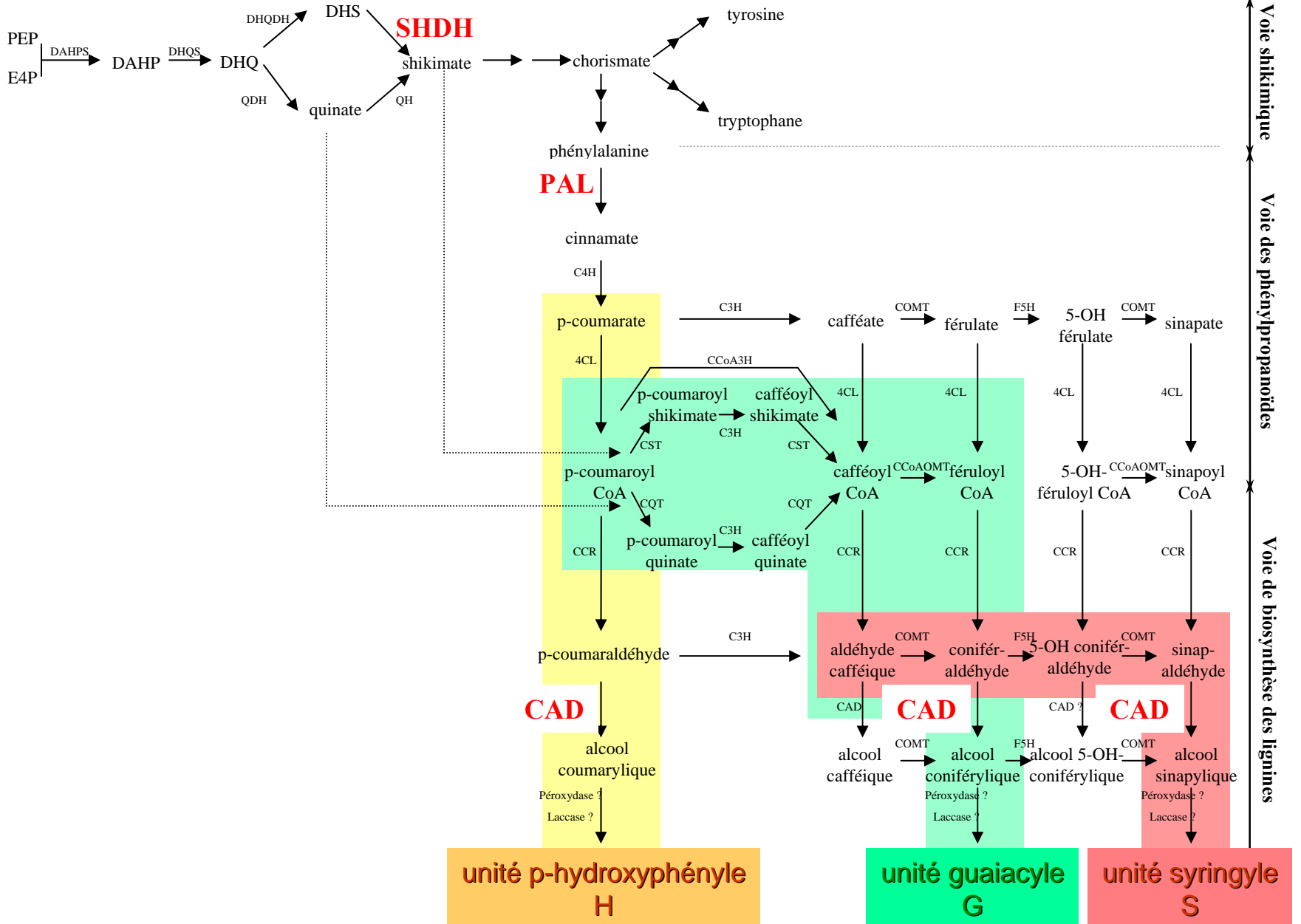
Effect of ozone on lignification in poplar leaves: lignin content

Klason lignin

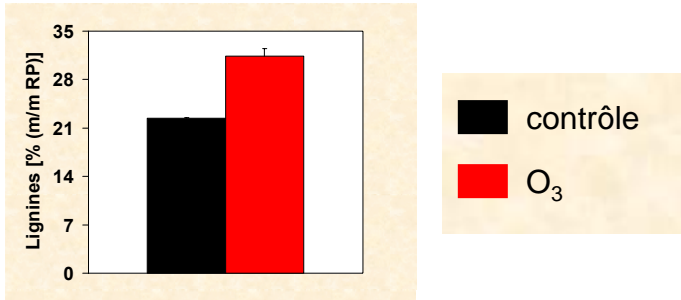


**Increase of lignin biosynthesis
in leaves under ozone treatment**

Voies métaboliques conduisant à la synthèse des lignines

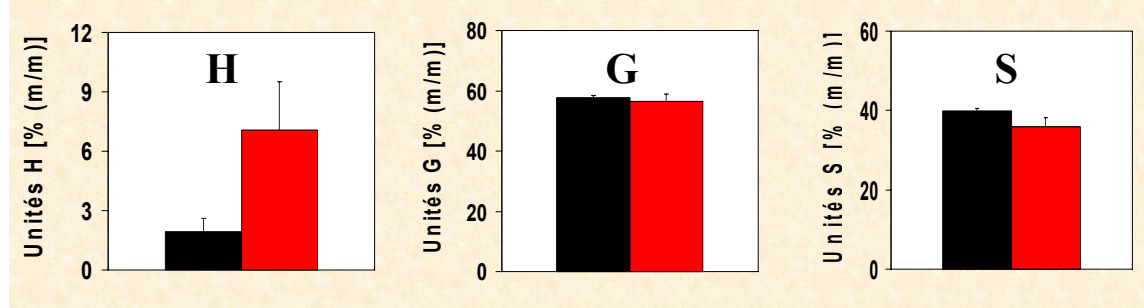


❖ teneurs en lignines



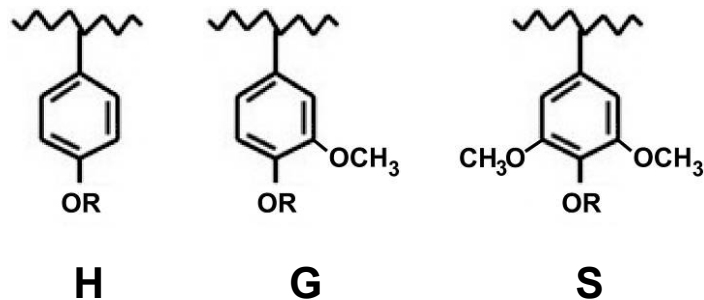
augmentation de 40%

❖ composition monomérique des lignines



lignines fortement enrichies en unités H
au détriment des unités S

❖ deux types de liaisons : C-C et β -O-4



plus de liaisons C-C possibles avec les unités H
plus de liaisons C-C: lignines plus condensées

↳ synthèse de lignines plus condensées sous un stress ozone

