Plant Physiology

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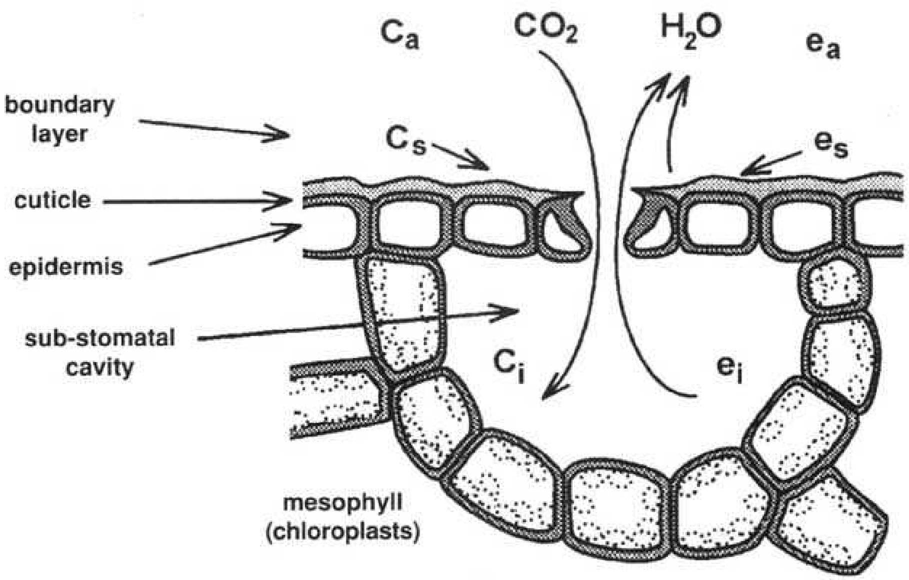
JULES Science Meeting, 07-08 January 2008

OUTLINE

- Overview of JULES current formulation
  - Coupled model of stomatal conductance and photosynthesis
  - Leaf Photosynthesis
  - Radiation interception
  - Plant Respiration
- Developments
  - Plant N-Cycle
  - Advanced Light Interception (SunFleck Model)
  - Plant-Ozone Interactions

Met Office Hadley Centre

Coupled model of stomatal conductance and leaf photosynthesis



$$A = \frac{g_s}{1.6RT_*}\left(C_c - C_i\right)$$

$$A = A(\overrightarrow{X}, c_i)$$

Collatz et al., 1991, 1992

$$\frac{c_i - \Gamma}{c_c - \Gamma} = F_0\left\{1 - \frac{D_*}{D_c}\right\}$$

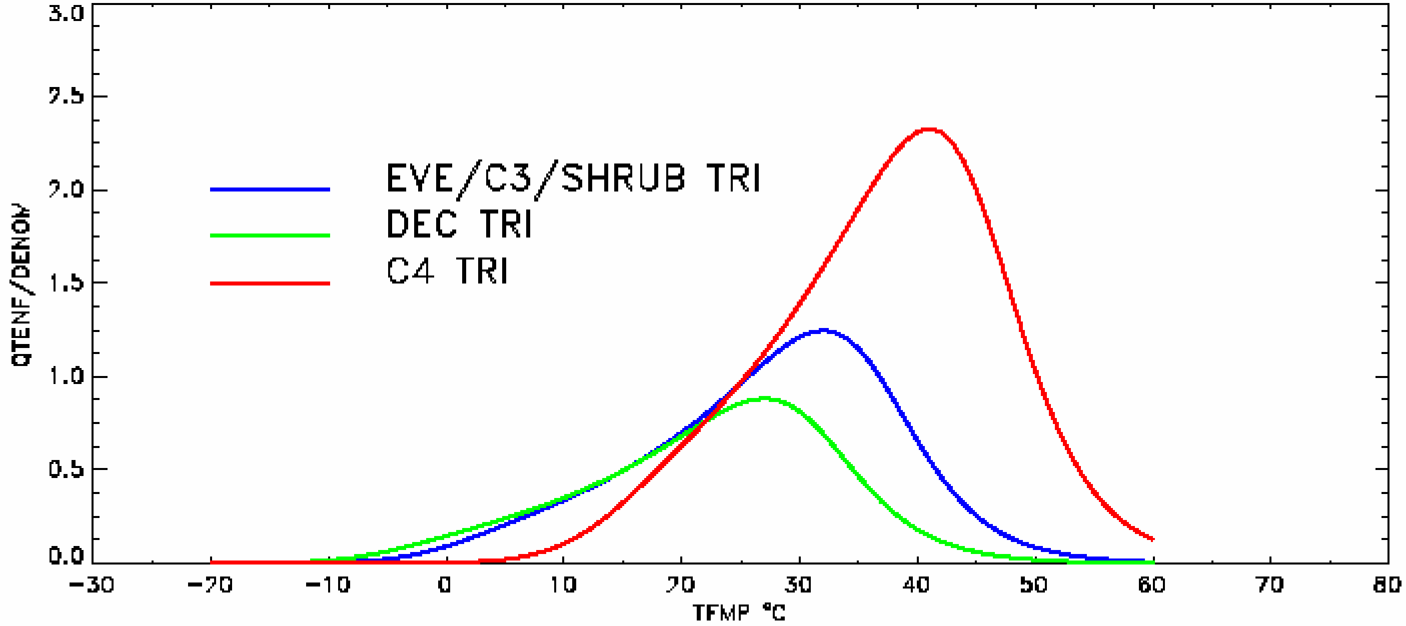
$$A = A_p \beta$$

$$\beta = 'FSMC' = \frac{\theta - \theta_w}{\theta_c - \theta_w} \quad for\, \theta_w < \theta < \theta_c$$

JULES – Plant physiology meeting,

Wallingford, Feb 4

Leaf Photosynthesis



$$V_m = \frac{V_{\max} f_T(2.0)}{\{[1+\exp(T_c - T_{upp})][1+\exp(T_{low} - T_c)]\}}$$

$$V_{\max} = 0.0008 n_l$$

$$R_d = 0.015 V_{\max} f_T(2.0)$$

Radiation Interception

Beer's law

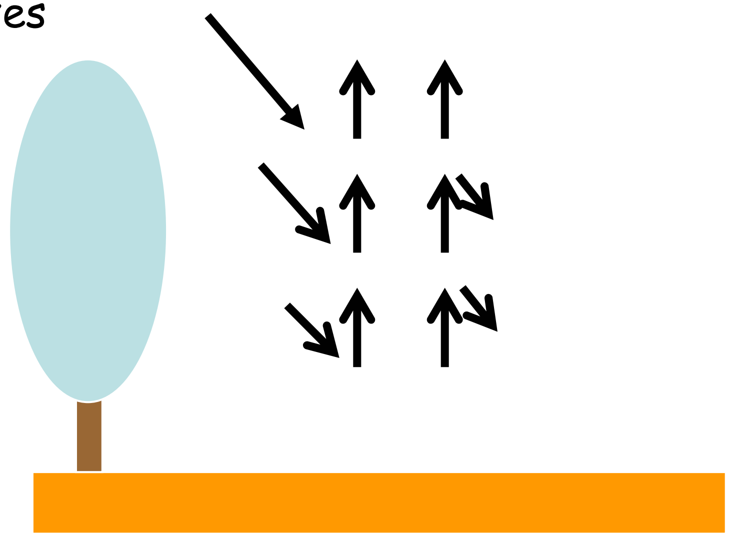
$I = Io * e^{-k * LAI}$

No scattering: i.e. sum of reflected and transmitted light

Two stream approximation (Suits, 1972; Sellers, 1995) :

Vertical profiles:

upward and downward diffusive radiative fluxes



Takes into account:

Leaf and soil scattering

LAI and Leaf angle distribution

Angle of incident radiation

Diffuse and direct radiation

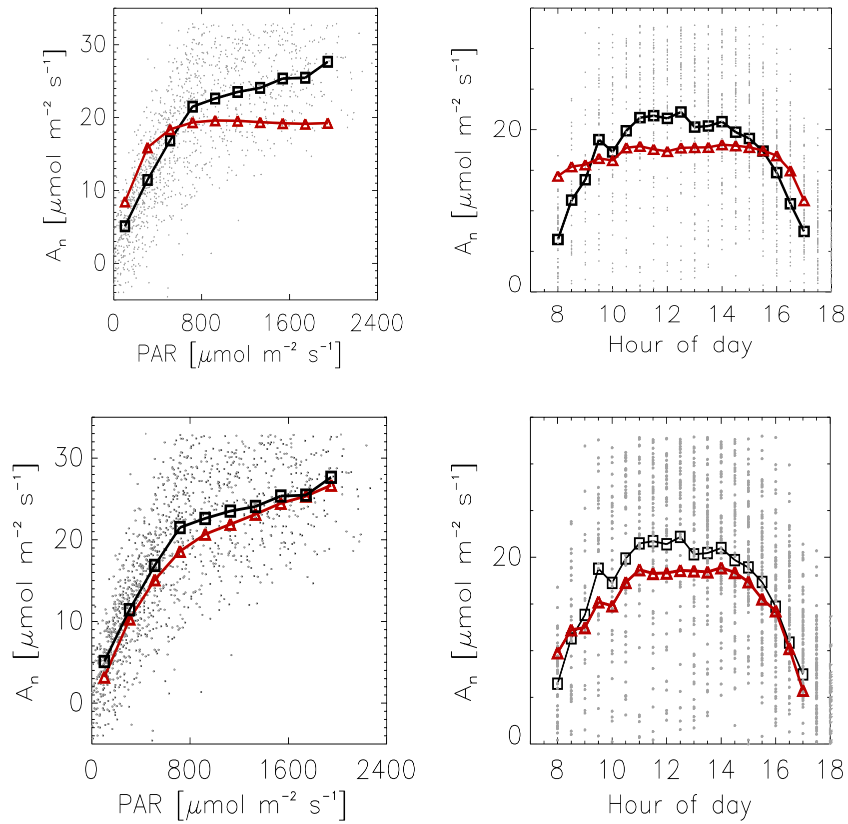
Radiation Interception

A_n= net carbon uptake = Total photosynthesis (GPP) – leaf respiration

Light response **diurnal cycle**

Big leaf model

Multi-layer model



➢ Jules with multilayer gives improved results to big leaf

Plant Respiration

$$R_p = R_{pm} + R_{pg}$$

$$R_{pg} = 0.25\left\{GPP - R_{pm}\right\}$$

$$R_{pm} = 0.012 R_{dc}\left\{\beta + \frac{(N_r + N_s)}{N_l}\right\}$$

$$N_l = n_l \sigma_l LAI$$

$$N_r = \mu_{rl} n_l R$$

$$N_s = \mu_{sl} n_l S,$$

$$S = 0.01 h LAI$$

Friend *et al.*, 1993

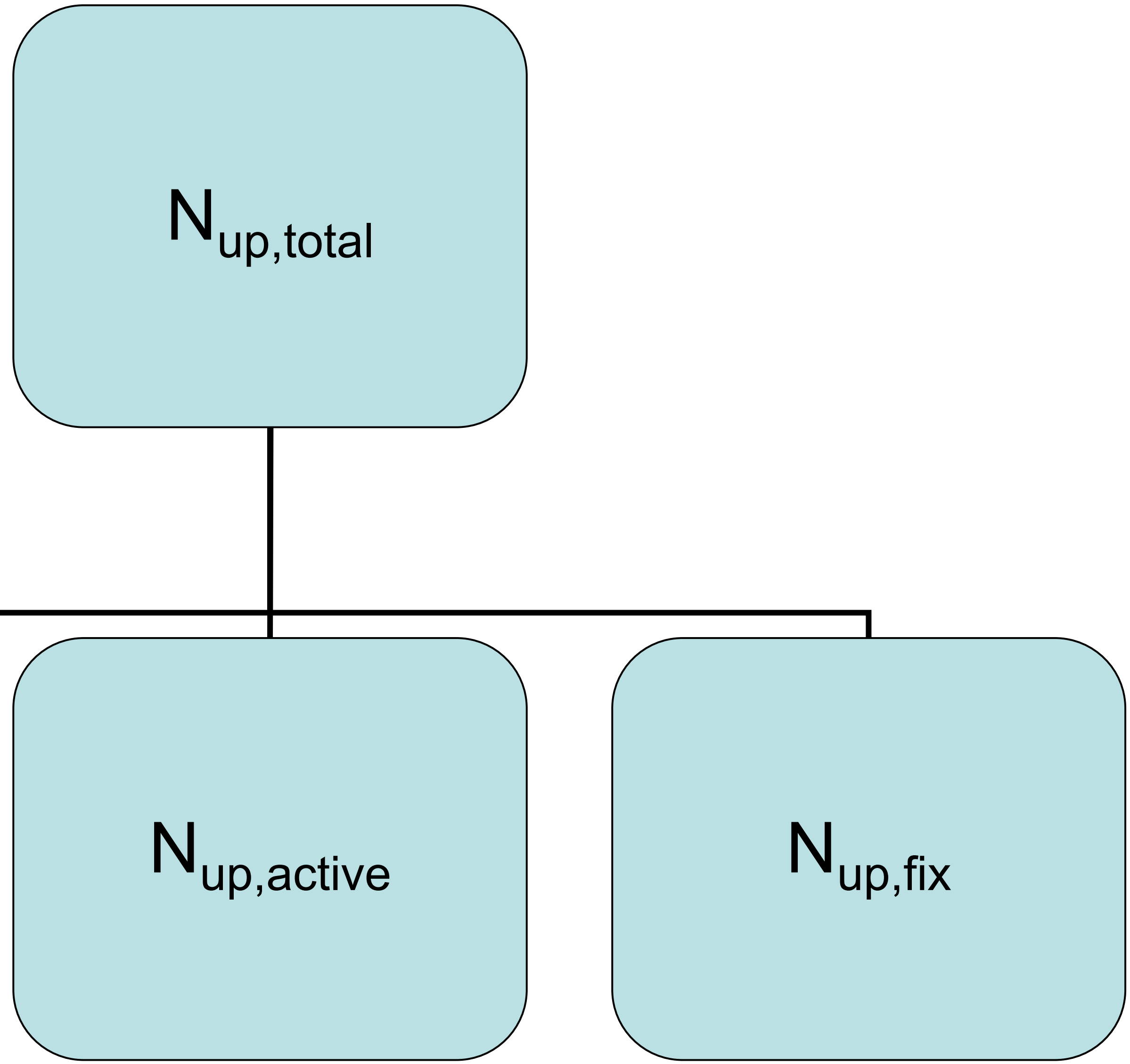
Recent Developments

Plant Nitrogen Cycle

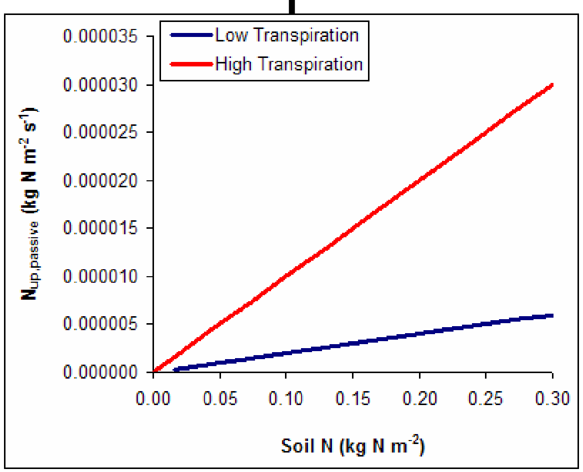
Fisher, J.B., Malhi, Y., Fisher, R.A., Sitch, S., Huntingford, C.

FUN
Fixation & Uptake of Nitrogen

Plant Nitrogen Cycle

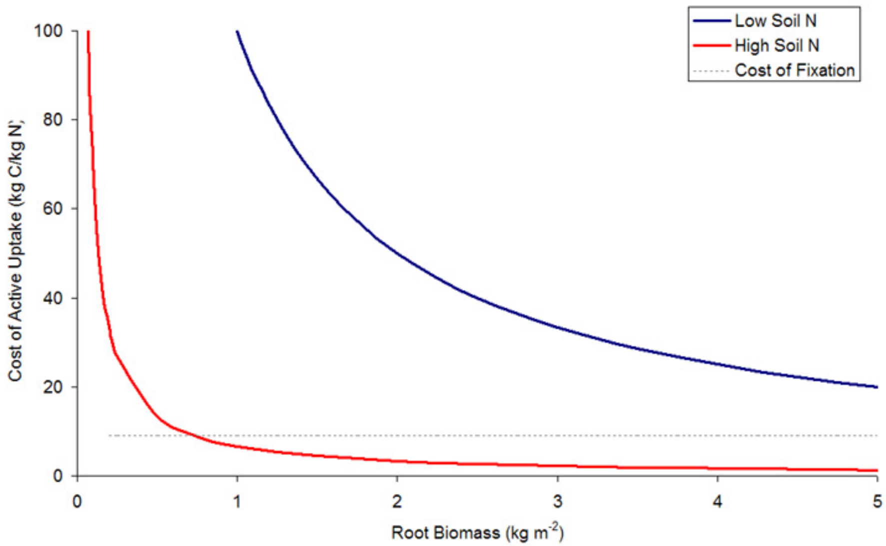


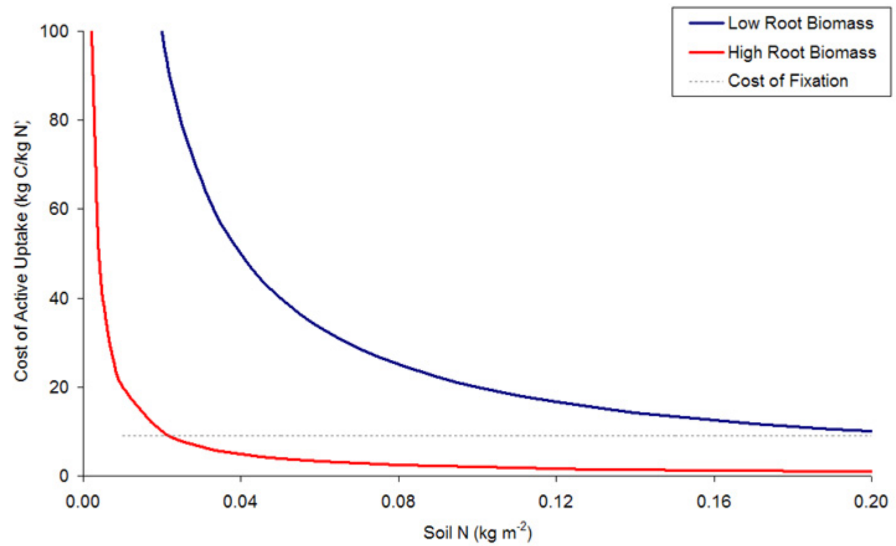
"Free"



Plant Nitrogen Cycle

Active Uptake or **Fixation**?





Solve decision equation

-NPP carbon cost on fixation or active uptake!

-<u>Assumption</u>: maintain C:N ratio over time-step

Plant Nitrogen Cycle

- **Outputs**
  - Plant Nitrogen
  - Available plant Carbon for growth
  - Nitrogen Deficit → Excess Carbon → ?
    Reduce LAI and/or down-regulate photosynthesis…
    Compare to other limitations (water, light, phosphorus, temperature,…)
  - Nitrogen reduction from soil
  - Carbon addition to soil: from respiration in fixation and/or active uptake (Michaelis-Menten kinetics)

Advanced Light Interception (SunFleck Model)

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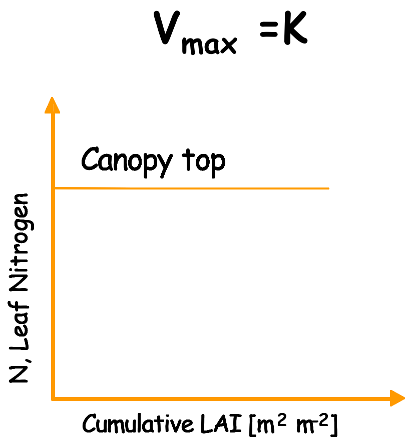
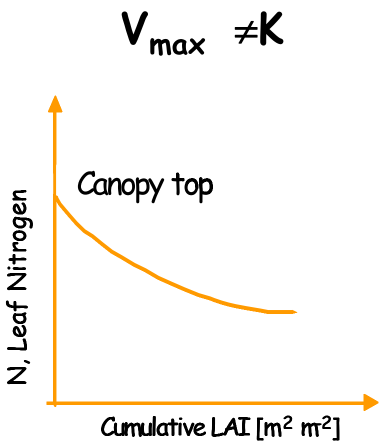
Lina Mercado et al.

"Volcanic sunset" 1991.

Sunfleck +Multi-Layer+

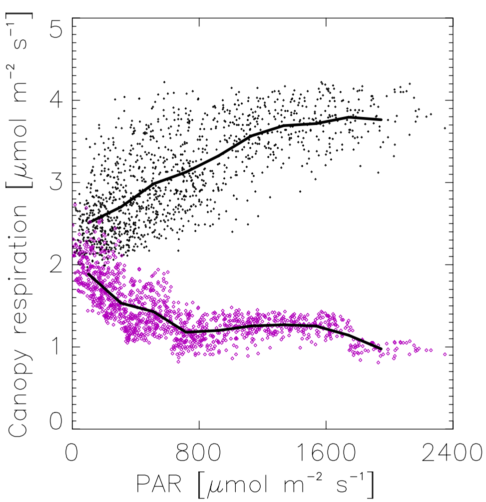




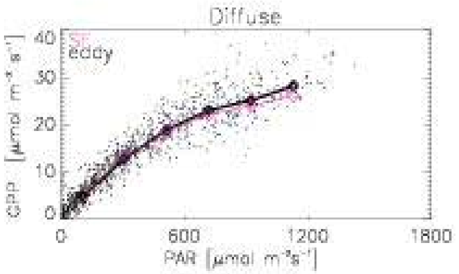
Vertical profile of leaf N

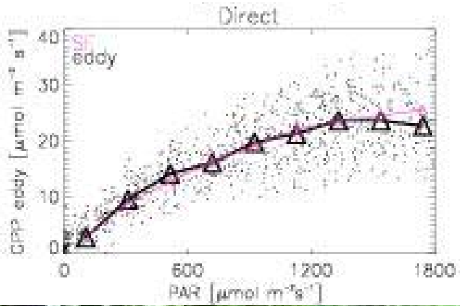
+

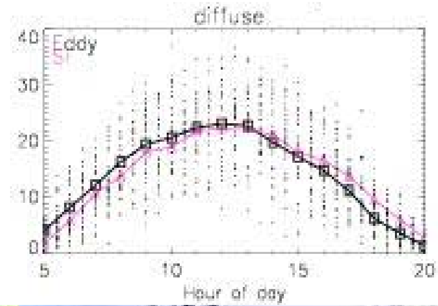
decrease leaf respiration due to light inhibition
(Brooks & Farquhar 1985)

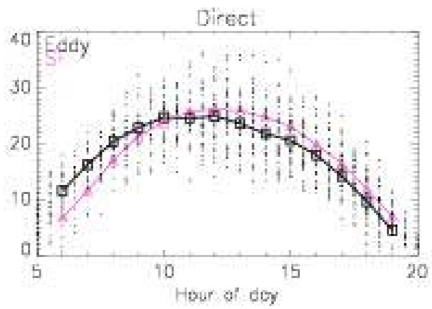


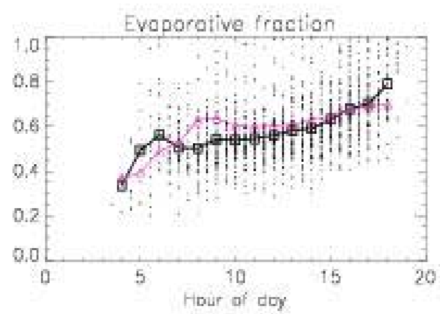
Sunfleck Evaluation: Hainich (obs Diffuse/Direct)





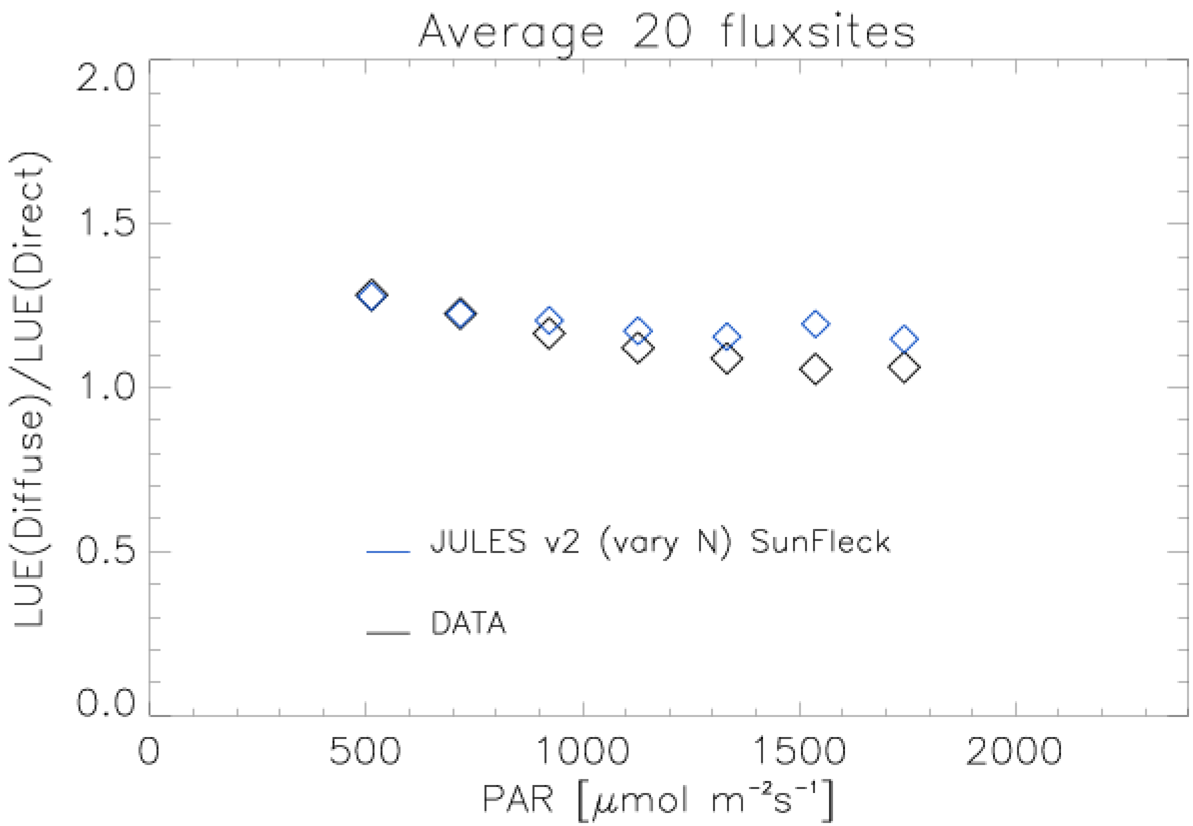






Beech forest, Germany

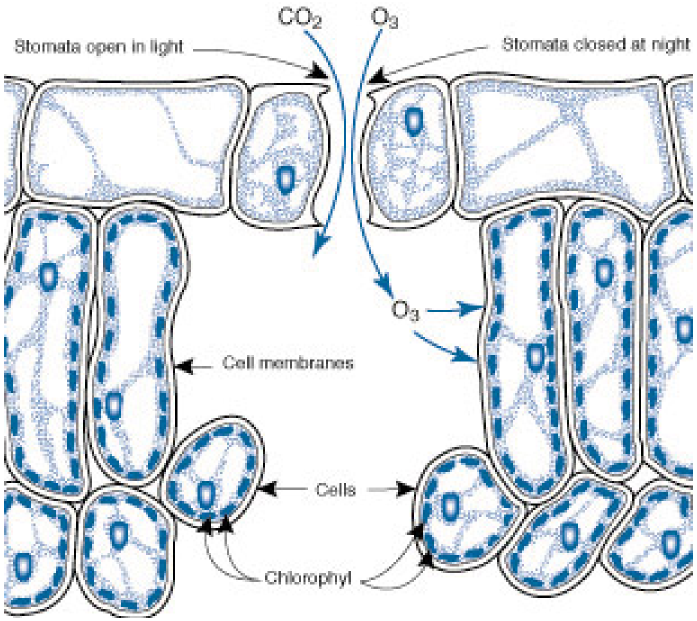
Sunfleck Evaluation: 20 Flux sites (derived Diffuse/Direct)



Plant Ozone Injury

Effects of Ozone Exposure on Plants

- O_3 reduces plant production
  - causes cellular damage inside leaves
  - reduced photosynthetic rates
  - Increased C-allocate to detoxify and repair leaves



- O_3 reduces stomatal conductance
  - lowers internal leaf [CO_2] reducing rates of photosynthesis
  - reduces O_3 uptake.

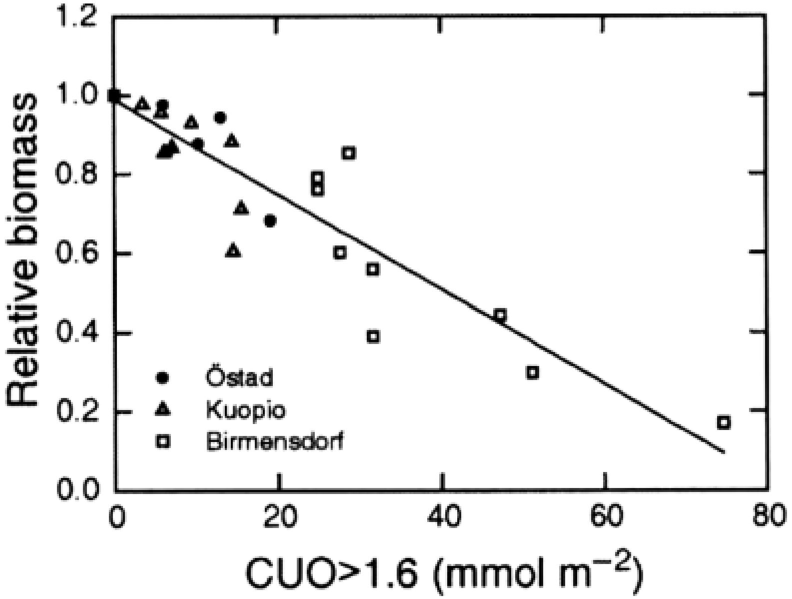
- Investigate interactions at elevated [CO_2] &[O_3]

MOSES-Ozone Model Calibration

Experimental Analysis

$$RelativeYield = 1 - b \cdot CUO_{>FO3crit}$$

CUO$_{>FO3crit}$ is the Cumulative leaf Uptake of O_3, over the experimental period. *b* is a plant type specific parameter.



Uddling *et al.* 2004, Ashmore 2005

MOSES-Ozone Model

$$A = A_p \cdot F$$

$$F = 1 - a \cdot UO_{>FO3crit}$$

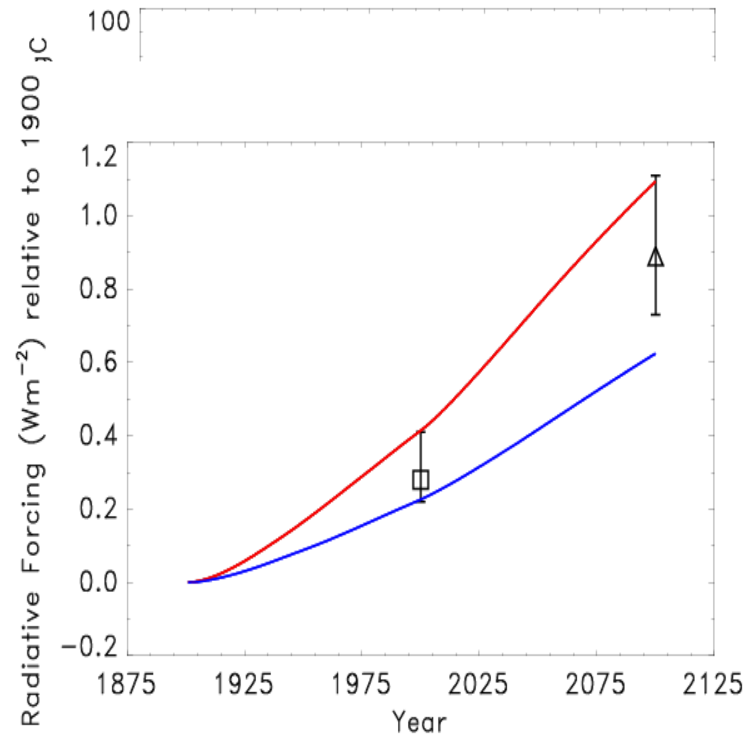
UO$_{>FO3crit}$ is the instantaneous leaf uptake of O_3, and *a* is a plant type specific parameter.

Plant – Ozone interactions

- Large reductions in productivity and land carbon storage over temperate and tropical regions
- Elevated CO_2 affords some protection for plants against O_3 damage (~1/3)
- Large potential threat of elevated future [O_3] on the ability of many land ecosystems to sequester carbon
- Large indirect radiative forcing due to additional CO_2 in the atmosphere
  - Chemistry more important driver of climate change than hitherto expected

% Δ GPP due to <u>O_3-effect</u>

Alleviation <u>O_3-effect</u> by CO_2 increases



Sitch et al., 2007

Future Developments

- Advanced light interception (i.e., sunfleck)
- Improve representation of drought stress on photosynthesis

  (β 'FSMC' – Workshop Feb 4., Wallingford)
- Coupled Plant-Soil C/N cycle
- Plant-Ozone interactions
- Evaluate phenology scheme