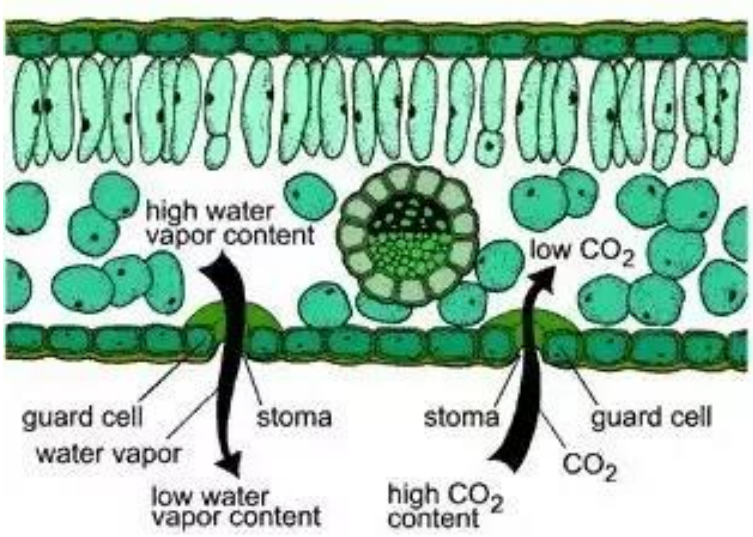
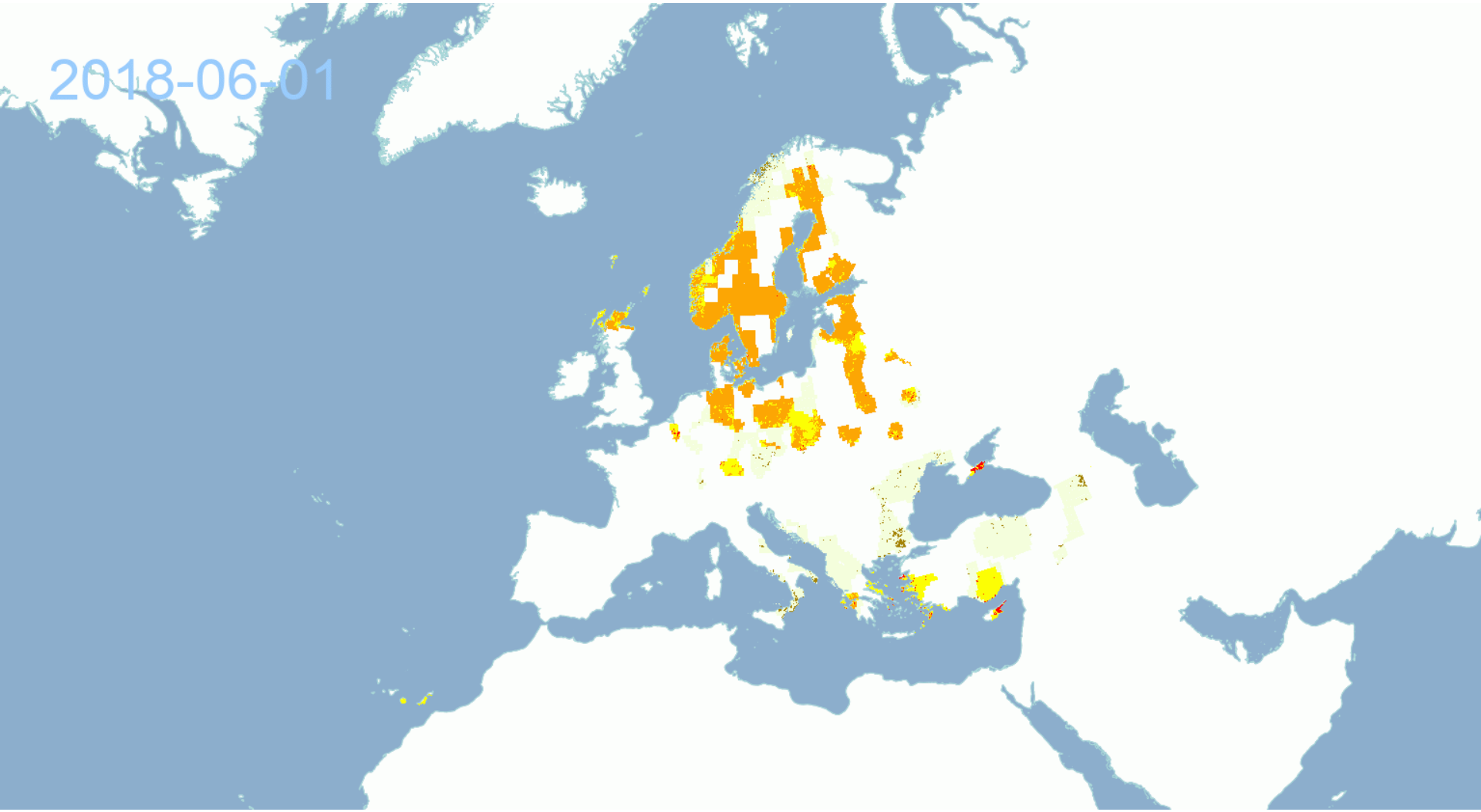
Quantification of the 2018 drought for European forests and impacts of stomatal and non stomatal limitation of photosynthesis



Stomata open to allow carbon dioxide (CO_2) to enter a leaf and water vapor to leave.

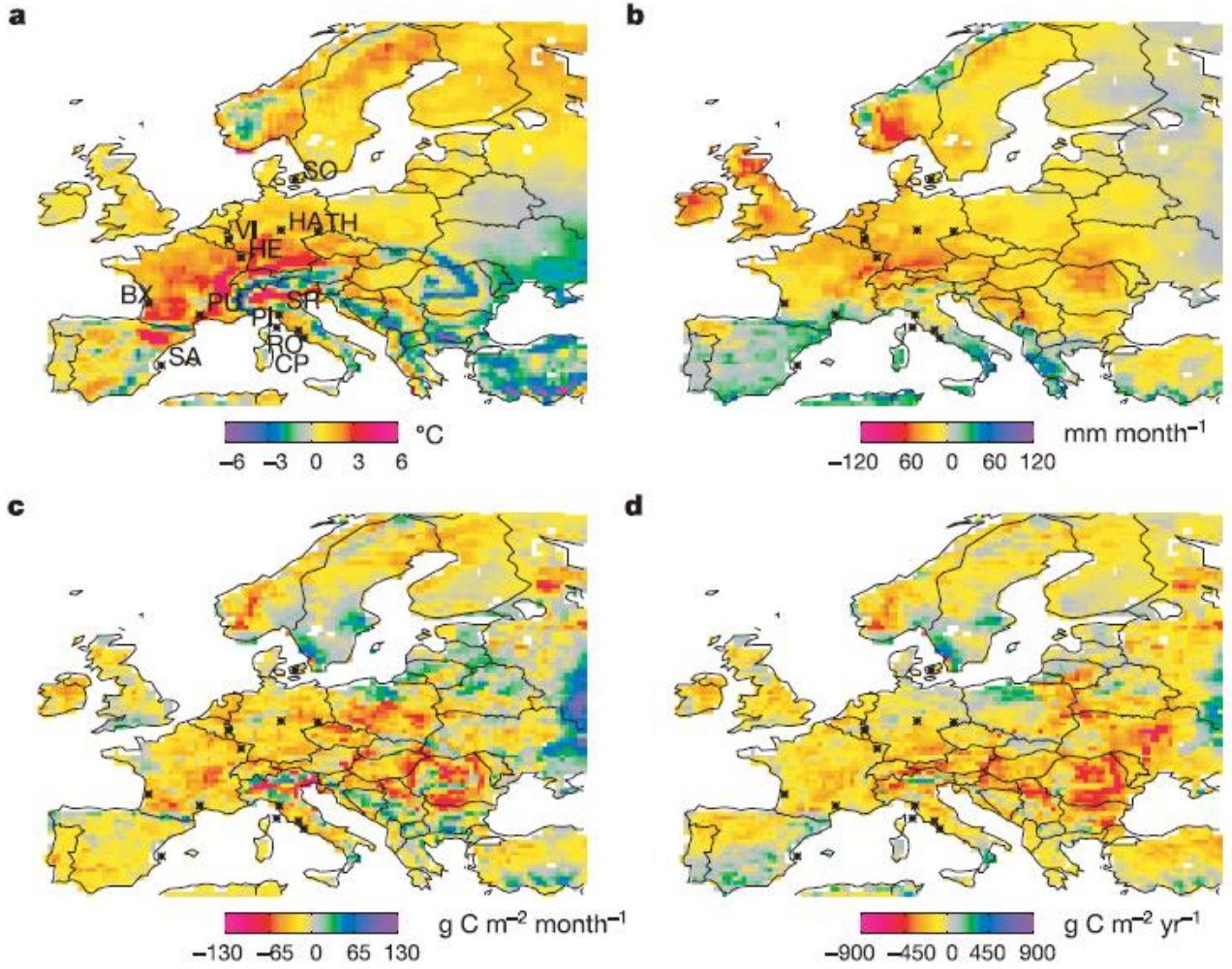
European 2018 drought



European Drought Observatory, combined drought indicator (CDI)
Drought taskforce -> **Philosophical transaction of the royal society B**

What we know from 2003 : Anomalies

Temperatures

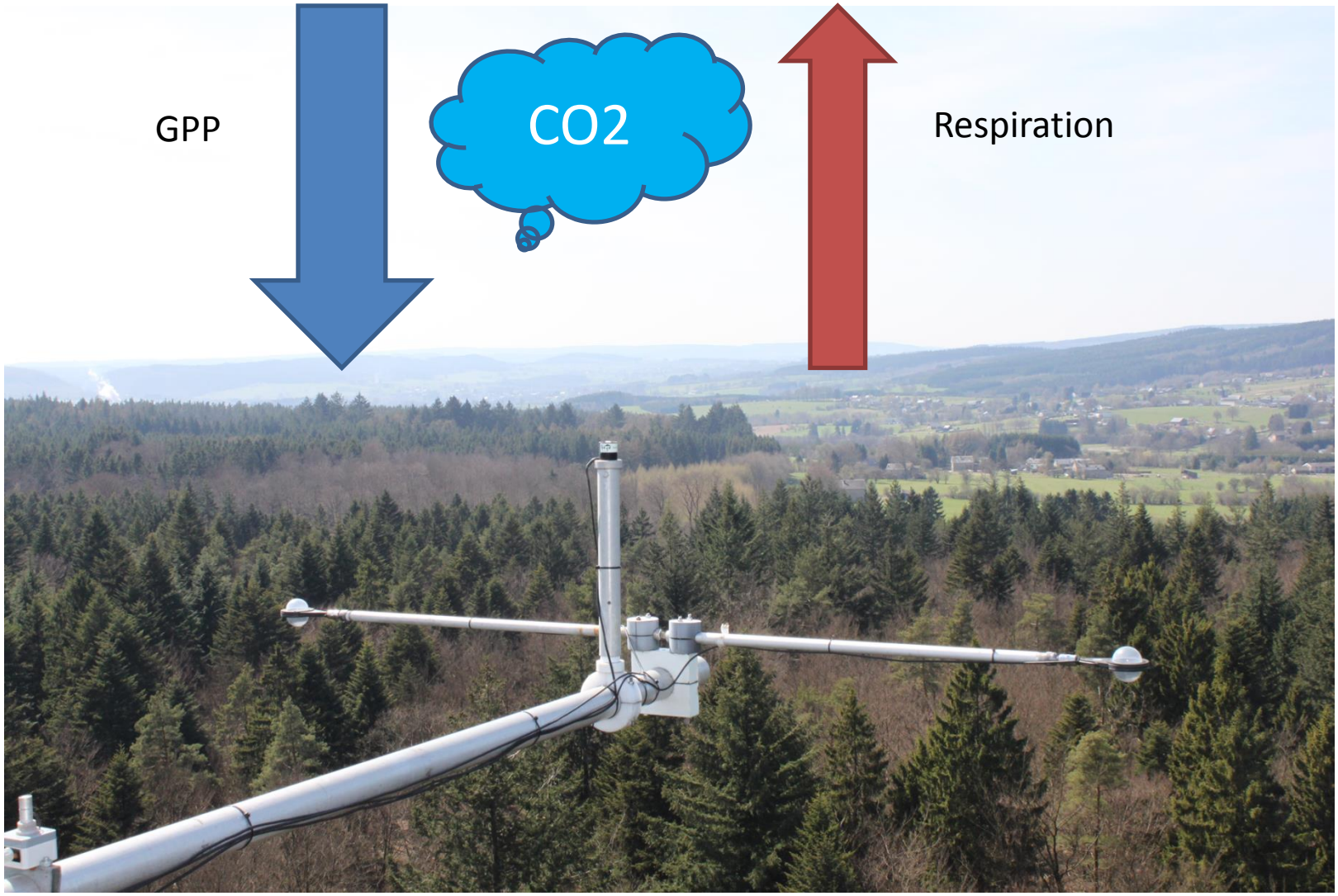


Precipitation

NPP (g C m-2)

Ciai et al., 2005 (Nature)

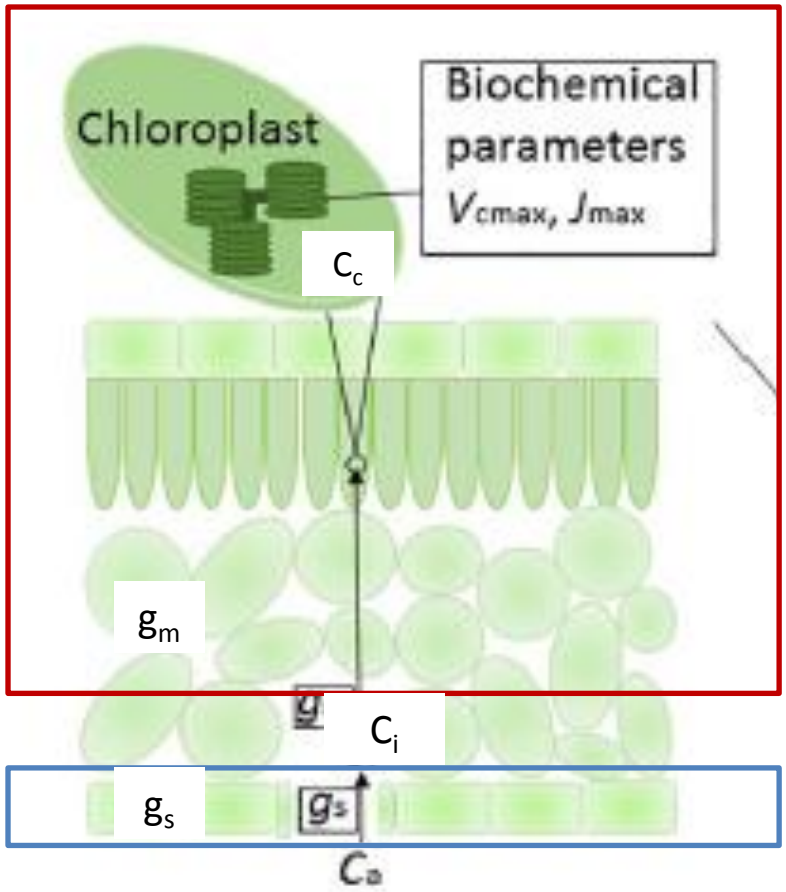
Photoynthesis and respiration



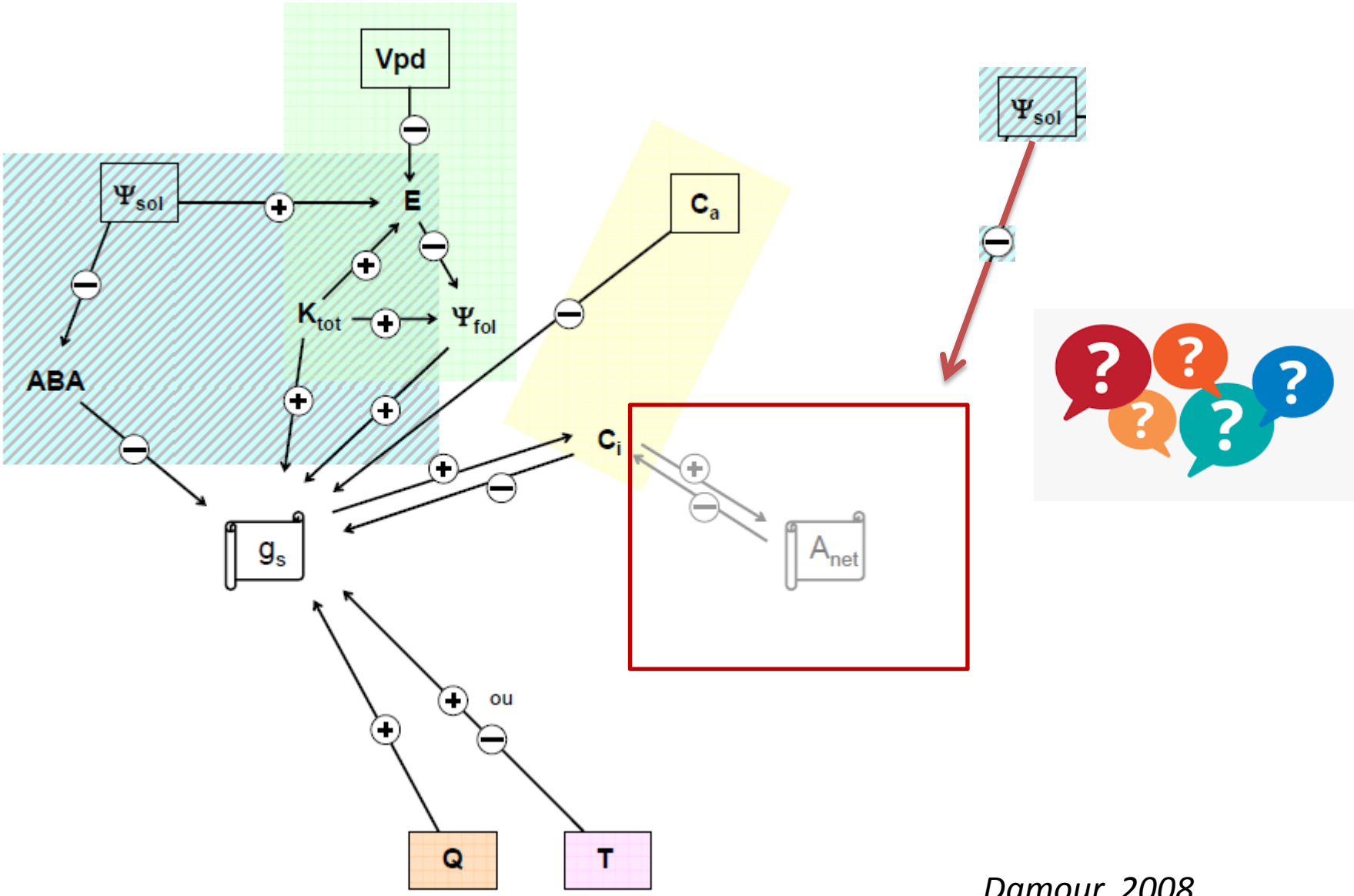
A bit of theory

Non-stomatal

Stomatal



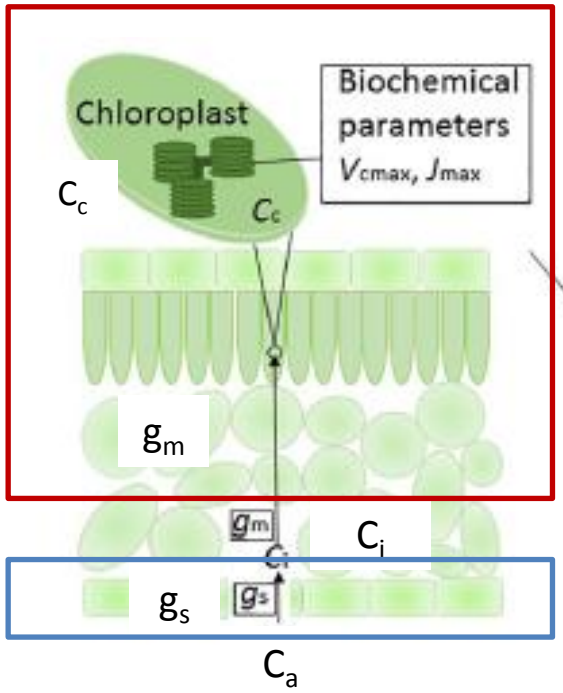
A bit of theory

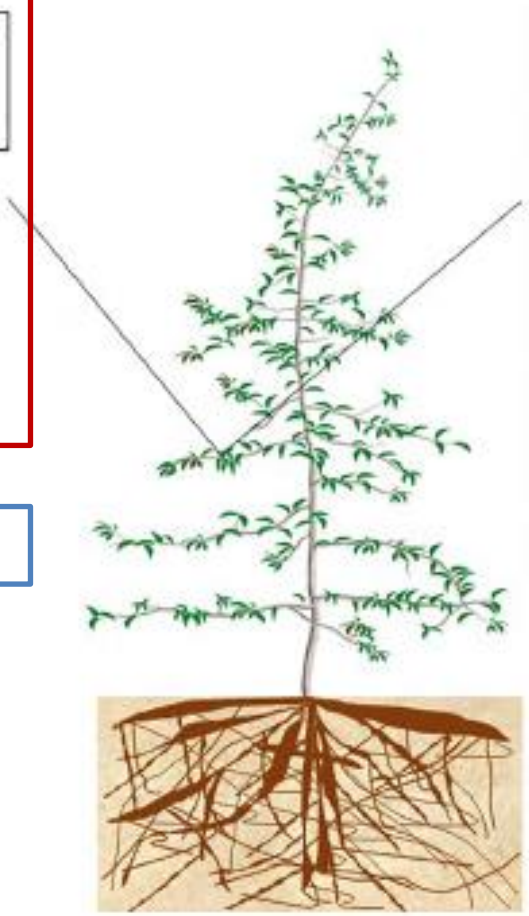


Damour, 2008

A bit of modeling

Non-stomatal





At light saturation :

$$GPP_c = \frac{V_{cmax}(C_i - \Gamma*)}{(C_i + K_m)}$$

$$C_i = C_a - \frac{GPP}{g_{s,co2}}$$ Stomatal

$$g_{s,H2O} = g_0 + 1.6(1 + \frac{g_1}{\sqrt{VPD}})\frac{GPP}{C_a}$$ *Medlyn et al.,2011*

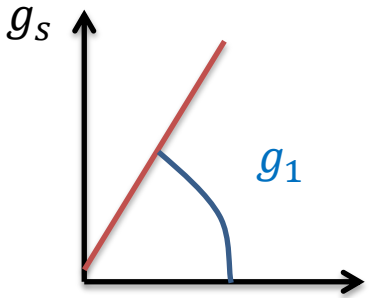
gs can be obtained from PM equation

$$g_{s,H2O} = \frac{LEG_a\gamma}{s(R_n - G - S) + \rho C_p C_a VPD_a - LE(s + \gamma)}$$

Figure from *Zhou et al., 2019*

$$\frac{g_{s,H2O}}{1.6} = g_{s,CO2}$$

Stomatal and non stomatal limitation of photosynthesis : models



$$\begin{cases} GPP = \dfrac{V_{cmax}(C_i - \Gamma*)}{(C_i + K_m)} \\ C_i = C_a - \dfrac{\boldsymbol{GPP}}{\boldsymbol{g_c}} \\ g_s = g_0 + 1.6\left(1 + \dfrac{g_1}{\sqrt{VPD}}\right)\dfrac{GPP}{C_a} \end{cases}$$

Non stomatal limitation

Changes in **apparent V_{cmax}** with measured C_i values

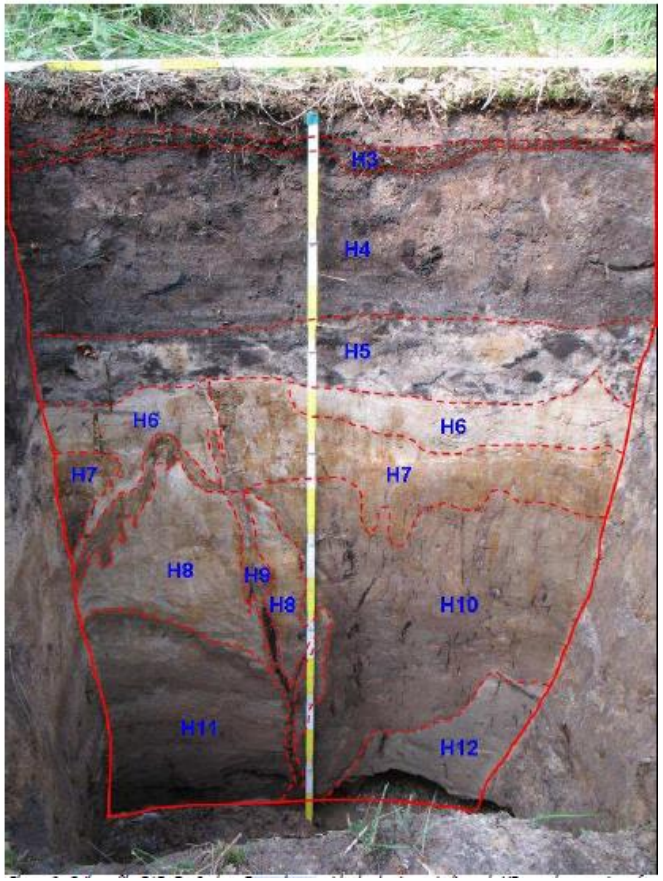
Stomatal limitation

Changes in C_i which are associated with changes in **g1**
(changes in the GPP-gs slope)

g1 is inversely proportional to iWUE

Quantification of drought

- In lack of soil and pre-dawn leaf water potential at flux tower sites , Relative Extractable Water (REW):



$$\mathrm{REW_t} = \frac{\mathrm{SWC_t} - \mathrm{SWC_{WP}}}{\mathrm{SWC_{FC}} - \mathrm{SWC_{WP}}}$$

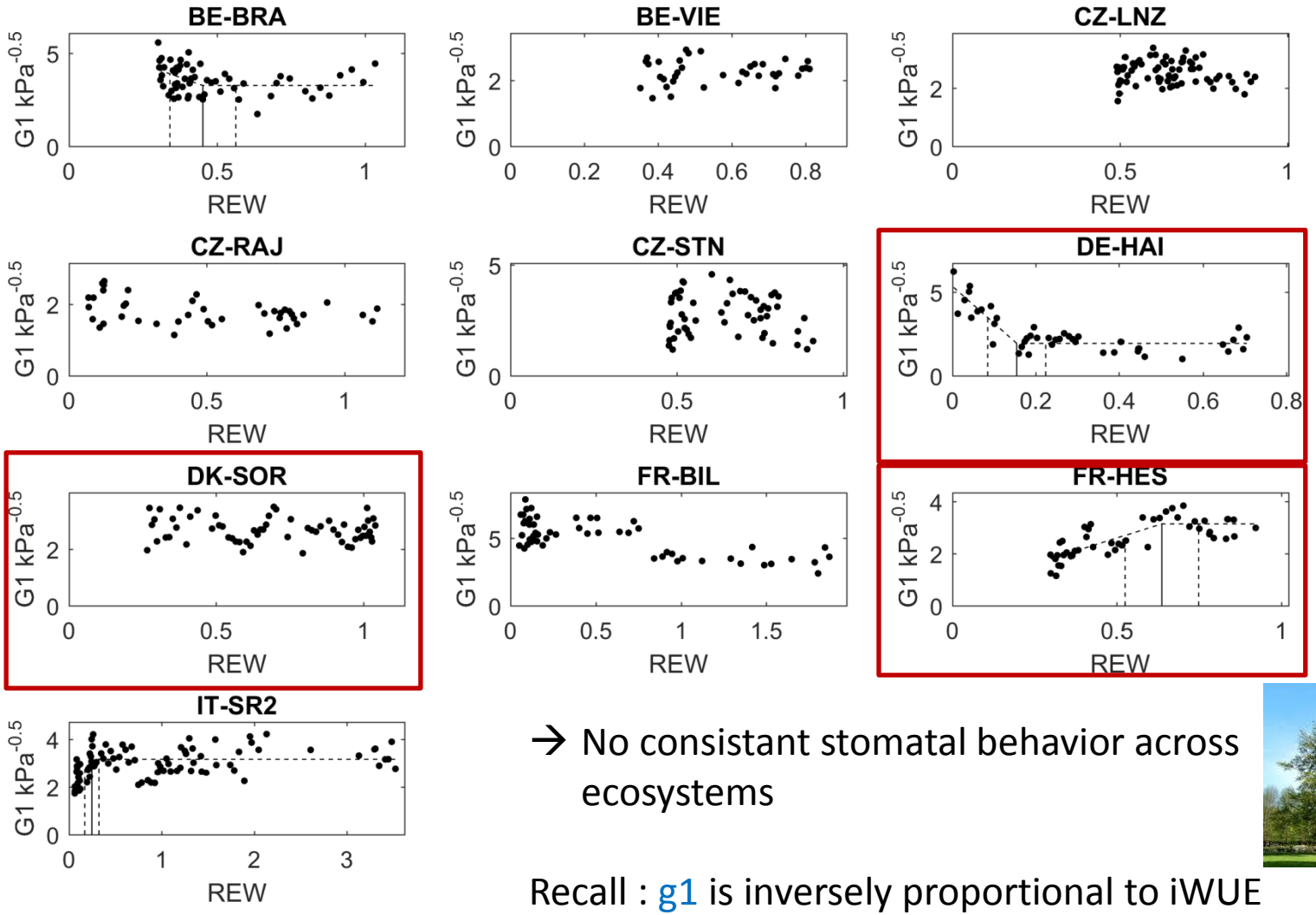
REW varies from 1 (Field capacity) and 0 (wiliting point)

Soil humidity sensors

Cumulated over the root zone

Ecosystem stations

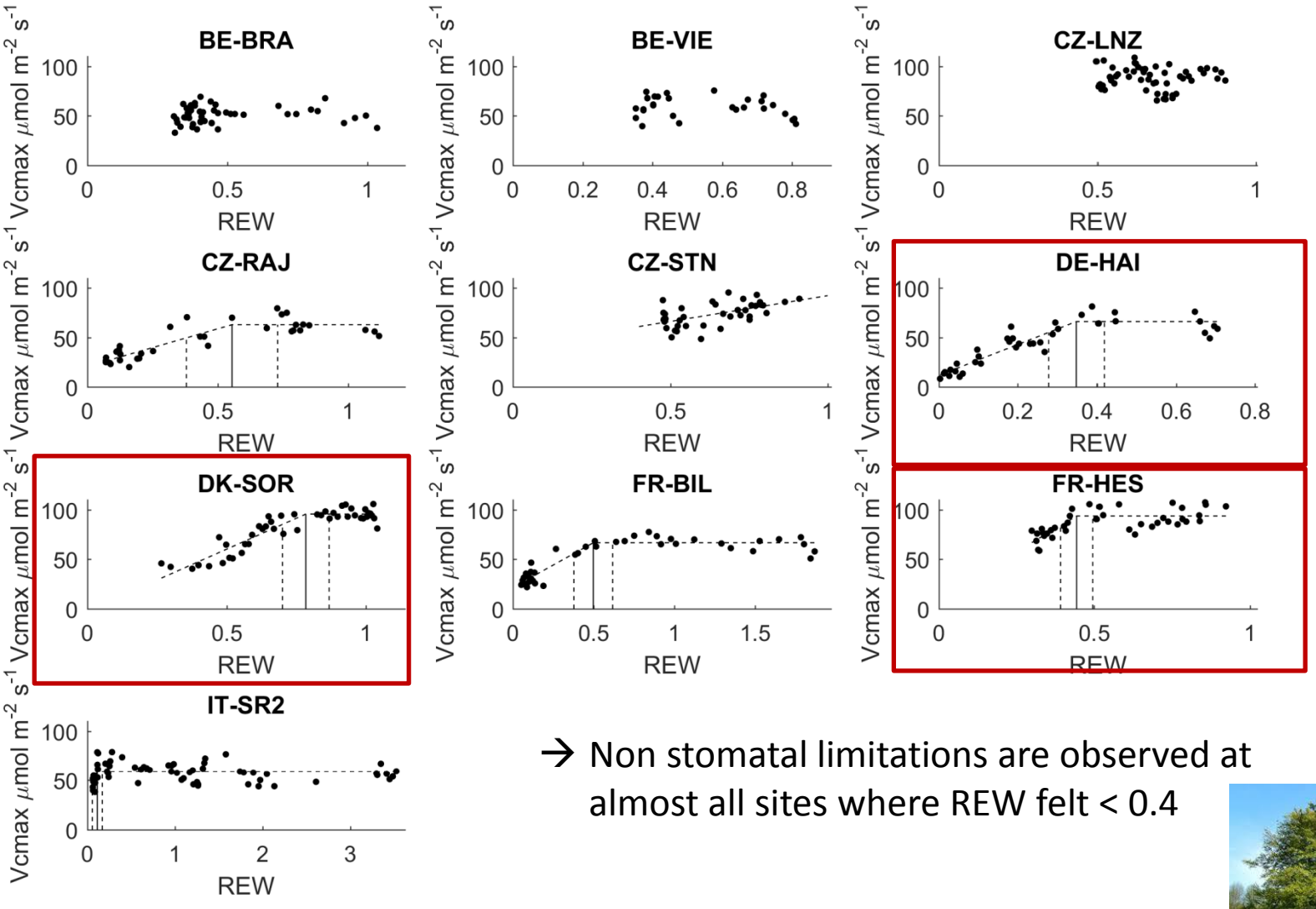
Results : stomatal limitation



→ No consistant stomatal behavior across ecosystems

Recall : g1 is inversely proportional to iWUE

Results : non stomatal limitation



→ Non stomatal limitations are observed at almost all sites where REW felt < 0.4

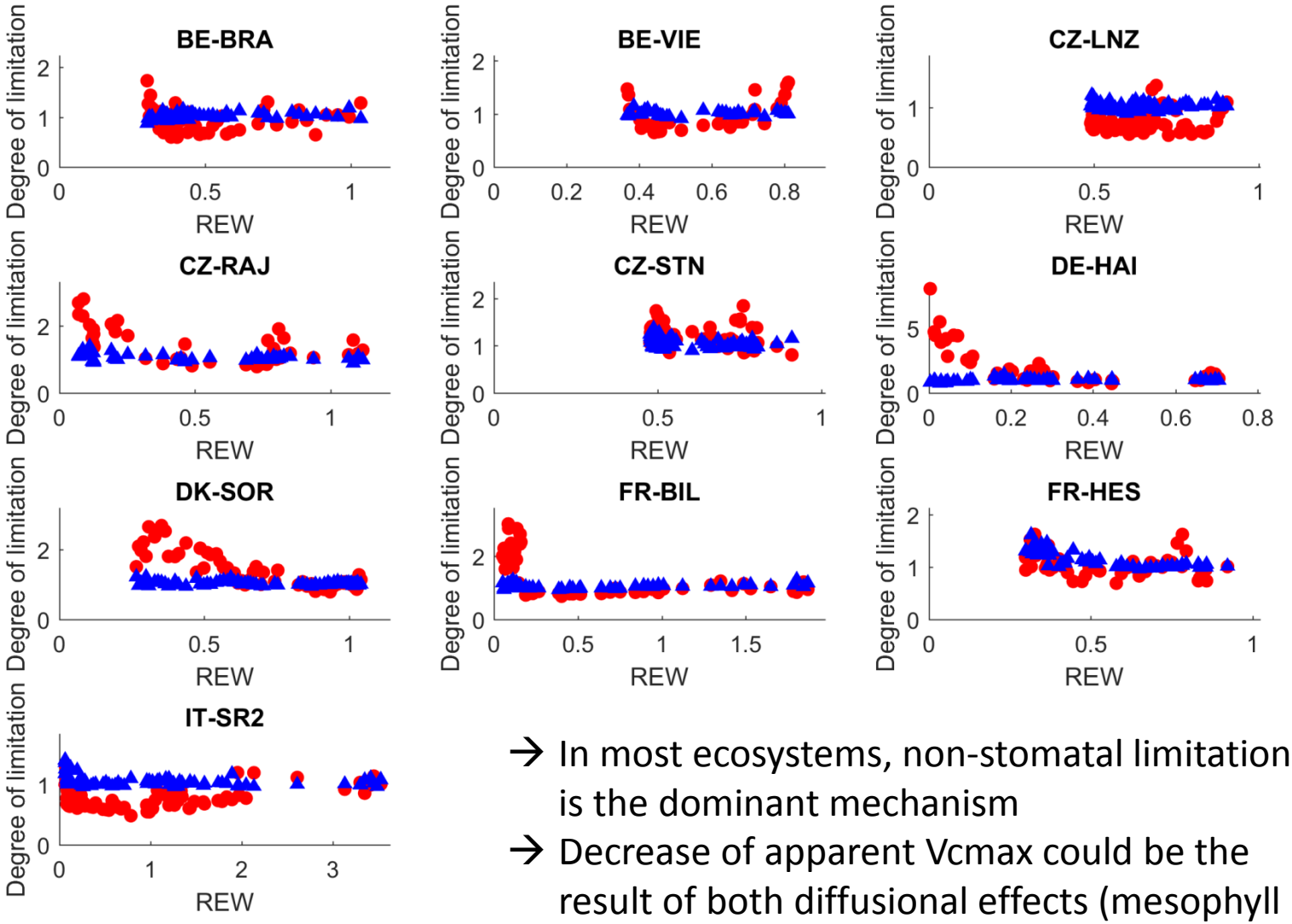
Degree of limitation

We quantify the degree of limitation by :

- Fixing V_{cmax} at unstressed value and computing GPP with observed C_i
- Fixing G_1 at unstressed value and compute GPP with observed V_{cmax} values

Compute the ratio of $GPP_{modelled}/GPP_{observed}$

Degree of stomatal and non stomatal reduction



→ In most ecosystems, non-stomatal limitation is the dominant mechanism

→ Decrease of apparent Vcmax could be the result of both diffusional effects (mesophyll conductance) or biochemical effects

Focus on 3 beech forests

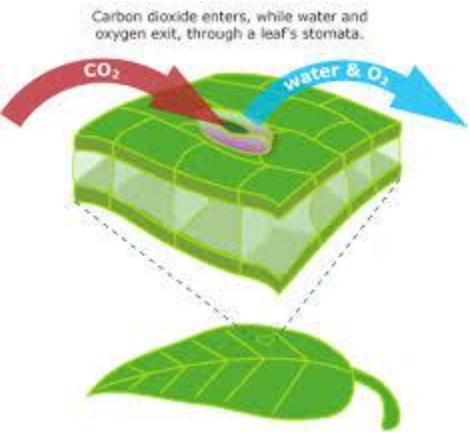
- FR-HES, DK-SOR and DE-HAI are 3 beech forests
- We observe non-stomatal limitation at all 3 sites

In term of water use efficiency (iWUE) we observe :

- Constant g1 at **DK-SOR** (constant iWUE)
- Decreasing g1 at **FR-HES** (increased iWUE) which has a visible impact on GPP
- Increasing g1 at **DE-HAI** (decreased iWUE) but with no visible impact on GPP (GPP is already too low)

-> unsolved question !

Implications for drought modeling



$$g_{s,H2O} = g_0 + 1.6(1 + \frac{g_1}{\sqrt{VPD}})\frac{GPP}{C_a}$$

How should plante regulate stomata ? (Cowan & Farquhar, 1977)

Stomata regulate both photosynthesis and transpiration
Stomata should maximise :

$$A - \lambda E$$

where λ is the carbon cost of water. $g1 \sim \sqrt{\frac{1}{\lambda}}$

If $\lambda = \frac{\delta A}{\delta E} = constant$ (water spent now can't be spent later) **but does not apply when water availbility decrease !**
-> when soil water depletes, the cost should increase (λ ↗ and g1 ↘) *Makëla et al., 1996*

Results from this study do no support this ! → the costs of stomatal opening are probably not well identified
Ideas :

- Loss of hydraulic conductivity
- Limit non-stomatal limitation

} *Dewar et al., 2018*

Conclusions

- Non stomatal limitation was the dominant short term mechanism limiting GPP in forest at flux tower sites
- Apparent V_{cmax} has proven a useful way of modeling these NSL
- Future optimal conductance models should take NSL into accounts
- REW has proven a very useful index of edaphic drought at flux tower sites

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