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An improved and more flexible representation of water stress in coupled A-gs models;

Implications for simulated land surface fluxes and variables at various spatiotemporal scales

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Based on: *Egea, G., Verhoef, A. and Vidale, P. L. (2011) Towards an improved and more flexible representation of water stress in coupled photosynthesis–stomatal conductance models.* ***Agricultural and Forest Meteorology, 151: 1370-1384.***

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STOMATAL CONDUCTANCE MODELS

- **Multiplicative models** (Jarvis, 1976)

$$g_s = g_{s,max}\, f(Q)\, f(T)\, f(D)\, f(\Psi_l)\, f(C_a)$$

- **Coupled photosynthesis-stomatal conductance models (A-g_s)** (Ball et al., 1987)

$$g_s = g_0 + m\, \mathbf{A}\, f(C_s)\, f(D)$$

- **Mechanistic models** (i.e. Buckley et al., 2003)

$$g_s = \frac{g_m(\alpha - \gamma)}{\alpha + K_g}$$

$$g_m = \frac{\psi_s + \pi_e}{RD_s} \quad \alpha \equiv \beta\tau - M + \rho \quad k_g = \frac{1}{\chi RD_s} \quad \gamma = \frac{\pi_e - \pi_a}{\pi_e + \psi_s} + \rho$$

STOMATAL CONDUCTANCE MODELS

- **Coupled photosynthesis-stomatal conductance models (A-g_s)** (Ball et al., 1987)

$$g_s = g_0 + m\,\mathbf{A}\,f(C_s)\,f(D)$$

- Models photosynthesis in a **relatively mechanistic** way.
- Built on **physiological hypotheses**.
- **Good compromise** between ease of use and predictive accuracy.

COUPLED A-GS MODELS

DRAWBACK

The **original** A-g_s models is that they did not take into account the **response to water stress**.

¿How did scientists overcome this limitation?

1.By applying a **water stress index** to the **slope** of the A-g_s relationship:

$$g_s = g_0 + m' A f(C_s) f(vpd)$$

$$m' = m f(\theta)$$

2. By applying a **water stress index** to the **photosynthetic capacity**.

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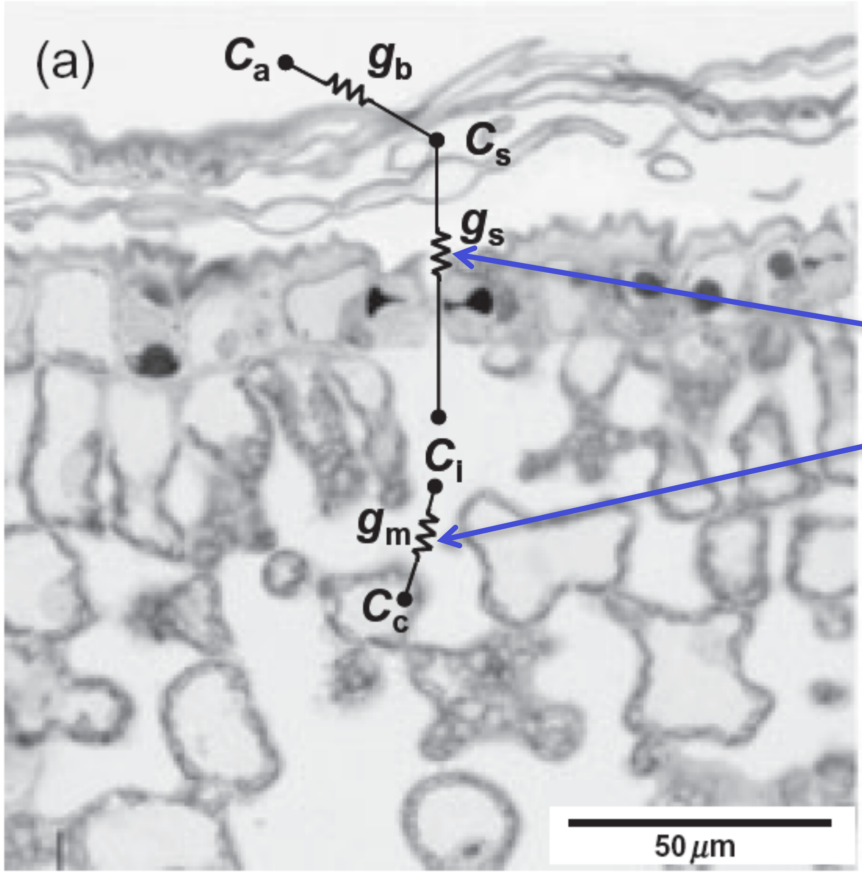
HOW DOES WATER STRESS LIMIT CO_2 ASSIMILATION?



Flexas et al. (2008)

Water stress affects CO_2 concentration at the chloroplast level $\mathbf{C_c}$ by:

a. Reducing g_s **(SCL)**
b. Reducing mesophyll conductance to CO_2 diffusion (g_m) **(MCL)**

BL: Water stress affects the **biochemical capacity** by:

a. Reducing V_{cmax}
b. Reducing J_{max}

LEAF GAS EXCHANGE IN LSMs

Leaf gas exchange in **land surface models** (LSM) such as **JULES** is based on the works by Collatz et al. (1991; 1992) and Jacobs et al. (1996). See also Calvet et al. (2004)

1. **C_i** is computed as (Jacobs et al., 1996)

$$\frac{C_i - \Gamma}{C_s - \Gamma} = f_o\left(1 - \frac{D_s}{D_{\max}}\right)$$

f_0 and D_{max} are empirical parameters

2. Once C_i is known, net photosynthesis (**A**) is computed independently (Collatz et al., 1991; 1992).

3. **g_s** is finally computed from **C_i** and **A** as:

$$g_s = \frac{A}{C_s - C_i}$$

HOW DOES JULES ACCOUNT FOR WATER STRESS?

JULES applies a **soil-moisture dependent water stress index** to the potential (non-stressed) leaf photosynthesis rate (A_p):

$$A = A_p \beta$$

where β is:

$$\beta = \begin{cases} 1 & \text{for } \theta \geq \theta_c \\ \frac{\theta - \theta_w}{\theta_c - \theta_w} & \text{for } \theta_w < \theta < \theta_c \\ 0 & \text{for } \theta \leq \theta_w \end{cases}$$

θ_w = soil moisture content at PWP
θ_c = critical soil moisture content

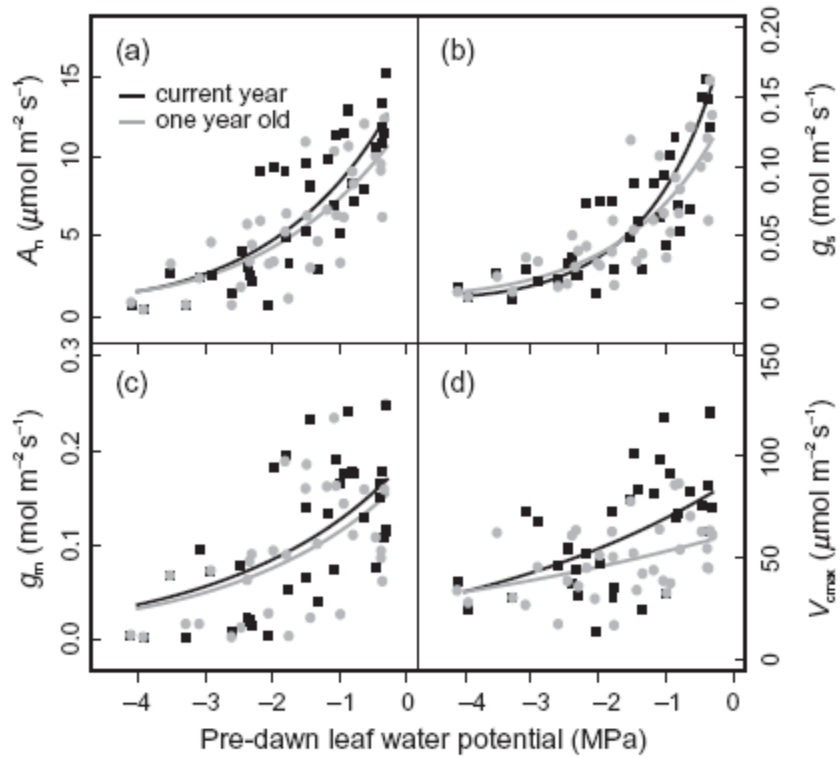
MODELS SUCH AS JULES NEGLECT DIFFUSIONAL LIMITATIONS (I.E. STOMATAL AND/OR MESOPHYLL CONDUCTANCE LIMITATIONS)

IMPLICATIONS OF INCLUDING DIFFUSIONAL LIMITATIONS OF PHOTOSYNTHESIS UNDER DROUGHT

The following water stress index was used:

$$\beta_i = \begin{cases} 1 & \theta \geq \theta_c \\ \left[\dfrac{\theta - \theta_w}{\theta_c - \theta_w}\right]^{q_j} & \theta < \theta_c \\ 0 & \theta \leq \theta_w \end{cases}$$

The exponent q_j is a measure of the **nonlinearity of the effects of soil moisture deficit** on the limiting mechanisms of photosynthesis.



Misson et al. (2010)

IMPLICATIONS OF INCLUDING DIFFUSIONAL LIMITATIONS OF PHOTOSYNTHESIS UNDER DROUGHT

$$\beta_i = \begin{cases} 1 & \theta \geq \theta_c \\ \left[\dfrac{\theta - \theta_w}{\theta_c - \theta_w}\right]^{q_j} & \theta < \theta_c \\ 0 & \theta \leq \theta_w \end{cases}$$

q_S ➔ Limitation strength of g_s

q_M ➔ Limitation strength of g_m

q_B ➔ Limitation strength of biochemistry

$$g_s = g_0 + \beta_S a_1 \frac{1.6A}{(C_s - \Gamma)(1 + (D_s/D^*))}$$

Stomatal conductance limitations (SCL)

$$g_m = \beta_M g_{m,0}$$

Mesophyll conductance limitations (MCL)

$$V_{cmax} = \beta_B V_{cmax,0}$$

$$J_{max} = \beta_B J_{max,0}$$

Biochemical limitations (BL)

IMPLICATIONS OF INCLUDING DIFFUSIONAL LIMITATIONS OF PHOTOSYNTHESIS UNDER DROUGHT

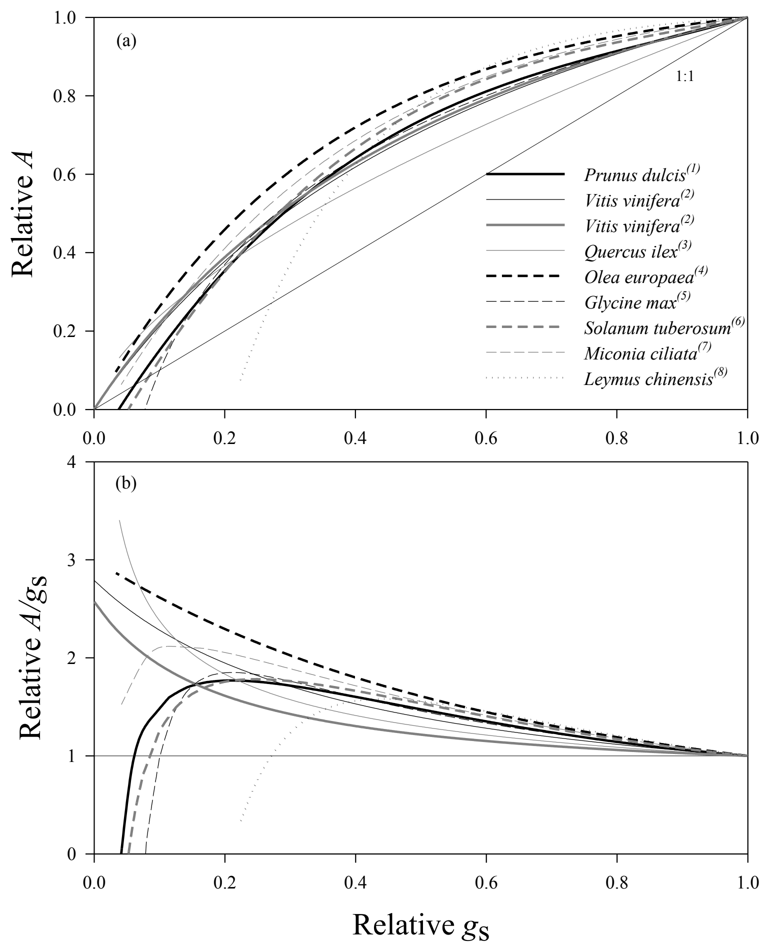
Sensitivity analyses were performed to assess **six** different configurations of **water stress on leaf-level photosynthesis and stomatal conductance**:

C1: Only SCL
C2: Only BL
C3: SCL+MCL
C4: MCL+BL
C5: SCL+BL
C6: SCL+MCL+BL

where

SCL = Stomatal conductance limitations
MCL= Mesophyll conductance limitations
BL= Biochemical limitations

IMPLICATIONS OF INCLUDING DIFFUSIONAL LIMITATIONS OF PHOTOSYNTHESIS UNDER DROUGHT

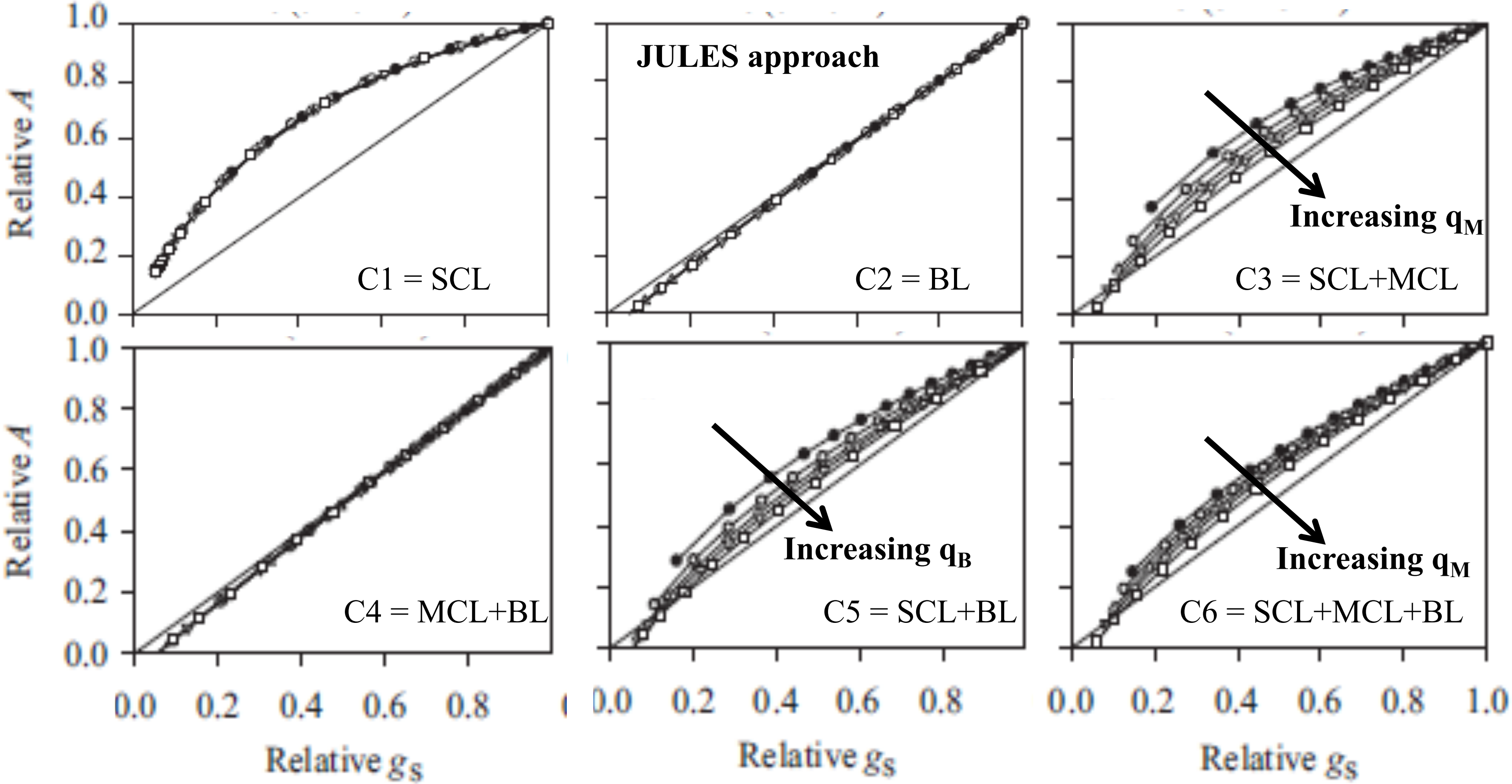


Results of a literature survey to analyze the relationships **A vs g_s** and **A/g_s vs g_s** in response to water stress.

Egea, Verhoef & Vidale (2011; AFM 151)

SENSITIVITY ANALYSES

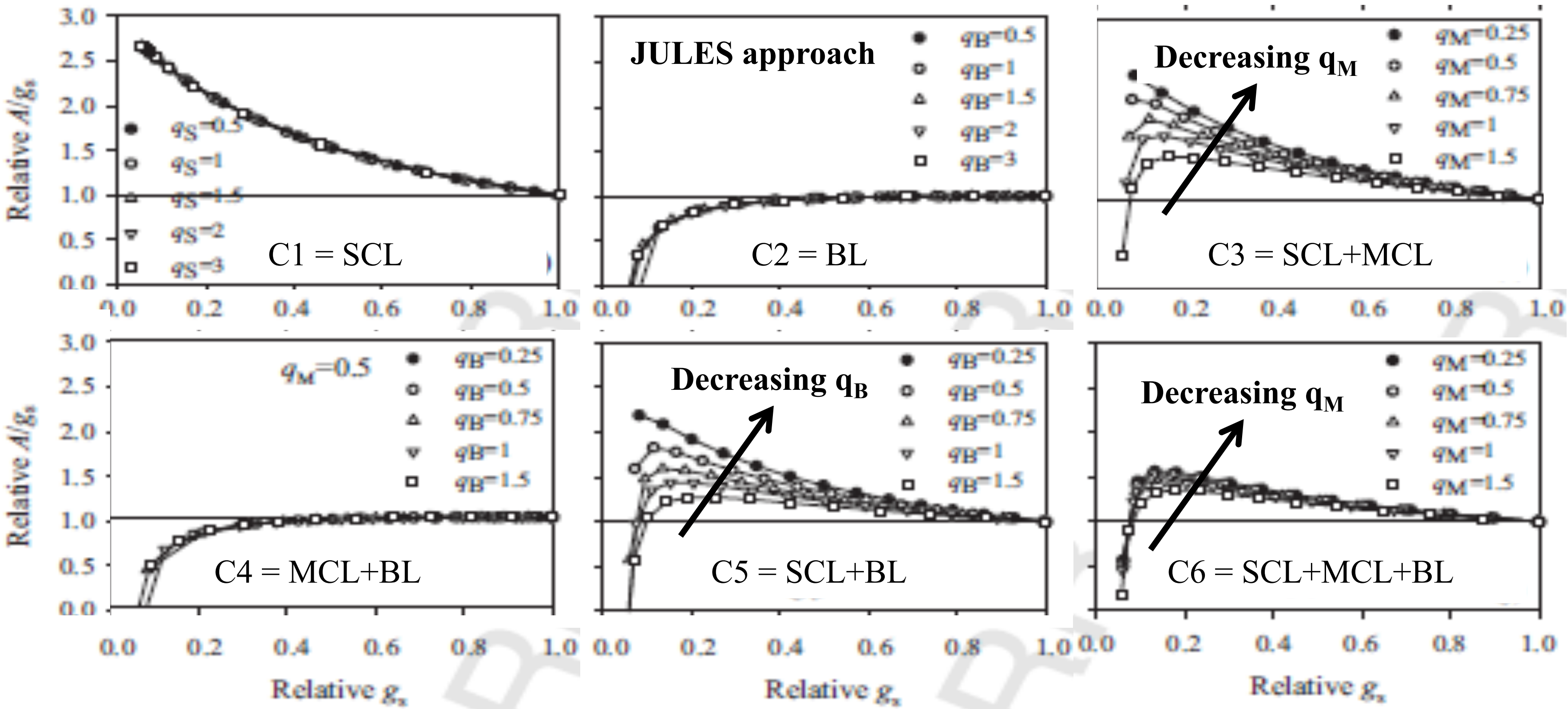
Relationship A vs g_s in response to soil water deficit



Egea, Verhoef & Vidale (2011; AFM 151)

SENSITIVITY ANALYSES

Relationship A/g_s vs g_s in response to soil water deficit



Egea, Verhoef & Vidale (2011; AFM 151)

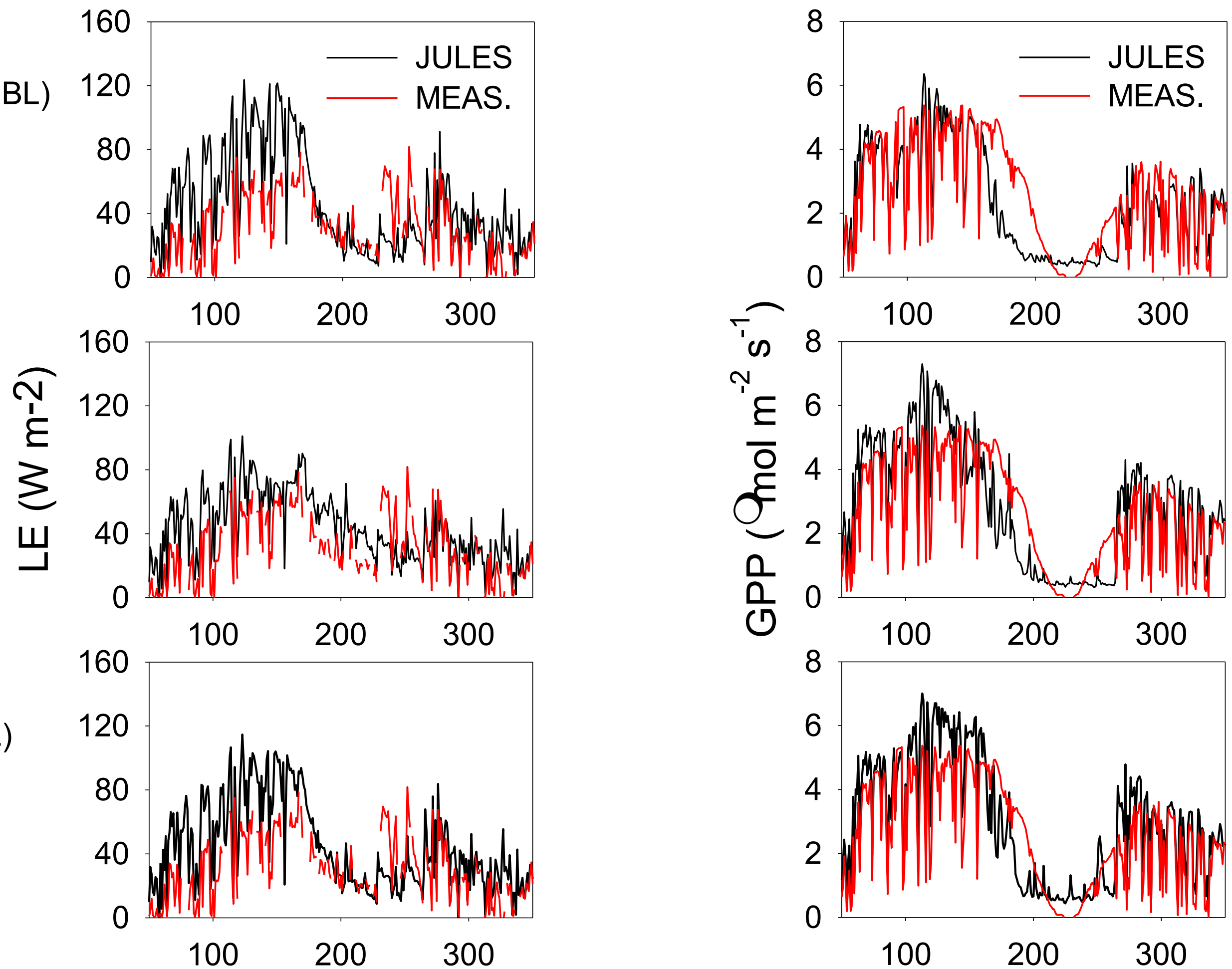
Off-line JULES runs for FLUXNET sites

Year 2003

Standard (only BL)
qS=0
qM=0
qB=1

(only SCL)
qS=1
qM=0
qB=0

(SCL+MCL+BL)
qS=0.5
qM=0.25
qB=0.25



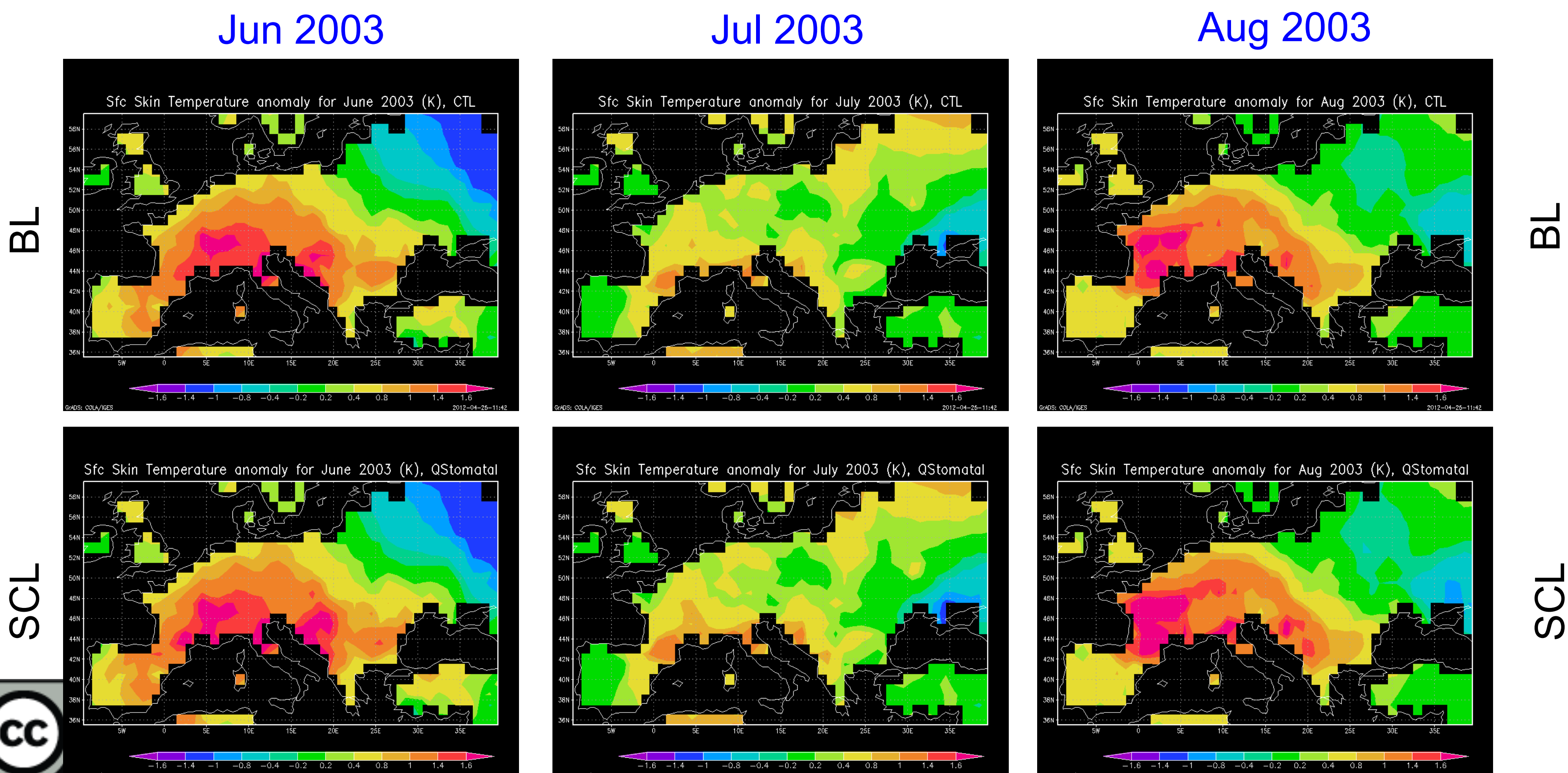
Puechabon site (*Quercus ilex, Southern France*)

Implementation of the Egea et al. 2011 scheme into climate models

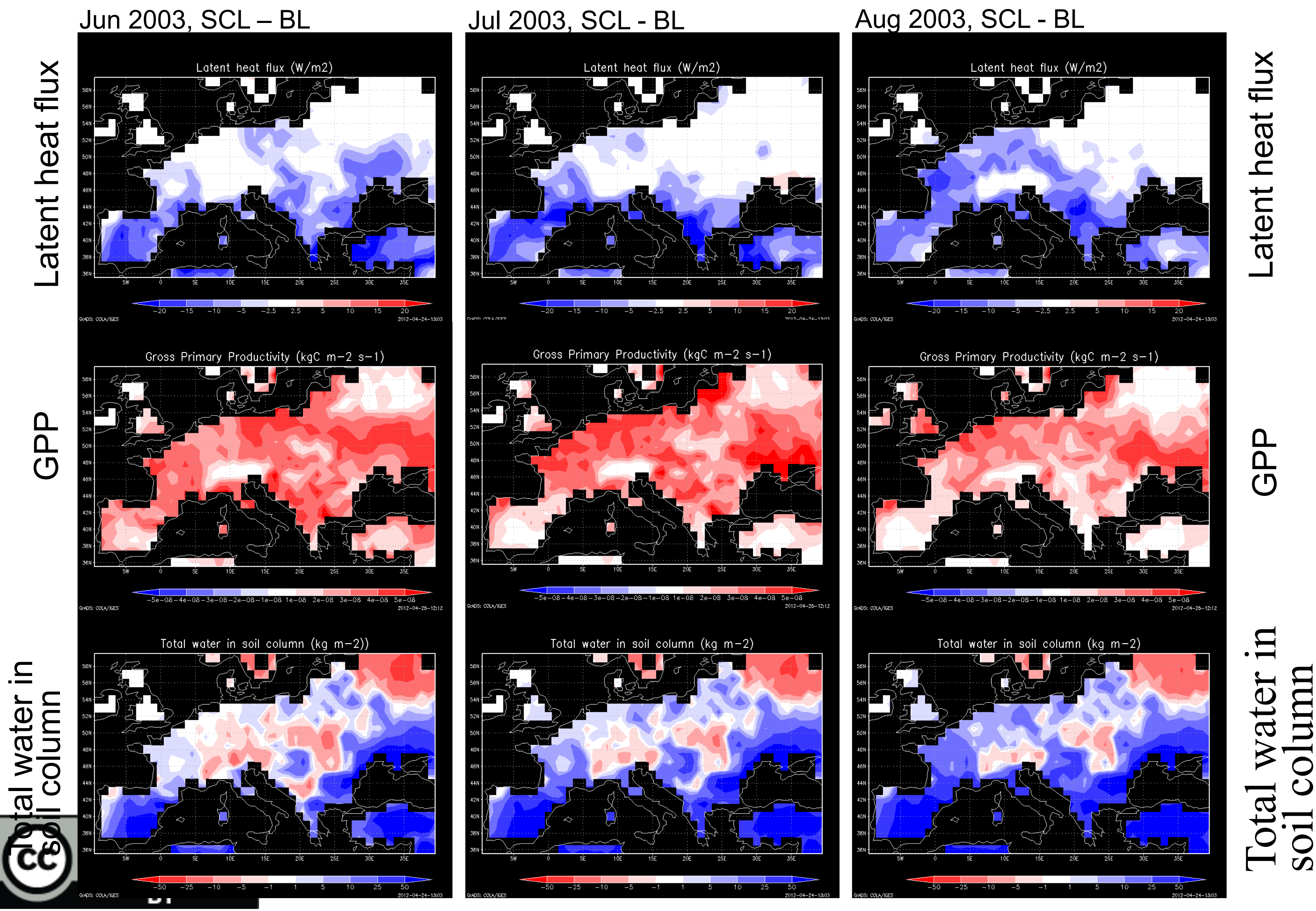
Here JULES is used **offline**, driven with **observed meteorology** (Princeton dataset)

Focus on the **2003 European heat wave**, coinciding with significant seasonal anomalies in precipitation → soil moisture deficit → **surface temperature.**

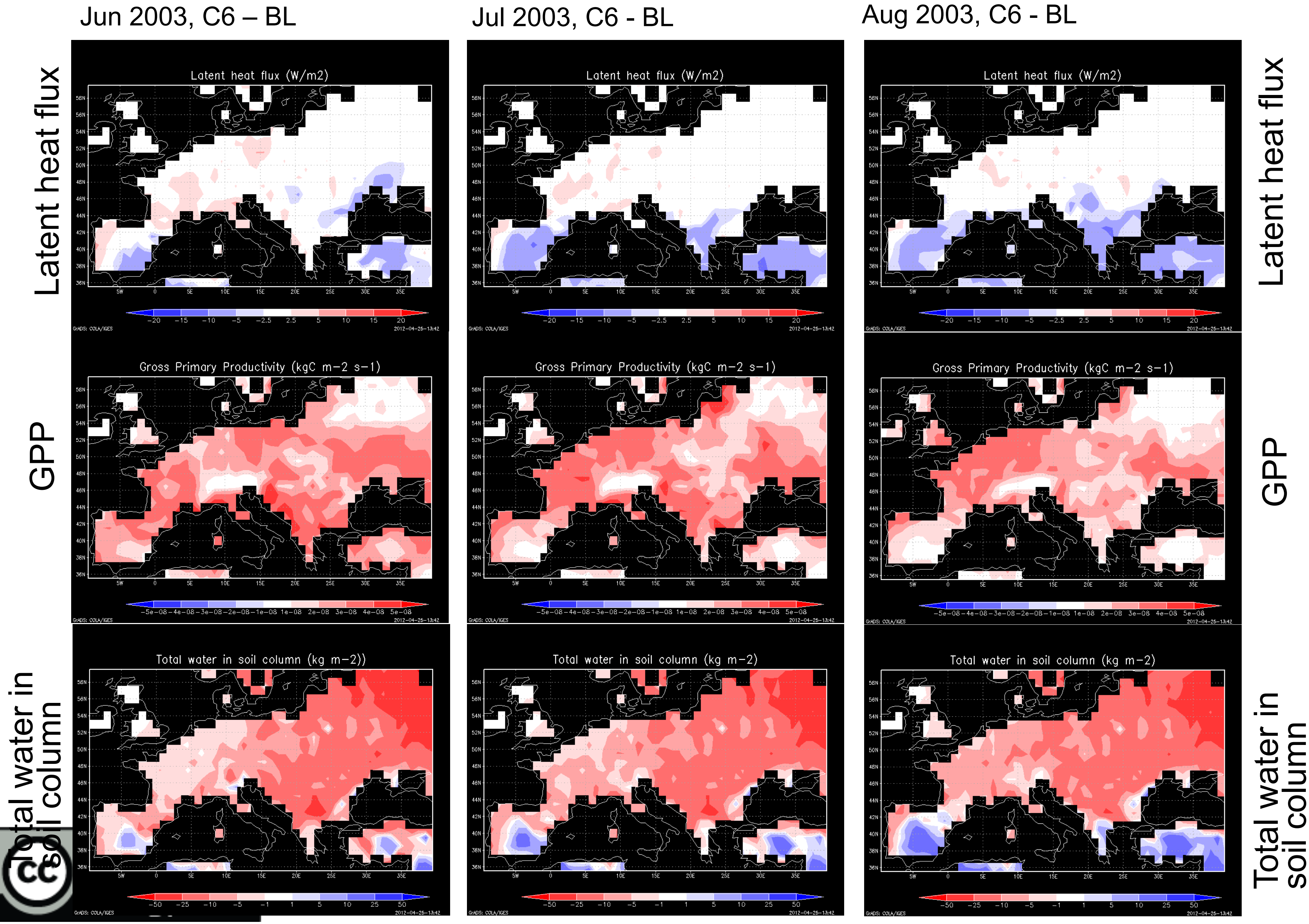
<u>QUESTION</u>: how does vegetation stress depend on the application of the β factor on the model's: **biochemistry** (<u>BL</u>: q_B=1.0, q_M=0.0, q_S=0.0) or **stomatal conductance** (<u>SCL</u>:q_B=0.0, q_M=0.0, q_S=1.0)



Significant impacts on the surface energy balance, GPP and available soil water for SCL combination of water stress limitations: q_B=0.0, q_M=0.0, q_S=1.0



Significant impacts on the surface energy balance, GPP and available soil water
C6 combination (BL + MC + SCL) of water stress limitations: q_B=0.25, q_M=0.25, q_S=0.5



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CONCLUSIONS and OUTLOOK

-The combination of BOTH **stomatal** and **non-stomatal limitations** of photosynthesis is needed to adequately represent **functional relationships** between leaf-level photosynthetic traits in response to **soil water deficit**.

- Outputs of **land surface models** such as JULES are **highly sensitive** to the way plant water stress is modelled, in particularly under **strong drought** conditions

- This will have **implications** for weather forecasts, **climate change studies**, **water resource** management etc.

- We are currently testing the effect of the Egea et al. scheme for other key regions, e.g. **Sahel, Amazon**

-Next, we focus on **coupled runs with GCM**