JULES meeting on forest processes 19-20 June 2013

JULES and CTESSEL: Representing carbon and energy fluxes in forests

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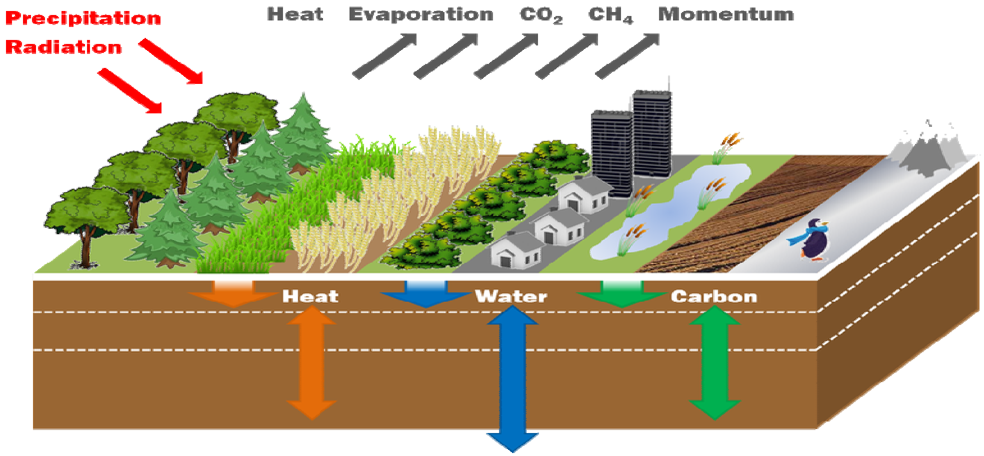
Outline

1. Model descriptions JULES vs CTESSEL
    - Tiles
    - Surface energy balance
    - Photosynthesis

2. Model results for a forest site
    - Energy fluxes
    - Carbon fluxes

1.Model description: Tiles

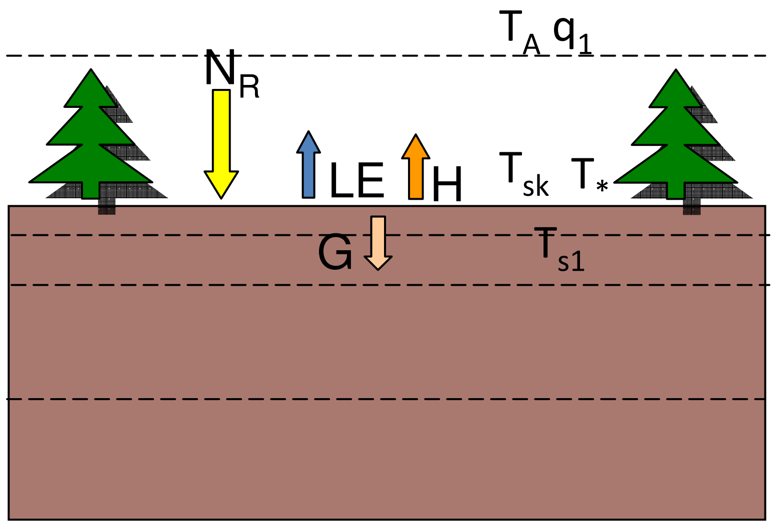


Index	Vegetation type	H/L	$r_{s,min}$ (sm^{-1})	c_{veg}	g_D (hPa^{-1})	a_r	b_r
1	Crops, mixed farming	L	100	0.90	0	5.558	2.614
2	Short grass	L	100	0.85	0	10.739	2.608
3	Evergreen needleleaf trees	H	250	0.90	0.03	6.706	2.175
4	Deciduous needleleaf trees	H	250	0.90	0.03	7.066	1.953
5	Deciduous broadleaf trees	H	175	0.90	0.03	5.990	1.955
6	Evergreen broadleaf trees	H	240	0.99	0.03	7.344	1.303
7	Tall grass	L	100	0.70	0	8.235	1.627
8	Desert	–	250	0	0	4.372	0.978
9	Tundra	L	80	0.50	0	8.992	8.992
10	Irrigated crops	L	180	0.90	0	5.558	2.614
11	Semidesert	L	150	0.10	0	4.372	0.978
12	Ice caps and glaciers	–	–	–	–	–	–
13	Bogs and marshes	L	240	0.60	0	7.344	1.303
14	Inland water	–	–	–	–	–	–
15	Ocean	–	–	–	–	–	–
16	Evergreen shrubs	L	225	0.50	0	6.326	1.567
17	Deciduous shrubs	L	225	0.50	0	6.326	1.567
18	Mixed forest/woodland	H	250	0.90	0.03	4.453	1.631
19	Interrupted forest	H	175	0.90	0.03	4.453	1.631
20	Water and land mixtures	L	150	0.60	0	–	–

CTESSEL

High vegetation
Low vegetation
Snow on high vegetation
Exposed snow
Interception reservoir
Bare ground
Lake (LAKEHTESSEL)

Surface energy balance



JULES

$$C_s \frac{\delta T_*}{\delta t} = (1-\alpha)\,Sw\downarrow + \varepsilon\left(Lw\downarrow - \sigma T_*^4\right) - H - LE - G$$

$$\mathrm{H} = \frac{\rho c_p}{r_a}(T_* - T_A) \qquad G = \nu[\sigma\varepsilon\varepsilon_s T_*{}^4 - \sigma\varepsilon\varepsilon_s T_{s1}{}^4 + \frac{\rho c_p}{r_{a_{can}}}(T_* - T_{s1})] + (1-\nu)\lambda_{soil}(T_* - T_{s1})$$

$$E = \frac{\rho}{r_a + r_s}(q_{sat}(T_*) - q_1)$$

Radiative Turbulent Conductive

CTESSEL

$$0 = (1 - f_{Rs})(1-\alpha)\,Sw\downarrow + \varepsilon\left(Lw\downarrow - \sigma T_{sk}^4\right) + H + LE - G$$

$$\mathrm{H} = \frac{\rho c_p}{r_a}\left(T_A - \frac{gz}{c_L} - T_{sk}\right) \qquad G = \Lambda_{sk}(T_{sk} - T_{s1})$$

$$E = \frac{\rho}{r_a + r_s}(q_{1-}q_{sat}(T_{sk}))$$

Skin conductivity

Photosynthesis

JULES

- A-g_s scheme
- Differentiates C_3 and C_4 photosynthesis
- Soil moisture stress applied to leaf level net assimilation
- T dependence with Q_{10} functions
- Scaling from leaf level photosynthesis:
  1. Big leaf approach
  2. Multilayer approach

CTESSEL

- A-g_s scheme
- Only one type
- Soil moisture stress applied to mesophyll conductance
  - Low vegetation formulation
  - High vegetation formulation
- T dependence with Q_{10} functions
- Big leaf approach with differentiation between direct and diffuse radiation

Leaf level photosynthesis

JULES: Potential gross photosynthesis is obtained combining 3 regimes:

1. Rubisco-limited rate

$$Wc = \begin{cases} V_{cmax}\left(\dfrac{c_i - \Gamma}{c_i + K_c + \left(1 + \dfrac{O_a}{K_o}\right)} = \right) & for\ C_3 \\ V_{cmax} & for\ C_4 \end{cases}$$

V_{cmax}: max rate of carboxylation of Rubisco
c_i: Internal CO_2 partial pressure
O_a: Partial pressure of O_2
Γ: Compensation point
K_c, K_o: Michelis-Menten parameters

2. Light-limited rate

$$W_l = \begin{cases} \alpha(1-\omega)I_{par}\left(\dfrac{c_i - \Gamma}{c_i + 2\Gamma}\right) & for\ C_3 \\ \alpha(1-\omega)I_{par} & for\ C_4 \end{cases}$$

α: Quantum efficiency of photosynthesis
I_{par}: Incident photosyntetically active radiation
ω: leaf scattering coefficient

3. Rate of transport of photosynthetic products (C_3)and PEPCarboxylase limitation (C_4)

$$We = \begin{cases} 0.5\ V_{cmax} & for\ C_3 \\ 2 \times 10^4 V_{cmax}\left(\dfrac{c_i}{P_*}\right) & for\ C_4 \end{cases}$$

P_*: Surface air pressure

Vcmax, Γ, K_c, K_o depend on temperature according to Q_{10} fuctions

Leaf level photosynthesis

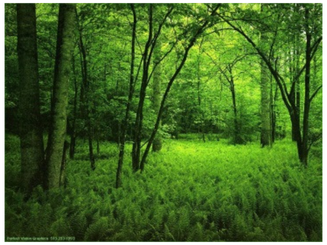
JULES

Soil moisture stress

$$A_l = \beta A_p$$

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

Canopy level photosynthesis



1. Big leaf (can_rad_mod=1)
    - Radiation is attenuated according to Beer's law
    - Photosynthetic rate integrated to LAI

$$A_c = \int_0^{L_c} A_l dL$$

2. Multi-layer (can_rad_mod=2)
    - Radiation uses 2-stream approach by Sellers (1985) allowing differentiation of direct and diffuse radiation.

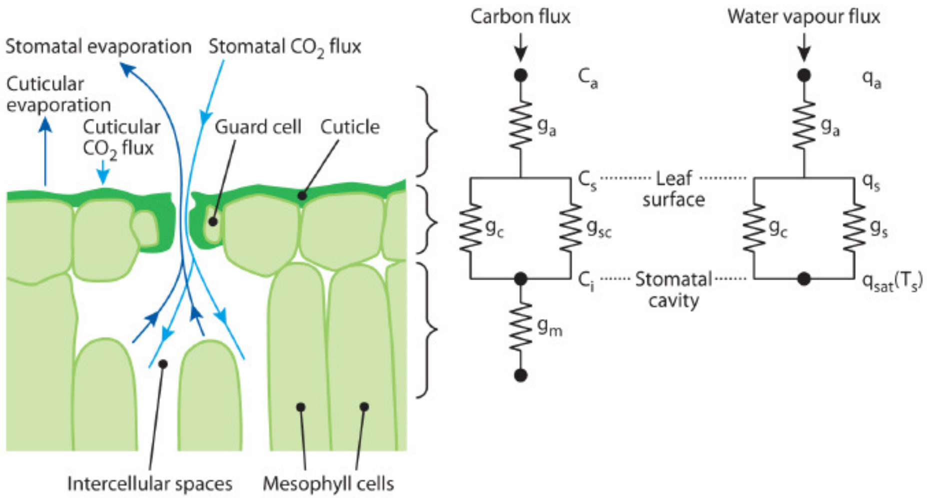
3. Multi-layer (can_rad_mod=3)
    - Differentiation of shaded and sunlit leaves

4. Multi-layer (can_rad_mod=4)
    - Exponential profile of canopy nitrogen
    - Inhibition of leaf respiration in the light

5. Multi-layer (can_rad_mod=5)
    - Sunfleck penetration
    - Inhibition of leaf respiration in the light

Leaf level photosynthesis

CTESSEL



1. <u>Radiation limiting regime</u>

$$A_n = \varepsilon I_a - R_d$$

ε: Quantum efficiency

2. <u>CO_2 limiting regime</u>

$$A_m = \frac{c_i - \Gamma}{g_m}$$

c_i: Internal CO2 concentration
Γ: Compensation point
g_m: Mesophyll conductance

Leaf level photosynthesis

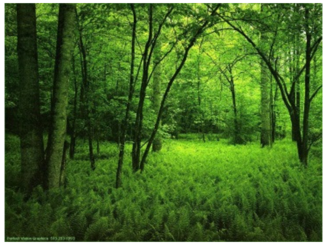
CTESSEL

Soil moisture stress from Calvet (2000) and Calvet et al (2004)

Driven by:
- Mesophyll conductance
- Maximum specific humidity deficit tolerated by the vegetation
- Ratio c_s /c_i

Different formulation for high and low vegetation

Canopy level photosynthesis



CTESSEL

Radiation attenuation according to Beer's law with differentiation between diffuse and direct radiation

$$I_a(z) = I_0\big(1 - K(z)\big)$$

I_0: Radiation above the canopy

$K(z)$ Extinction function

$$K(z) = \delta(\mu_s)K_{df}(z) + \big(1 - \delta(\mu_s)K_{dr}(z)\big)$$

K_{df}: extinction coeff. for diffuse light
K_{dr}: extinction coeff. for direct light
δ: ratio of diffuse to total radiation at the top of the canopy
μ_s : solar zenith angle

$$A_{nI} = LAI \int_0^1 A_n d(z/h)$$

Respiration

JULES

Dark respiration

$$R_d = f_{dr} V_{cmax}$$

Plant respiration = maintenance + growth
(nitrogen contents of stem, roots and leaves)

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

CTESSEL

Dark respiration (leaves only)

$$R_d = A_m / 9$$

Soil and structural biomass respiration:
(T, snow cover, soil moisture, vegetation)

$$R_{soilstr} = R_0(25) Q10Ro^{\left(\frac{T_{soil-25}}{10}\right)} f_{sm} f_{sn}$$

Soil moisture attenuation (f_{sm})

Snow cover attenuation (f_{sn})

2. Model results

Hyytiälä forest (SMEAR II) (61˚51’N, 24˚17’E, 179 m a.s.l)

Vegetation: Scots pines (Needle leaf trees)

Observations : FLUXNET

- Fluxes: eddy-covariance measurements
- Respiration estimated according to Reichstein (2005)
- NEE gapfilled with marginal distribution sampling (MDS)

Meteorological forcing: Half-hourly FLUXNET data

JULES

•Big leaf approach (crm1) and multilayer approach (cmr3)

•Phenology and TRIFFID off

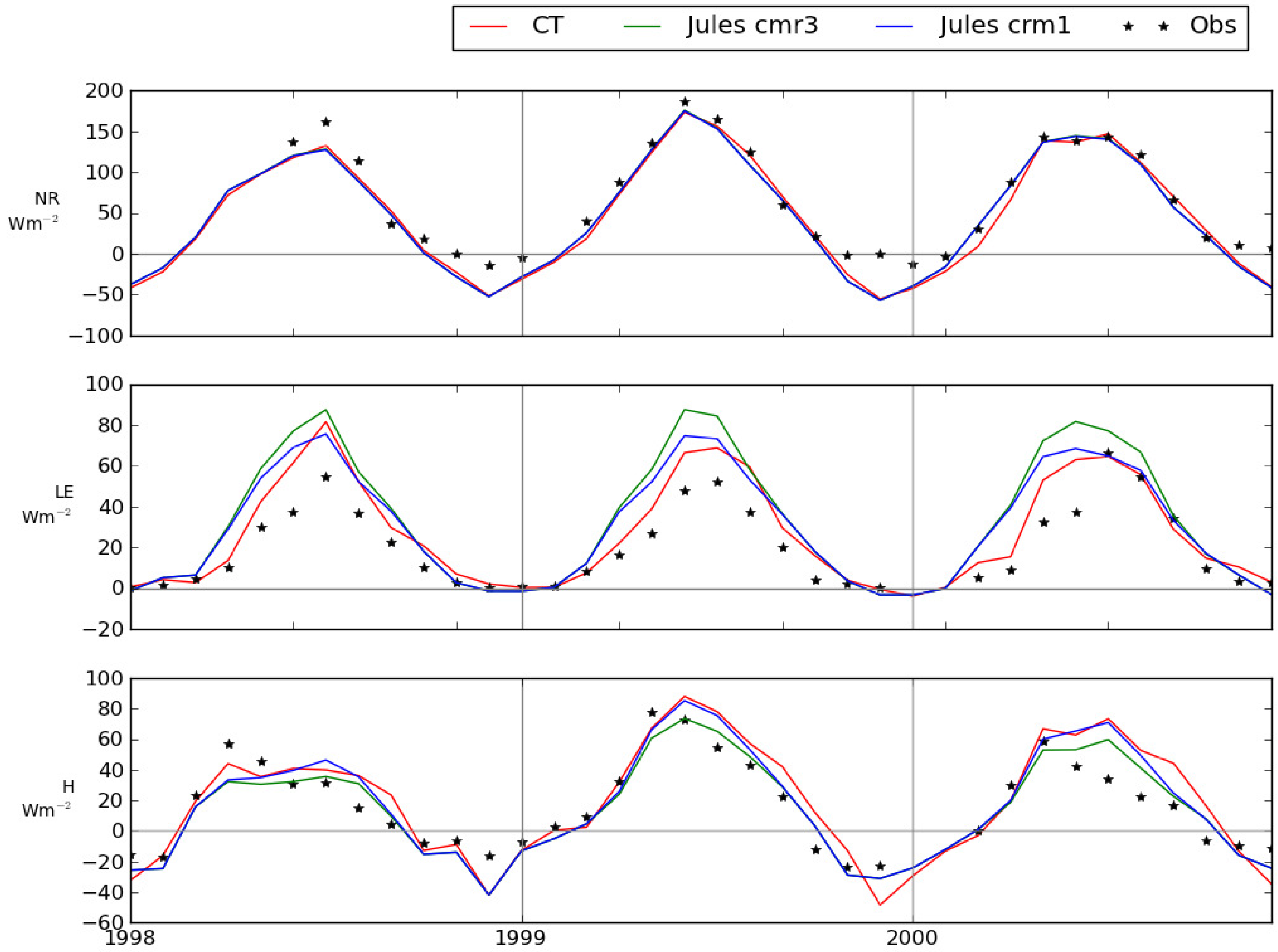
•Prescribed LAI

CTESSEL

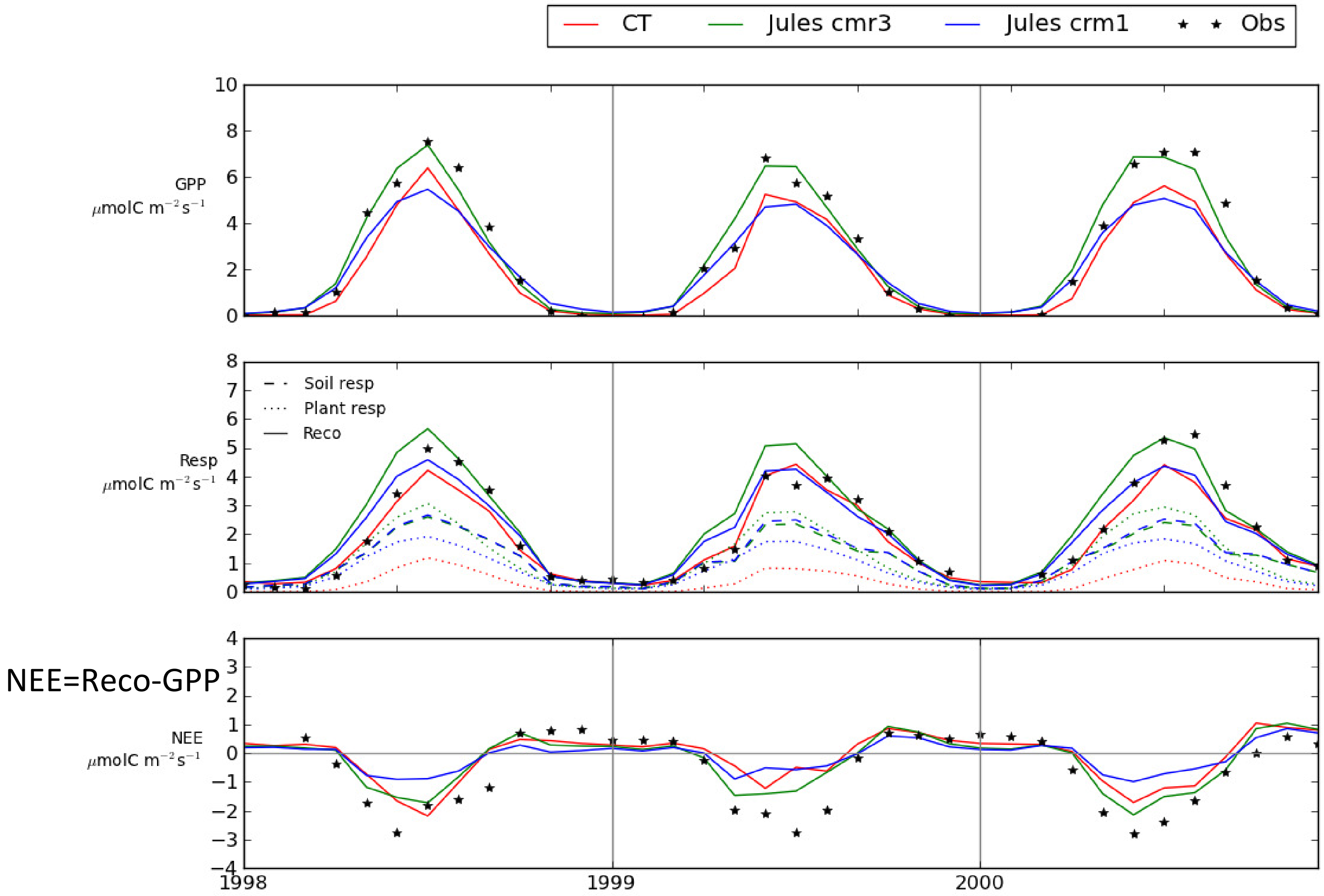
•without coupling A-g_s to evaporation

•Prescribed LAI

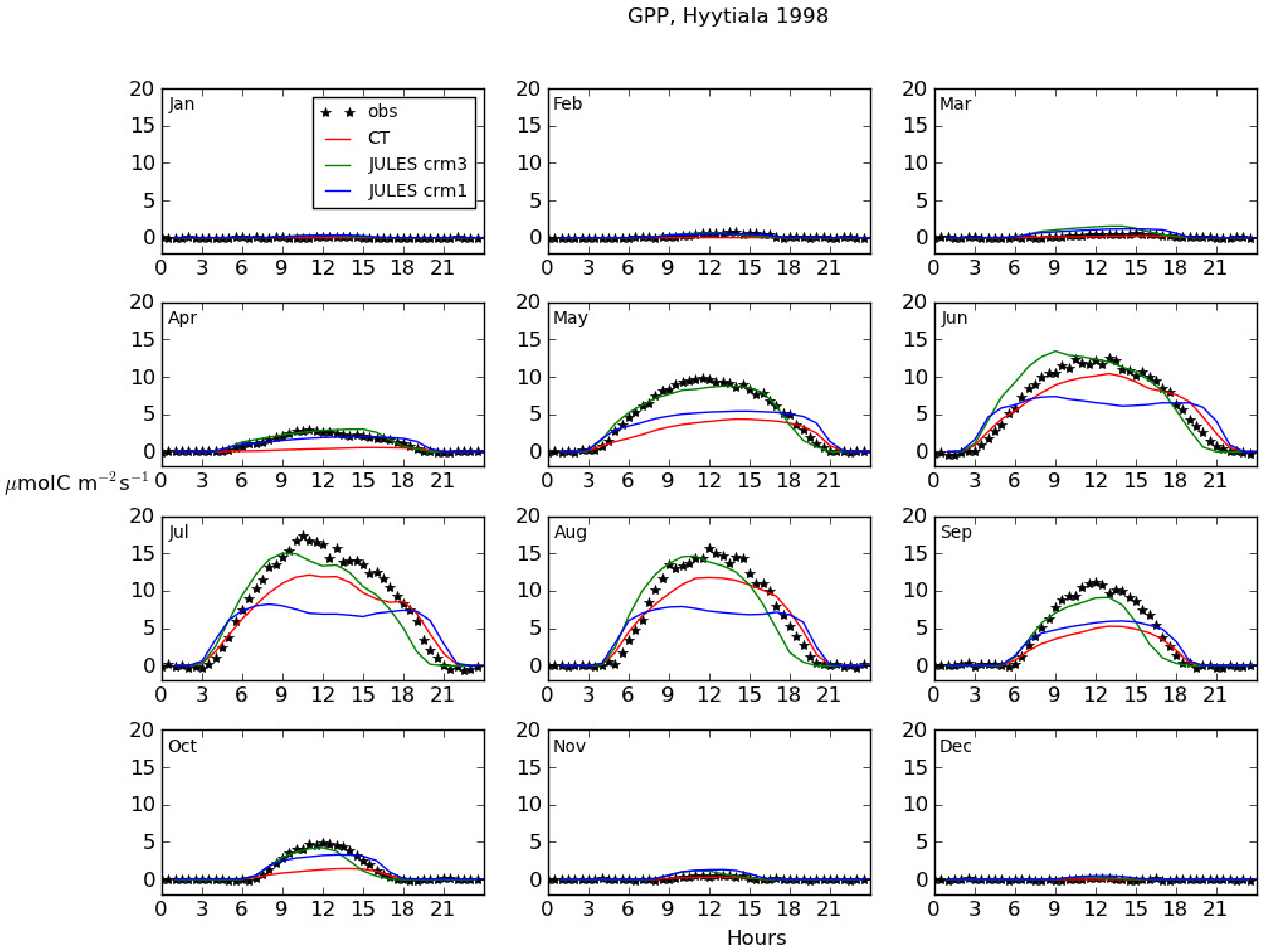
Energy fluxes



Carbon fluxes

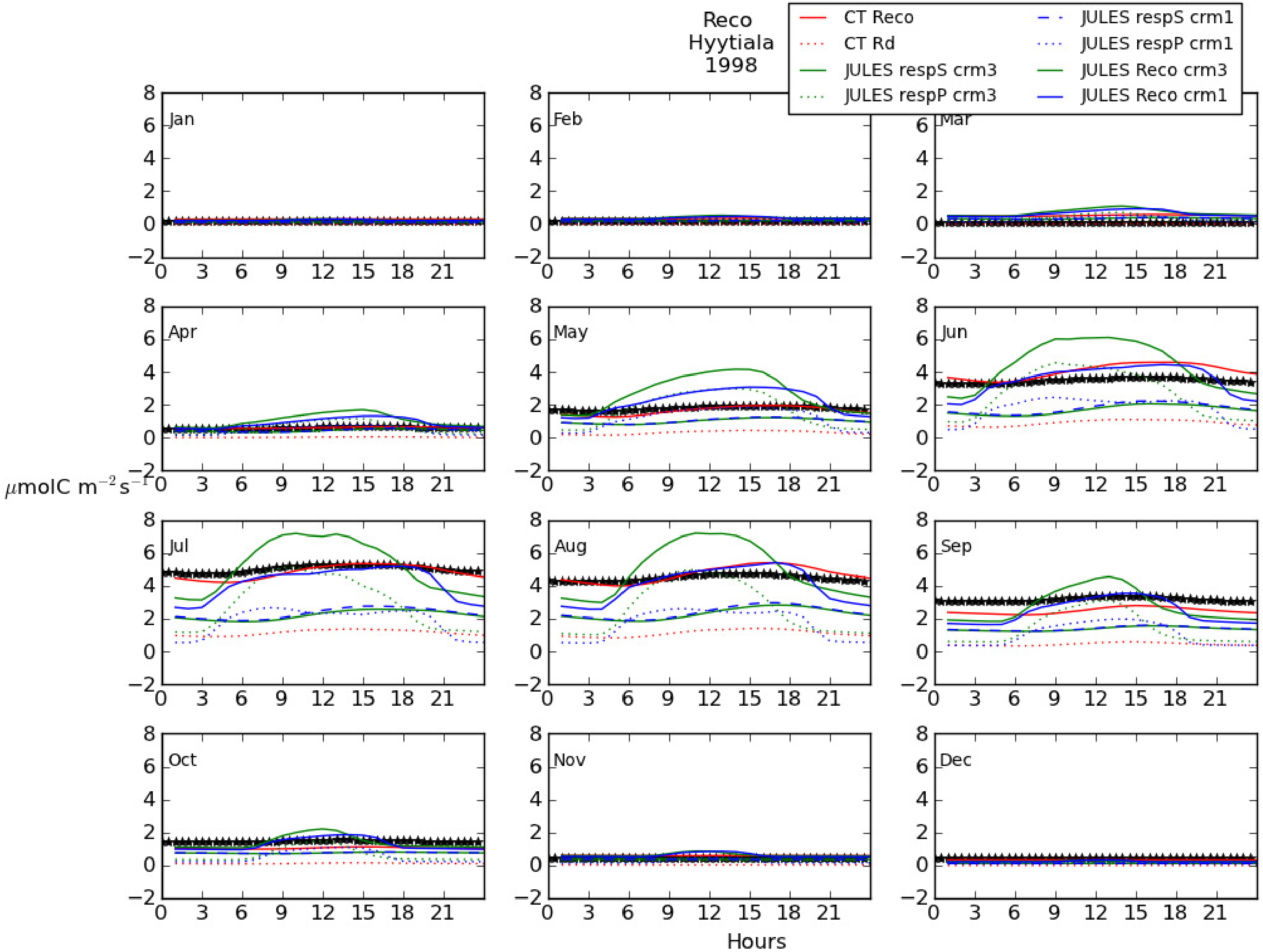


Diurnal GPP



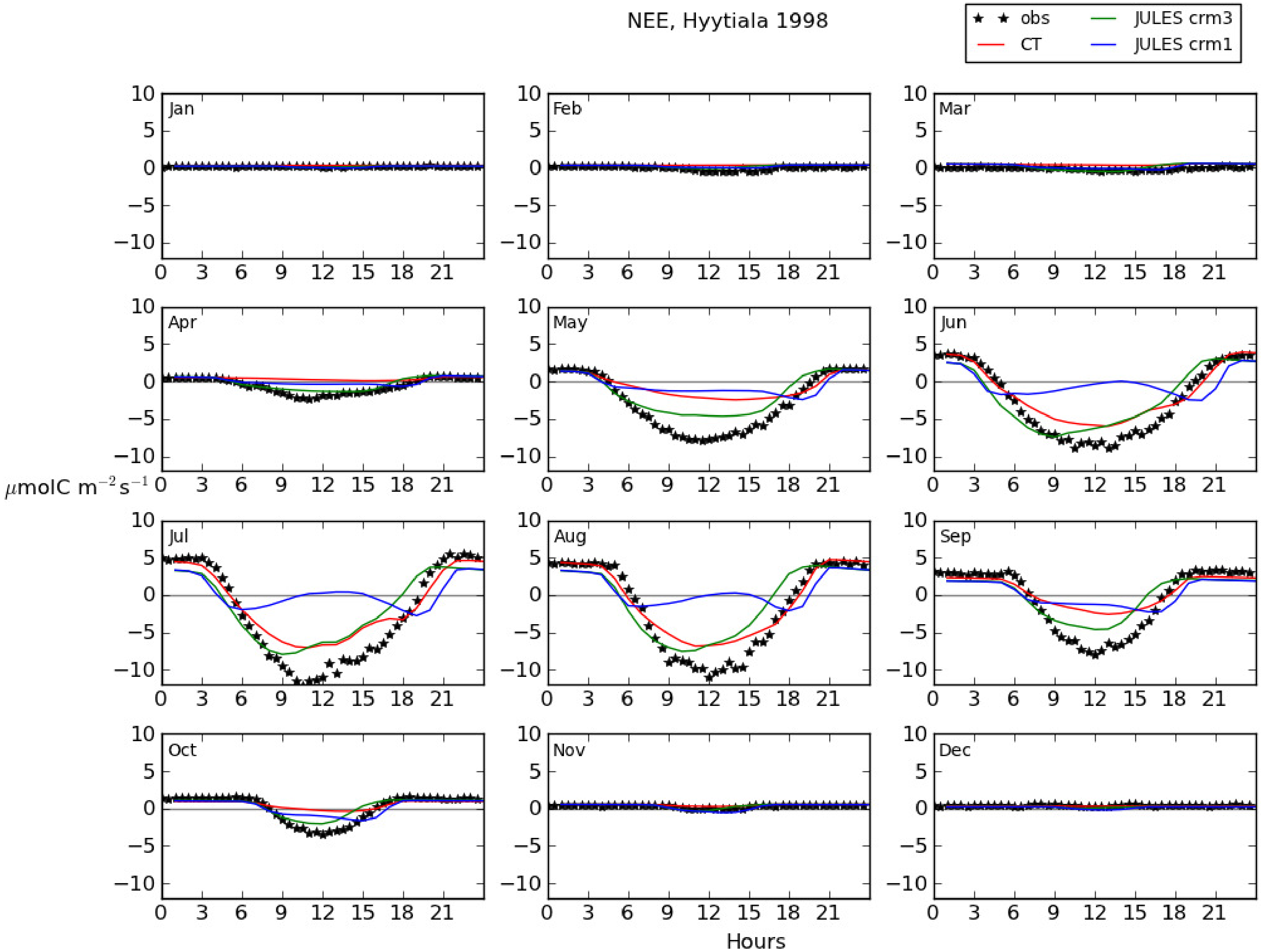
GPP, Hyytiala 1998
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
obs
CT
JULES crm3
JULES crm1
μmolC m^{-2}s^{-1}
Hours
20
15
10
5
0
0
3
6
9
12
15
18
21

Diurnal respiration

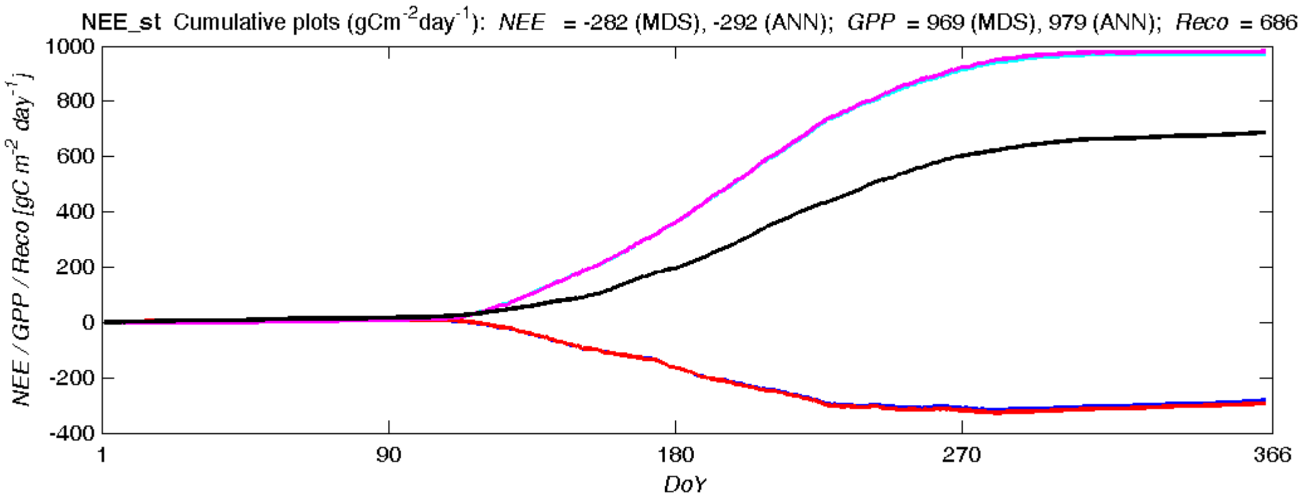


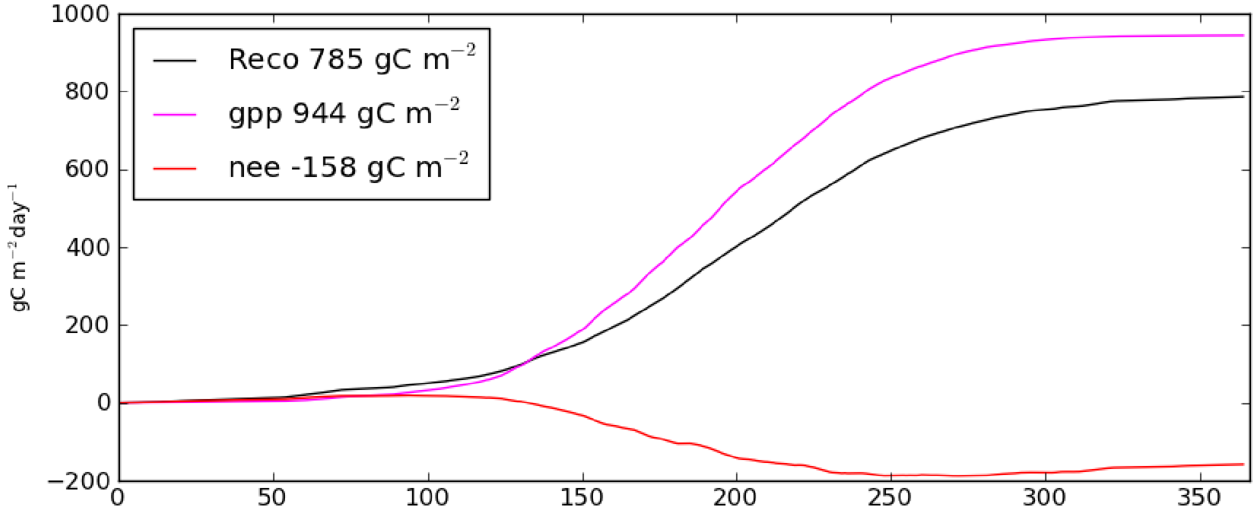
Diurnal NEE

NEE=Reco-GPP

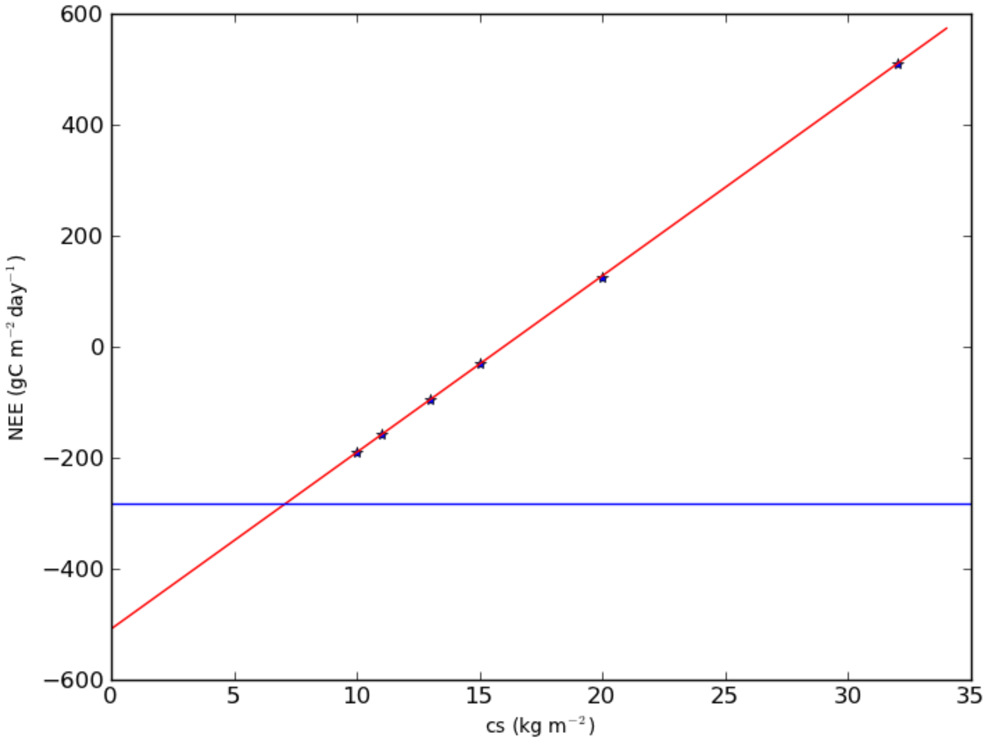


GPP, NEE, Reco Accumulations 1998





Accumulated NEE-initial soil carbon



Measured
NEE 1998
-282 g C/m^2 day

Soil respiration is very sensitive to initial soil carbon pool
Values of soil carbon above 15 kg/m^2 will result in a positive NEE (net source of CO_2)

Concluding remarks

1. **Model comparison: JULES and CTESSEL**

- Physical processes involving energy and water are very similar
- The carbon module presents more differences: treatment of vegetation, soil moisture stress

2**. Model performance in boreal needle leaf site:**

- Energy fluxes are similar, both overestimate latent heat
- The use of multilayer photosynthesis in JULES improves the diurnal cycle of GPP compared to the big leaf approach.
- CTESSEL is able to reproduce the diurnal cycle with the big leaf approach by differentiating between direct and diffuse radiation
- Soil respiration in JULES presents high sensitivity to initial soil carbon pool