A new leaf phenology for the land surface scheme TERRA of the COSMO atmospheric model

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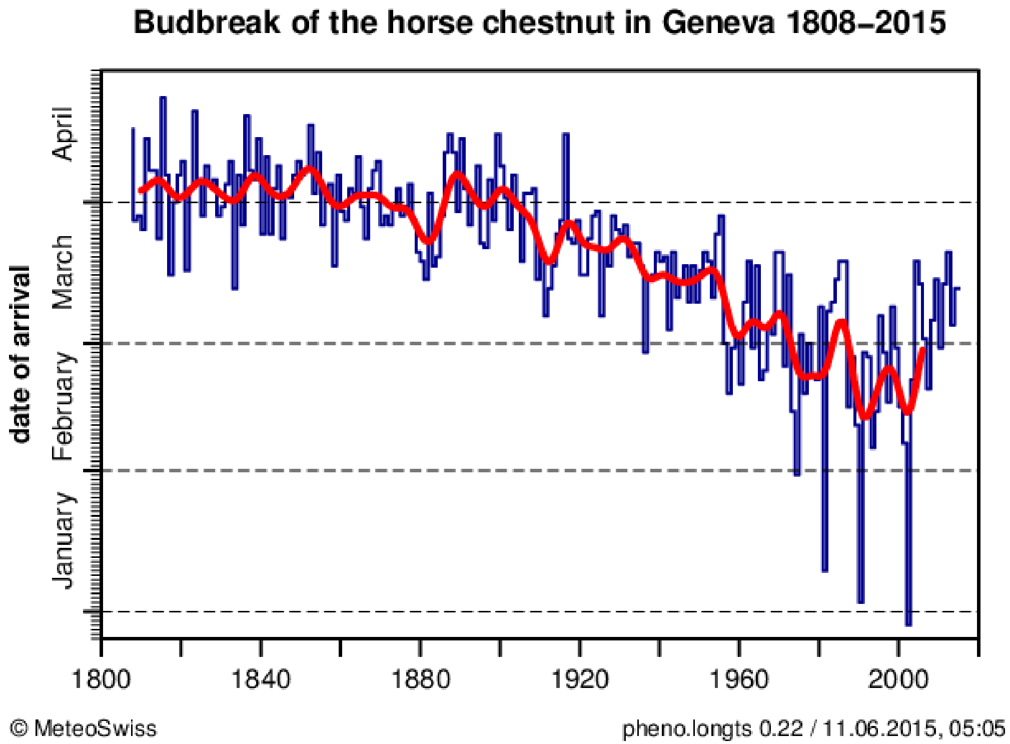
What is phenology?

Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonal and inter-annual variations in climate, as well as habitat factors (such as elevation).

Wikipedia, 4 Mar. 2014

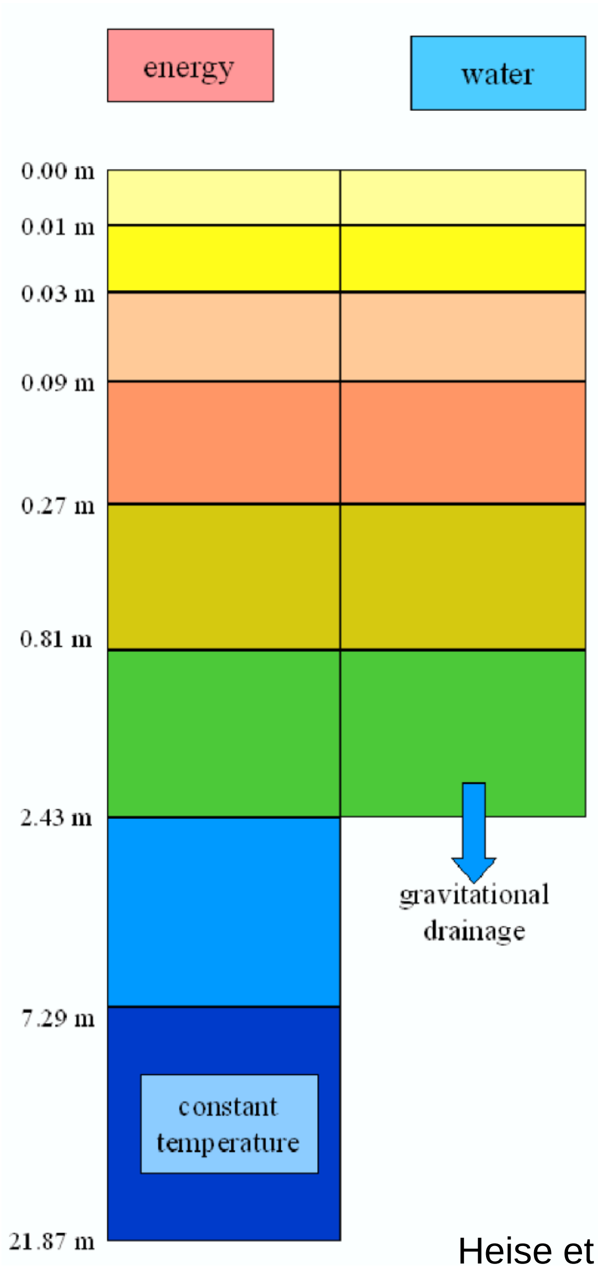


Phenology is governed, or limited, by:

- Temperature
- Day length
- Water availability
- ~~NPP (net primary productivity)~~

Two approaches for phenology not depending on NPP adopted from:

- Polcher, J. (1994), *Thèse de doctorat, Univ. Pierre et Marie Curie, Paris*
- Knorr, W., et al. (2010), *J. Geophys. Res.*, **115**, G04017



Heise et al. (2006)

Land surface scheme TERRA

Layers for temperature and soil water content

Experiments:

- Use atmospheric forcing to run TERRA in offline mode
- Here, observed forcing from DWD observatory Lindenberg is used (Falkenberg site)

Phenology determining temperature

$$T(t)=\frac{\int_{-\infty}^{0} T_S(t+\tilde{t})\,e^{\tilde{t}/t}\,d\tilde{t}}{\int_{-\infty}^{0} e^{\tilde{t}/t}\,d\tilde{t}}$$

This is equivalent to an exponentially declining memory of the plants for the surface temperature T_S. t is the averaging period for T_S.

Phenology as function of temperature

based on Polcher (1994)

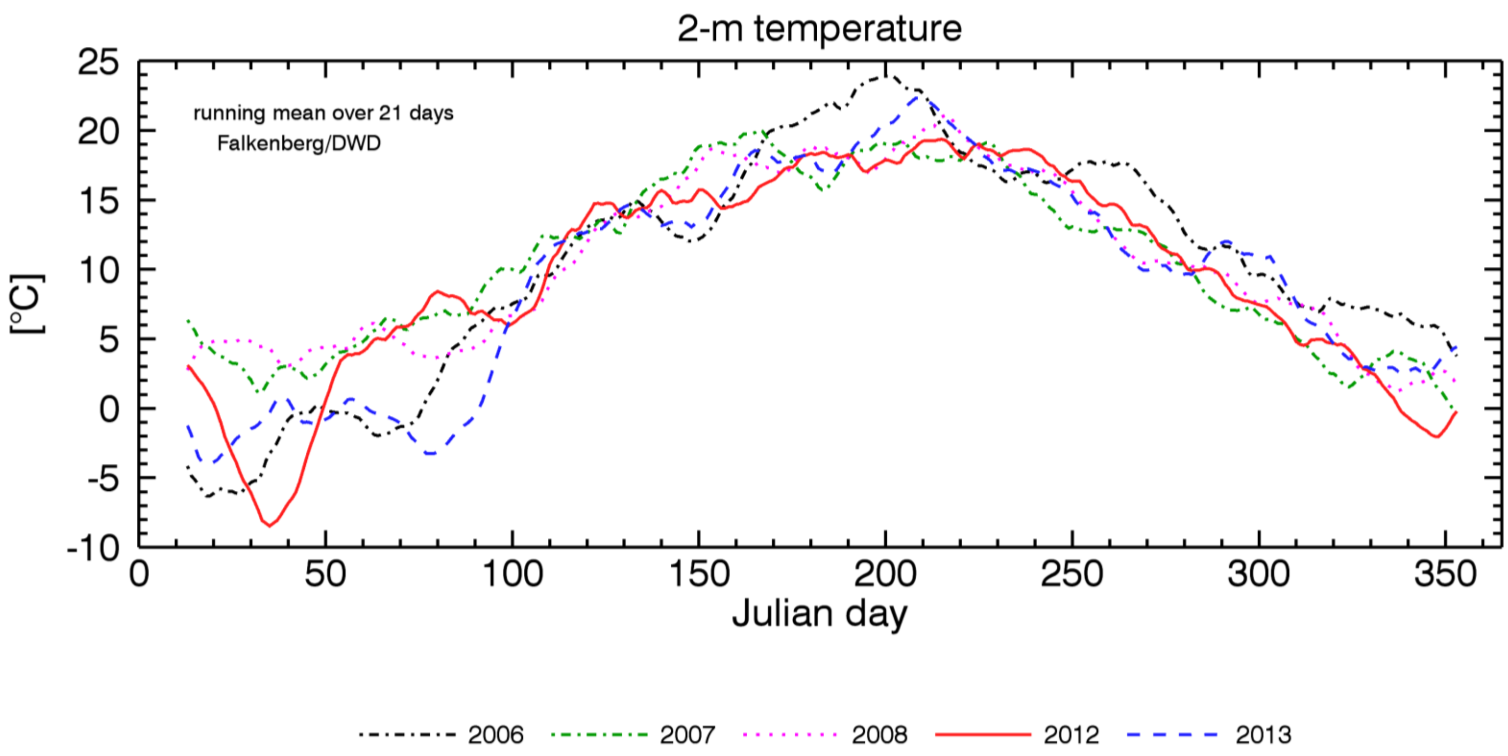
$$\mathrm{LAI}(t) = \begin{cases} \mathrm{LAI}_{min} & \text{if } T(t) \le T_1 \\ \mathrm{LAI}_{min} + \dfrac{T(t) - T_1}{T_2 - T_1}(\mathrm{LAI}_{max} - \mathrm{LAI}_{min}) & \text{if } T_1 < T(t) \le T_2 \\ \mathrm{LAI}_{max} & \text{if } T_2 < T(t) \end{cases}$$

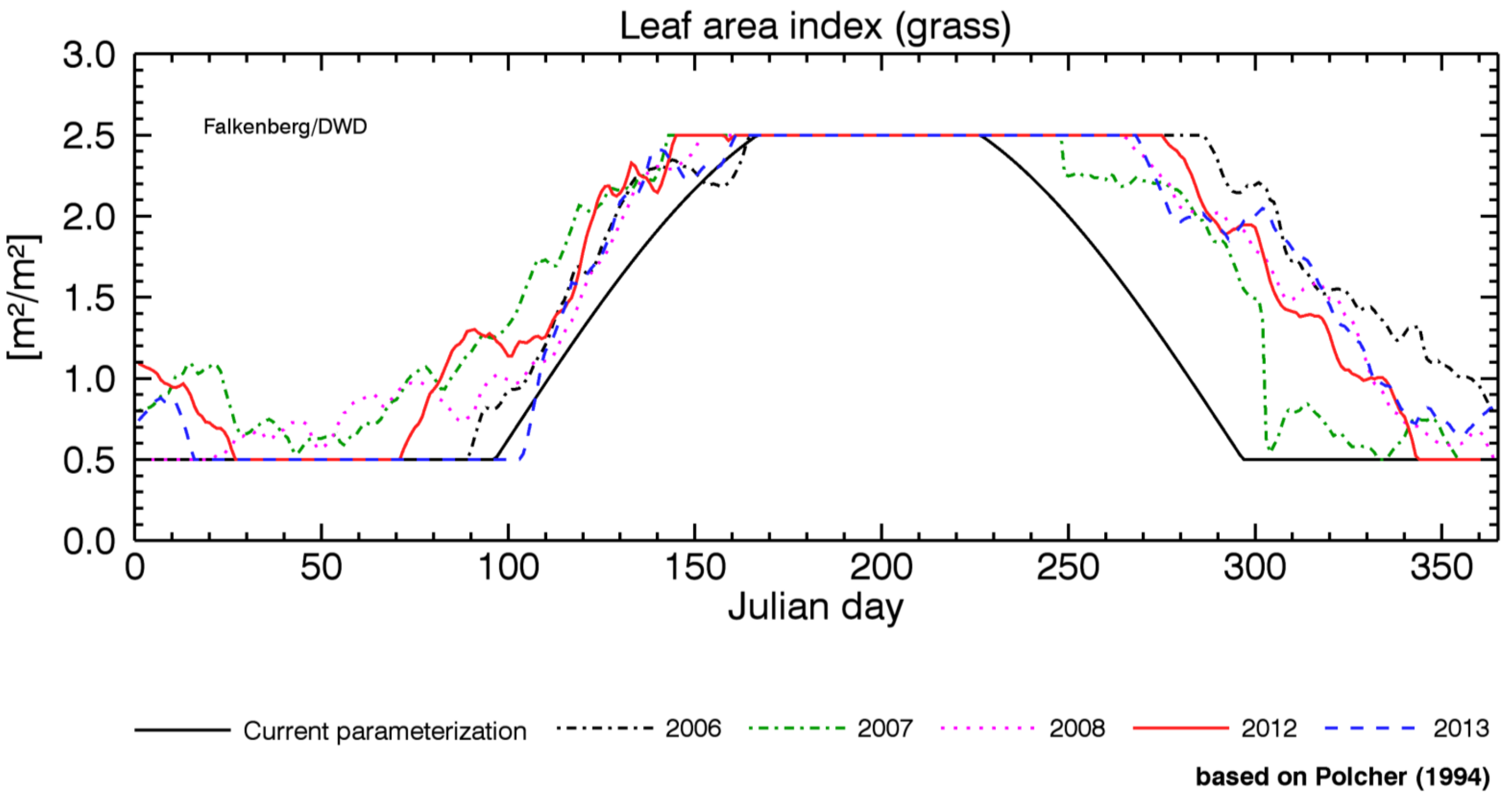
T_1 : minimum limiting temperature

T_2 : maximum limiting temperature

LAI_{min} , LAI_{max} : minimum and maximum value of LAI

Inter-annual variability at Lindenberg




Leaf area index (grass)
Falkenberg/DWD
[m²/m²]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
350
Julian day
Current parameterization
2006
2007
2008
2012
2013
based on Polcher (1994)

Phenology as function of temperature

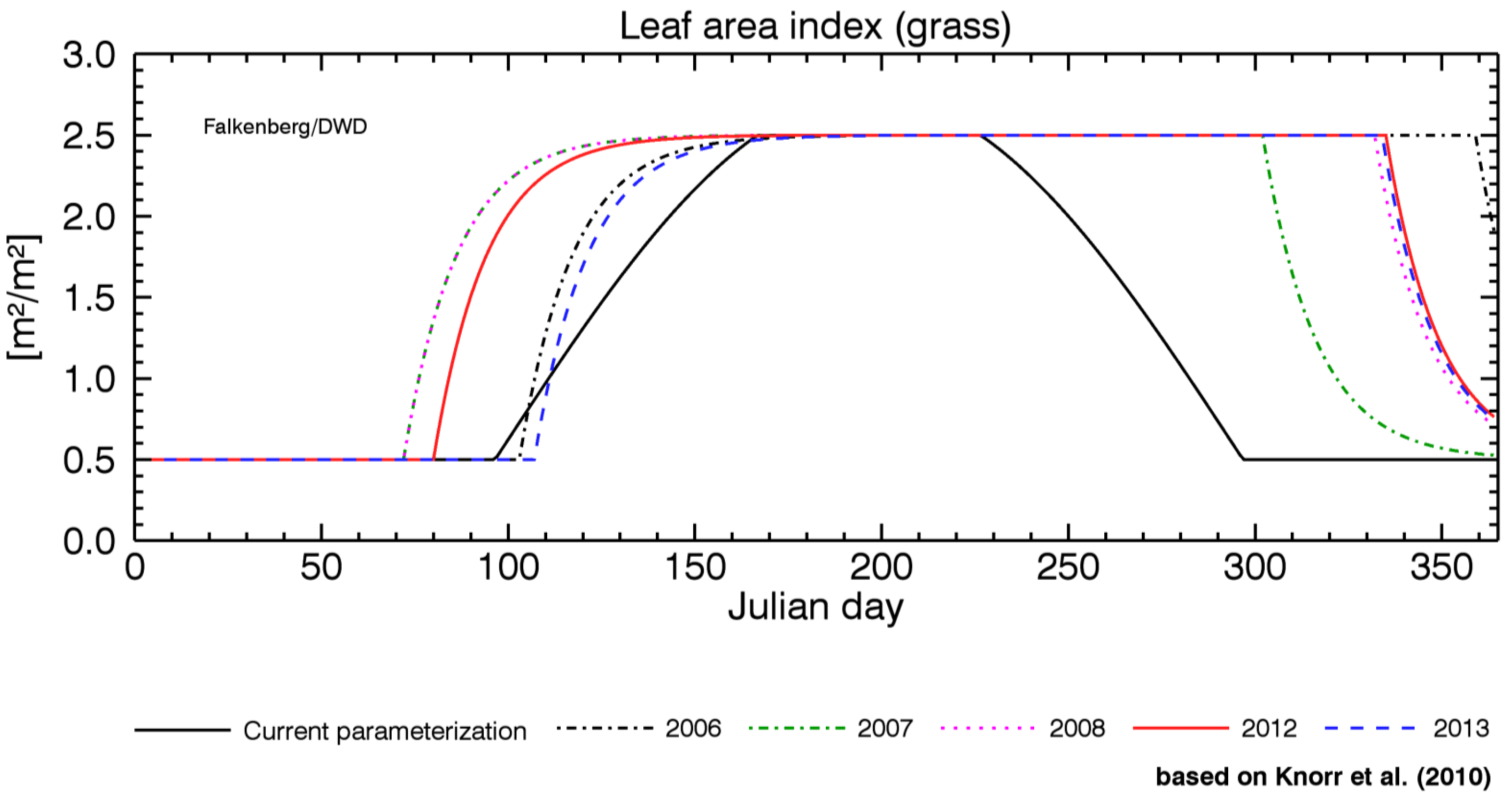
based on Knorr et al. (2010)

$$\frac{d\mathrm{LAI}(t)}{dt} = \begin{cases} k_{grow}(\mathrm{LAI}_{\max} - \mathrm{LAI}(t)) & \text{if } T(t) \geq T_{\mathrm{on/off}} \\ k_{shed}(\mathrm{LAI}_{\min} - \mathrm{LAI}(t)) & \text{else} \end{cases}$$

$T_{\mathrm{on/off}}$: leaf onset and offset temperature

k_{grow} , k_{shed} : growth rate and shedding rate

$\mathrm{LAI}_{\max}$, $\mathrm{LAI}_{\min}$: maximum and minimum value of LAI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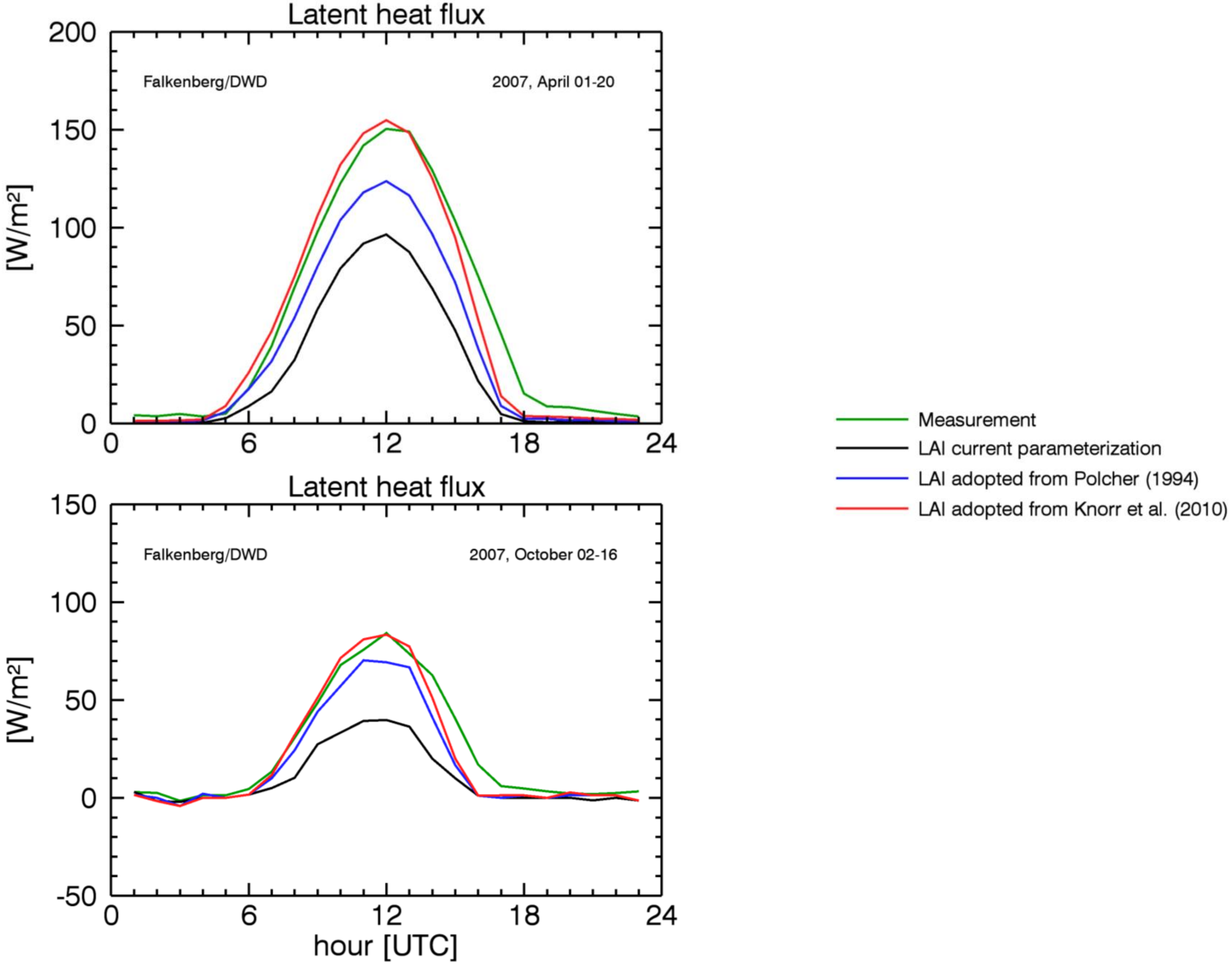
Latent heat flux
Falkenberg/DWD
2007, April 01-20
[W/m²]
200
150
100
50
0
6
12
18
24
Latent heat flux
Falkenberg/DWD
2007, October 02-16
[W/m²]
-50
hour [UTC]
Measurement
LAI current parameterization
LAI adopted from Polcher (1994)
LAI adopted from Knorr et al. (2010)

Phenological Data Assimilation

A gap-free Leaf-Area Index Climate Data Record

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Colorado State University
Knowledge to Go Places

NEWS

NASA

NASA NEWS (NASA Energy and Water Cycle Study), Grant NNG06CG42G

The GSI diagnostic phenology model

The GSI model was developed based on the insight that also the state of vegetation on the global scale can be determined by only 3 climatic driving states:

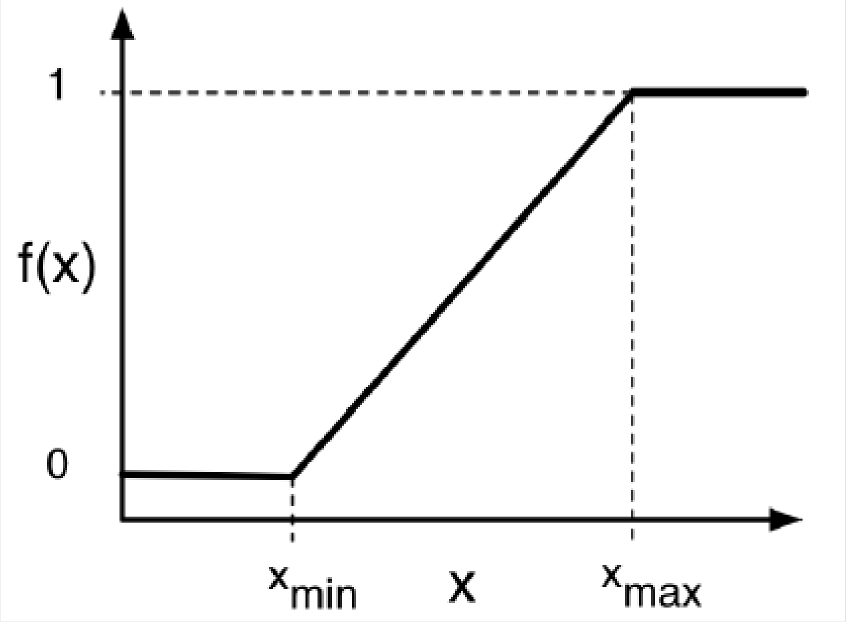
- Temperature T (air temperature)
- Radiation R (daylength or global radiation)
- Water W (vapor pressure deficit)

$$\mathrm{GSI} = f(T) \cdot f(R) \cdot f(M)$$

$$f(T) = \frac{T - T_{min}}{T_{max} - T_{min}}$$

$$f(R) = \frac{R - R_{min}}{R_{max} - R_{min}}$$

$$f(W) = 1 - \frac{W - W_{min}}{W_{max} - W_{min}}$$



Growing Season Index (GSI)
Jolly et al. (2005)

From diagnostic to prognostic phenology

Steady-state GSI:

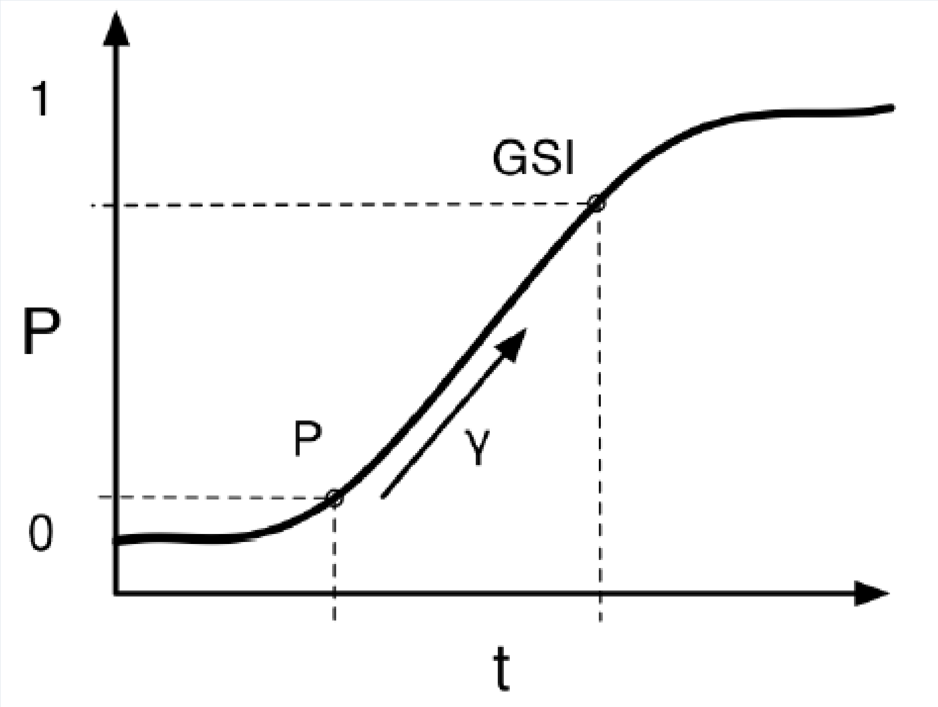
$$\mathrm{GSI} = f(T) \cdot f(R) \cdot f(M)$$

Prognostic state P:

$$P = f(\mathrm{LAI})$$

Deviation of P from "potential" GSI:

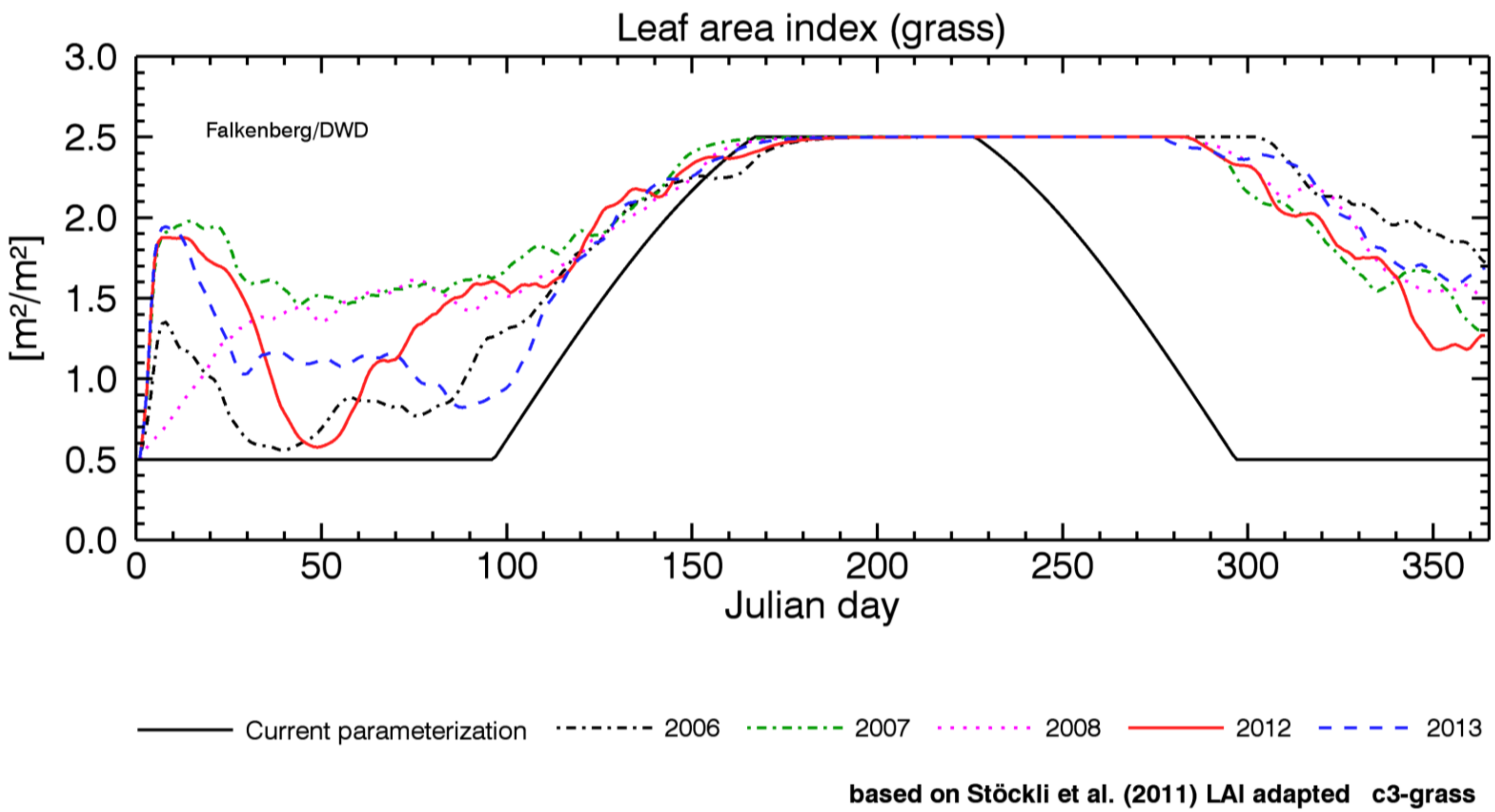
$$\frac{\partial \mathrm{GSI}}{\partial t} = \mathrm{GSI} - P$$



Modify LAI at each time step towards diagnostic GSI by logistic growth and defined growth rate:

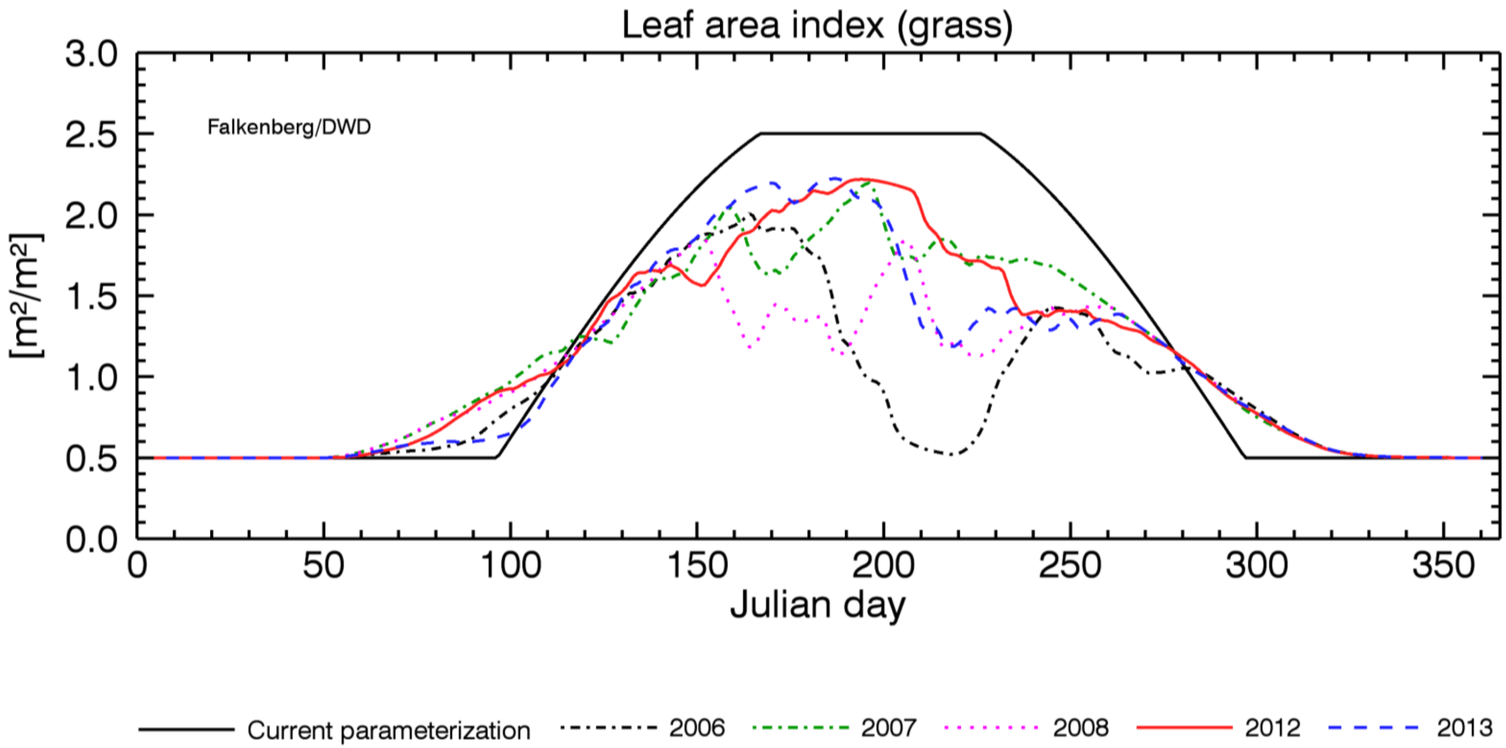
$$\frac{\partial \mathrm{LAI}}{\partial t} = \gamma \cdot \frac{\partial \mathrm{GSI}}{\partial t} \cdot P(1-P) \qquad \gamma = \begin{cases} \gamma_g & \text{if } \partial \mathrm{GSI} \geq 0 \\ \gamma_d & \text{if } \partial \mathrm{GSI} < 0 \end{cases} .$$

Stockli et al. (2008,2011)



C3 grass

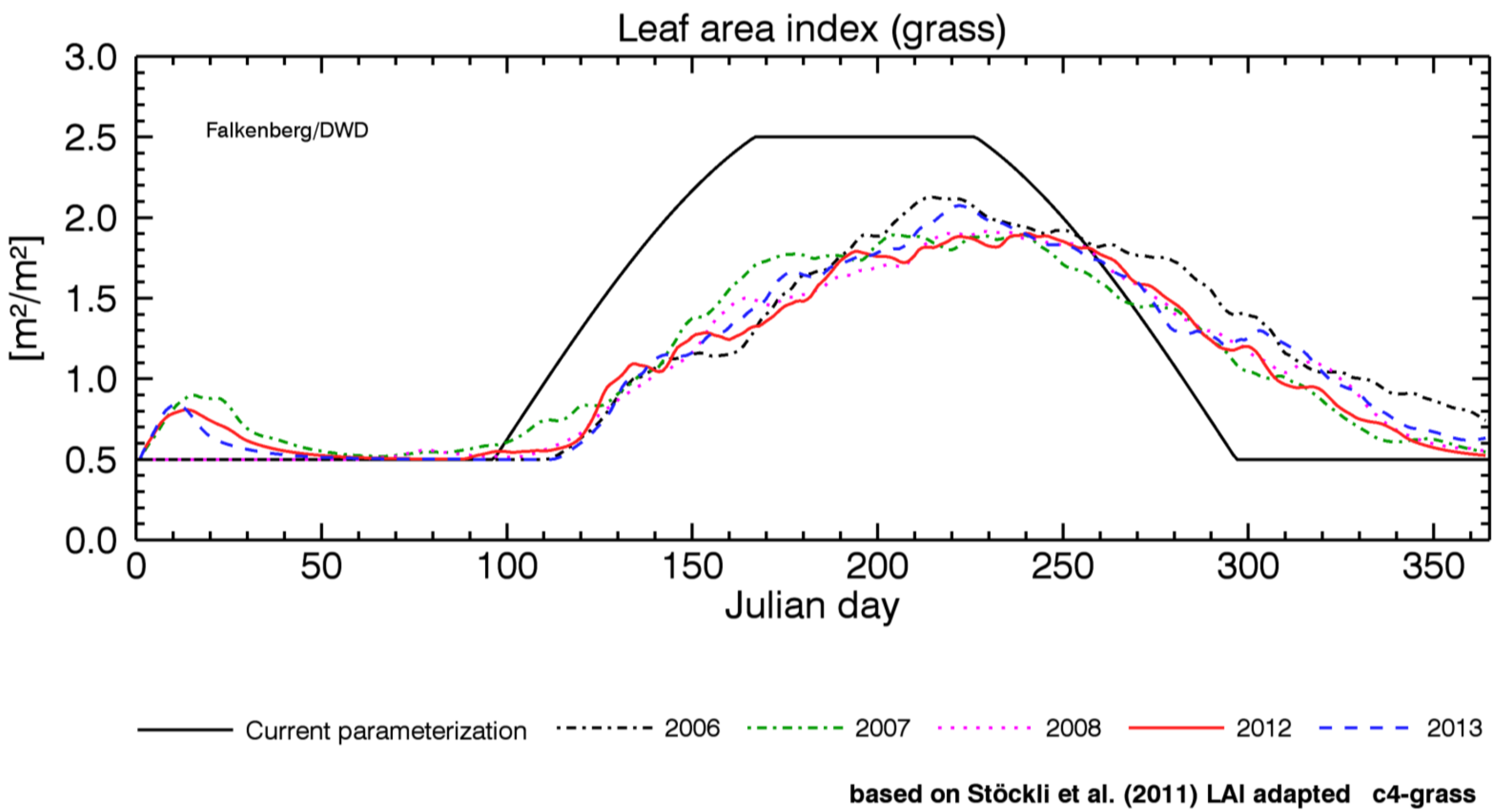
Stress functions: Temperature only



based on Stöckli et al. (2011) LAI adapted c3-grass

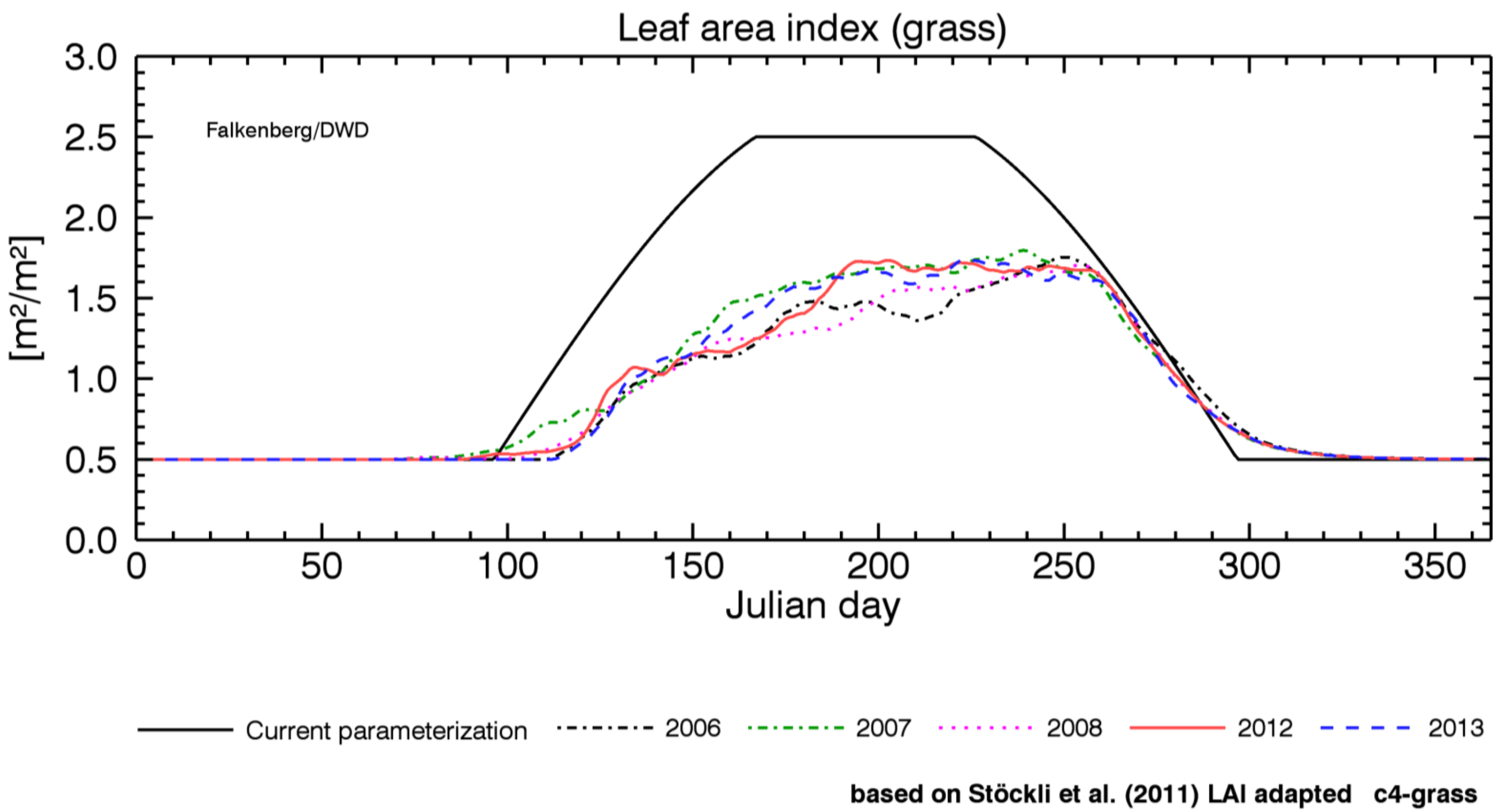
C3 grass

Stress functions: Temperature, day length, vapour pressure deficit



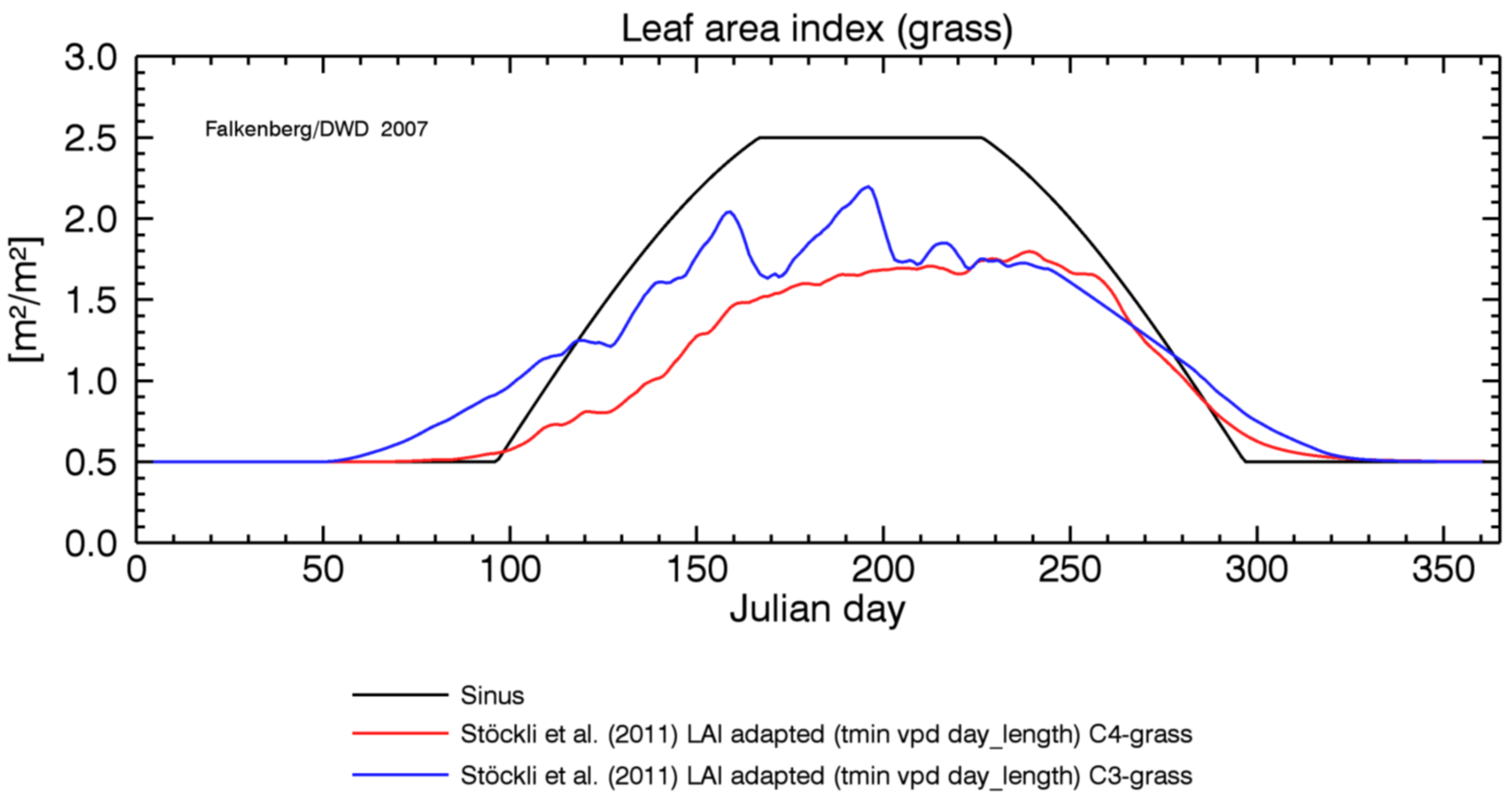
C4 grass

Stress functions: Temperature only



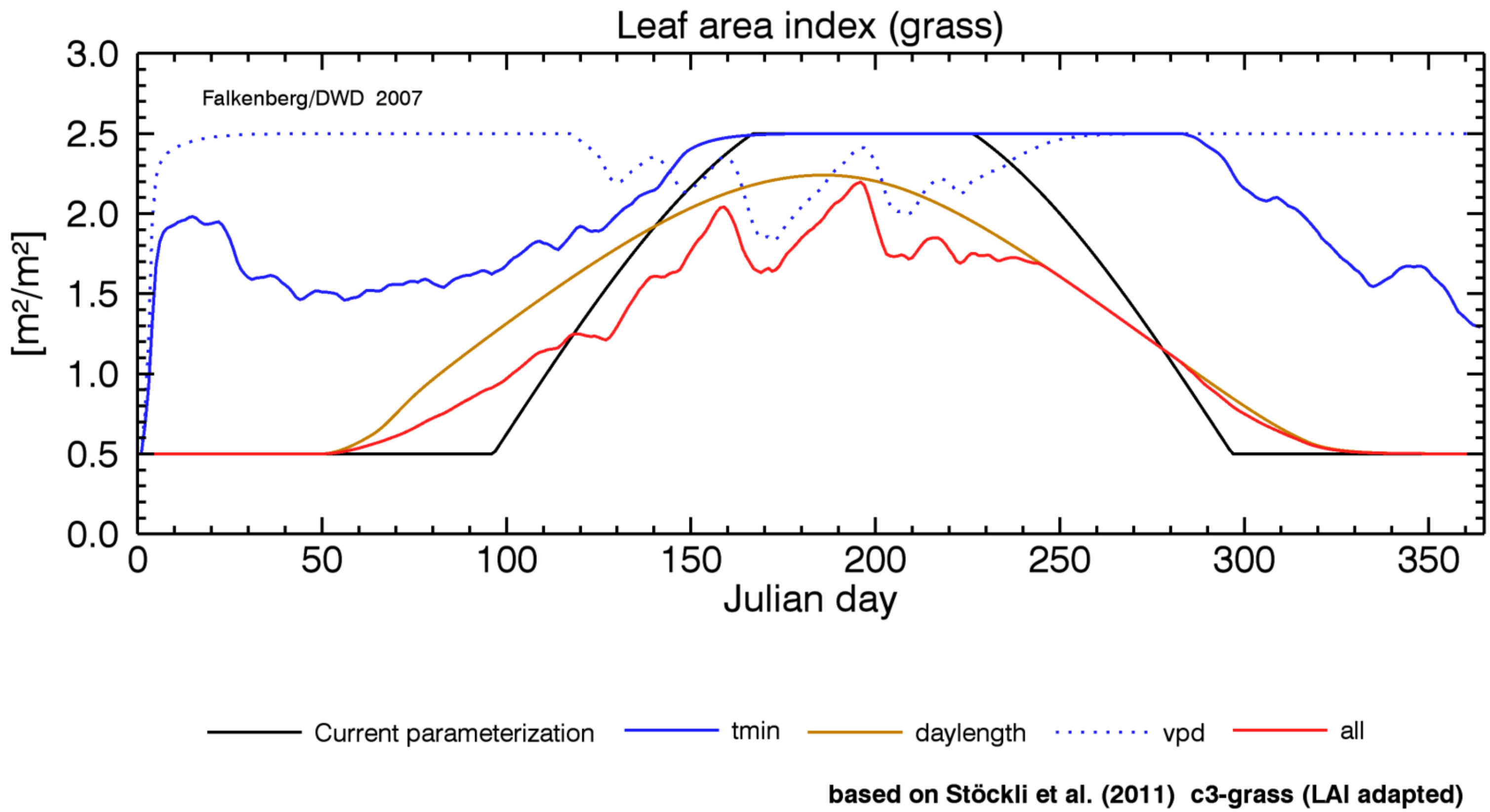
C4 grass

Stress functions: Temperature, day length, vapour pressure deficit



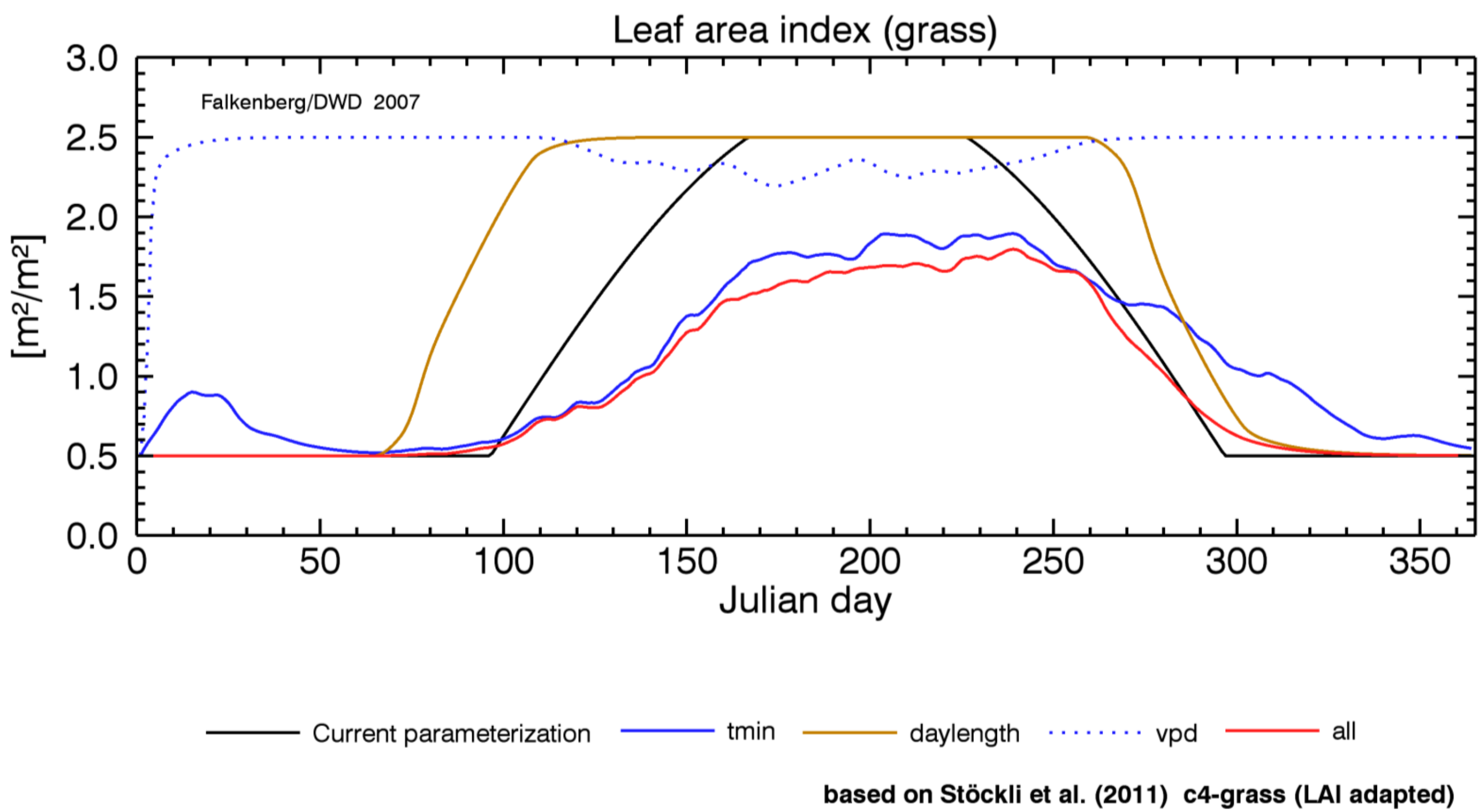
C3 and C4 grass in 2007

Stress functions: Temperature, day length, vapour pressure deficit



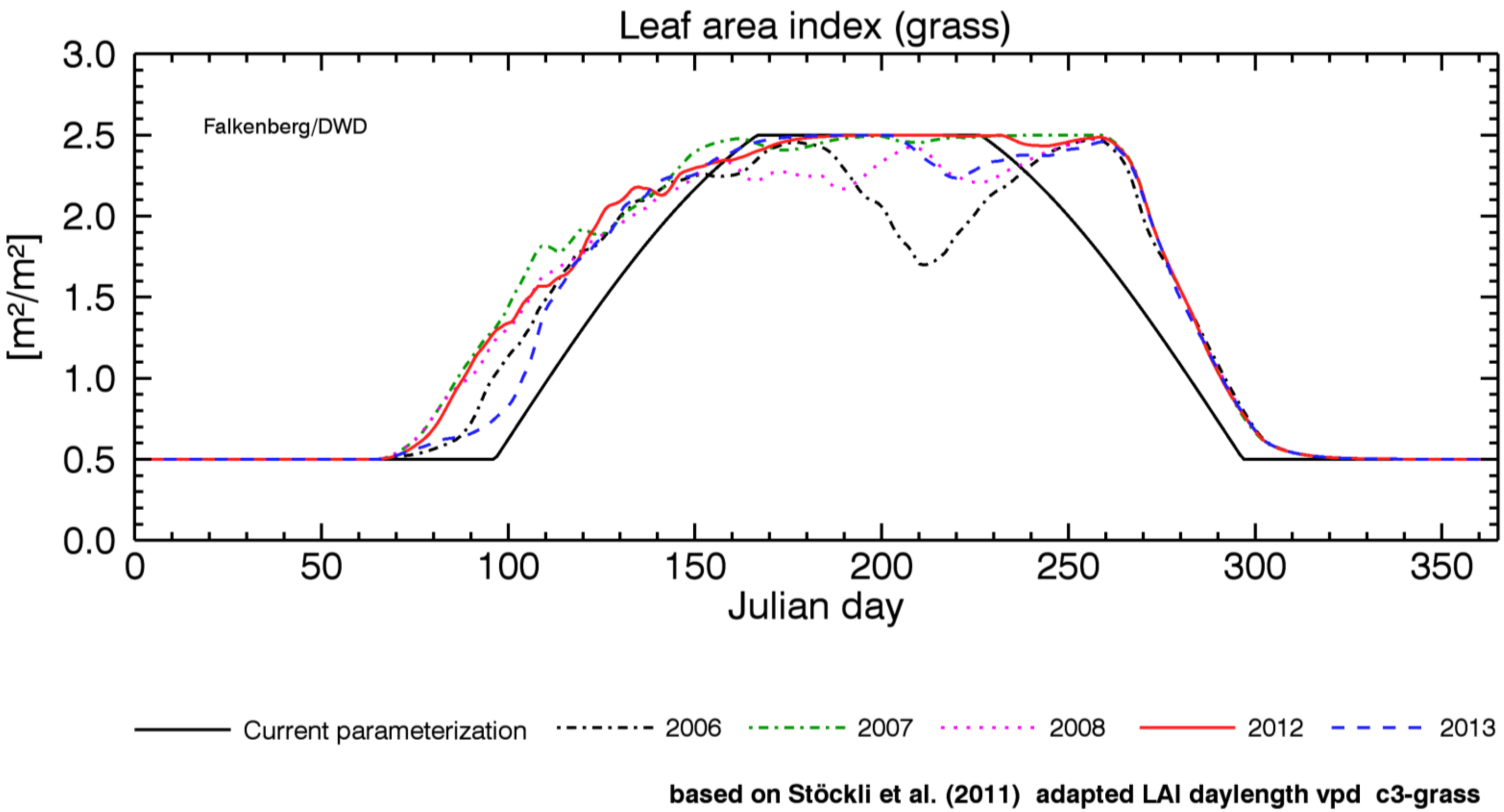
C3 grass in 2007

Stress functions: Individual behaviour and their product



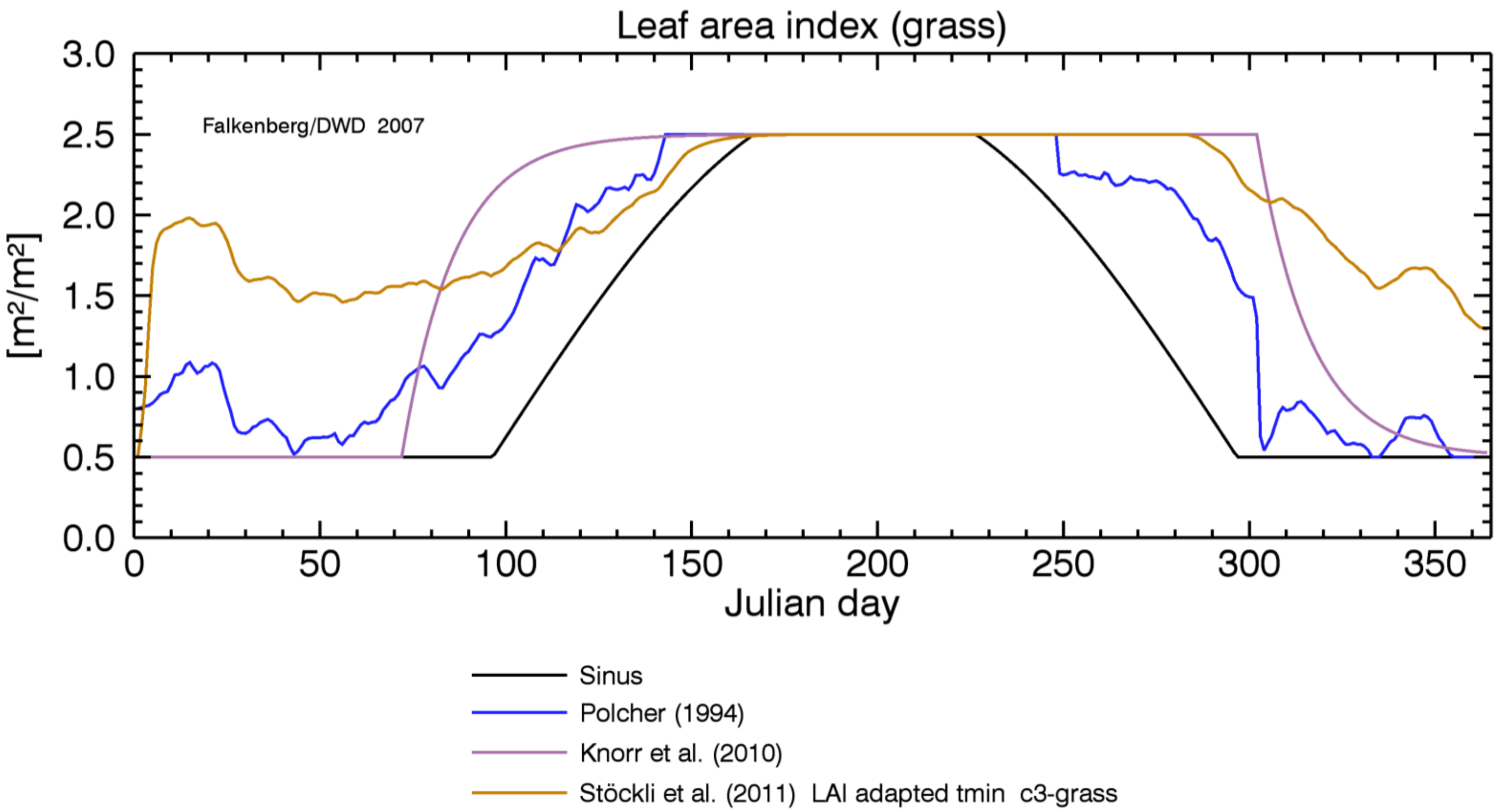
C4 grass in 2007

Stress functions: Individual behaviour and their product



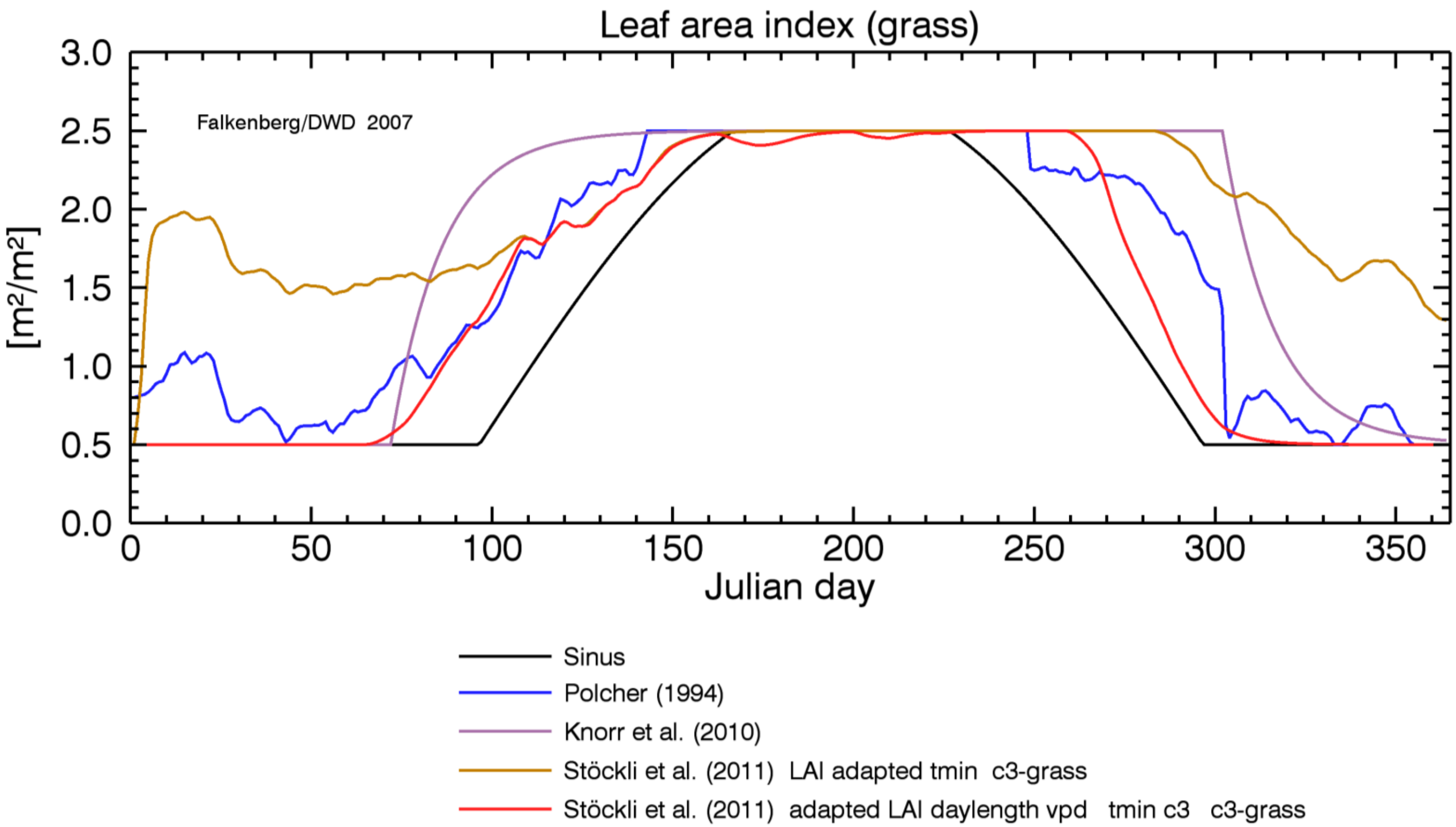
C3 grass tuned for Falkenberg

Stress functions: Temperature C3, day length C4, vapour pressure deficit 7,C4

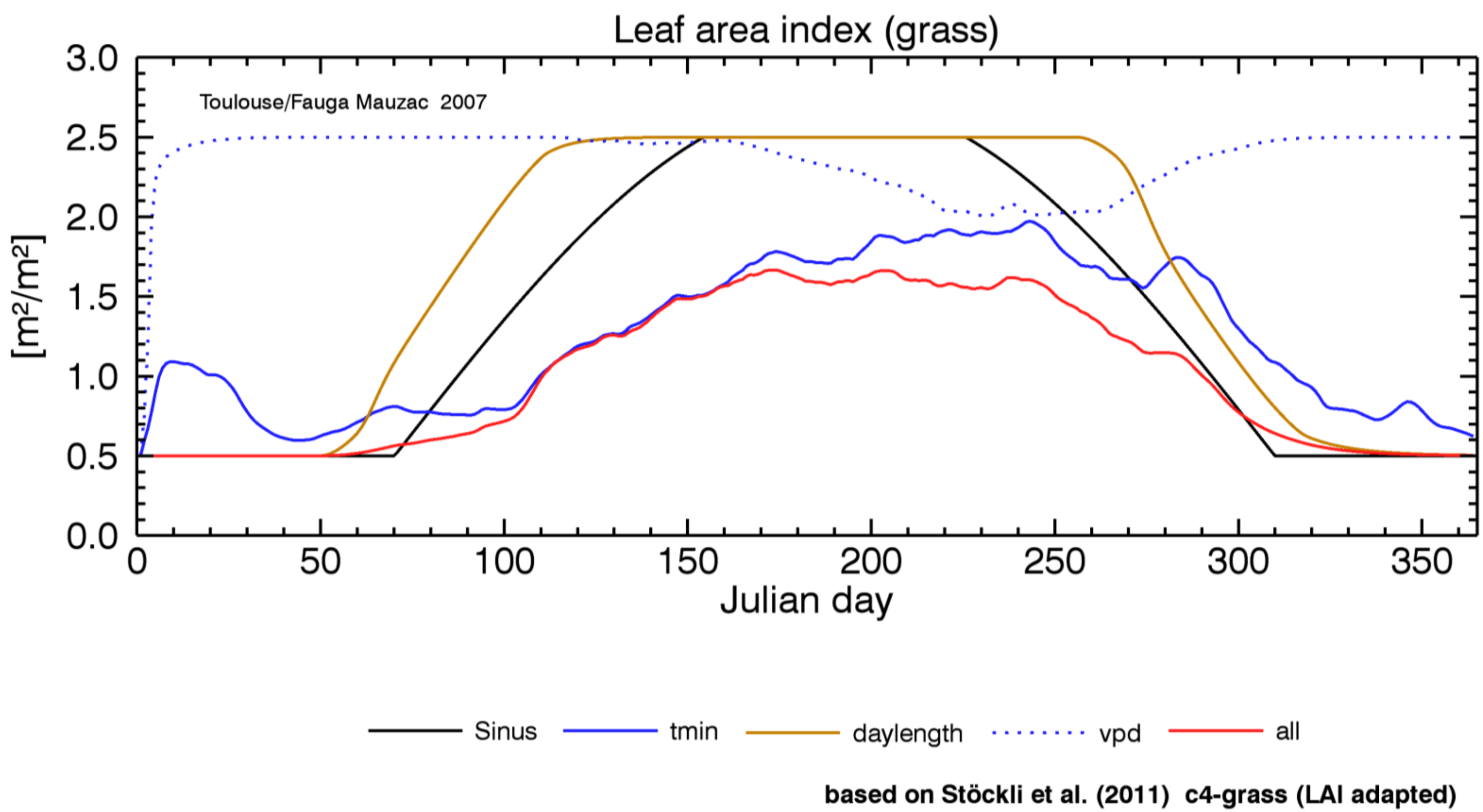


Stöckli: C3 grass in 2007

Stress functions: Temperature only

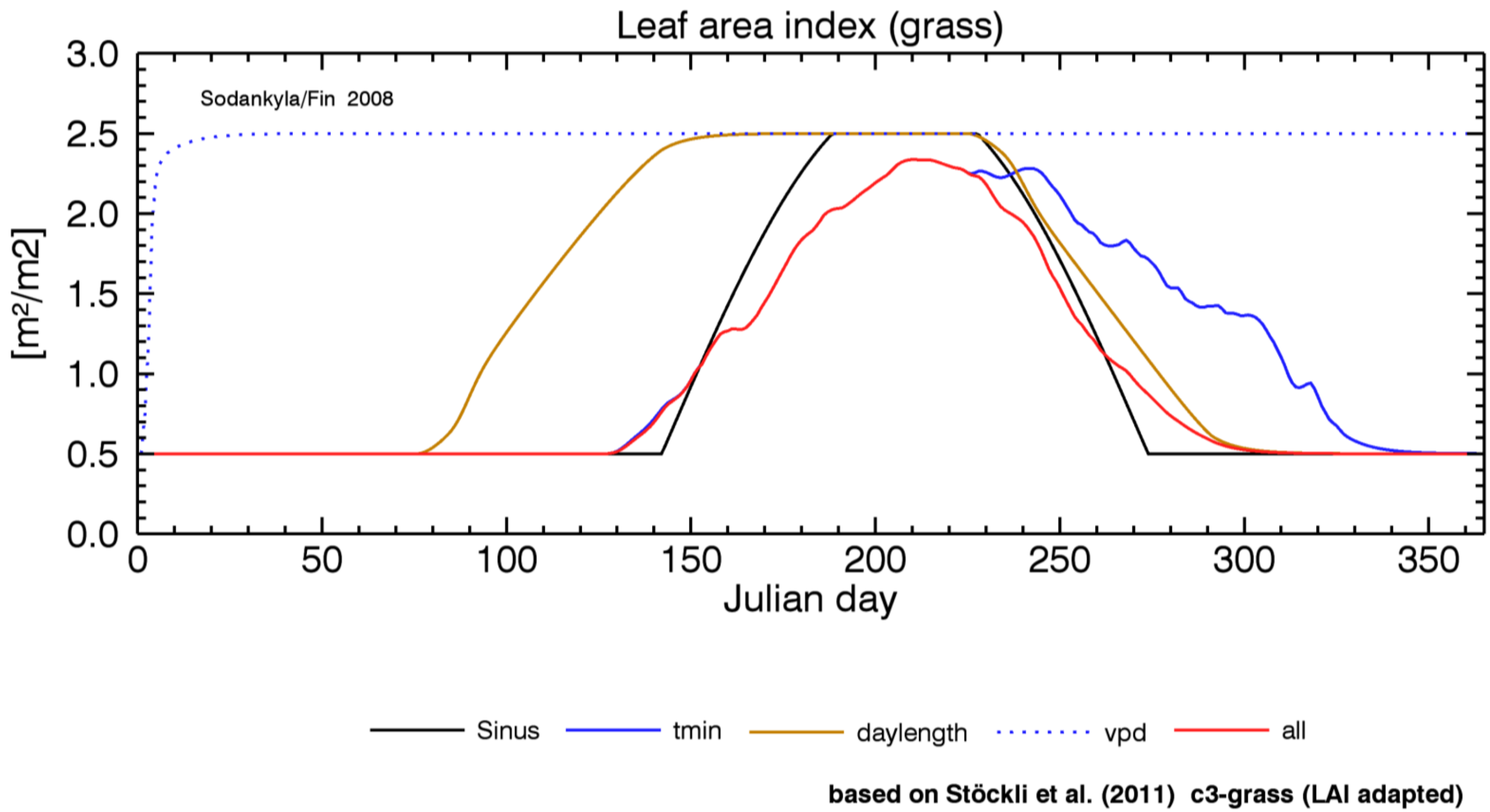


alai_master_PolcherKnorrStoeckli_LGS_LN09LN13LN14OS72LS77.isv
LN09: Sinus LN13: Polcher (1994) LN14: Knorr et al. (2010) OS72: Stöckli et al. (2011) LAI adapted tmin c3-grass
LS77: Stöckli et al. (2011) adapted LAI daylength c4 vpd_min 7 vpd_max c4 c3-grass



C4 grass (original) at Toulouse in 2007

Stress functions: Individual behaviour and their product



C3 grass (original) at Sodankylä in 2007

Stress functions: Individual behaviour and their product

Conclusions

- With the current parameterization TERRA can not account for the inter-annual variability of the phenology.
- Two approaches based on Polcher (1994) and Knorr et al. (2010) for simulating the seasonal cycle of phenology as function of temperature were implemented.
- The first one improves the simulations, the second one even gets very close to the observations of latent heat flux.
- The approach by Knorr et al. (2010) appears to be favourable due to the use of the concept of growth and shedding rates.
- The next steps are the extension of the scheme to more vegetation types, e.g. trees (deciduous and evergreen), and the implementation into the three-dimensional coupled model code.

Conclusions

- With the current parameterization TERRA can not account for the inter-annual variability of the phenology.
- Two approaches based on Polcher (1994) and Knorr et al. (2010) for simulating the seasonal cycle of phenology as function of temperature were implemented.
- In addition, the approach by Stöckli et al. (2008, 2011) was implemented, which includes stress functions of temperature, but also of day length and water availability. It combines the concepts of threshold values (Polcher 1994) and of growth and decay rates (Knorr et al. 2010).
- The scheme was tested at three different sites. With some tuning involved the site specific behaviour can be well described.
- The next steps are the inclusion of the full 35 plant functional types, and the implementation into the three-dimensional coupled model code.