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

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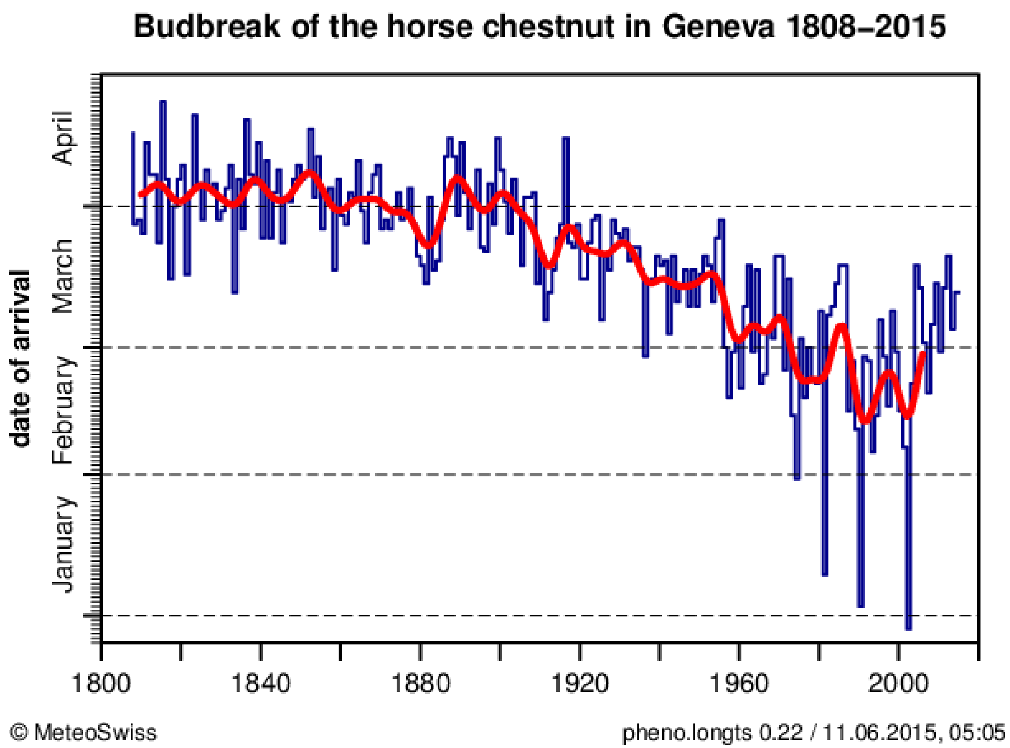
What is phenology?

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

Phenology determining temperature

$$T(t) = \frac{\int_{-\infty}^{0} T_S(t+\tau')\, e^{\tau'/\tau}\, d\tau'}{\int_{-\infty}^{0} e^{\tau'/\tau}\, d\tau'}$$

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

$\mathrm{LAI}_{\min}$, $\mathrm{LAI}_{\max}$: minimum and maximum value of LAI

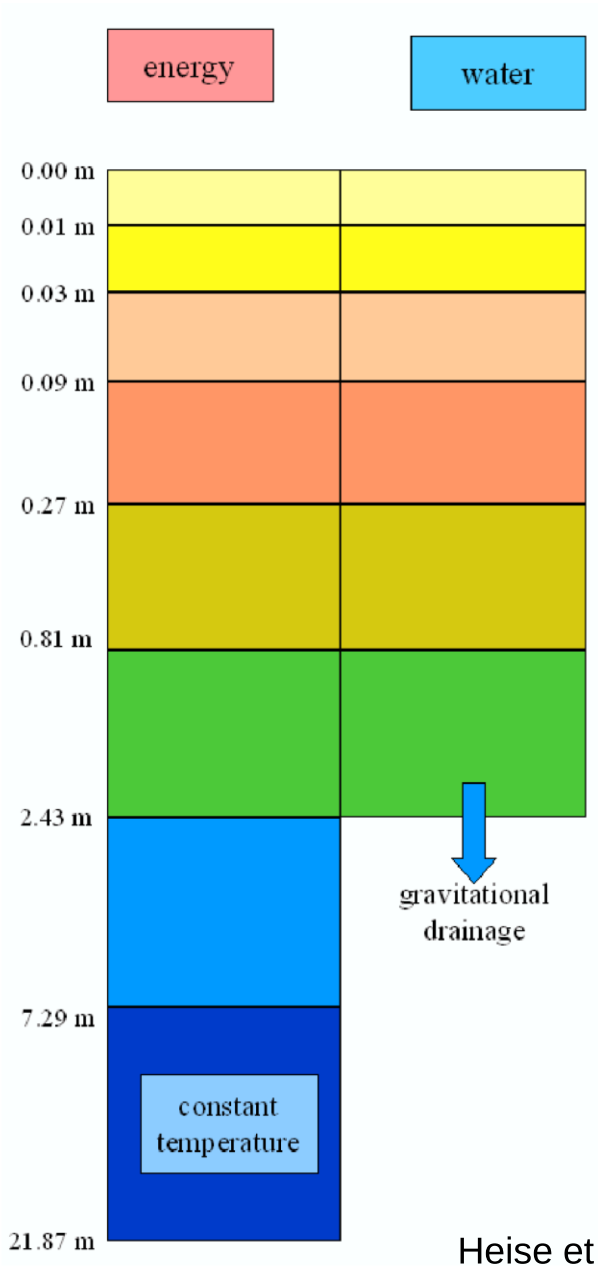
LAI max

Plant type/Land use type	LAI_Wikipedia	LAImax-GLC2009
farmland (winter)	0,2	
intensively used grassland (summer)	7	
"usual" grassland	1-2	2,5
coniferous forest	5	5
Douglas fir	10-13	
spruce	5-10	
Scots pin	3-4	
European larch tree	2-4	5
deciduous broadleaved forest		6
beech (winter)	0,2	
beech (summer)	6-8	

C3-grass
Lolium perenne

- Species represents c3-grass (vigorous, rapid-growing, easily regenerable, responds well to the water balance)
- Flowering time from may until autumn, canopy height up to 70cm
- Dark green, shiny leaves up to 4mm broad and up to 20cm long
- Grass kind often used for robust lawn retaining its colour for a longer time.

Source: Wikipedia



Heise et al. (2006)

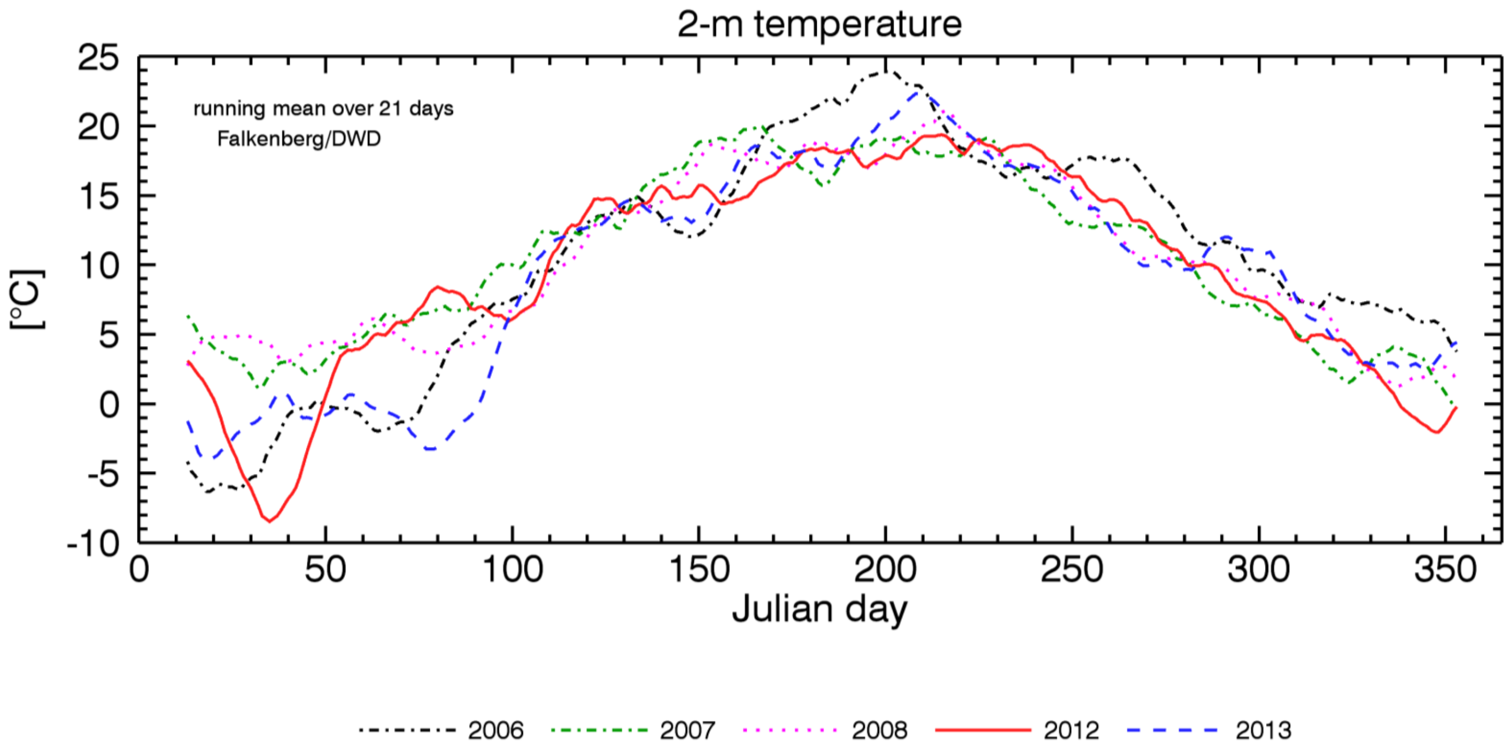
Land surface scheme TERRA

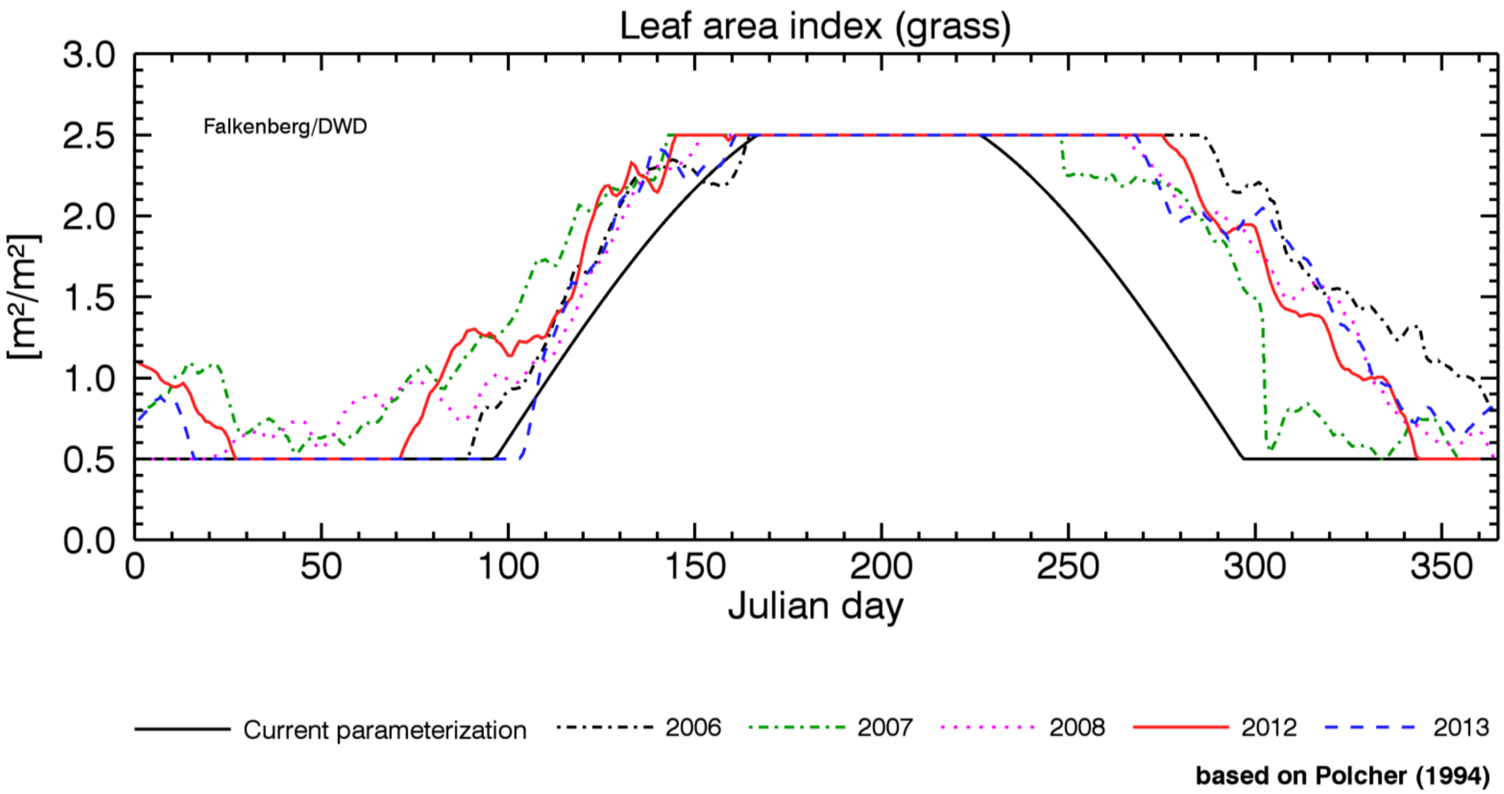
Layers for temperature and soil water content

Experiments:

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

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

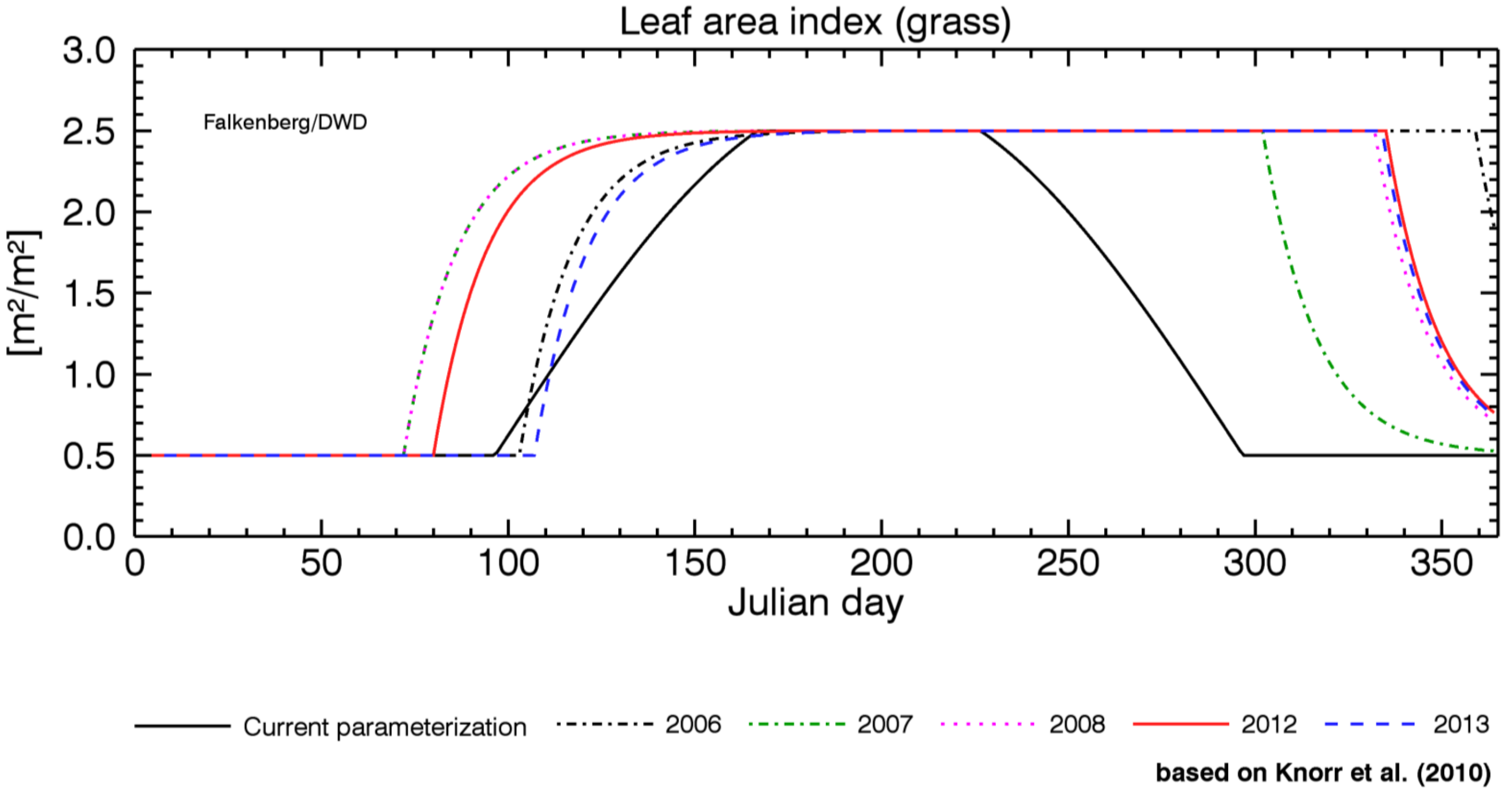
based on Knorr et al. (2010)

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

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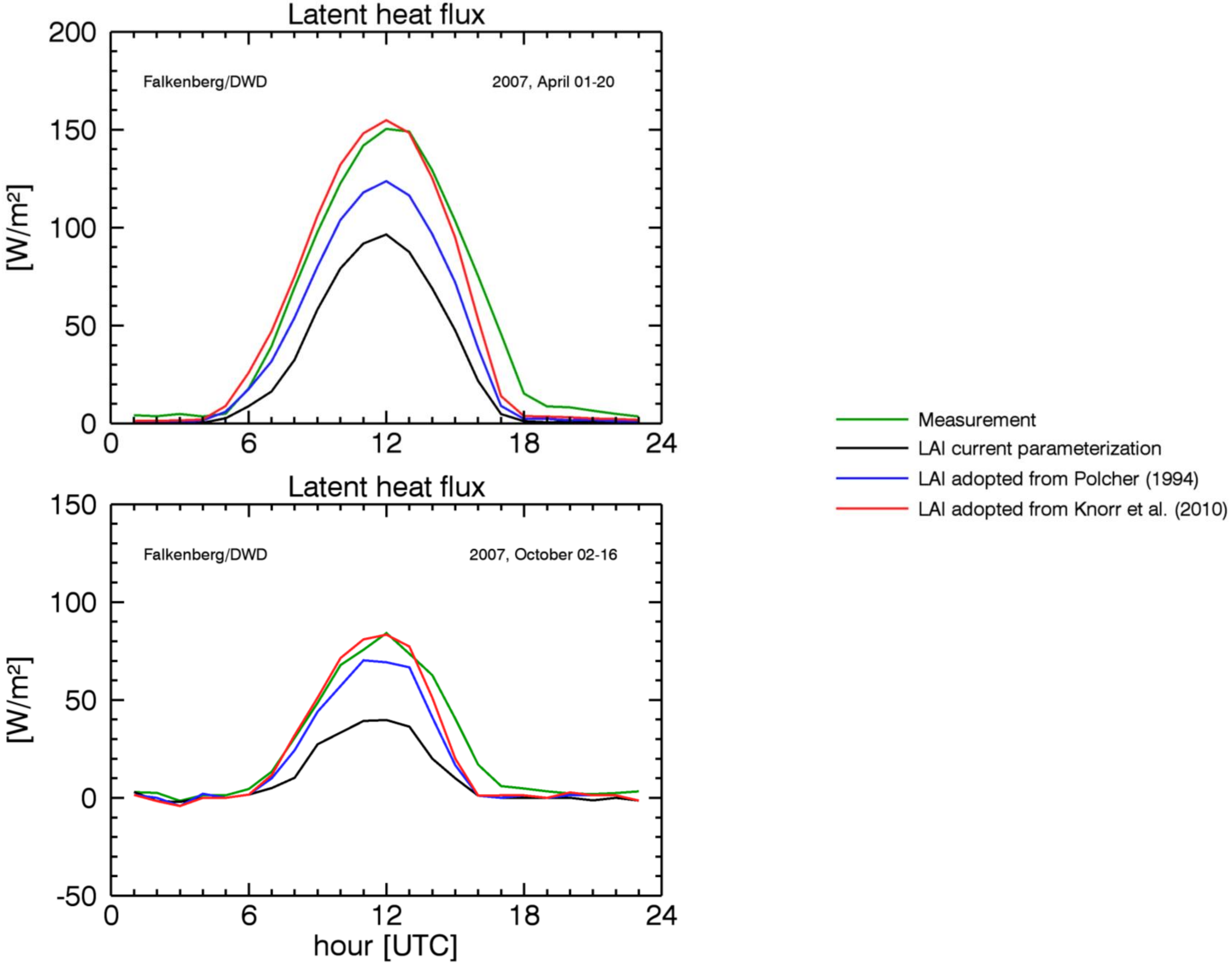
Latent heat flux
200
150
100
50
0
[W/m²]
Falkenberg/DWD
2007, April 01-20
0
6
12
18
24
Latent heat flux
150
100
50
0
-50
[W/m²]
Falkenberg/DWD
2007, October 02-16
0
6
12
18
24
hour [UTC]
Measurement
LAI current parameterization
LAI adopted from Polcher (1994)
LAI adopted from Knorr et al. (2010)

Phenological Data Assimilation

A gap-free Leaf-Area Index Climate Data Record

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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:

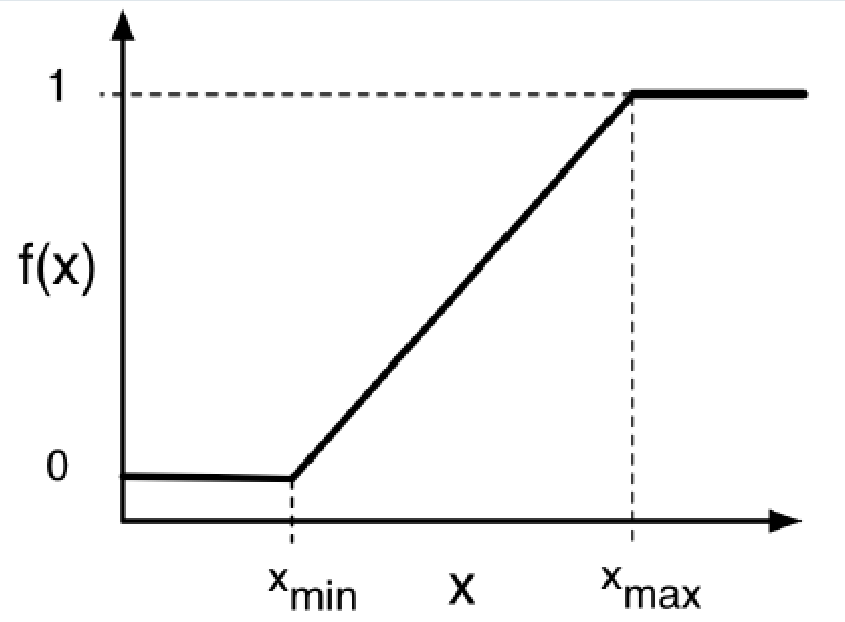
- Temperature T (air temperature)
- Radiation R (daylength or global radiation)
- Water W (vapor pressure deficit)

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

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

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

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



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

From diagnostic to prognostic phenology

Steady-state GSI:

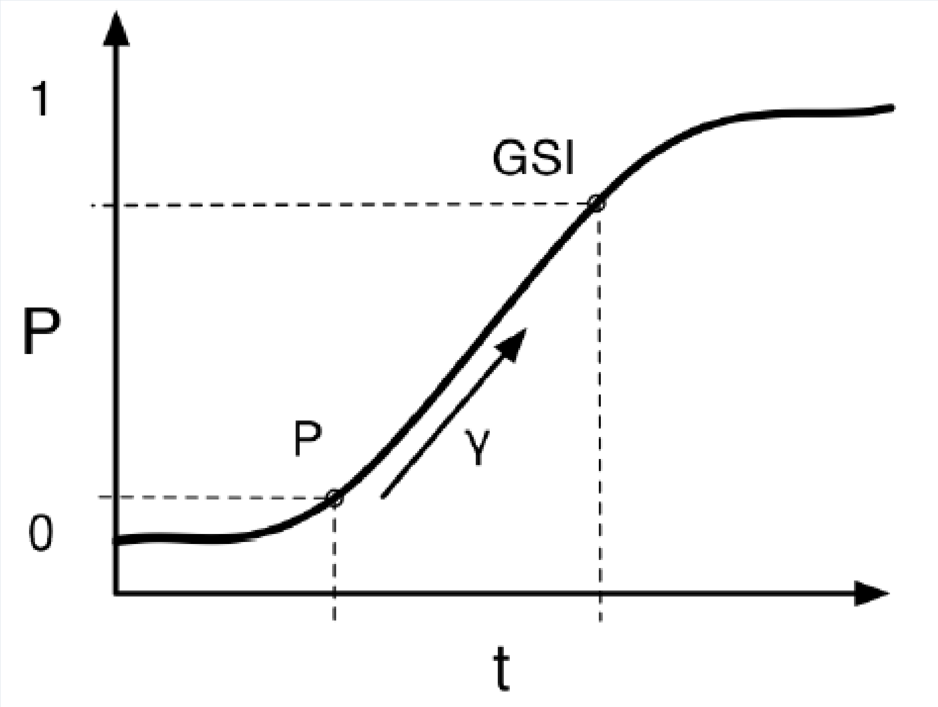
$$\mathrm{GSI} = f(T) \cdot f(R) \cdot f(M)$$

Prognostic state P:

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

Deviation of P from "potential" GSI:

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



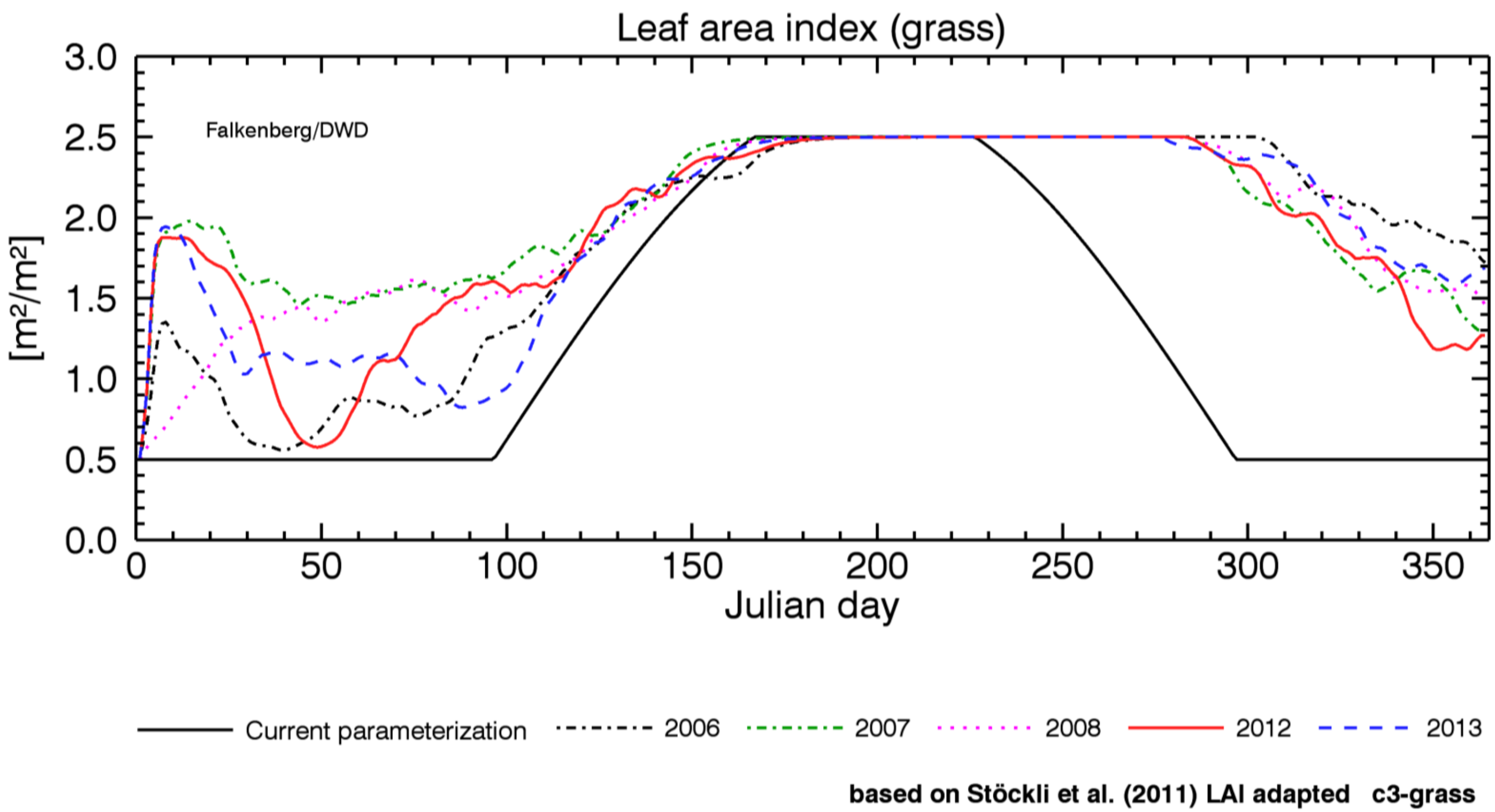
Modify LAI at each time step towards diagnostic GSI by logistic growth and defined growth rate:

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

Stockli et al. (2008,2011)

Stöckli, stress T only, 2006 – 2013

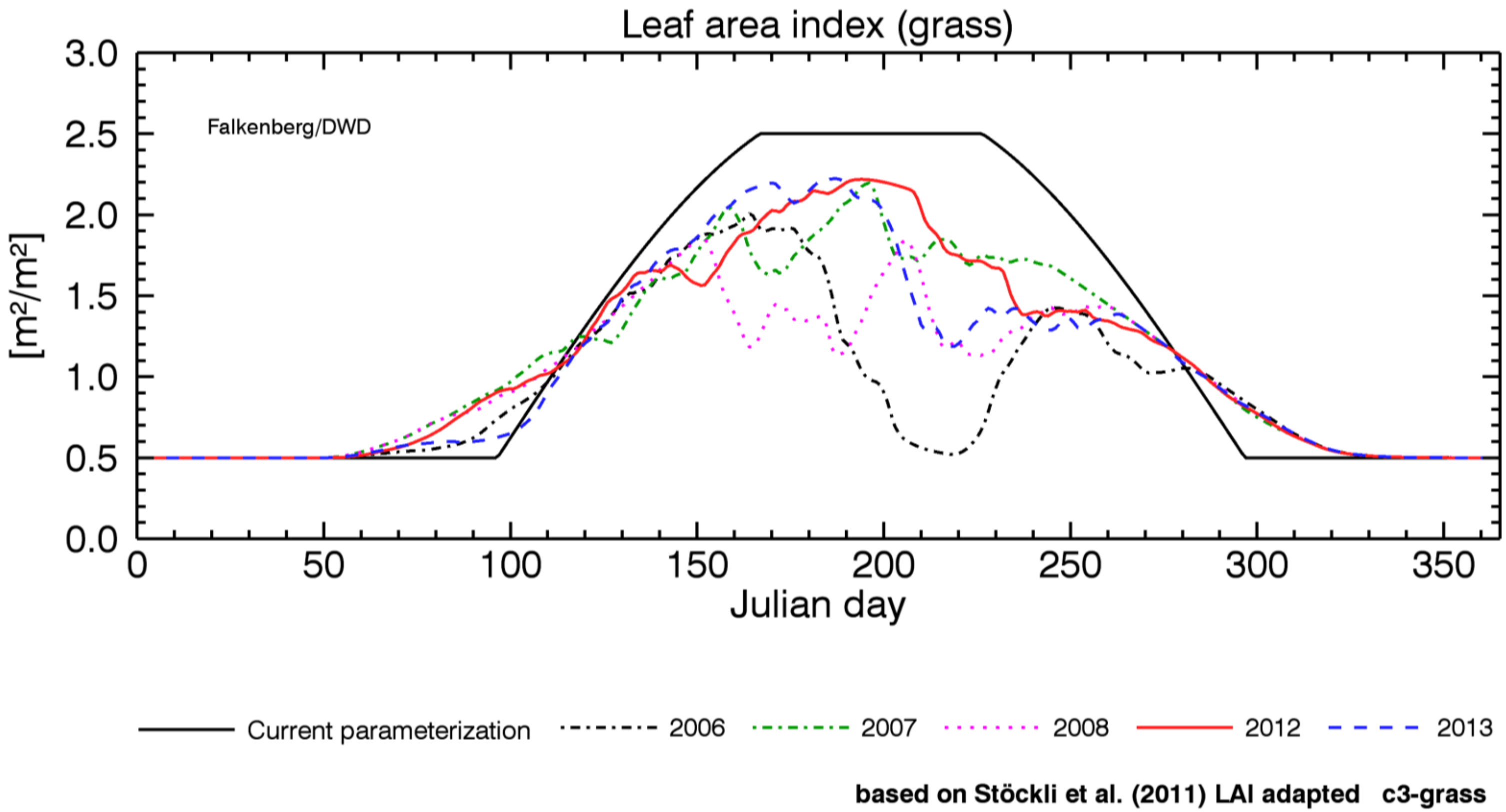
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



C3 grass

Stress functions: Temperature only

Stöckli, all stress factors, 2006 – 2013



C3 grass

Stress functions: Temperature, day length, vapour pressure deficit

Plant type sensitivity, 2007

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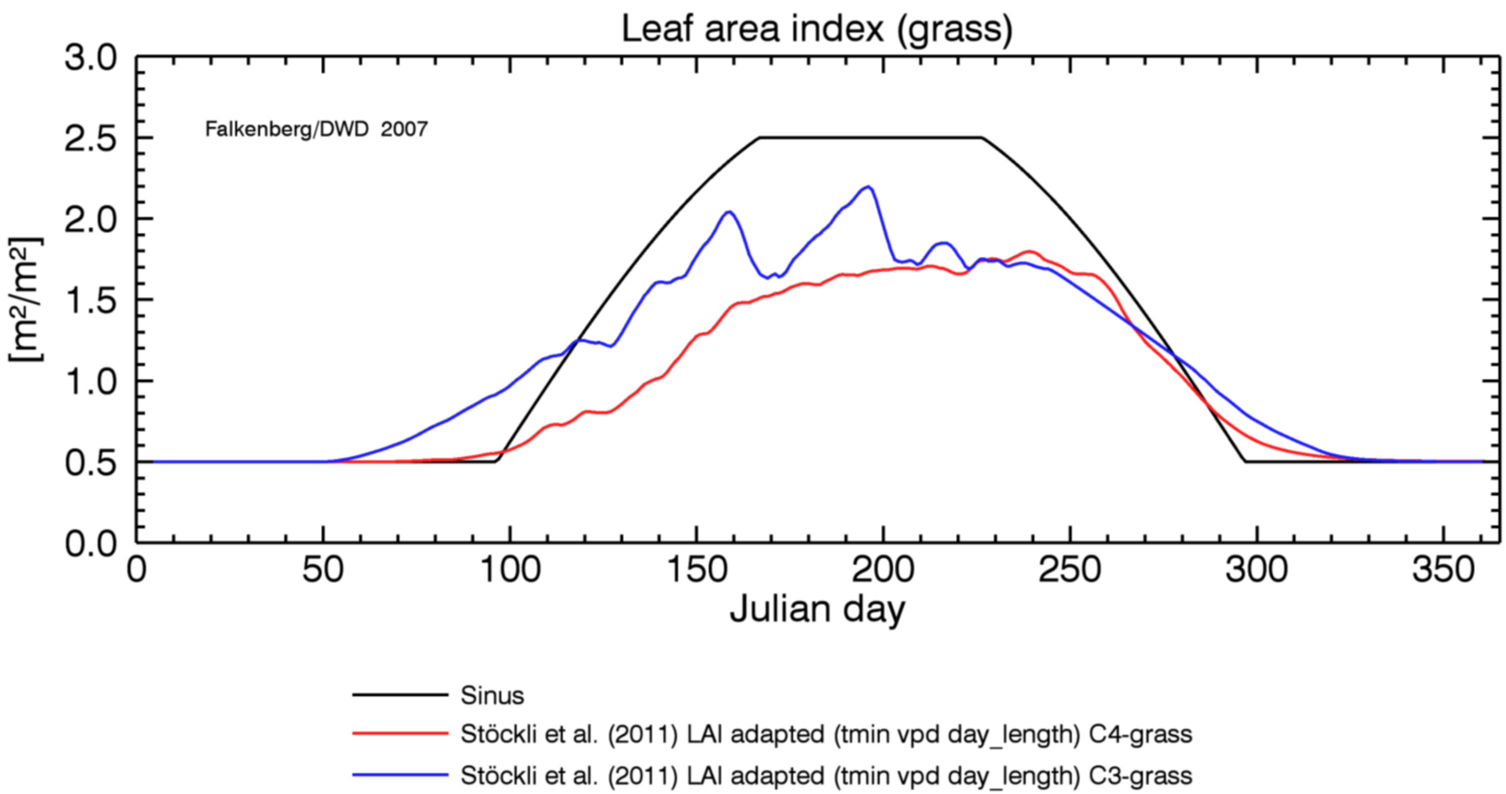

C3 and C4 grass in 2007

Stress functions: Temperature, day length, vapour pressure deficit

Stress factors comparison, 2007

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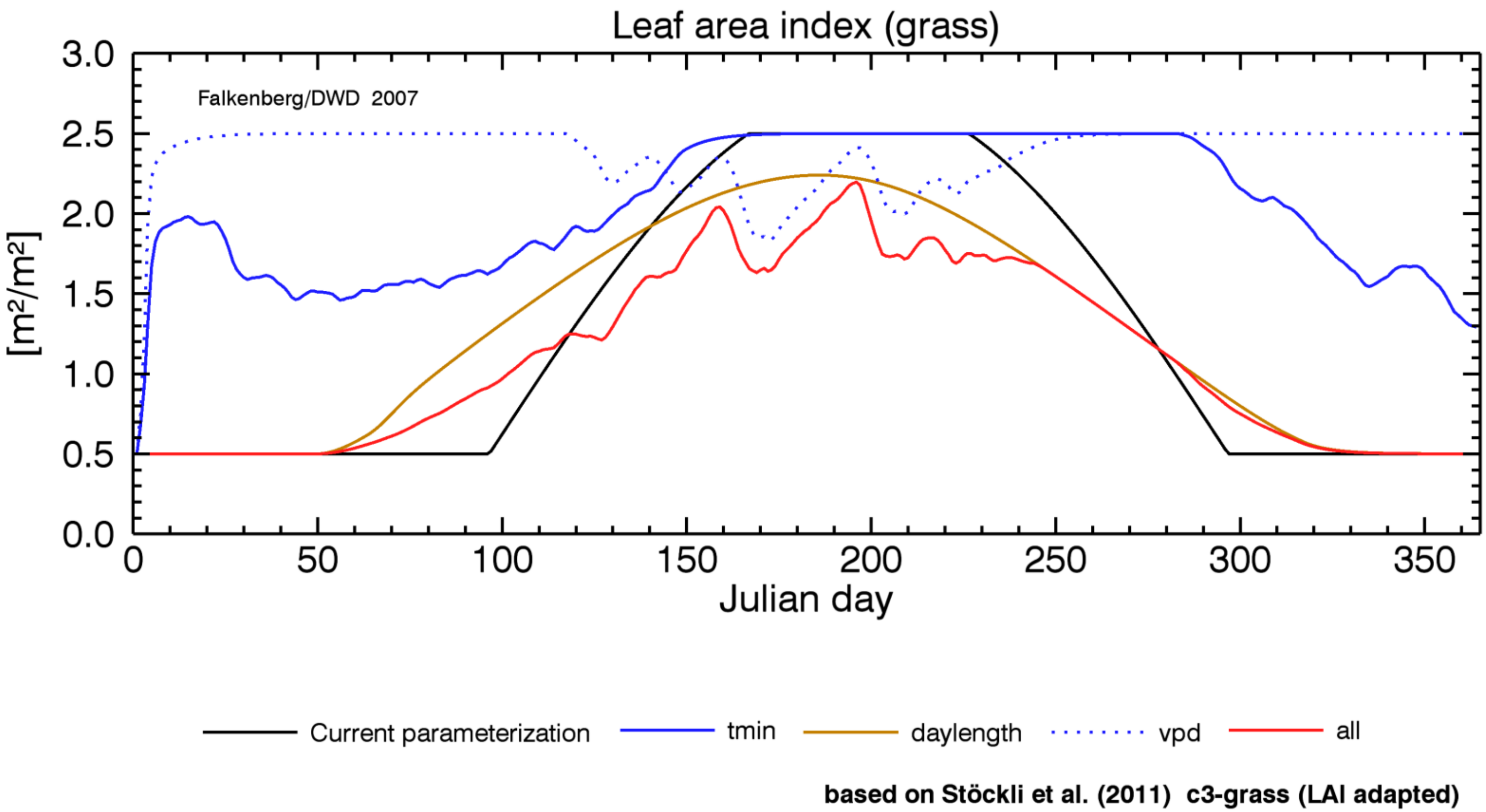
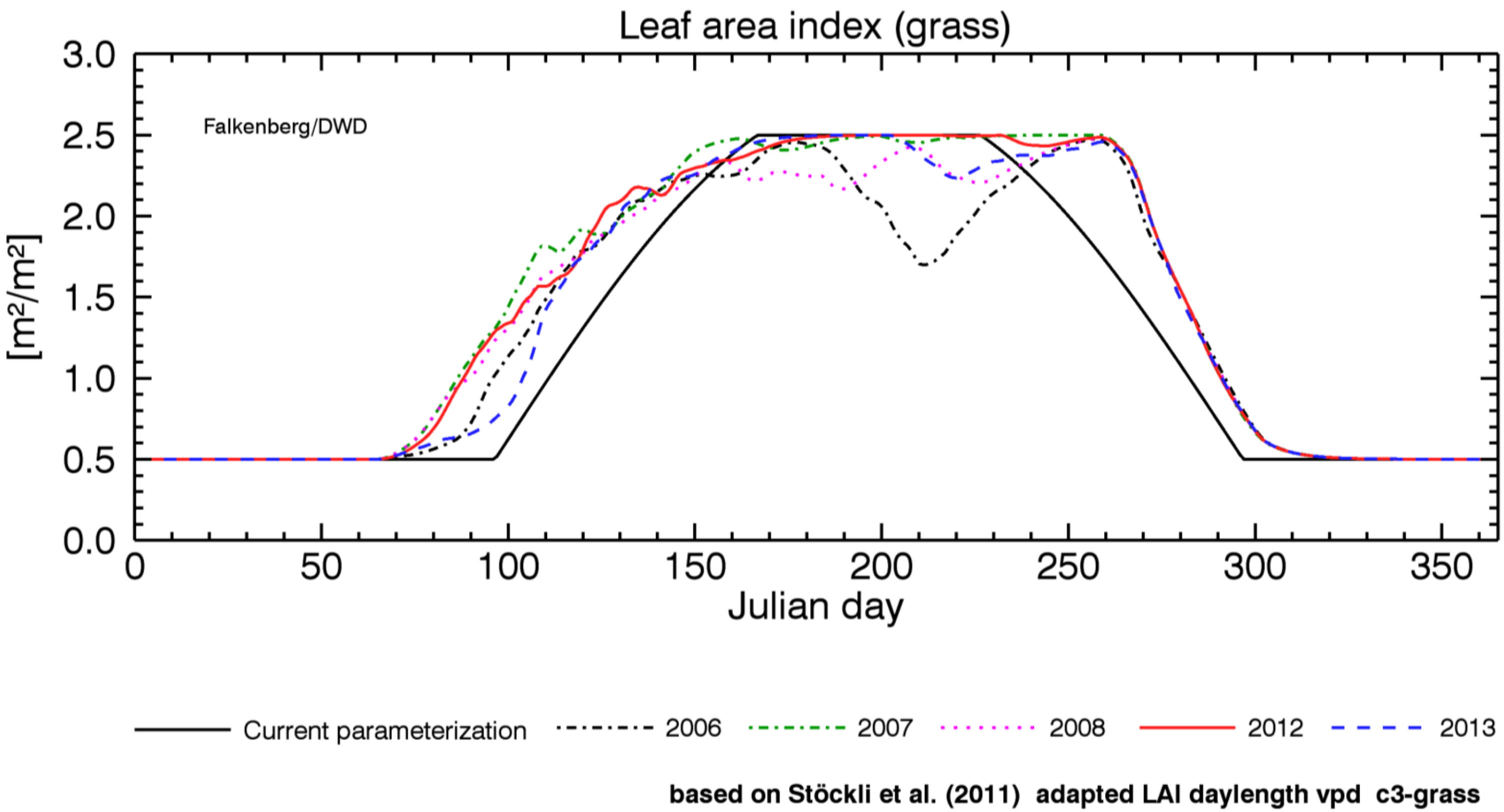


C3 grass in 2007

Stress functions: Individual behaviour and their product

Stöckli, tuned, all stress factors, 2006 – 2013

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



C3 grass tuned for Falkenberg

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

Different parameterizations, 2007

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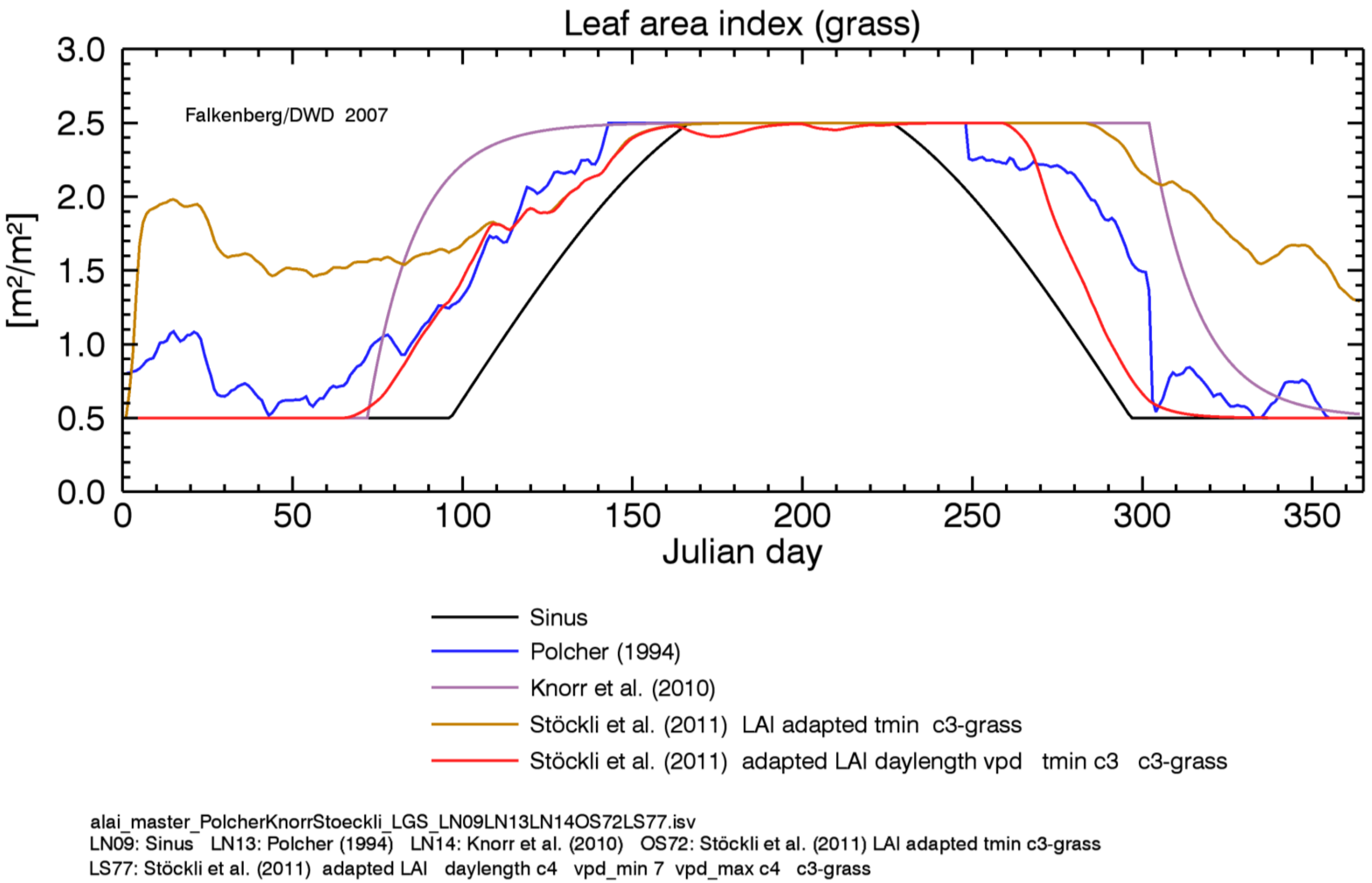
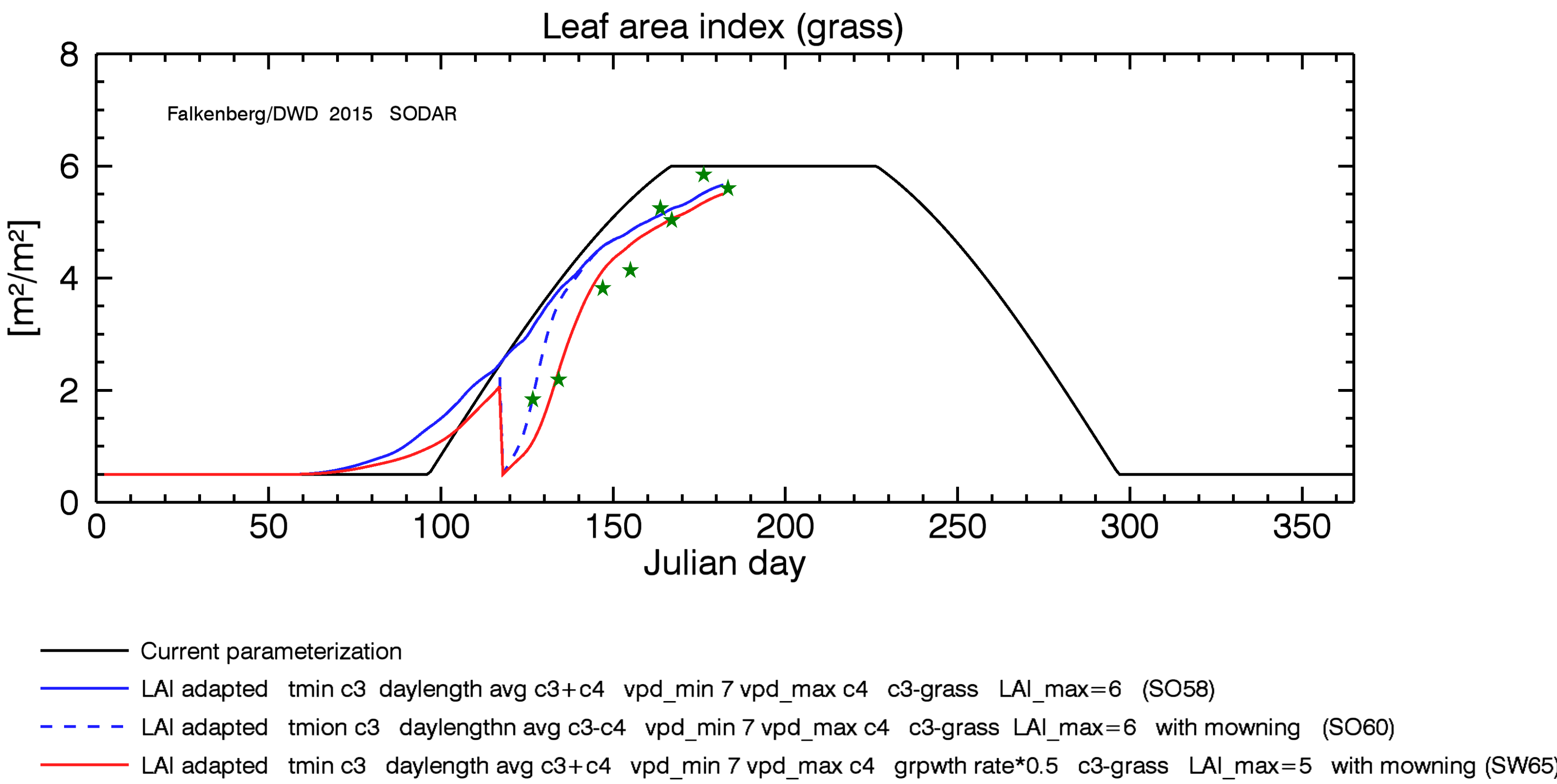
Wetter und Klima aus einer Hand



LAI observations, first half 2015

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



based on Stöckli et al. (2011)

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.
- Parameter tuning against in-situ measurements will only possible if a sufficiently large data base is available.
- The next steps are the inclusion of the full 35 plant functional types, and the implementation into the three-dimensional coupled model code.