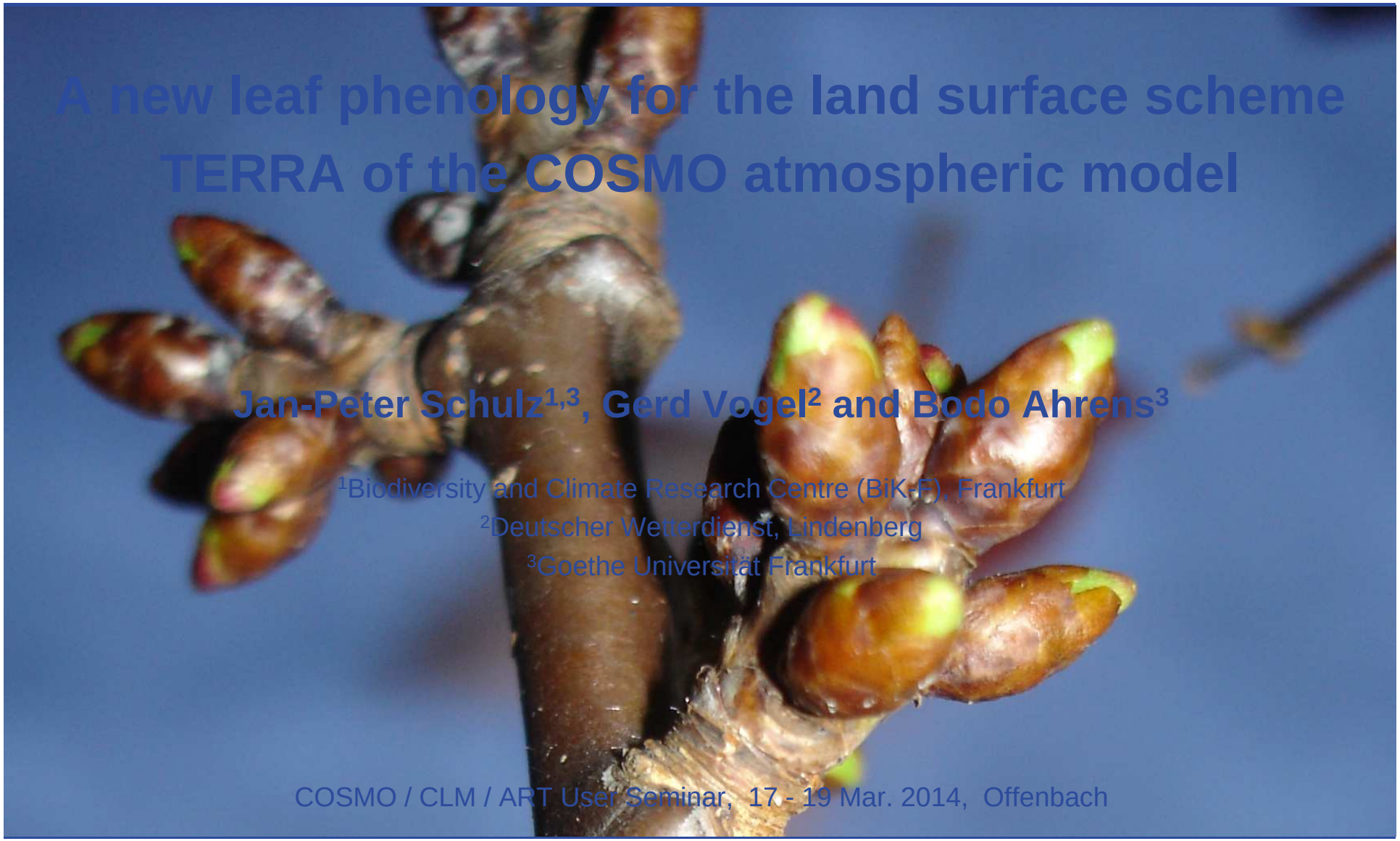

A new leaf phenology for the land surface scheme TERRA of the COSMO atmospheric model

Jan-Peter Schulz[1,3], Gerd Vogel[2] and Bodo Ahrens[3]

[1]Biodiversity and Climate Research Centre (BiK-F), Frankfurt
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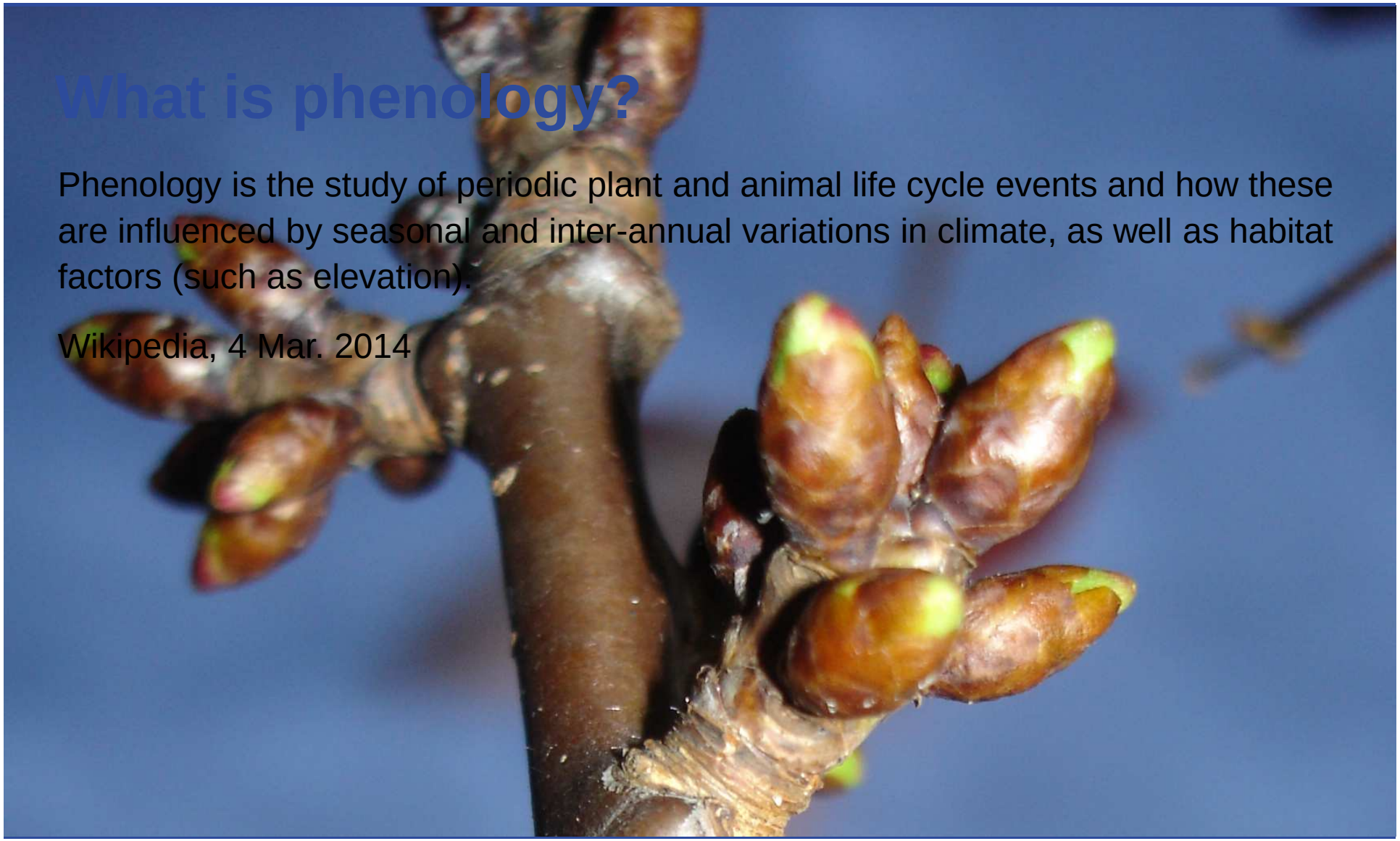
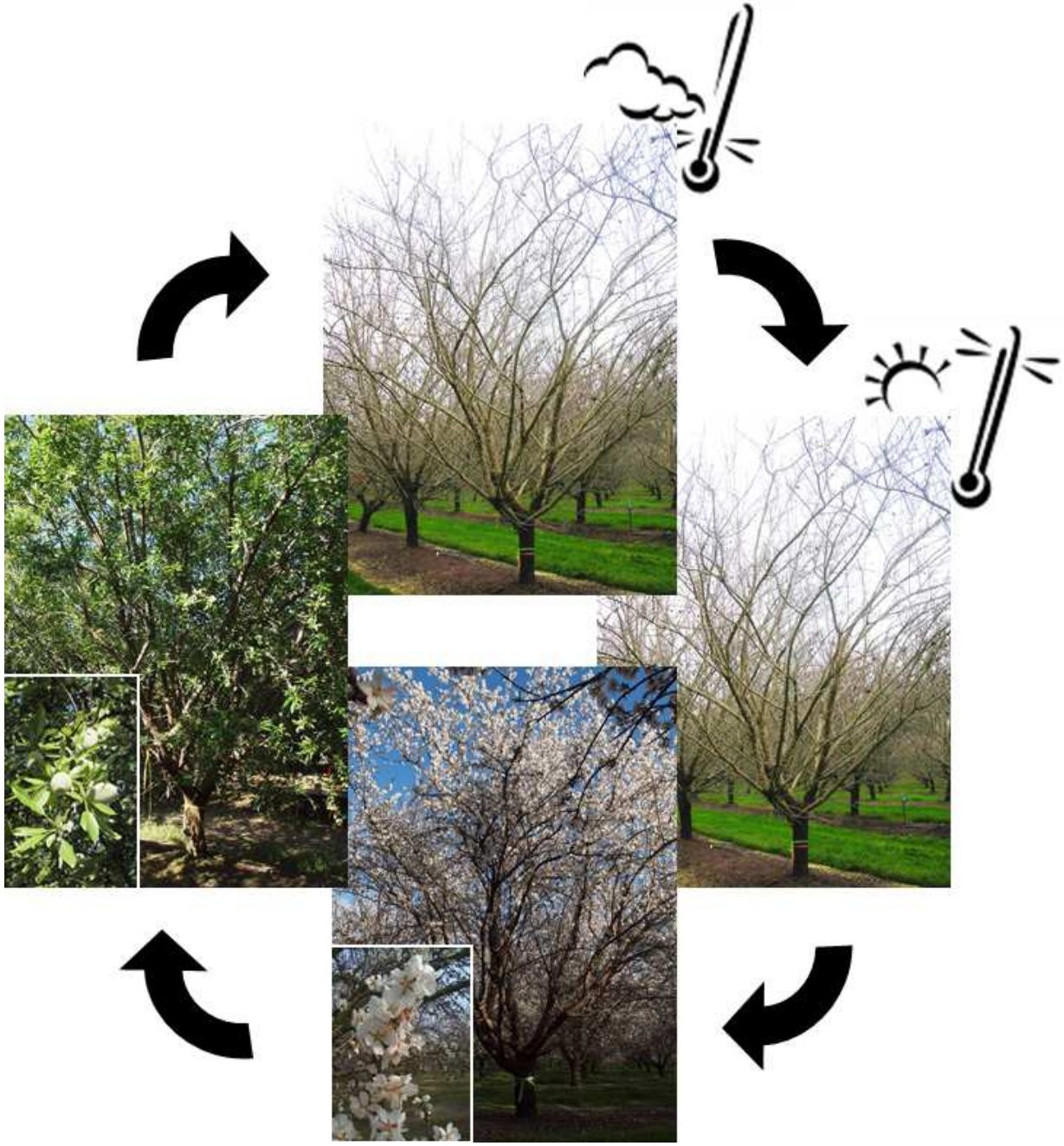
COSMO / CLM / ART User Seminar, 17 - 19 Mar. 2014, Offenbach

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





Phenological stages in the production of almonds include

- winter chilling
- spring heat forcing flowering and leaf-out
- pollination of flowers
- development and growth of fruits during spring and summer

http://treephenology.ucdavis.edu/

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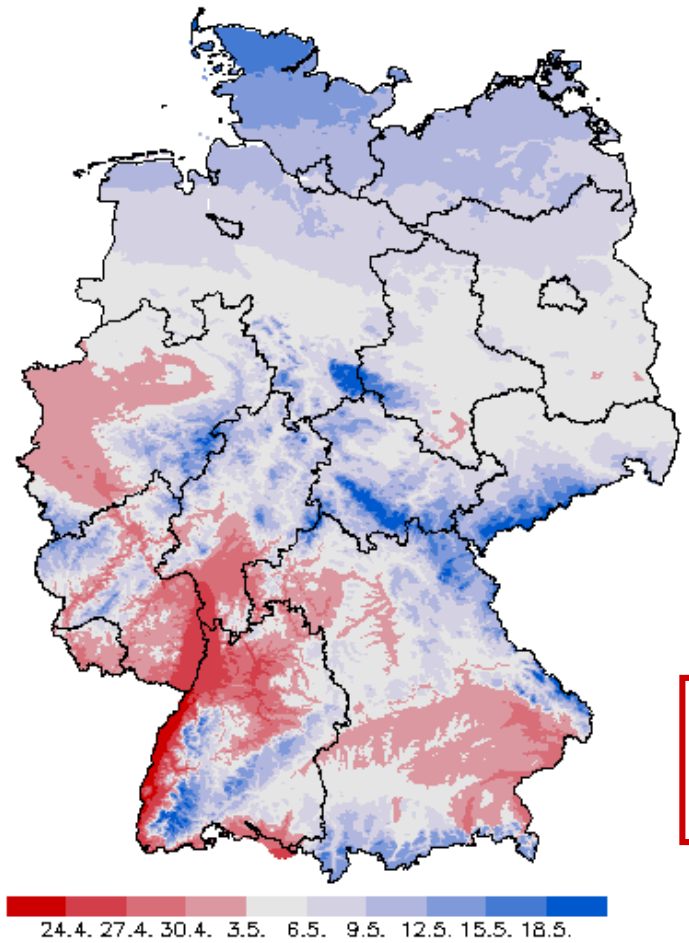
Wikipedia, 4 Mar. 2014

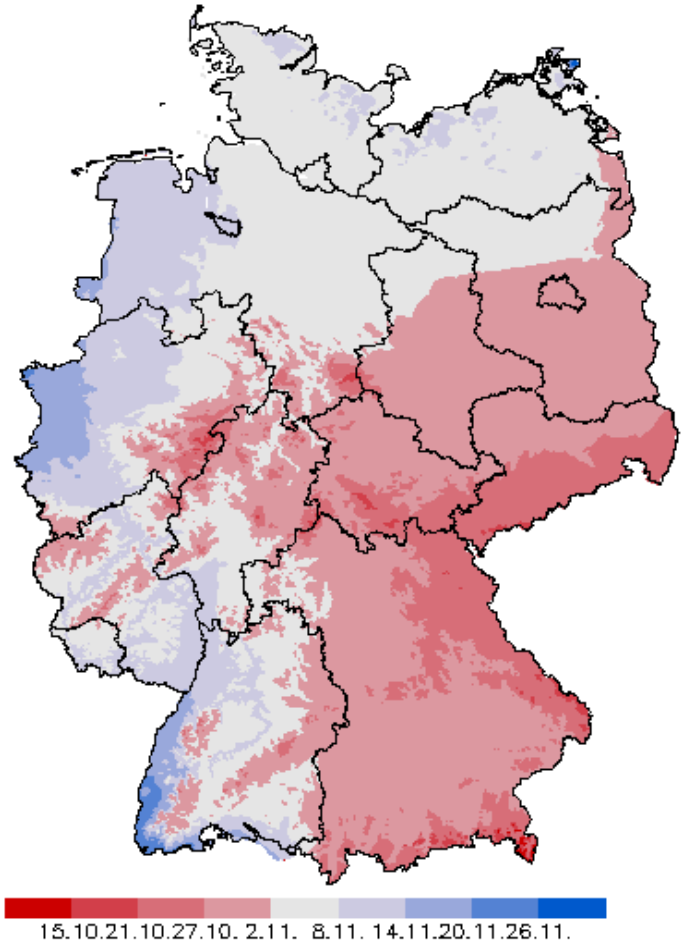
Phenology depends on:

- Region

Begin of flowering 2013



Fall of leaves 2013



Apple tree

Deutscher Wetterdienst (erstellt 09.01.2014 09:31 UTC)
Kontakt: Landwirtschaft@dwd.de
Geobasisdaten © Bundesamt für Kartographie und Geodäsie (www.bkg.bund.de)

The flowering of the apple trees starts in the southwest of Germany and progresses towards the northeast. The fall of leaves evolves roughly in opposite direction.

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

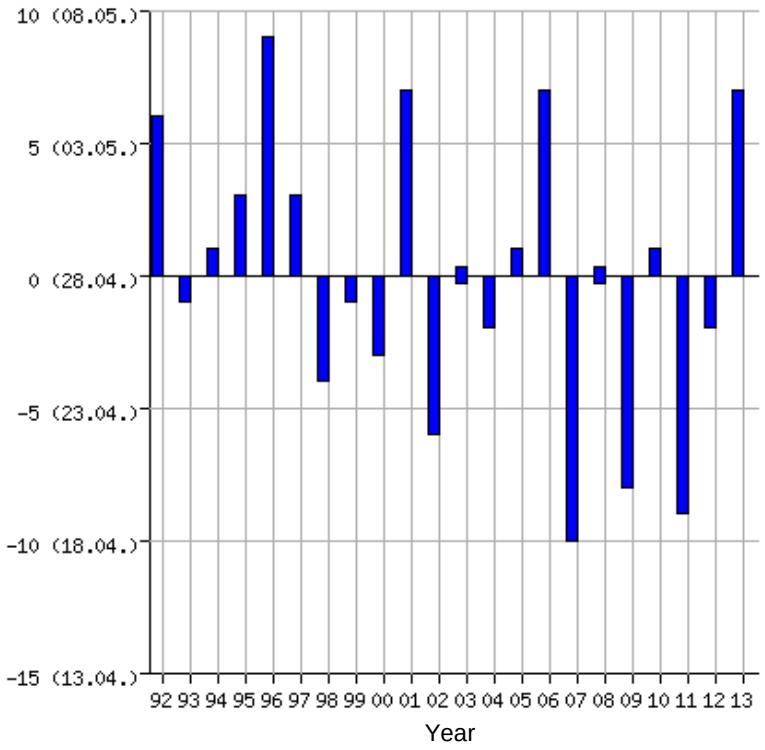
Phenology depends on:

- Region
- Year

Begin of flowering

Fall of leaves

Deviation from multi-annual mean (in days)



Deutscher Wetterdienst (erstellt 09.01.2014 09:31 UTC)
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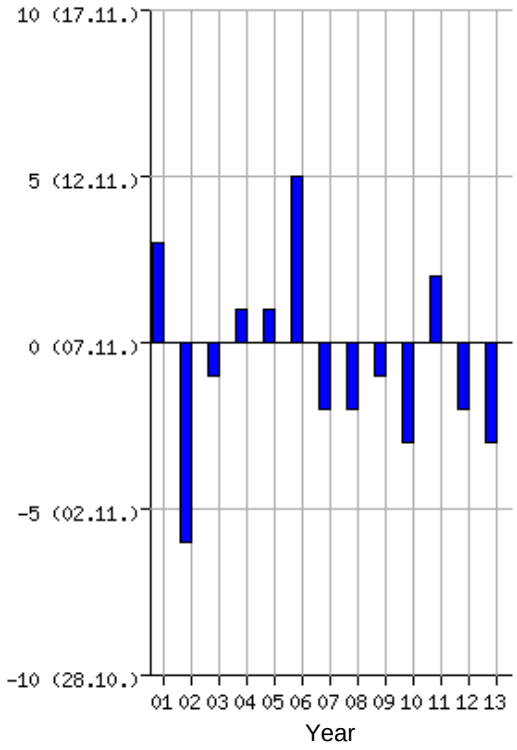
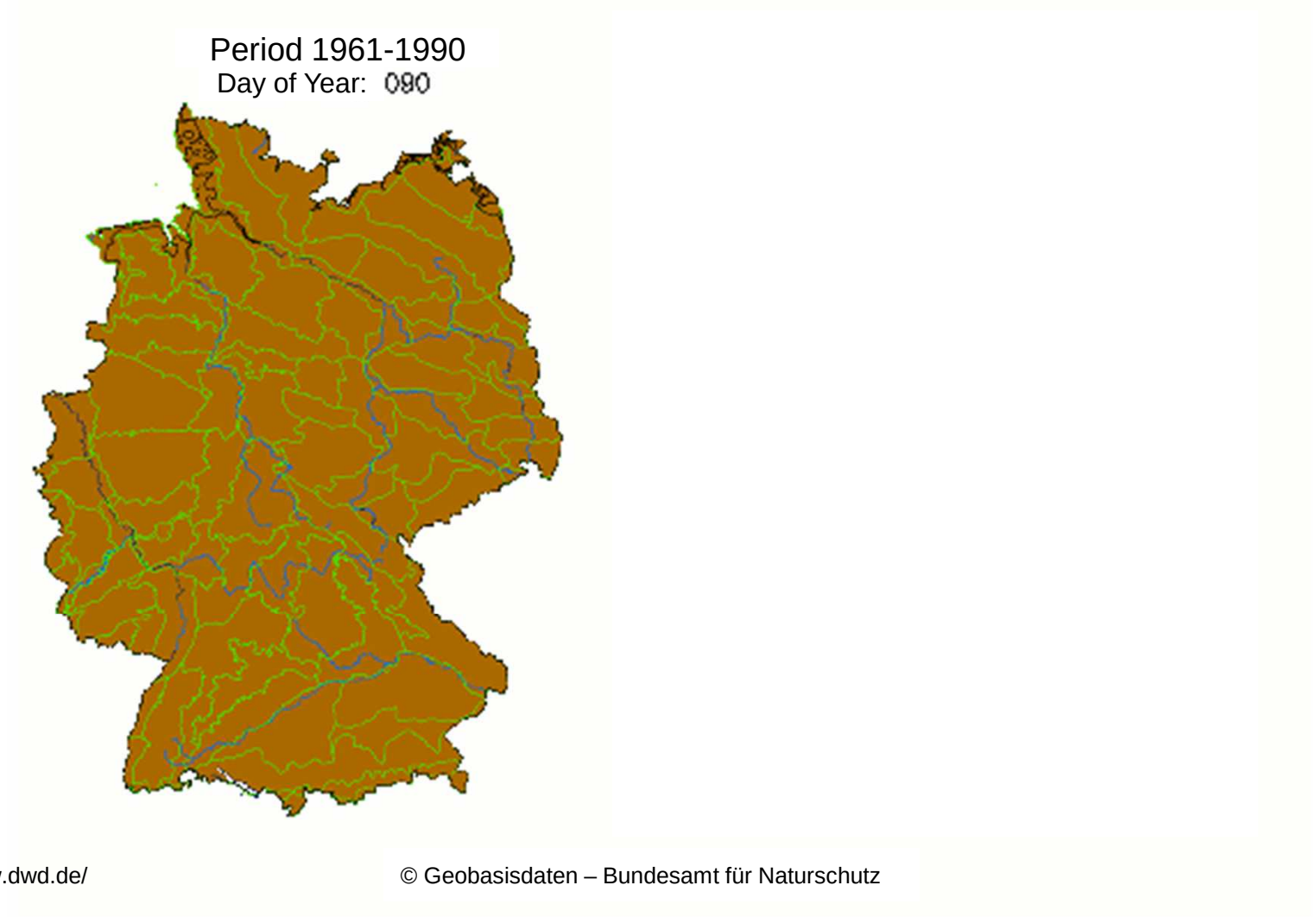
Geobasisdaten © Bundesamt für Kartographie und Geodäsie (www.bkg.bund.de)

Apple tree



There is a high inter-annual variability of the dates of flowering and fall of leaves of apple trees. In spring, there is a trend towards earlier dates of occurence.

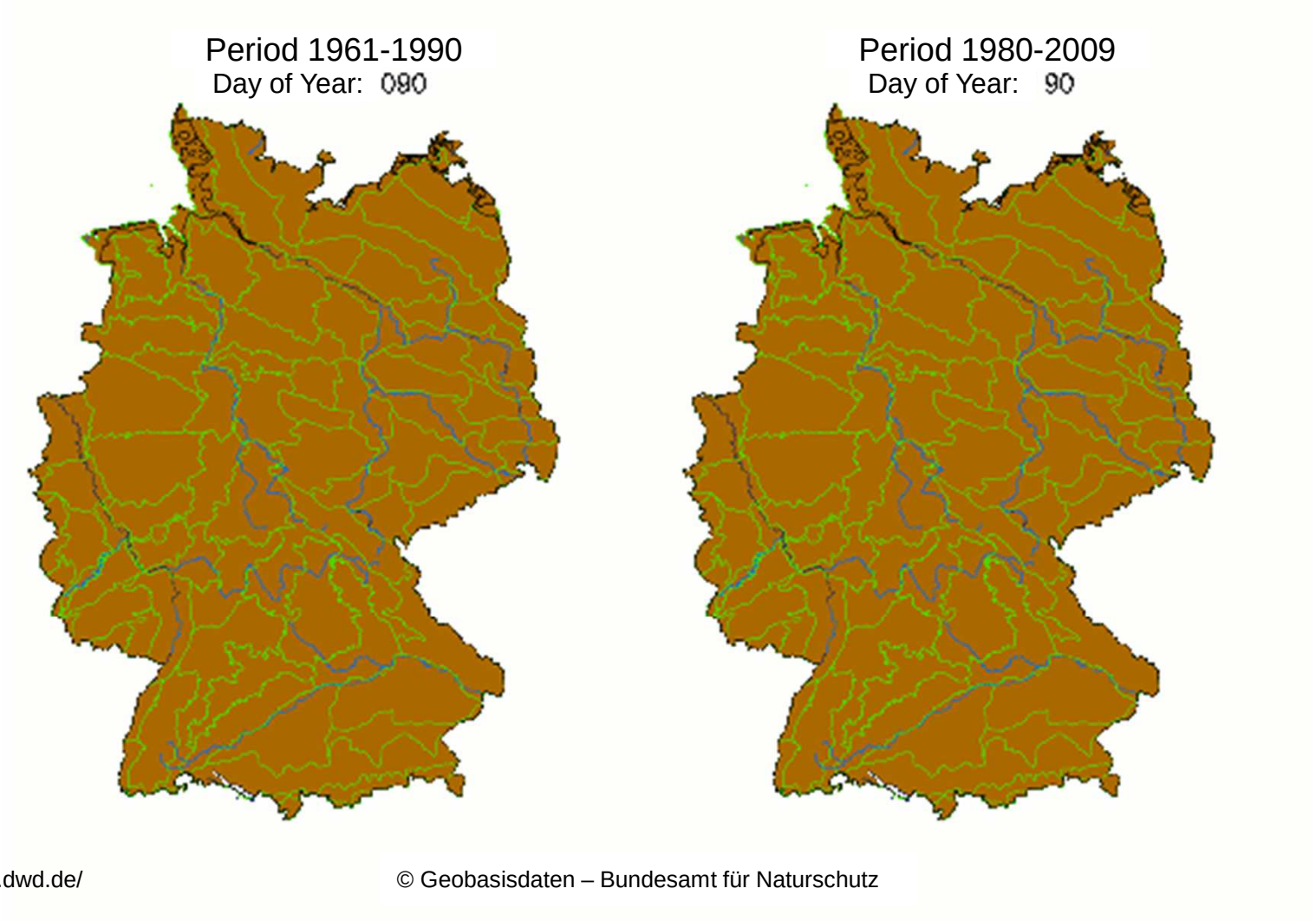
Beginning of the phenological early spring



http://www.dwd.de/

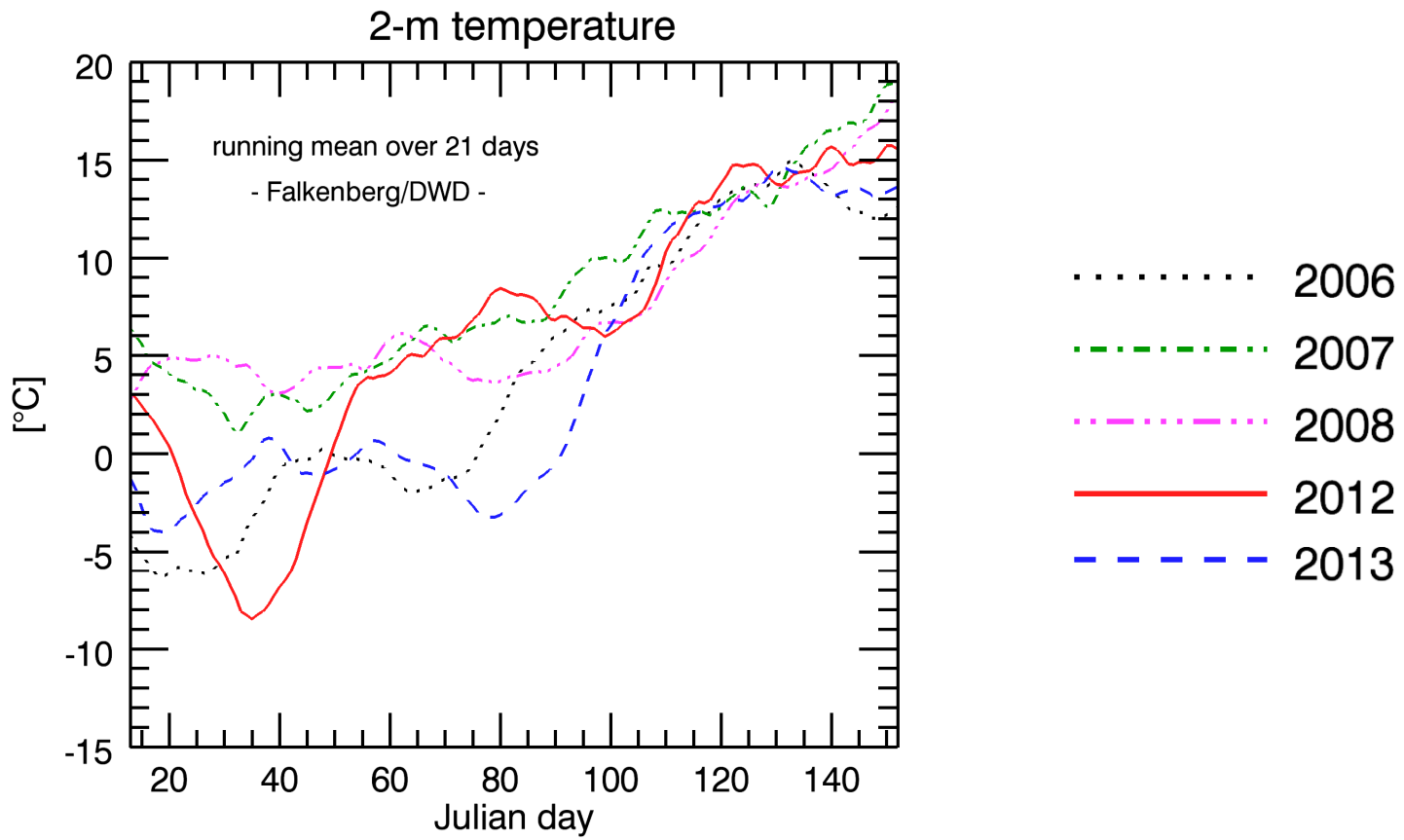
The phenological early spring starts in the southwest of Germany and progresses towards the northeast. This is also the case for the whole of Europe.

Beginning of the phenological early spring



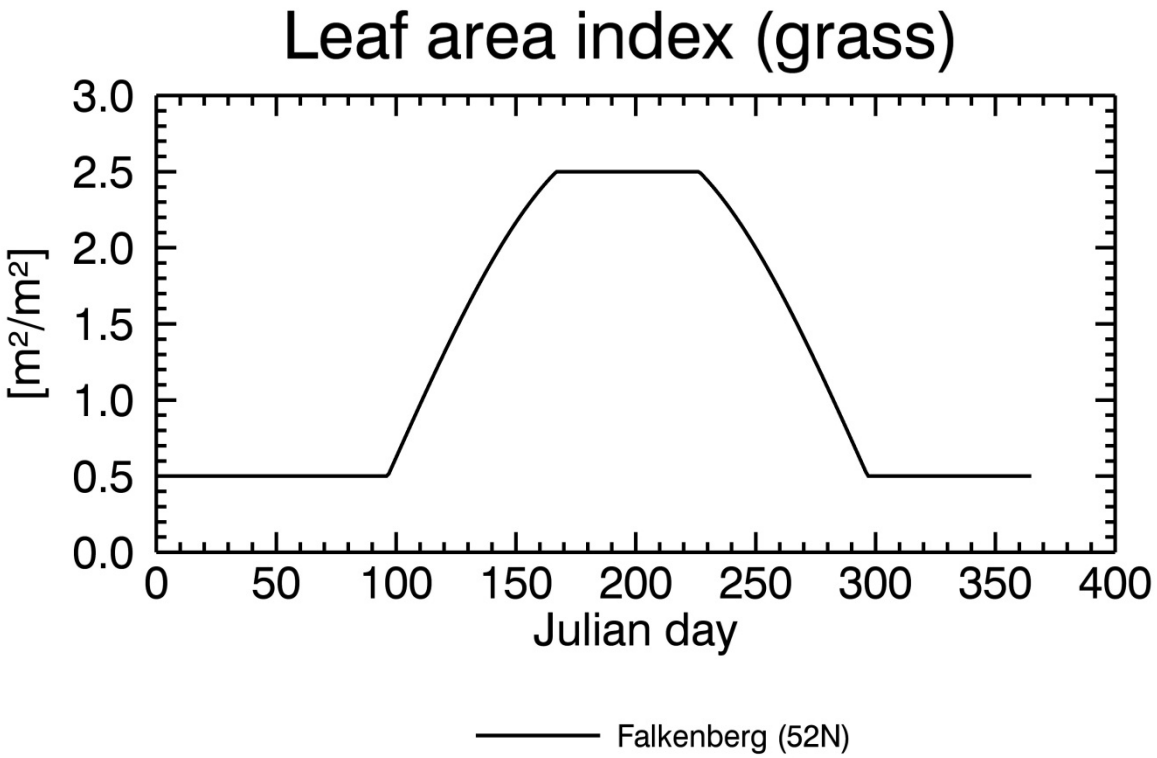
In recent years the phenological early spring shows a clear tendency to arrive earlier. This can be explained by the increase of spring temperatures.

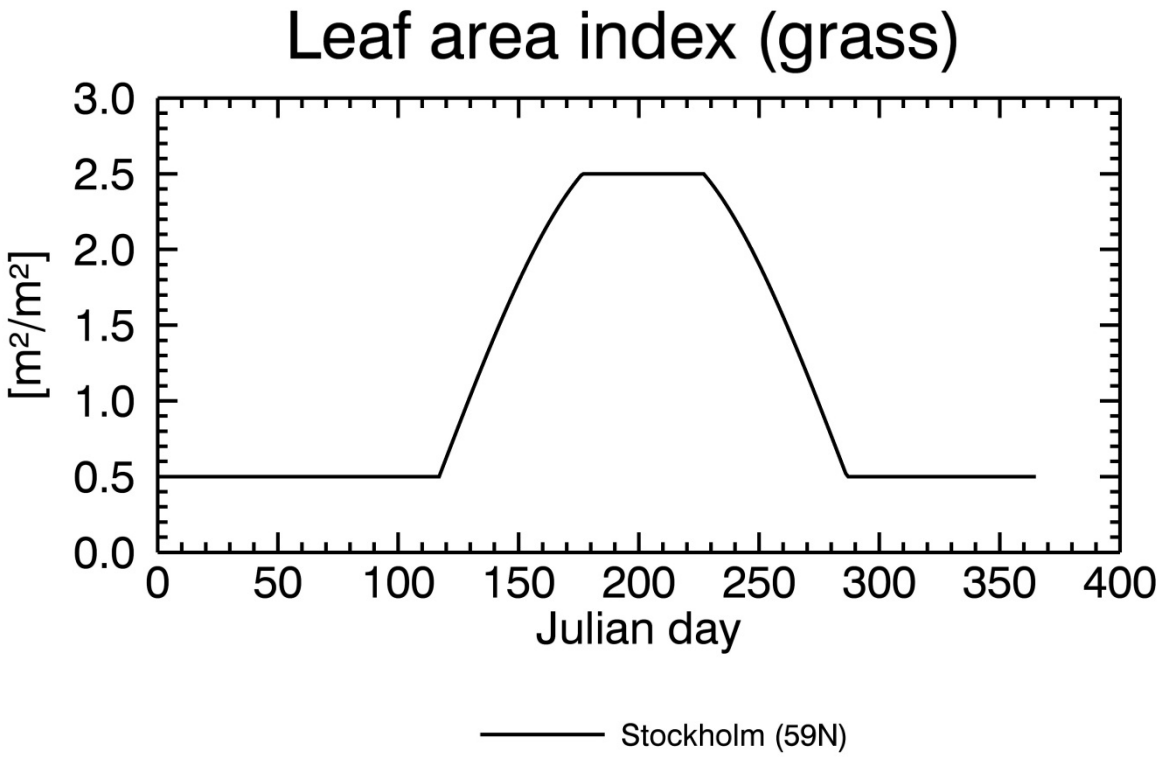
Inter-annual variability at Lindenberg

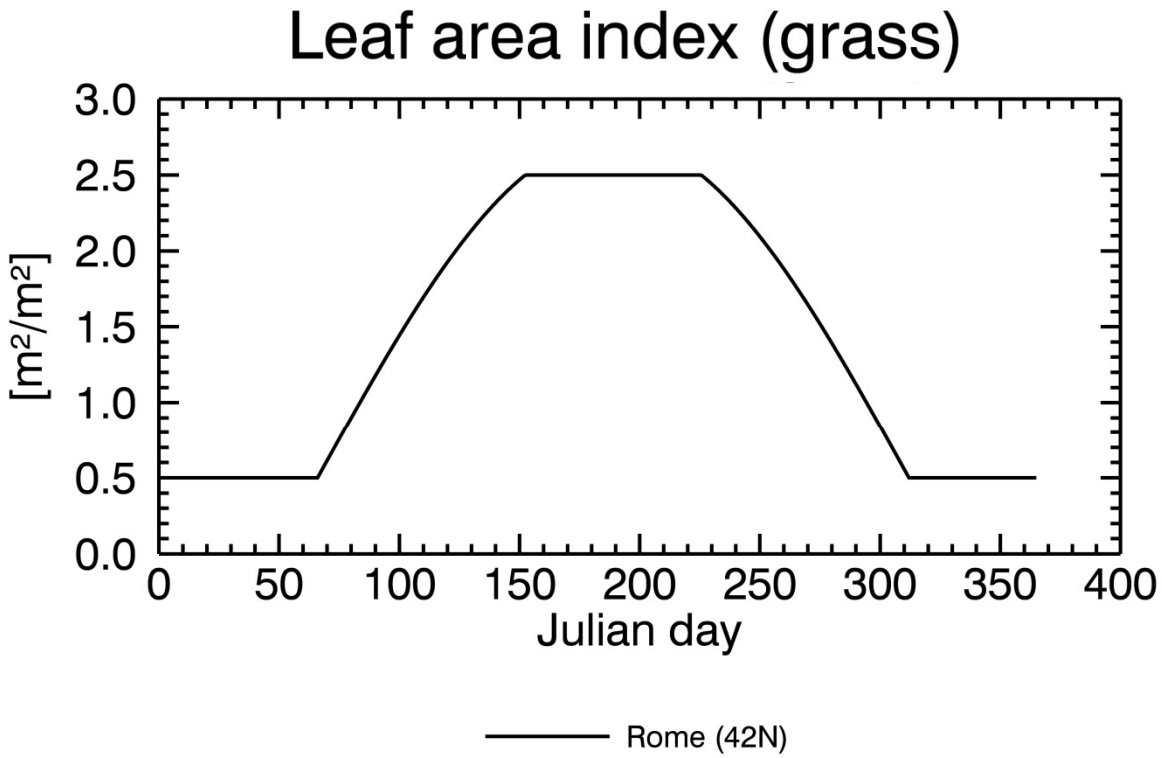


Currently the seasonal cycle of leaf area index (LAI) is prescribed as climatology, based either on

- a sinusoidal fit between a minimum and maximum value of LAI

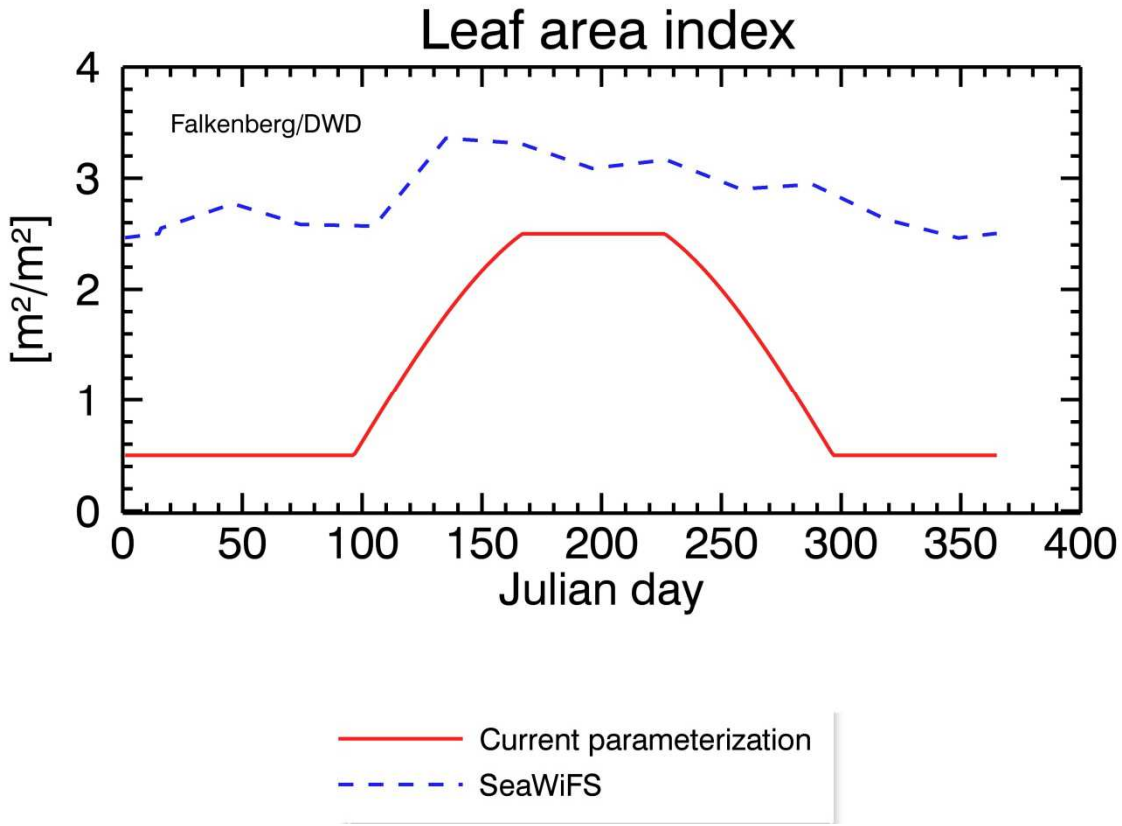

Leaf area index (grass)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
[m²/m²]
0
50
100
150
200
250
300
350
400
Julian day
Falkenberg (52N)


Leaf area index (grass)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
[m²/m²]
0
50
100
150
200
250
300
350
400
Julian day
Stockholm (59N)


Leaf area index (grass)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
[m²/m²]
0
50
100
150
200
250
300
350
400
Julian day
Rome (42N)

Currently the seasonal cycle of leaf area index (LAI) is prescribed as climatology, based either on

- a sinusoidal fit between a minimum and maximum value of LAI
- monthly mean values of LAI based on satellite retrievals


Leaf area index
Falkenberg/DWD
[m²/m²]
0
1
2
3
4
0
50
100
150
200
250
300
350
400
Julian day
Current parameterization
SeaWiFS

Currently the seasonal cycle of leaf area index (LAI) is prescribed as climatology, based either on

- a sinusoidal fit between a minimum and maximum value of LAI
- monthly mean values of LAI based on satellite retrievals

The model can not account for inter-annual variations of the growing season.

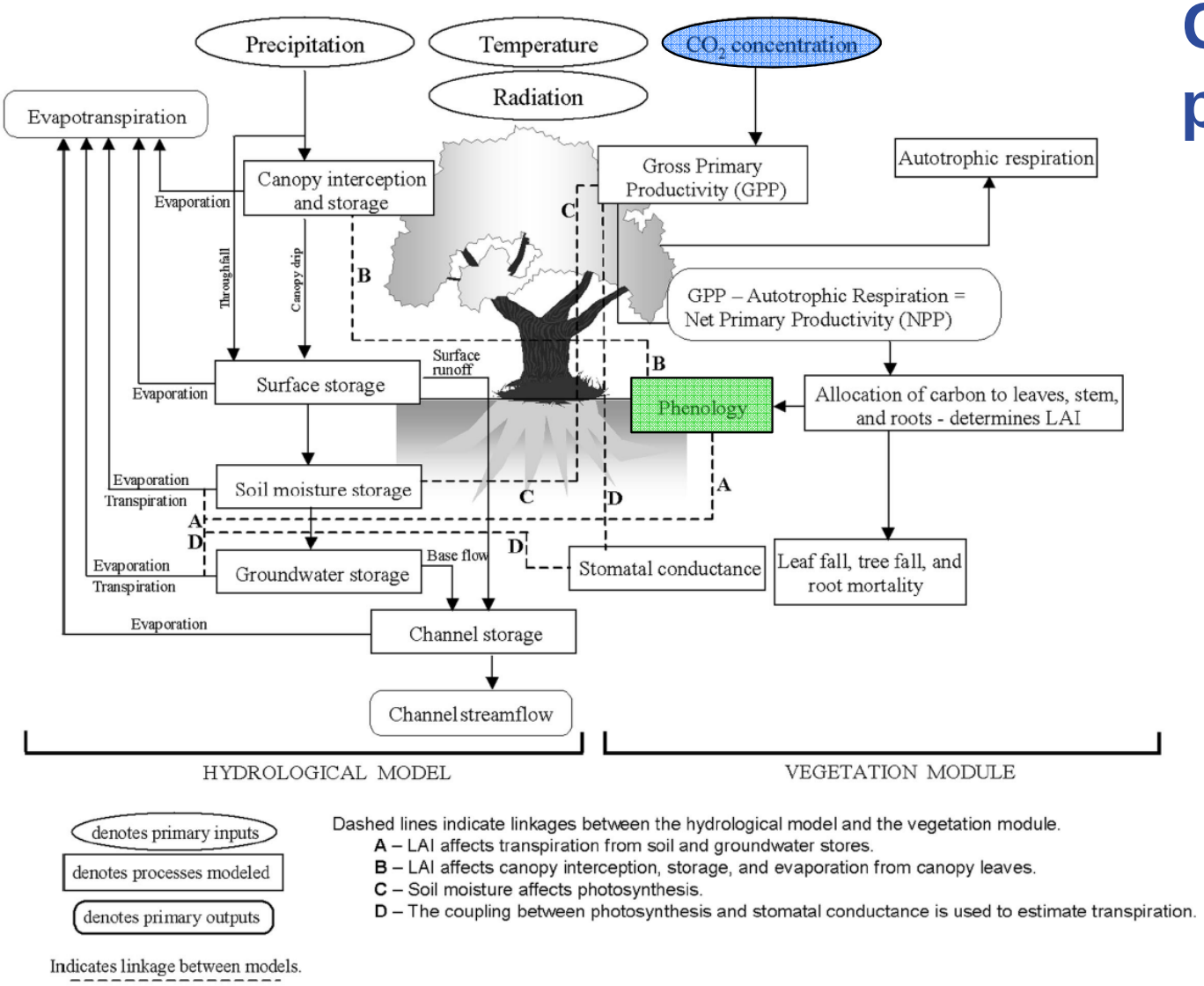
Therefore ...

… we need a phenology scheme in the COSMO / COSMO-CLM atmospheric model which allows the vegetation to adapt to the simulated seasonal and inter-annual variations in weather and climate, as well as to habitat factors (such as elevation).

Phenology is governed, or limited, by:

- Temperature
- Day length
- Water availability
- NPP (net primary productivity), used e.g. in JSBACH, CLM, ORCHIDEE ...

Governing phenology



Arora (2002)

Example for the coupling between a hydrologic model and a dynamic vegetation module. The two primary variables exchanged between the two models are leaf area index and soil moisture.

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

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

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)

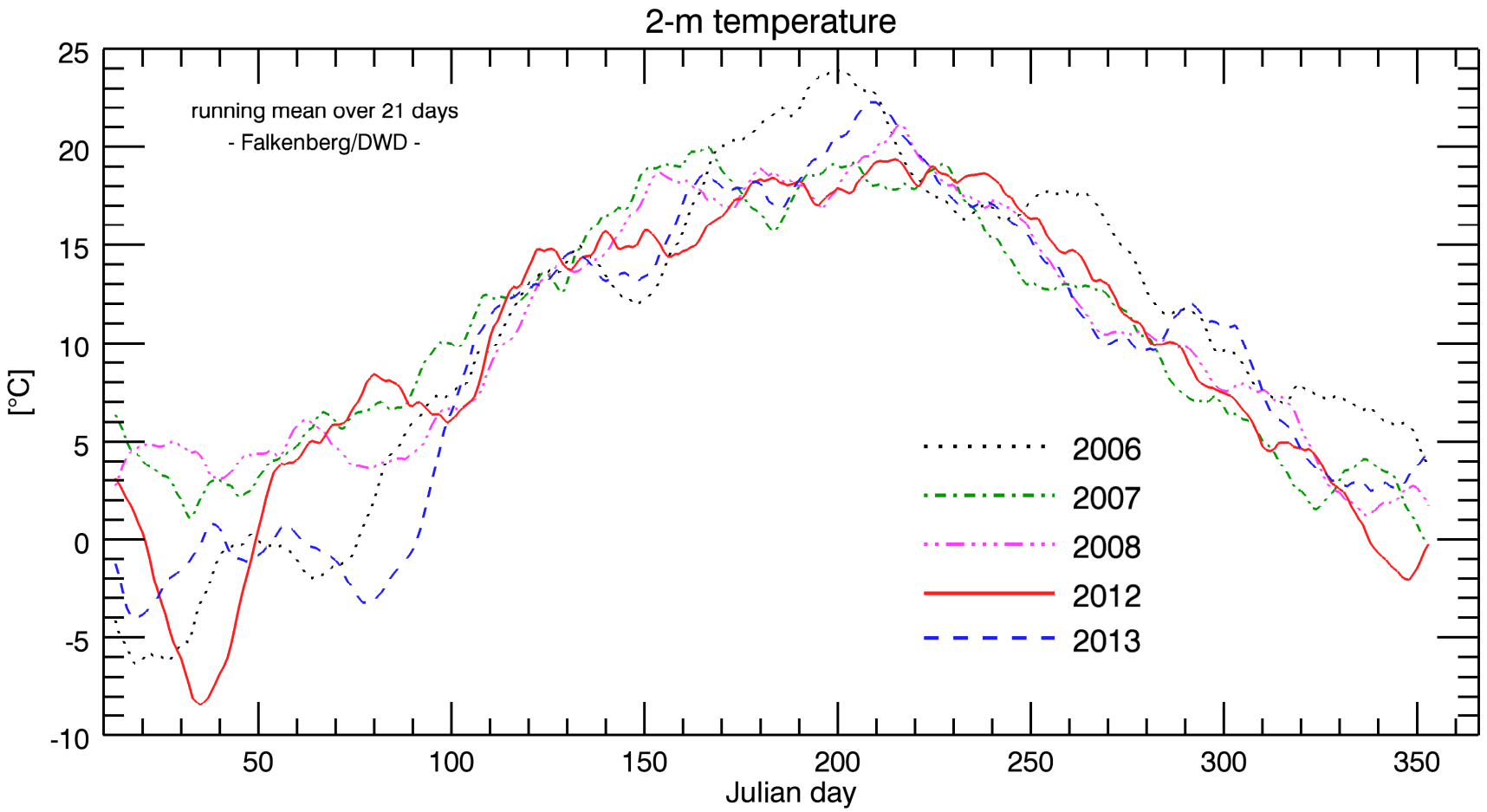
$$\mathrm{LAI}(t) = \begin{cases} \mathrm{LAI}_{\min} & \text{if } T(t) \le T_1 \\ \mathrm{LAI}_{\min} + \dfrac{T(t) - T_1}{T_2 - T_1}(\mathrm{LAI}_{\max} - \mathrm{LAI}_{\min}) & \text{if } T_1 < T(t) \le T_2 \\ \mathrm{LAI}_{\max} & \text{if } T_2 < T(t) \end{cases}$$

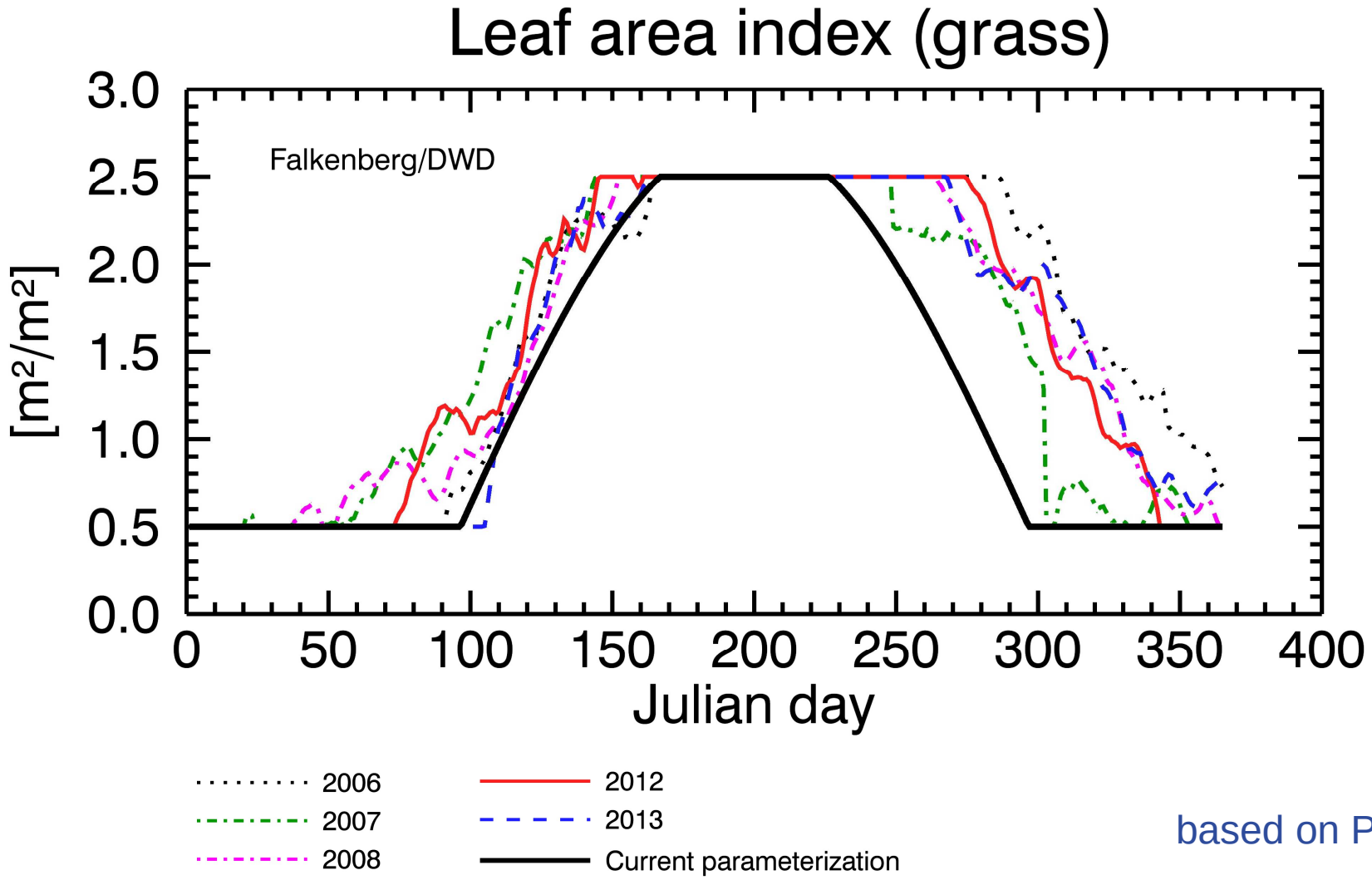
T_1 : minimum limiting temperature

T_2 : maximum limiting temperature

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

Inter-annual variability at Lindenberg





based on Polcher (1994)

Phenology as function of temperature

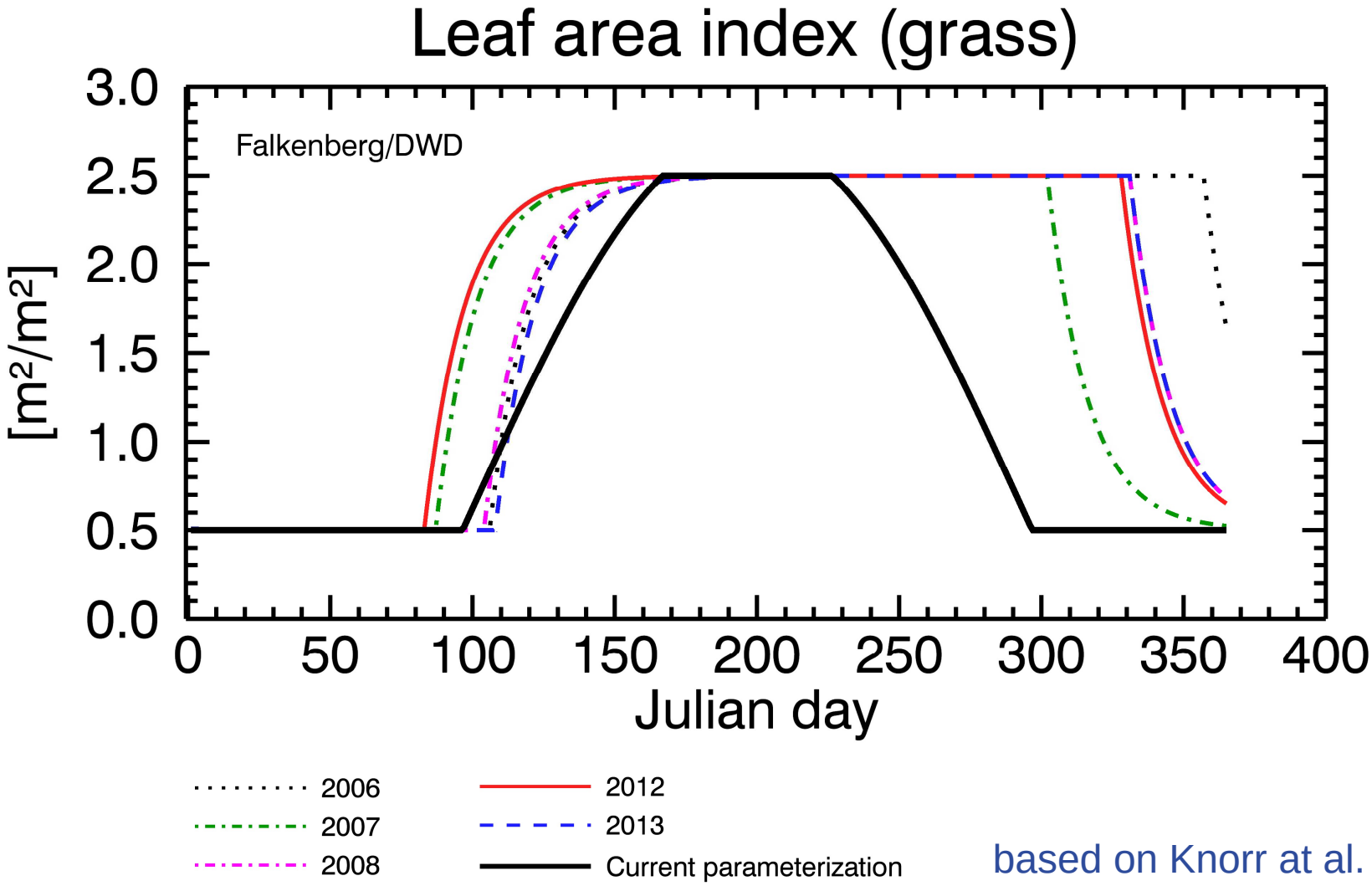
based on Knorr et al. (2010)

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

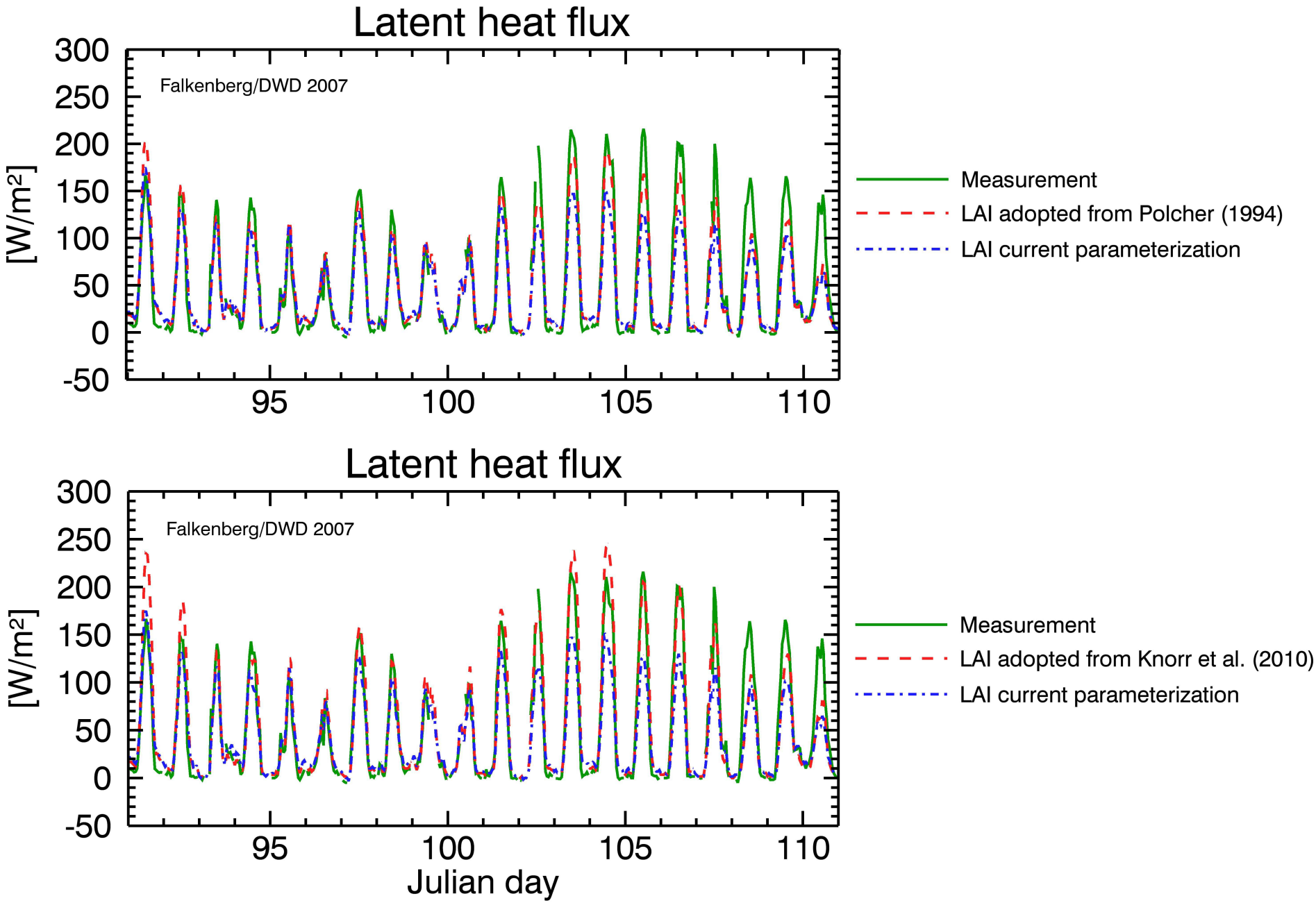
$T_{\text{on/off}}$: leaf onset and offset temperature

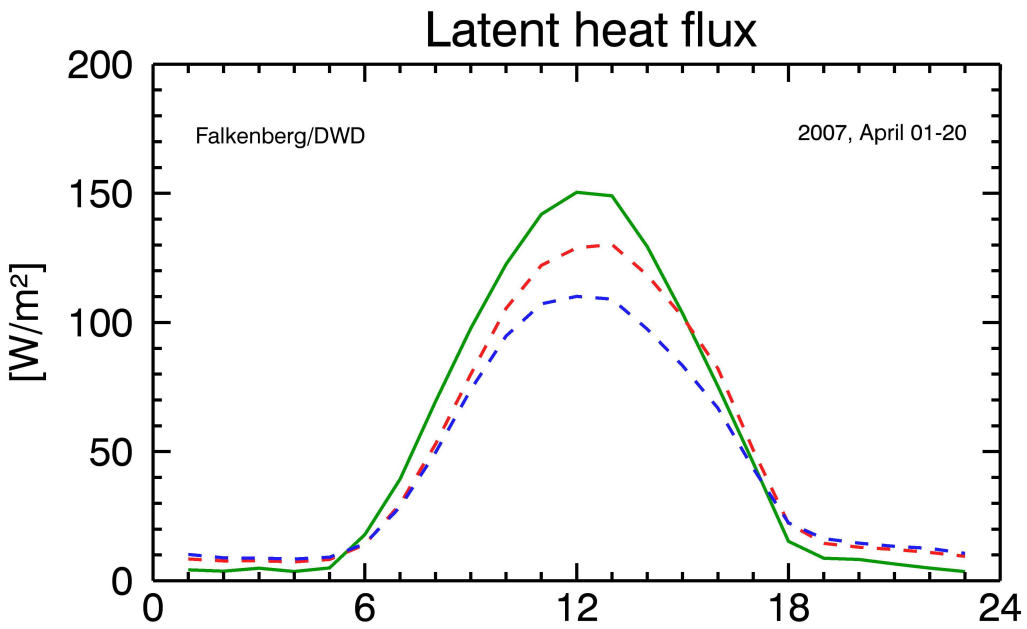
k_{grow} , k_{shed} : growth rate and shedding rate

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

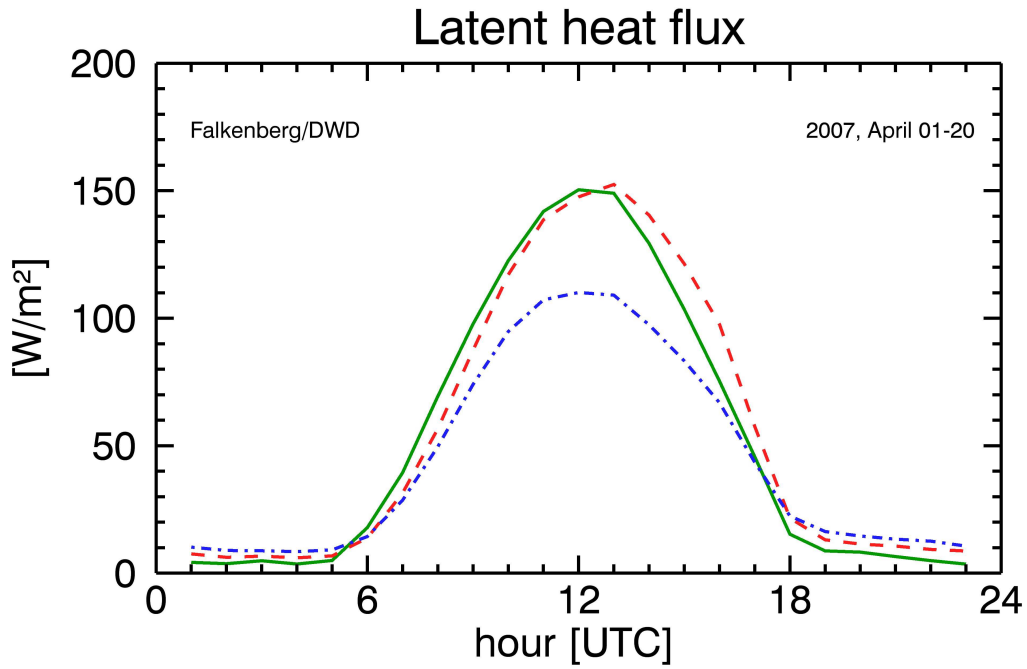


based on Knorr at al. (2010)

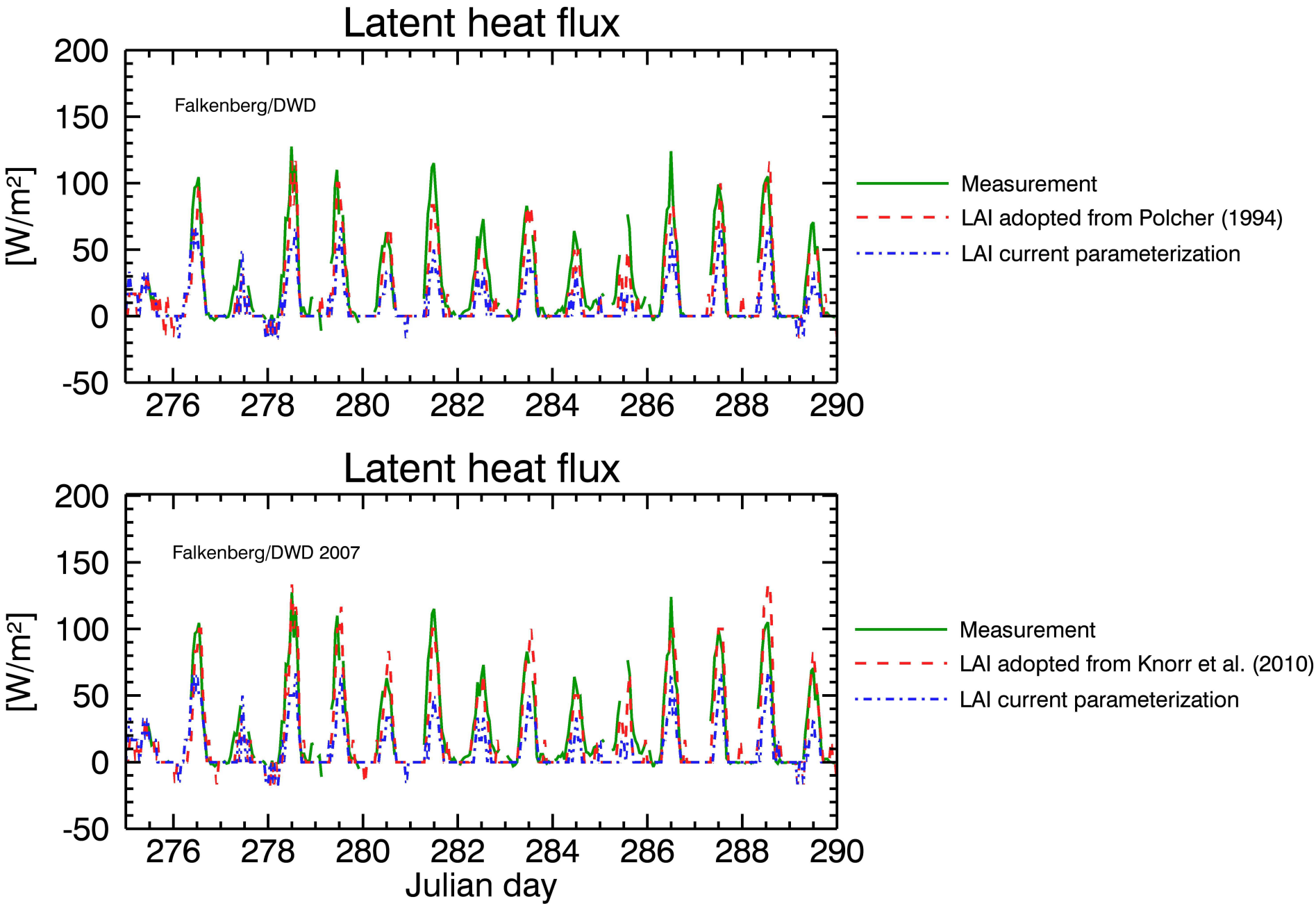

Latent heat flux
Falkenberg/DWD 2007
[W/m²]
300
250
200
150
100
50
0
-50
95
100
105
110
Measurement
LAI adopted from Polcher (1994)
LAI current parameterization
Latent heat flux
Falkenberg/DWD 2007
[W/m²]
Julian day
Measurement
LAI adopted from Knorr et al. (2010)
LAI current parameterization

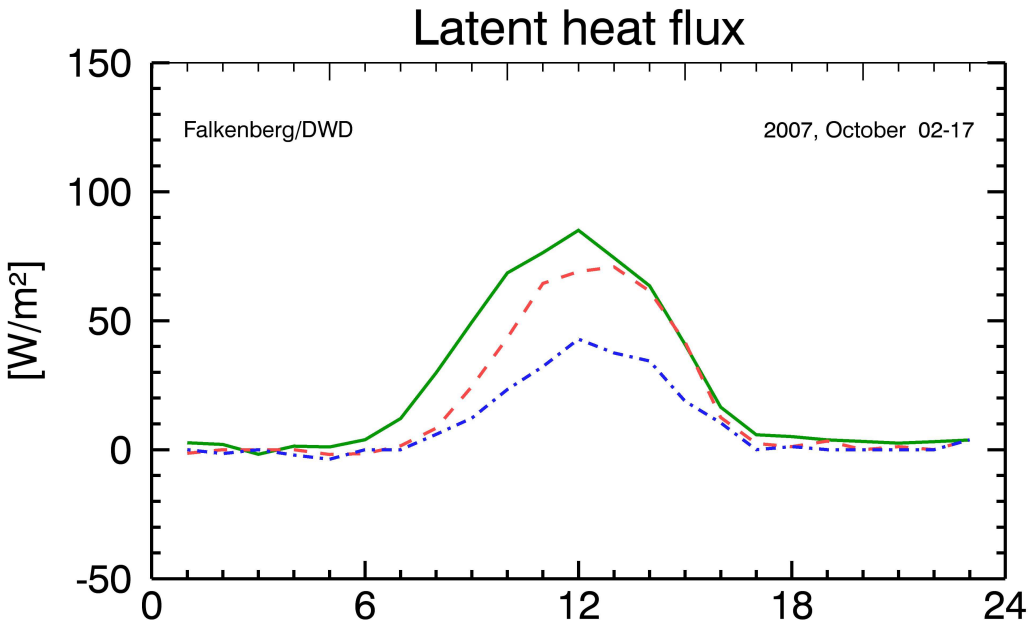


Measurement
LAI adopted from Polcher (1994)
LAI current parameterization

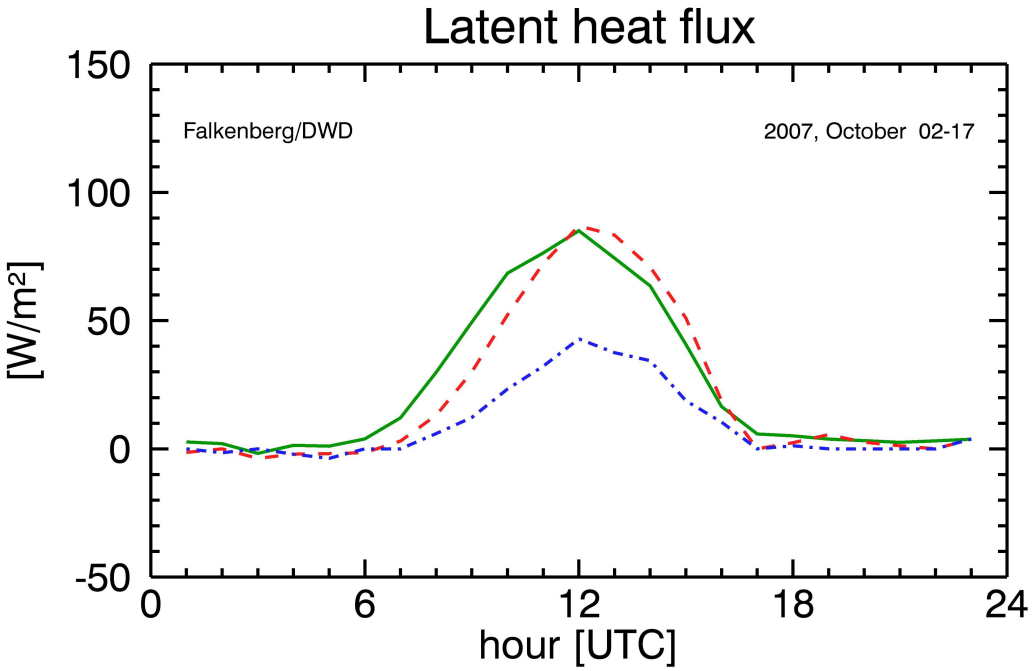


Measurement
LAI adopted from Knorr et al. (2010)
LAI current parameterization


Latent heat flux
Falkenberg/DWD
[W/m²]
200
150
100
50
0
-50
276
278
280
282
284
286
288
290
Measurement
LAI adopted from Polcher (1994)
LAI current parameterization
Latent heat flux
Falkenberg/DWD 2007
[W/m²]
Julian day
Measurement
LAI adopted from Knorr et al. (2010)
LAI current parameterization



Measurement
LAI adopted from Polcher (1994)
LAI current parameterization



Measurement
LAI adopted from Knorr et al. (2010)
LAI current parameterization

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.