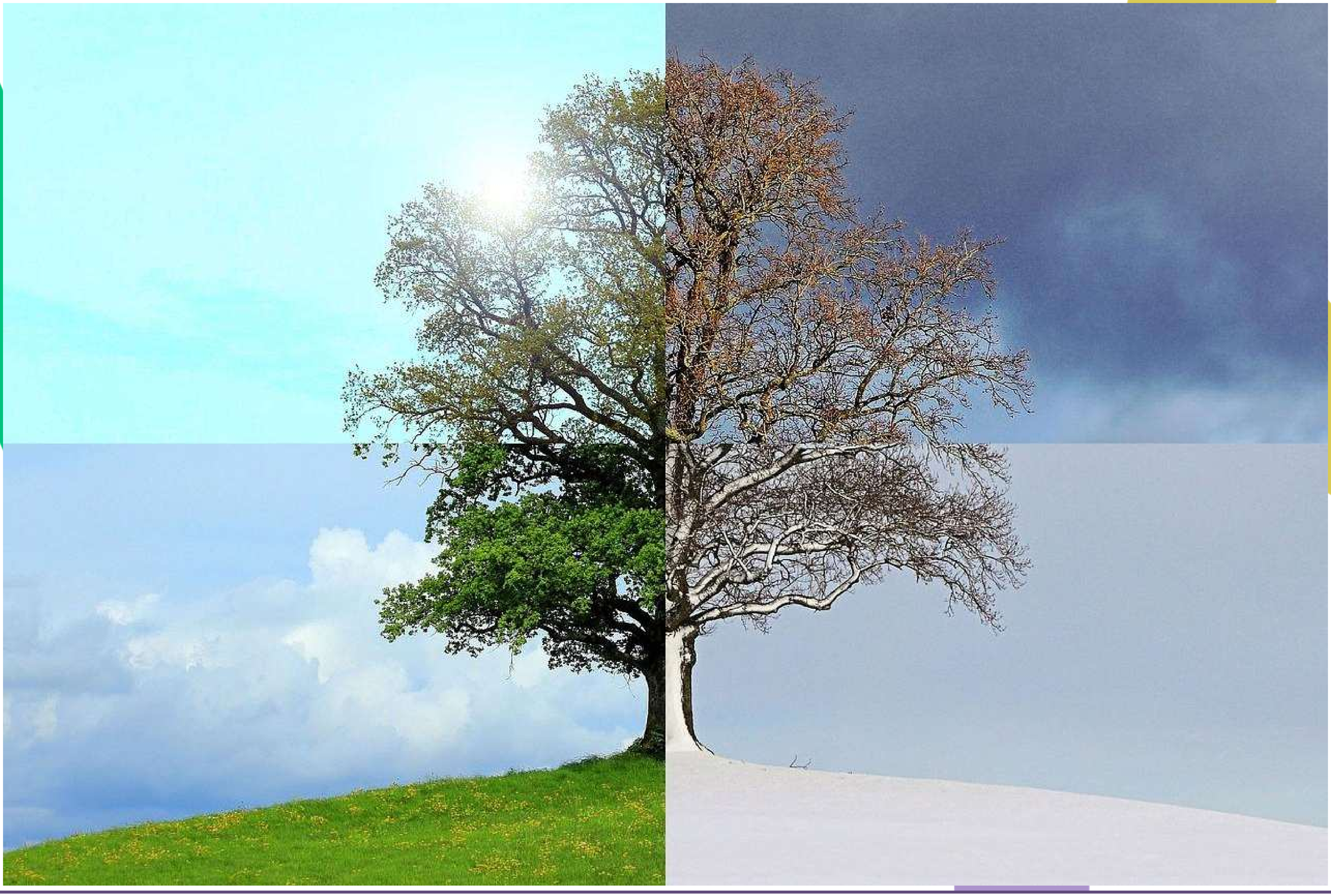
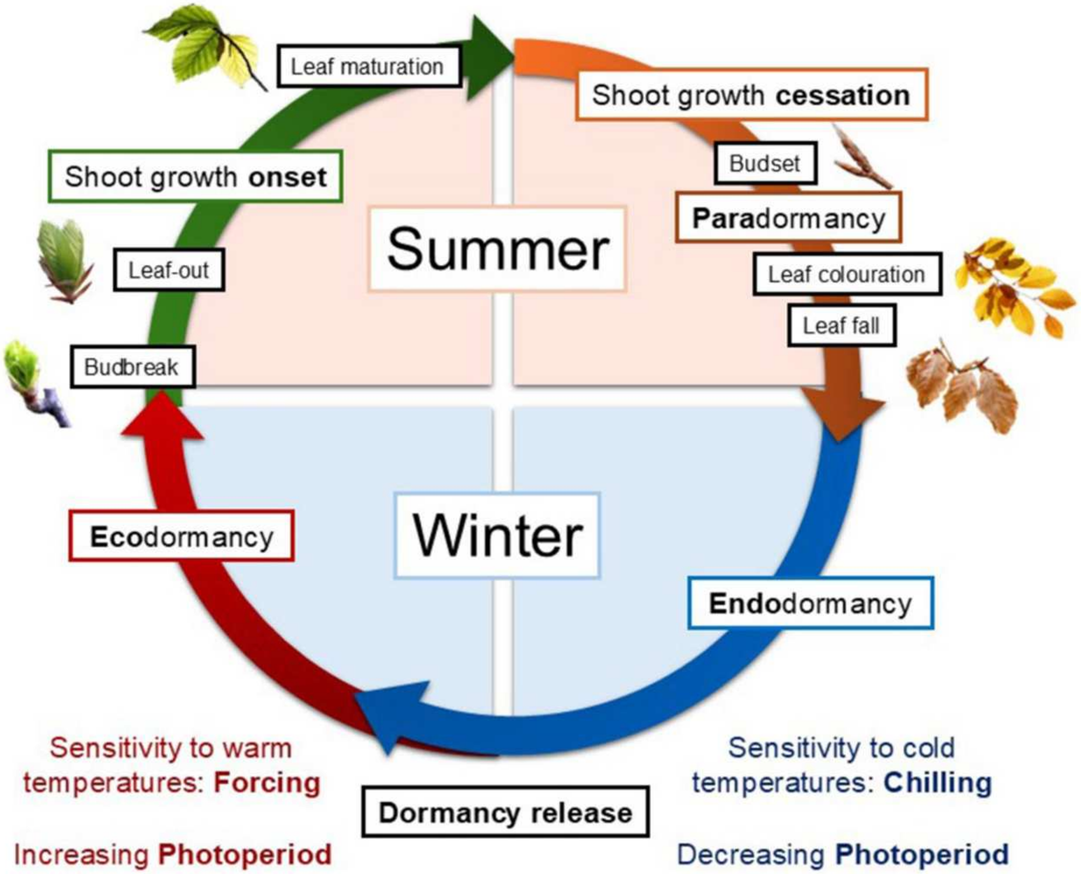


Phenology is the sequence of biological changes that determine the growth and development of plants

Phenology drivers

- During a growing season different phenological phases (phenophases), can be distinguished
- Each phenophase requires specific light (photoperiod) and temperature conditions
- Water scarcity and nutrients can also influence phenological events
- Climate requirements are specific for each species

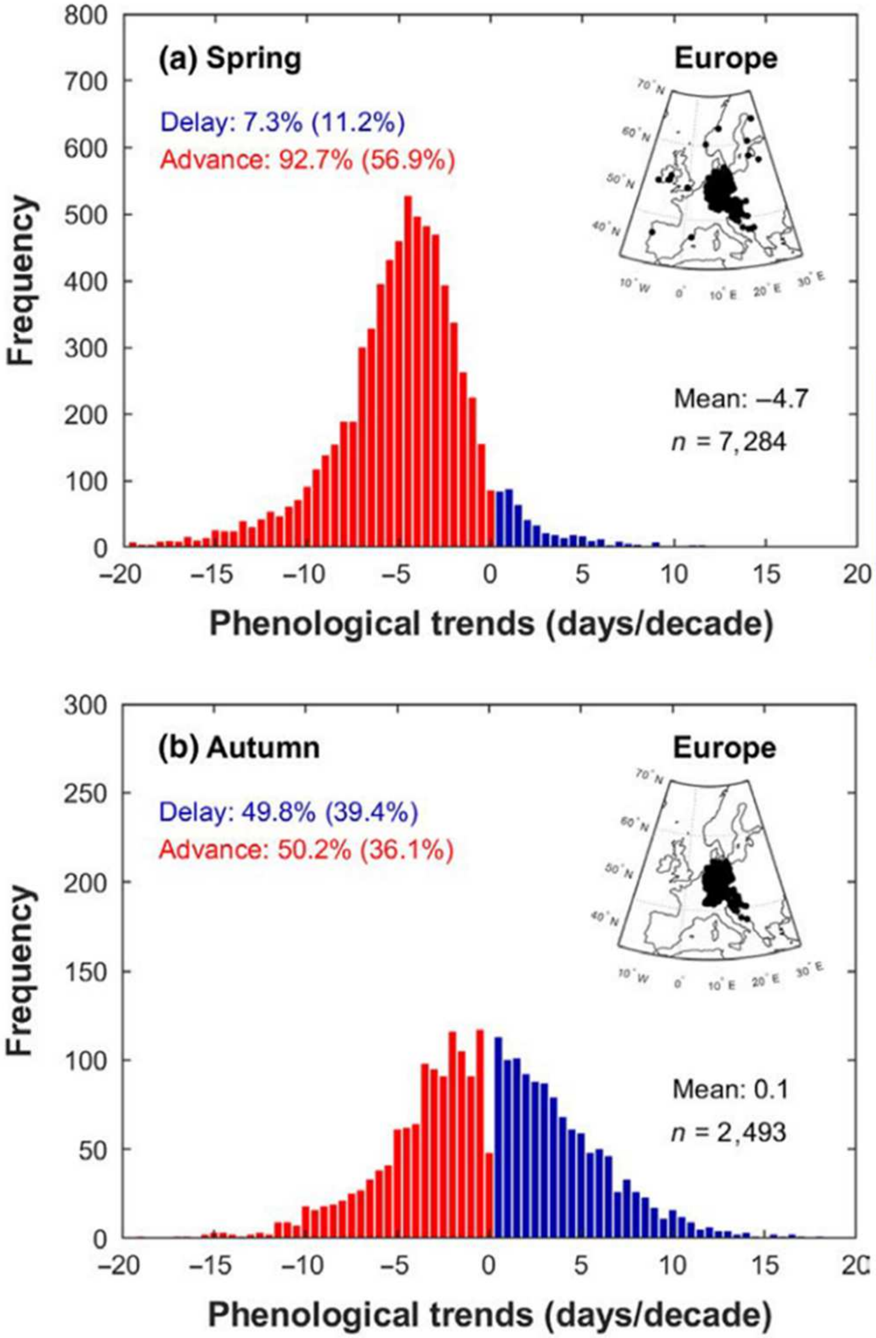


Silvestro, 2025

Dormancy are periods with no growth activity

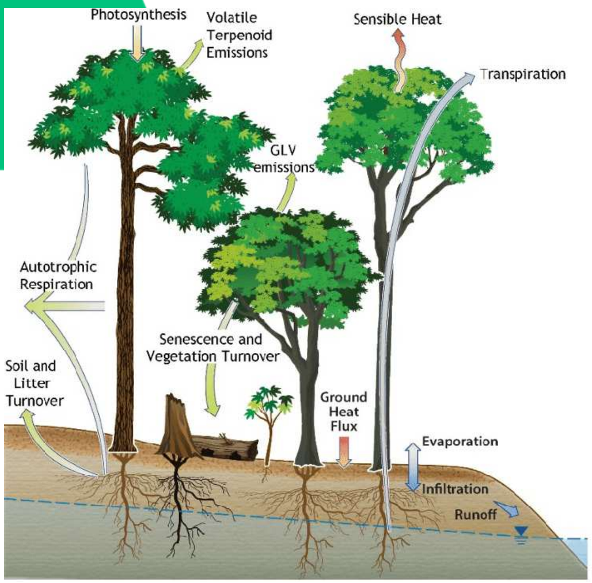
Phenology and Climate Change

- Climate change is causing shifts in the timing of phenological phases
- An earlier onset of spring has been observed in Europe, North America and Asia
- In Autumn, was frequently observed a delay but the tendency was less marked



Piao, 2019

CONSEQUENCES?



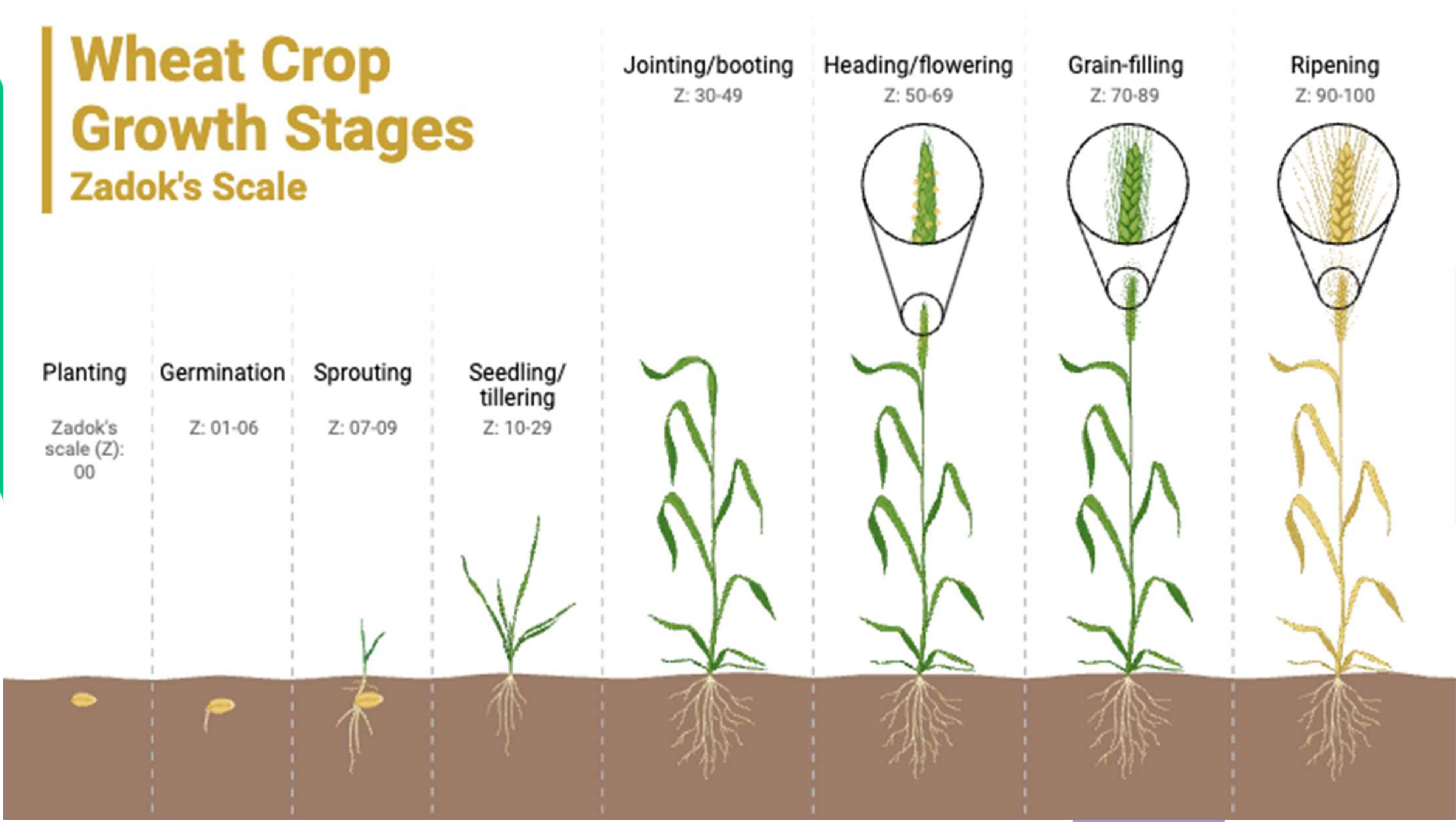
Changes in plant phenology have consequences on plants growth, productivity, species synchronization (e.g. plants-pollinators), carbon sequestration, energy release through evapotranspiration, human health

Corydalis ambigua and pollinators mismatch (northern Japan)

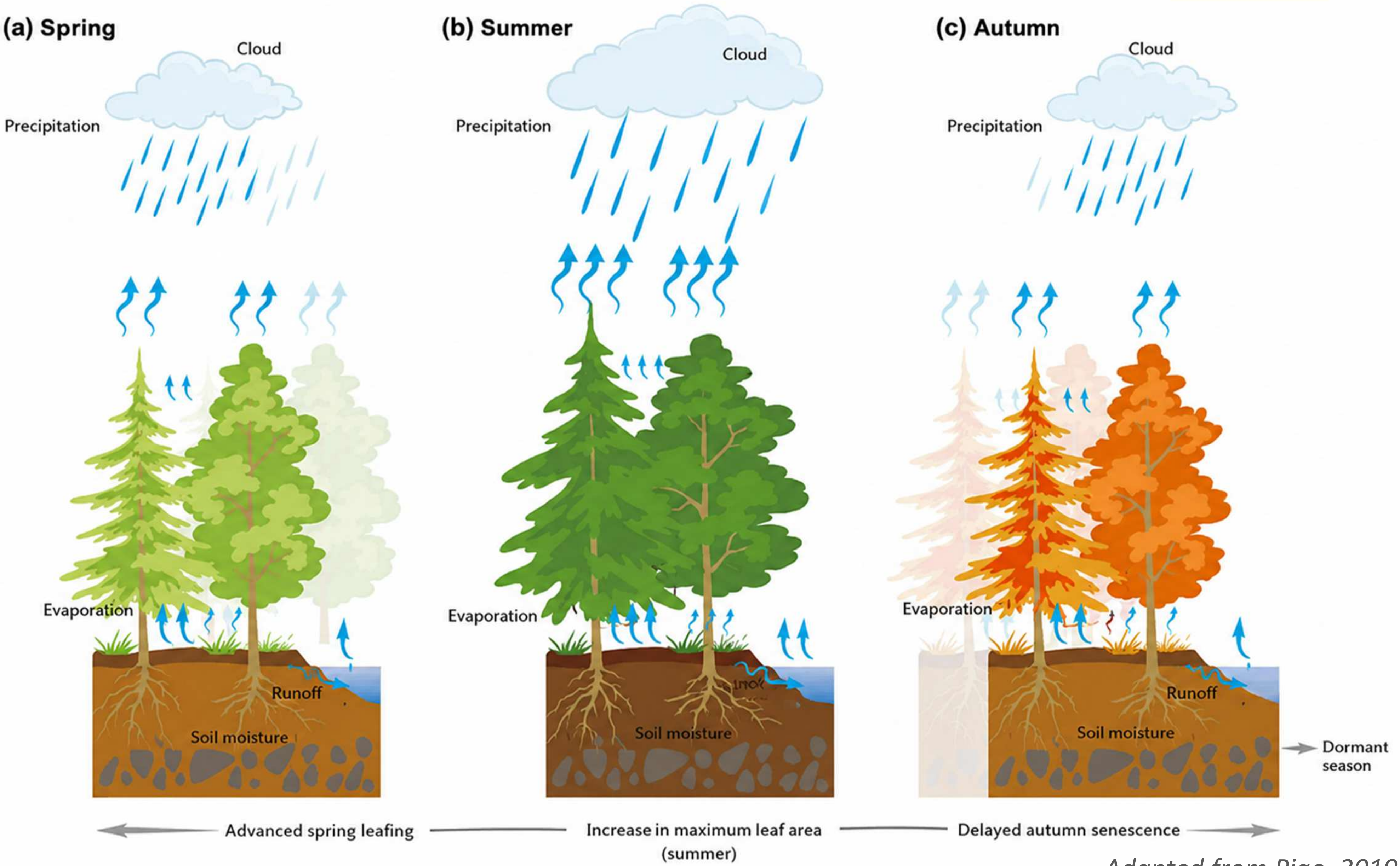
(Kudo and Cooper, 2019)

Climate warming caused earlier snowmelt, which advanced the flowering time of the plant faster than the emergence time of the bees which depends on soil, not air temperature.

Consequences:
- Reduced pollinator visits to flowers,
- Lower seed production and reproductive success in plants
- Increased risk of population decline for both species



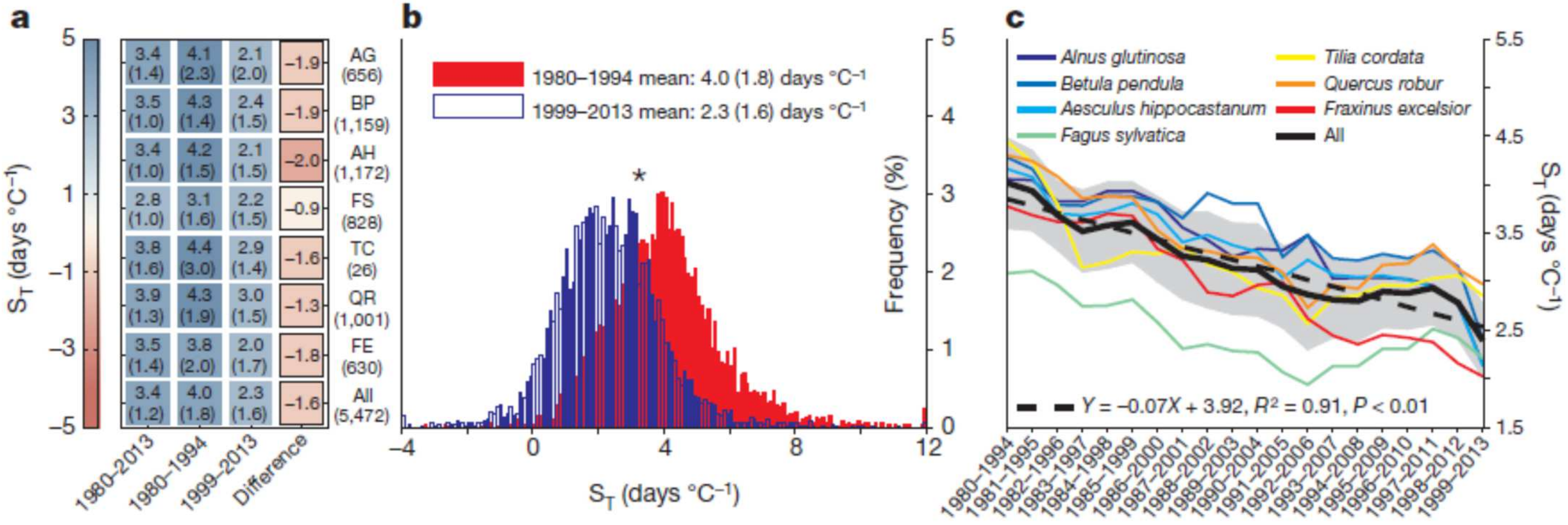
Climate warming advances crop phenology, especially flowering and maturity, shortening the grain-filling period and reducing grain yield in crops *(Zartash, 2026*)



Adapted from Piao, 2019

The advance of leafing in spring results in higher transpiration, higher water consumption and lower radiation reflectance (temperature increase)

WILL FUTURE WARMING LED TO PROGRESSIVE EARLIER SPRING?

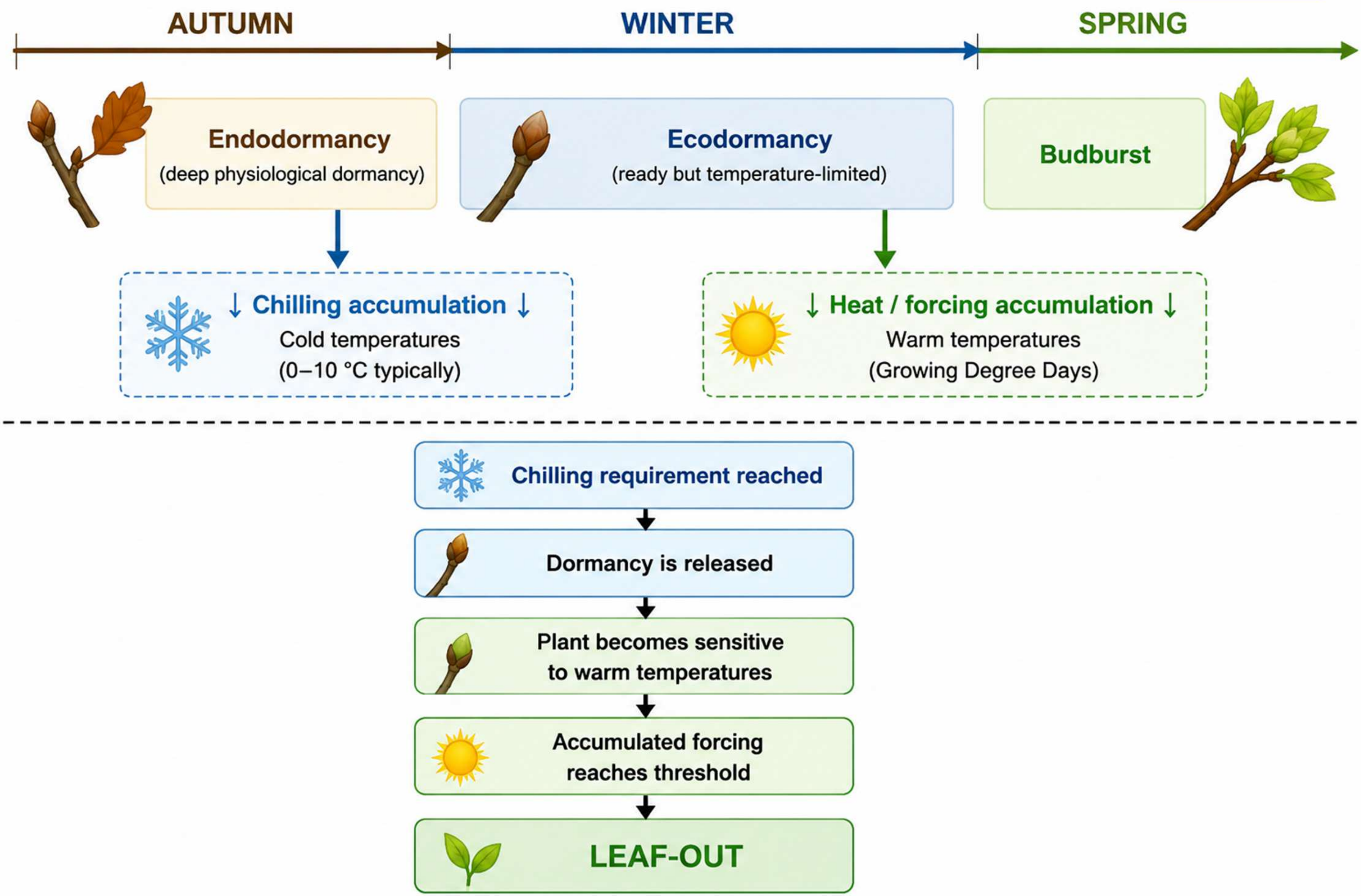


	1980–2013	1980–1994	1999–2013	Difference
AG (656)	3.4 (1.4)	4.1 (2.3)	2.1 (2.0)	−1.9
BP (1,159)	3.5 (1.0)	4.3 (1.4)	2.4 (1.5)	−1.9
AH (1,172)	3.4 (1.0)	4.2 (1.5)	2.1 (1.5)	−2.0
FS (828)	2.8 (1.0)	3.1 (1.6)	2.2 (1.5)	−0.9
TC (26)	3.8 (1.6)	4.4 (3.0)	2.9 (1.4)	−1.6
QR (1,001)	3.9 (1.3)	4.3 (1.9)	3.0 (1.5)	−1.3
FE (630)	3.5 (1.4)	3.8 (2.0)	2.0 (1.7)	−1.8
All (5,472)	3.4 (1.2)	4.0 (1.8)	2.3 (1.6)	−1.6

(*Fu, 2015*)

The sensitivity of leaf unfolding advance to increasing temperature in spring, S_T (days/ºC) showed a decrease in recent years (1999-2013) compared to the previous period (1980-1994) in deciduous species

This happens because plants require an accumulation of cold to break endodormancy



AUTUMN

WINTER

SPRING

Endodormancy
(deep physiological dormancy)

Ecodormancy
(ready but temperature-limited)

Budburst

↓ Chilling accumulation ↓
Cold temperatures
(0–10 °C typically)

↓ Heat / forcing accumulation ↓
Warm temperatures
(Growing Degree Days)

Chilling requirement reached

Dormancy is released

Plant becomes sensitive to warm temperatures

Accumulated forcing reaches threshold

LEAF-OUT

ISA

- SET-UP FOR GROUND SENSORS COLLECTING OPTICAL AND SPECTRAL OBSERVATIONS

SET-UP A FIXED CAMERA FOR PHENOLOGY

SELECT CAMERA AND POWER:

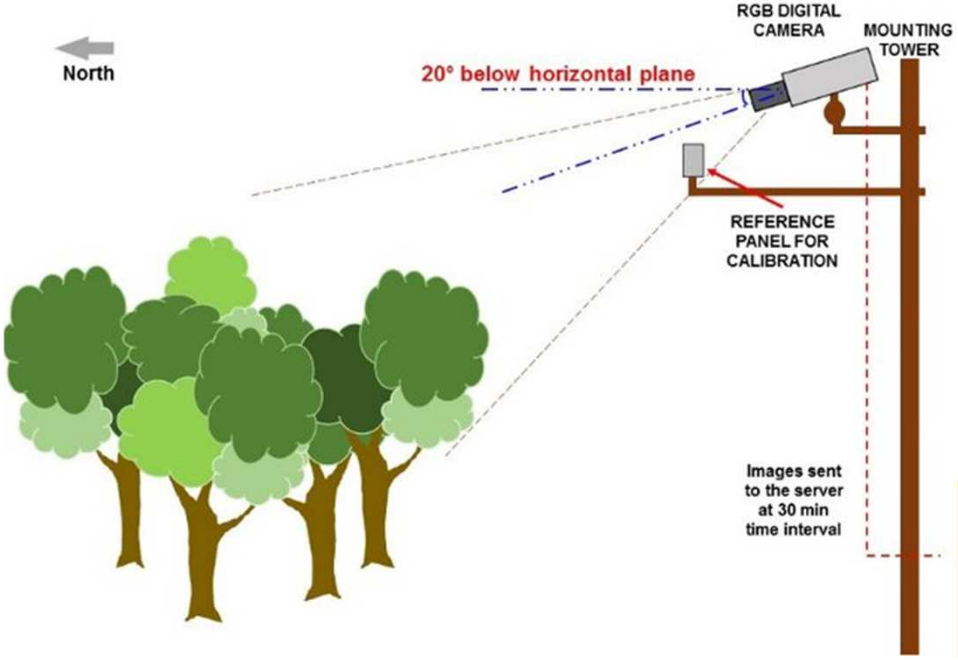
Select a reliable outdoor camera with a weatherproof housing

Use solar panels and batteries if AC power is not available

LOCATION:

Select a representative section of a canopy or landscape

Install on a stable pole or a tower



Sunoj et al. 2016

ORIENT THE CAMERA:

Prefer a North-facing view in the Northern Hemisphere to avoid shadows and sun glare

CAMERA SETTING:

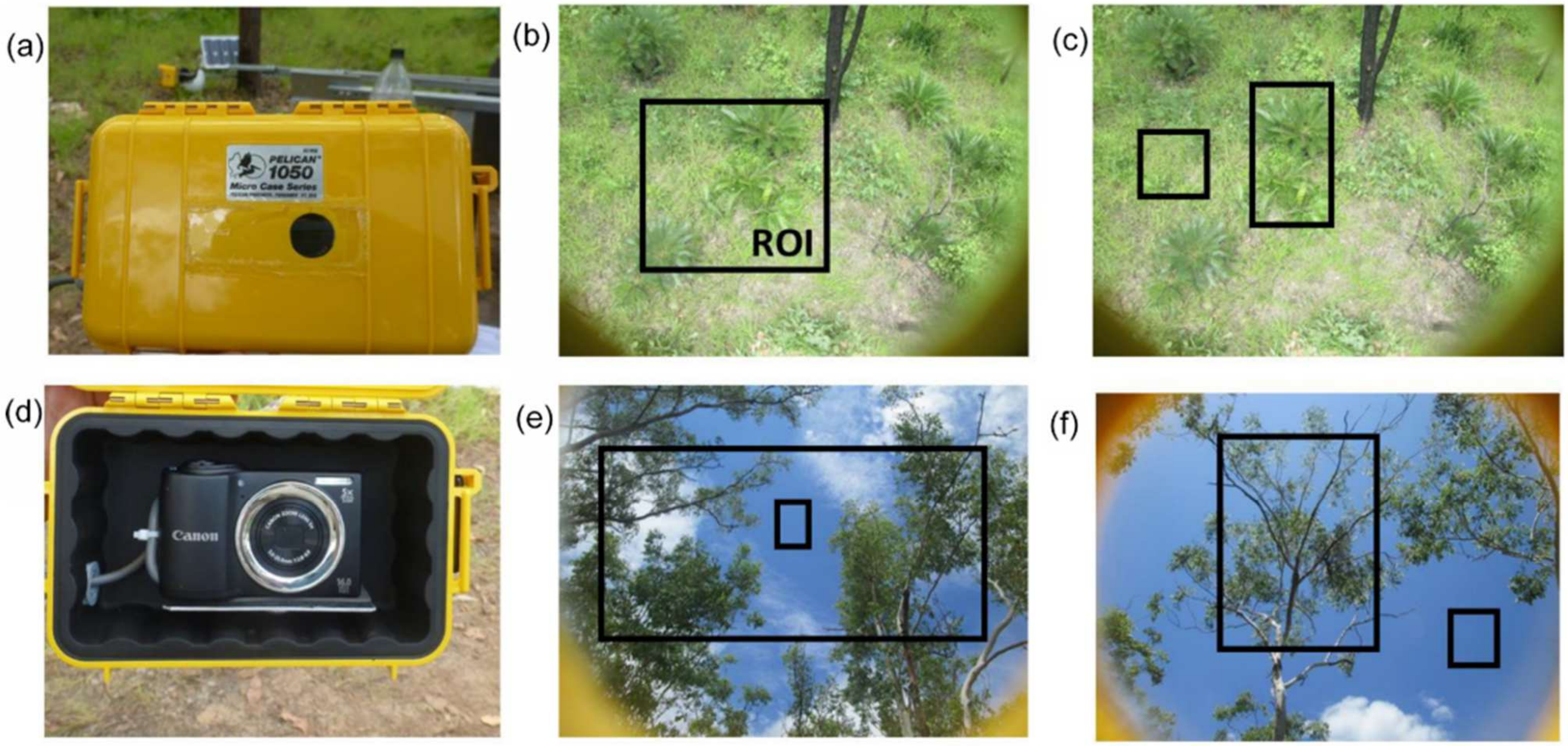
Resolution: at least 1280X960 pixels (standard PhenoCam resolution)

Use fixed white balance and automatic exposure to reduce variability

Time lapse: every 30-60 min during daylight (e.g.10:00-17:00, depending on location)

Add a grey reference panel for quality checking

MAIN UNCERTAINTY SOURCES

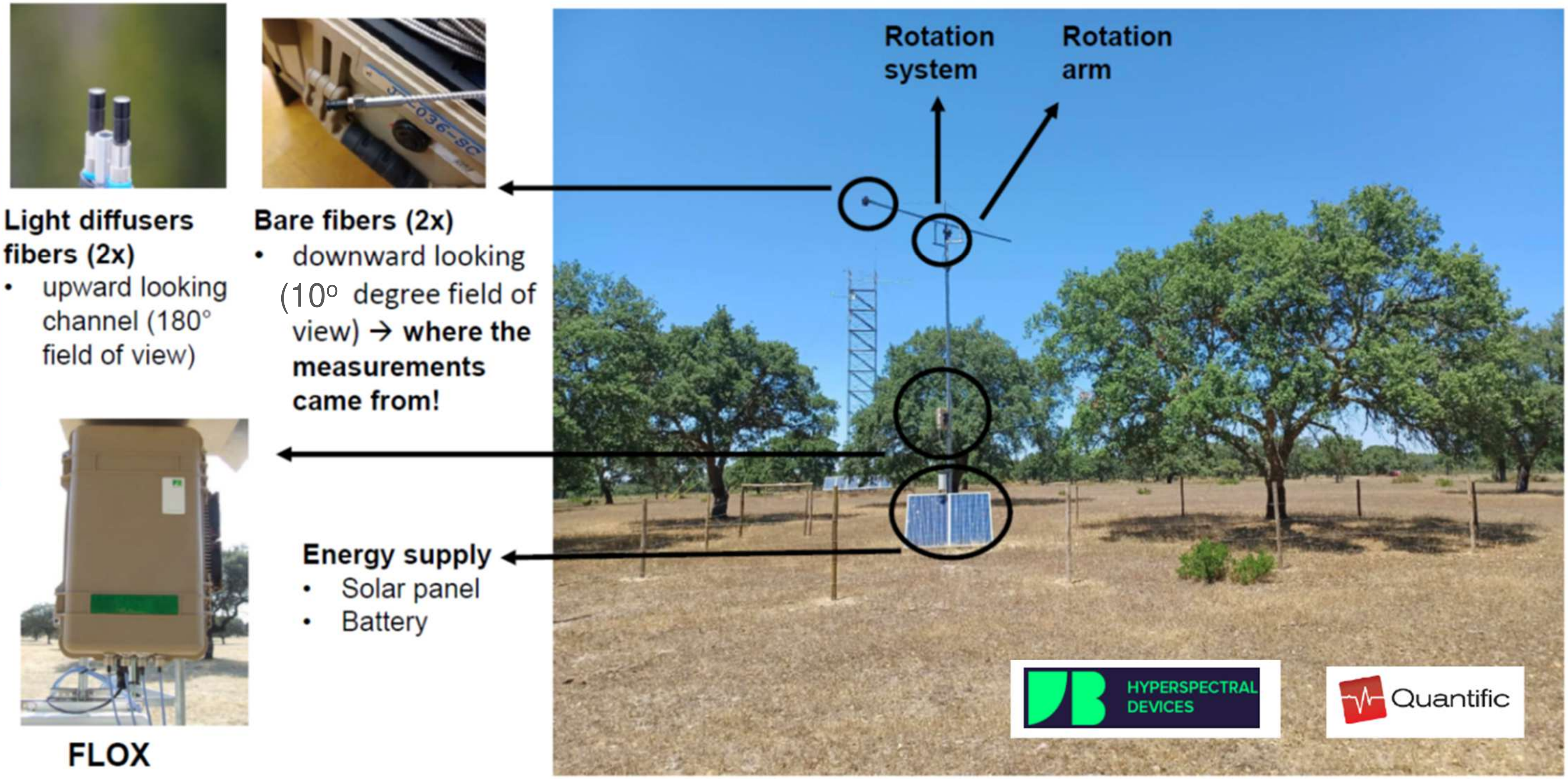


Moore, 2017

- Illumination variability

Changes in illumination variability are related with solar radiance, clouds, air humidity can be solved applying a filter for low luminosity conditions

- Shifts in the field of view



Light diffusers fibers (2x)
- upward looking channel (180° field of view)

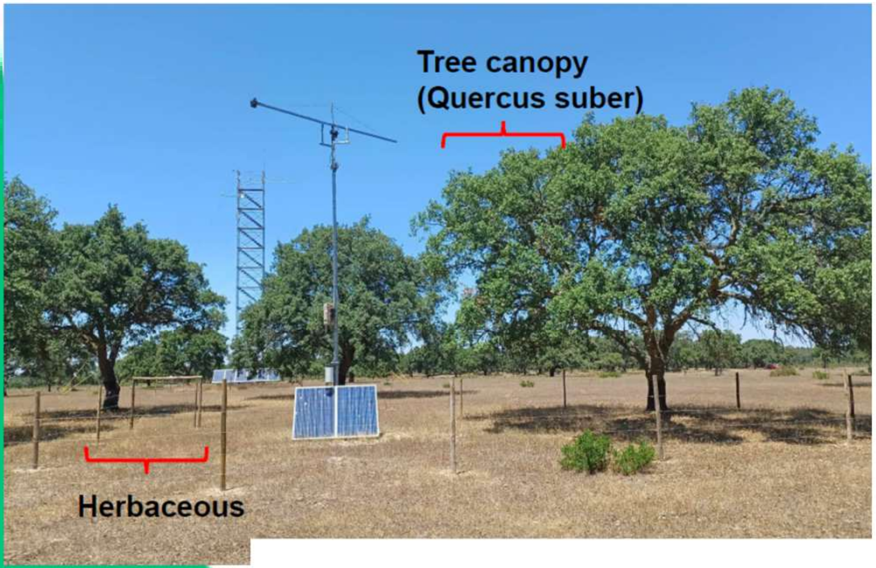
Bare fibers (2x)
- downward looking (10º degree field of view) → **where the measurements came from!**

Energy supply
- Solar panel
- Battery

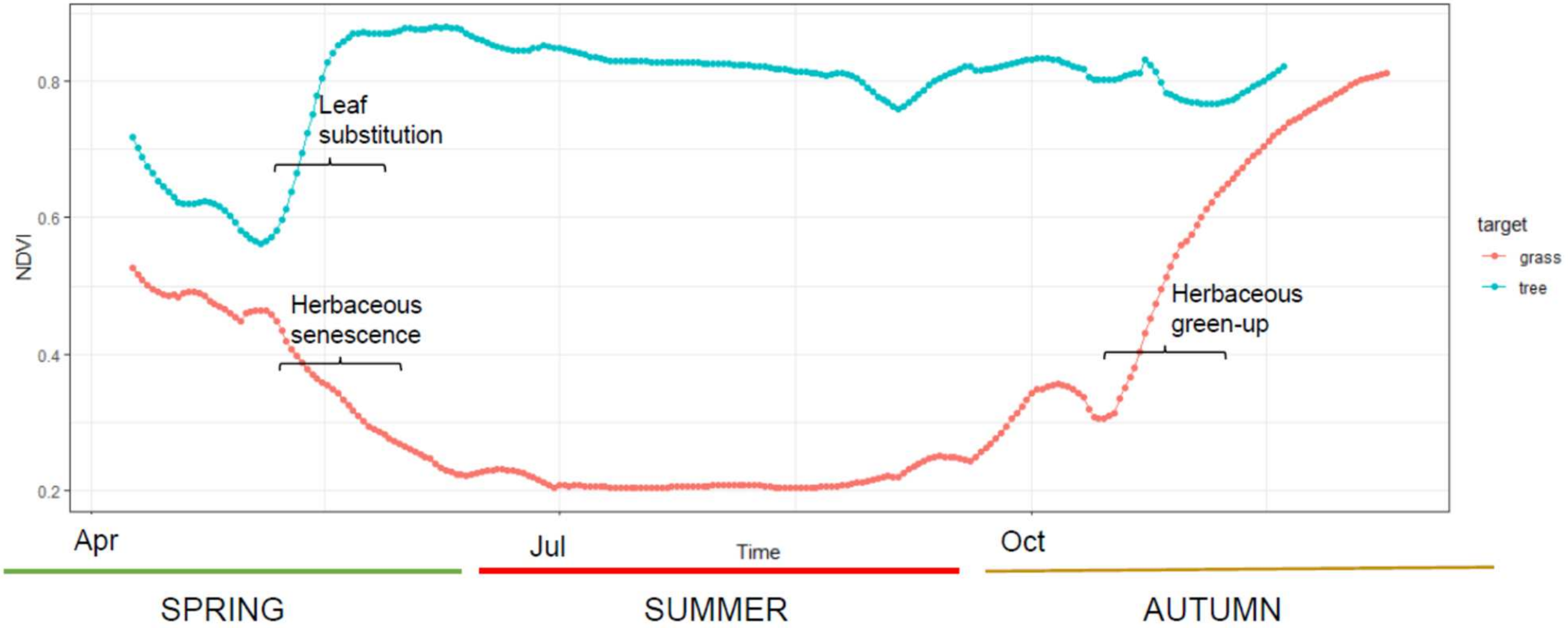
FLOX

IN- SITU SPECTRAL SENSOR

Two high resolution spectroradiometers measure **SIF (A and B)** and reflectance of vegetation (**NDVI, RedCI, PRI)** continuously from 9h to 18h. Nadir view or limited tilt angle.



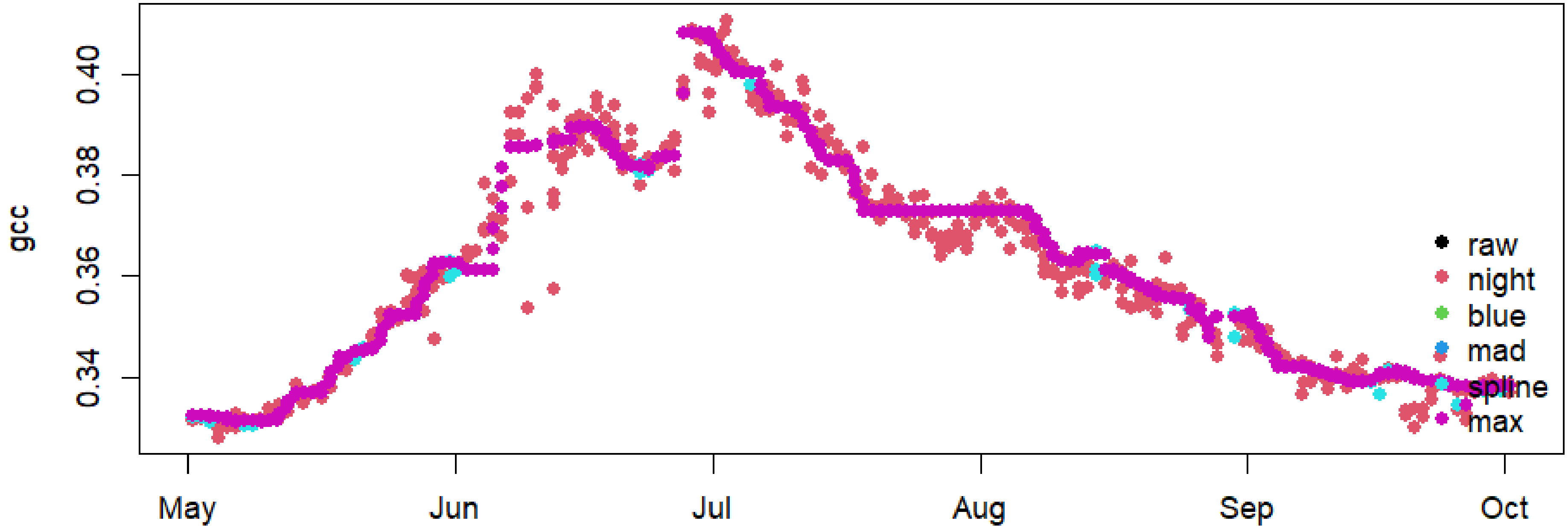
CORK OAK CANOPY



NDVI time series of cork oak (green) and grass (pink) measured by a ground spectral sensor (only midday data)

- THE DATA FILTER, THE FITTING METHODS AND THE EXTRACTION OF PLANT TRANSITION DATES (PTD) IN PHENOPIX

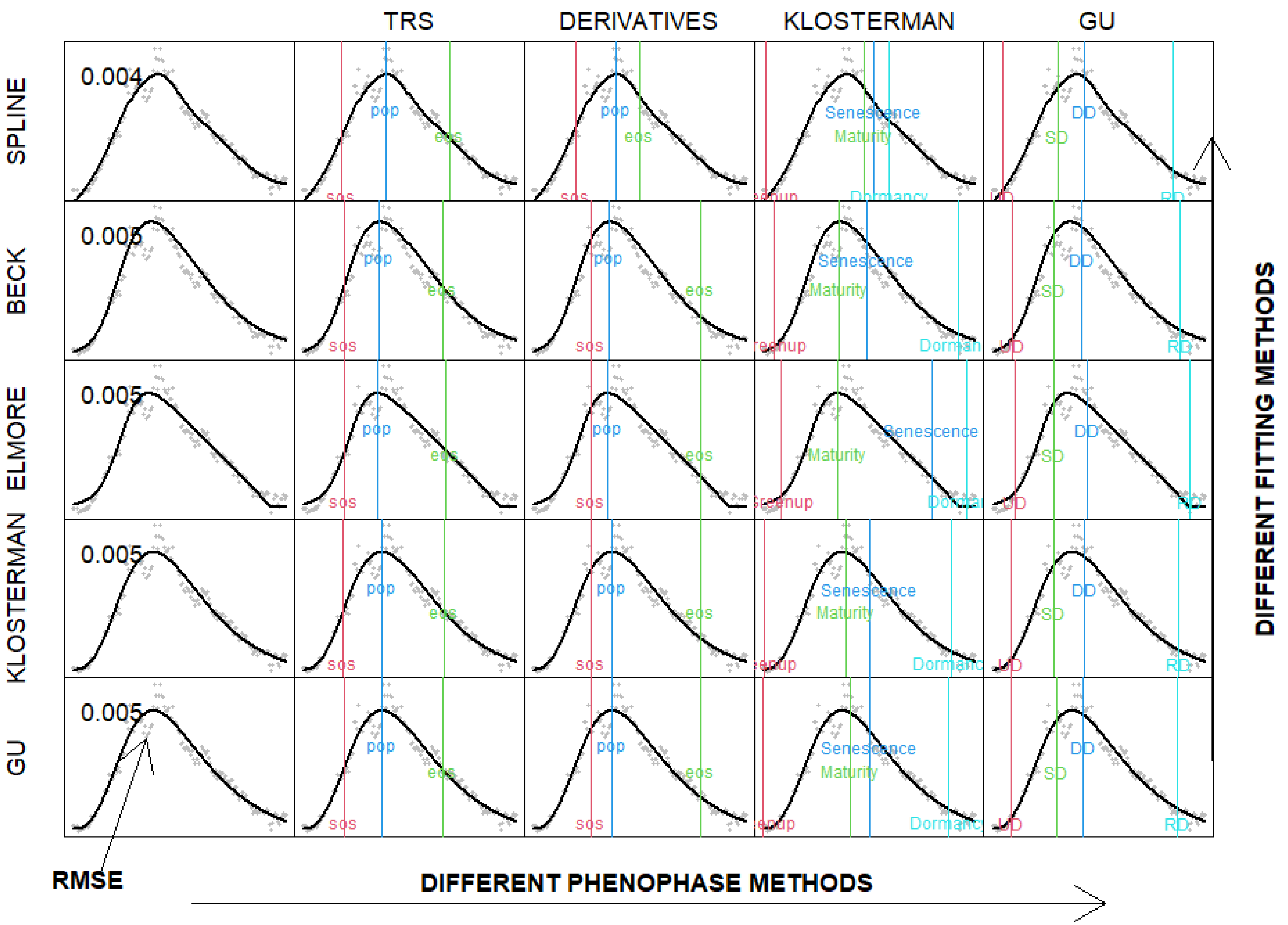
LECTURE 2 – PRACTICE – 25/05/2026



5 different filters available:

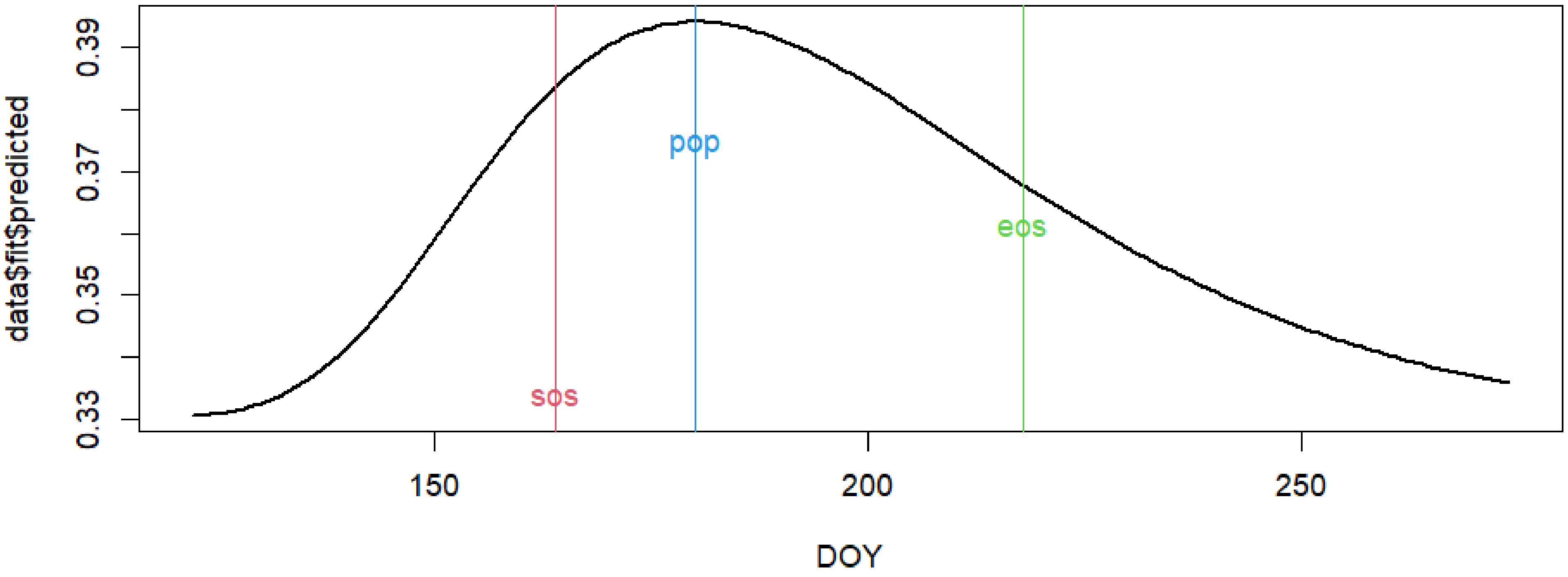
1) **night** - removes records with very low GCC (default = 0.2), considered night data or cloudy days
2) **blue** - sensitive to snow, very aggressive.
3) **mad** - absolute deviation form the median, robust outlier estimator
4) **spline** – recursive spline smoothing and removal of outliers
5) **max** – 90th percentile in 3-days moving windows. Minimize the impact changes in scene illumination

3. DATA FILTER -autofilter



4. EXPLORE DIFFERENT METHODS FOR FITTING AND PTD

greenExplore - compares visually and by RMSE different methods



5 methods for fittings: 4 double logistic (**Gu**, **Klosterman**, **Elmore** and **Beck**) and the **spline** method

4. FIT A TREND

- green Process

5. EXTRACT PHENOLOGICAL DATES-1

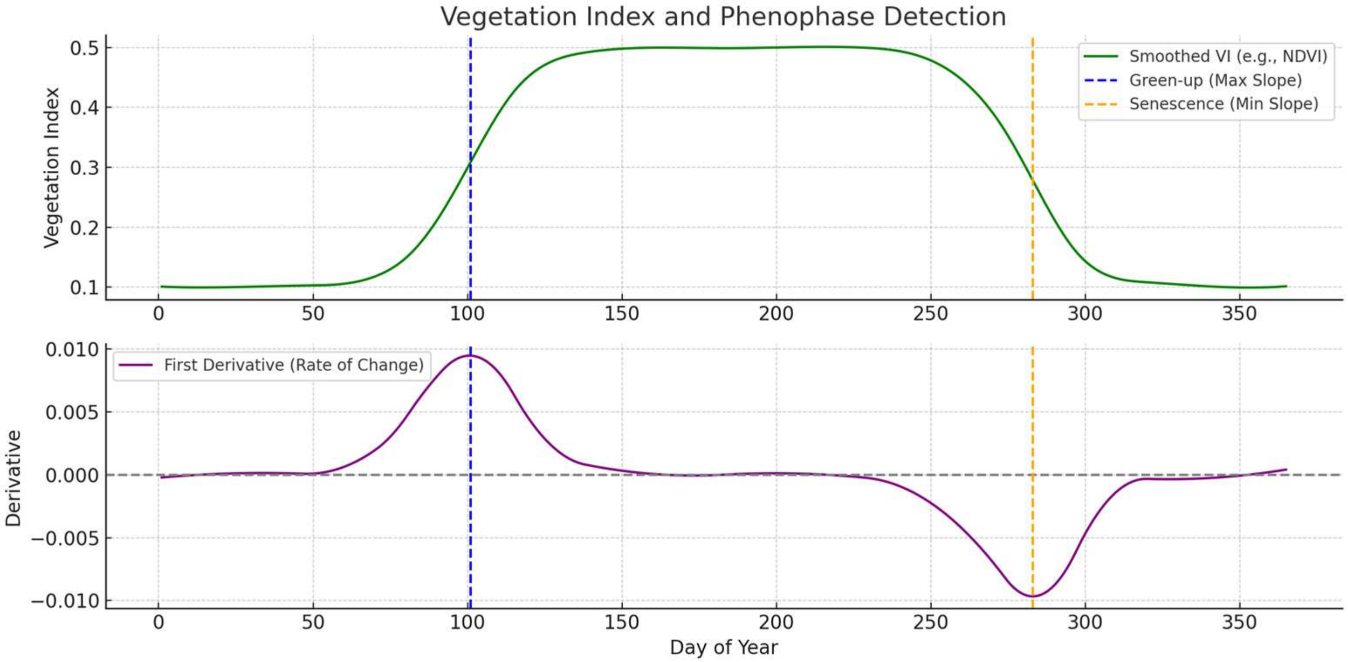
- 4 methods for extracting PTD:

1.**TRS** fixed threshold (50%) of GCC for both SOS and EOS

2.**DERIVATIVES:** the first derivative of the fitting curve

green-up onset, point where the first derivative is at its maximum in spring (the steepest positive slope)

senescence onset: point where the 1st derivative is at its minimum in fall (the steepest downward slope)



6. EXTRACT PHENOLOGICAL DATES-2

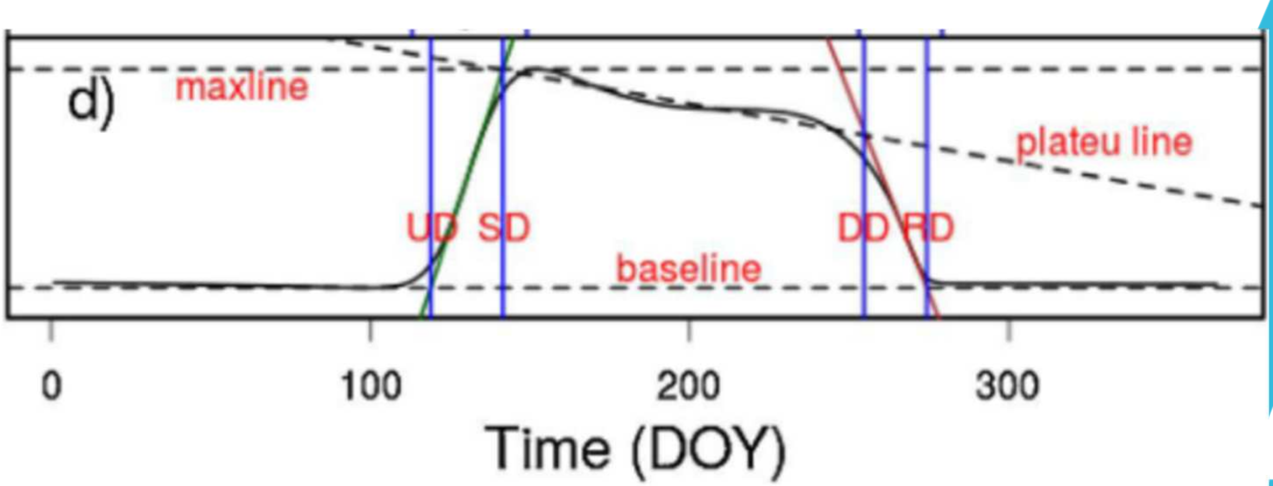
3.KLOSTERMAN define 4 transition date based on the rate of change of the curvature of the trendline

Green-Up - Maturity - Senescence - Dormancy

4. GU

Phenophases are determined based on the intersection between the slope, baseline and max line

UD: Upturn date (beginning of the growing season)
SD: Stabilization date (peak of productivity)
DD: Downturn date (beginning of senescence)
RD: Recession date (dormancy period)



Readings lecture 2:

Zartash, F., Ahmed, M., Hussain, M., Abbas, G., Ul-Allah, S., Ahmad, S., Ahmed, N., Ali, M. A., Sarwar, G., Ul Haque, E., Iqbal, P., and Hussain, S., 2020: The fingerprints of climate warming on cereal crops phenology and adaptation options, Scientific Reports |, 10, 18013, https://doi.org/10.1038/s41598-020-74740-3

Fu, Y. H., Zhao, H., Piao, S., Peaucelle, M., Peng, S., Zhou, G., Ciais, P., Huang, M., Menzel, A., Peñuelas, J., Song, Y., Vitasse, Y., Zeng, Z., and Janssens, I. A., 2015 Declining global warming effects on the phenology of spring leaf unfolding, Nature, https://doi.org/10.1038/nature15402.

Kudo, G. and Ida, T. Y.: Early onset of spring increases the phenological mismatch between plants and pollinators, 2013, Ecology, 94, 2311–2320, https://doi.org/10.1890/12-2003.1

Moore, C. E., Beringer, J., Donohue, R. J., Evans, B., Exbrayat, J. F., Hutley, L. B., and Tapper, N. J.: Seasonal, interannual and decadal drivers of tree and grass productivity in an Australian tropical savanna, Glob Chang Biol, 24, 2530–2544, https://doi.org/10.1111/gcb.14072.

Piao, S., Liu, Q., Chen, A., Janssens, I. A., Fu, Y., Dai, J., Liu, L., Lian, X., Shen, M., and Zhu, X., 2019 : Plant phenology and global climate change: Current progresses and challenges, Glob Change Biol, 25, 1922–1940, https://doi.org/10.1111/gcb.14619