Is ground-based phenology of deciduous tree species consistent with the temporal pattern observed from Sentinel-2 time series?

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What is phenology and why it may be useful?

- Annual cycle of the vegetation
- Different behaviours according to tree species
- Enhance tree species recognition
- Follow climate evolution
Annual phenological cycle

- Budset
- Budburst
- Leaf coloring and falling
- Branches bare
Annual phenological cycle
Annual phenological cycle
Annual phenological cycle
Research questions

1. Is Sentinel-2 time series able to identify tree species?

2. What is the consistency between the phenology observed in-situ and the one observed from S2 time series?
Study site

- Extent of 25x25km (Subset of Sentinel-2)
- Most of the site is composed of crops and small private forests
- Temperate mixed forest, less than 10% (54km²) of the landcover
Data / Images

Sentinel-2 Time Series, T31TCJ tile, Level 2A\(^1\): 

- 37 images, from 26 January 2017 to 27 December 2017
- Temporal resampling every 5 days

\[^1\text{Hagolle et al. 2015}\]

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
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<tbody>
<tr>
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<td></td>
</tr>
</tbody>
</table>

Clouds
- >80% or NA
- 60 to 80%
- 40 to 60%
- 20 to 40%
- <20%
## Tree species survey

1 sample = 1 pixel of Sentinel-2

<table>
<thead>
<tr>
<th>Species</th>
<th>Samples</th>
<th>Forest stands</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Broadleaf</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silver birch (<em>Betula pendula</em>)</td>
<td>64</td>
<td>3</td>
</tr>
<tr>
<td>Oak (<em>Quercus robur/pubescens/petraea</em>)</td>
<td>248</td>
<td>12</td>
</tr>
<tr>
<td>Red Oak (<em>Quercus rubra</em>)</td>
<td>209</td>
<td>7</td>
</tr>
<tr>
<td>European ash (<em>Fraxinus excelsior</em>)</td>
<td>130</td>
<td>4</td>
</tr>
<tr>
<td>Aspen (<em>Populus tremula</em>)</td>
<td>139</td>
<td>4</td>
</tr>
<tr>
<td>Black Locust (<em>Robinia pseudoacacia</em>)</td>
<td>88</td>
<td>6</td>
</tr>
<tr>
<td>Willow (<em>Salix alba</em>)</td>
<td>52</td>
<td>6</td>
</tr>
<tr>
<td>Eucalyptus (<em>Eucalyptus spp.</em>)</td>
<td>143</td>
<td>7</td>
</tr>
<tr>
<td><strong>Conifers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corsican Pine (<em>Pinus nigra subsp. Laricio</em>)</td>
<td>201</td>
<td>4</td>
</tr>
<tr>
<td>Maritime Pine (<em>Pinus pinaster</em>)</td>
<td>186</td>
<td>6</td>
</tr>
<tr>
<td>Black Pine (<em>Pinus nigra</em>)</td>
<td>52</td>
<td>2</td>
</tr>
<tr>
<td>Silver fir (<em>Abies alba</em>)</td>
<td>53</td>
<td>3</td>
</tr>
<tr>
<td>Douglas fir (<em>Pseudotsuga menziesii</em>)</td>
<td>72</td>
<td>8</td>
</tr>
<tr>
<td>Cypress (<em>Cupressus</em>)</td>
<td>42</td>
<td>1</td>
</tr>
</tbody>
</table>

Total: 1682 pixels
Data / Phenological survey

Since septembre 2017: **10-days revisit** of 14 plots (2 plots per species)

- **Phenological stage** (using standard BBCH-scale\(^1\))
- **Canopy Cover** computed with fisheye\(^2\)
  - Application GLAMA for Android
  - 230° Fisheye for smartphone devices
- **Chlorophyll measure** with SPAD
- Existence of the understory vegetation

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1 Badeau et al. 2017
2 Tichy L, Collins B. 2016
Stage 0
Awakening

BBCH 00: sleep
BBCH 05: bud swell

Stage 1
Leaves coming out

BBCH 12: 20%
BBCH 17: 70%

Stage 9
Leaves coloring/falling

BBCH 92: 20%
BBCH 97: 70%

BBCH 09: bud burst

Stage 3
Leaves growing

BBCH 32: 20% full size
BBCH 37: 70%
Quercus palustris

Quercus pubescens
Stage 1
Leaves coming out

BBCH = 15
Quercus palustris

BBCH = 18
Quercus pubescens

15: 50%
18: 80%
Methodology / 1 Classification

- Preprocessing: Gap-filling on detected clouds using linear interpolation
- Supervised classification:
  - SVM with RBF Kernel (hyperparameters fixed by cross-validation)
  - Cross-validation: Spatial Leave-One-Out (SLOO)¹ to limit spatial autocorrelation

¹ Le Rest et al. 2014
Methodology / Sampling references for classification

Spatial Leave-One-Out\(^1\) sampling.

\(^1\) Le Rest et al. 2014.
Methodology / Sampling references for classification

Spatial Leave-One-Out\(^1\) sampling.

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Methodology / Sampling references for classification

Spatial Leave-One-Out\(^1\) sampling.

\(^1\) Le Rest et al. 2014.

Using Moran’s Index to compute autocorrelation distance
Median value from all bands
Methodology / Sampling references for classification

Spatial Leave-One-Out\(^1\) sampling.

\(^1\) Le Rest et al. 2014.
Methodology / Sampling references for classification

Spatial Leave-One-Out¹ sampling.

¹ Le Rest et al. 2014.
Methodology / Sampling references for classification

Spatial Leave-One-Out\(^1\) sampling.

\(^1\) Le Rest et al. 2014.
Methodology / Sampling references for classification

Spatial Leave-One-Out\(^1\) sampling.

Validation pixel \(\downarrow\)

Training pixels

Repeated as many times as the number of samples in the least populated class.

Here 42 times (i.e. number of samples of cypress)

\(^1\) Le Rest et al. 2014.
Methodology / ② Phenology

- Smoothing with Double logistic\textsuperscript{1,2} using NDVI (+ 0.05 in R band)
- Seasonal amplitude for Start Of Season : 10\%\textsuperscript{3}
- Seasonal amplitude for End Of Season : 90\%
  - Objective is to find the time where all leaves fell/colored.
- Comparison with ground survey

\textsuperscript{1} Yang and Zhang (2012)  
\textsuperscript{2} Tan et al. (2010)  
\textsuperscript{3} Jönsson and Eklundh (2002)
Results
Results

1. Tree species classification

Phenology from ground survey (14 plots)

2. Phenology computed from NDVI (930 references, 7 species)
### Results / Species classification

#### Spatial Leave-One-Out (SLOO)

<table>
<thead>
<tr>
<th>True label</th>
<th>Silver birch</th>
<th>Oak</th>
<th>Red oak</th>
<th>Aspen</th>
<th>European ash</th>
<th>Black locust</th>
<th>Willow</th>
<th>Eucalyptus</th>
<th>Corsican pine</th>
<th>Maritime pine</th>
<th>Black pine</th>
<th>Silver fir</th>
<th>Douglas fir</th>
<th>Cypress</th>
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<td>0</td>
<td>9</td>
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<td>0</td>
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<td>21</td>
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<td>0</td>
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<td>0</td>
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<td>40</td>
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<td>Silver fir</td>
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<td>0</td>
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<td>0</td>
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<td>90</td>
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<tr>
<td>Douglas fir</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>19</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>73</td>
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<tr>
<td>Cypress</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>95</td>
<td>0</td>
<td>97</td>
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</tbody>
</table>

#### 77% kappa

(Positive Classification)
Results / Species classification

77% kappa using Spatial Leave-One-Out (SLOO)
Tree species map
with Spatial Leave-One-Out

- Green: Oak
- Red: Red oak
- Tan: Silver birch
- Light green: European ash
- Brown: Black locust
- Yellow: Aspen
- Light yellow: Willow
- Light green: Eucalyptus
- Purple: Corsican pine
- Magenta: Maritime pine
- Blue: Black pine
- Dark blue: Douglas fir
- Light blue: Silver fir
- Teal: Cypress
Tree species map with Spatial Leave-One-Out

Silver birch
Black pine
Douglas fir
Silver fir

Legend:
- Oak
- Red oak
- Silver birch
- European ash
- Black locust
- Aspen
- Willow
- Eucalyptus
- Corsican pine
- Maritime pine
- Black pine
- Douglas fir
- Silver fir
- Cypress

IGN - ORTHO-SAT® SPOT 6/7 2017
Tree species map with Spatial Leave-One-Out

- Green: Oak
- Red: Red oak
- Light brown: Silver birch
- Yellow: European birch
- Blue: Douglas fir
- Purple: Corsican pine
- Pink: Black pine
- Olive green: Black locust
- Burgundy: Black locust
- Yellow: Aspen
- Light green: Willow
- Pale green: Eucalyptus

150m
Fern is growing at the same time as the canopy.
Fern is growing at the same time as the canopy.
Results / 2 Phenology / Silver birch (plot n°1)
Results / 2 Phenology / Silver birch (plot n°1)

- **Beginning of leaf falling or colouring**: 90% of leaves still on tree
- **Still 20% leaves on tree**
- **No more leaves**
- **Budburst**: Start Of Season
- **All leaves are out**

**NDVI**

**CACO / Leaves fall / Leaves out (%)**

**NDVI**

**CACO / Leaves fall / Leaves out (%)**

**NDVI**

**CACO / Leaves fall / Leaves out (%)**

**NDVI**

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**NDVI**

**CACO / Leaves fall / Leaves out (%)**

**NDVI**

**CACO / Leaves fall / Leaves out (%)**

**NDVI**

**CACO / Leaves fall / Leaves out (%)**
Results / Phenology / Silver birch (plot n°1)

- **Beginning of leaf falling or colouring:** 90% of leaves still on tree
- **Still 20% leaves on tree**
- **No more leaves**
- **Budburst**
- **Start Of Season**
- **All leaves are out**

**NDVI**

**CACO / Canopy Cover (%)**

- **NDVI**
- **0.0** to **1.0**
- **CACO / Leaves fall / Leaves out (%)**
- **0.0** to **100.0**
Results / ② Phenology / Black locust (plot n°2)
Results / 2 Phenology / Black locust (plot n°2)

- **Beginning of leaf falling or colouring**: 90% of leaves still on tree
- **All leaves are out**
- **Still 20% leaves on tree**
- **No more leaves**
- **Budburst Start Of Season**
- **NDVI**

**Graph Details**:
- NDVI axis (y-axis): 0.0 to 1.0
- CACO / Leaves fall / Leaves out (%) axis (x-axis)
- Data points from 2017-09 to 2018-06
Results / 2 Phenology / Black locust (plot n°2)

<table>
<thead>
<tr>
<th>Event</th>
<th>Timeline</th>
<th>NDVI</th>
<th>CACO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budburst</td>
<td>Start Of Season</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beginning of leaf falling or colouring</td>
<td>90% of leaves still on tree</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No more leaves</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All leaves are out</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **NDVI** represents the Normalized Difference Vegetation Index, which is used to assess the health of vegetation.
- **CACO** measures the percentage of leaves out, indicating the stage of leaf fall or outgrowth.

The graph illustrates the progression of these events over the period from 2017-09 to 2018-06.
Results / 2 Phenology / Black locust
Results / ② Phenology from SITS (n = 980)
Results / Phenology from SITS (n = 980)
Red oak plantation
Aspen plantation

Start Of Season
- 02/05
- 03/02
- 03/27

End Of Season
- 09/18
- 11/07
- 12/27
Conclusion... and beyond

1. Classification, high potential but:
   - Importance of spatial autocorrelation (77% kappa Vs 97%)
   - Mixed effects with the *understory* vegetation (*Helman 2018*)
   - Unexpected high accuracy for several *conifer species* (F1>90%)
   - Inconsistency with previous results (S2 versus Formosat-2, *Sheeren et al. 2016*)

2. Phenology:
   - High influence of *understory vegetation* (changing the phenological cycle)
   - Consistent with ground survey, except Red oak
   - Need to finish year 2018 to have a full vegetation cycle and SOS validation.
Presented by Nicolas Karasiak
Thanks for listening

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97% ± 0
kappa
using
50% random sampling
\[ I = \frac{N}{W} \frac{\sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2} \]
Silver birch

Oak

NDVI (+0.05 in red)
mean ± std
**NDVI** (+0.05 in red)  
mean ± std

- **European ash**
- **Black locust**
- **Oak**