Monitoring and understanding the green-leaf phenology of tree species with Sentinel-2

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**Context: why phenology may be useful?**

**Phenology**

- annual cycle of the vegetation
- Different behaviours according to tree species

**Taking phenology into account may:**

- enhance tree species recognition
- and thus enable faster and cheaper updates for the current forest map of France (IGN BD Forêt ®)
Phenology cycle

- Budset
- Budburst
- Leaf colouring and falling
- Branches bare
Phenology cycle
Phenology cycle

- Winter
- Budset
- Budburst
- Spring
- Leaf colouring and falling
- Branches bare
- Summer
- Autumn
- Fall
Phenology cycle
State of the art

Tree species classification from image time series (SITS)
Old question but only few works because of lack of dense SITS

- Elatawneh et al. (2013), Rapideye, 7 species (3 deciduous and 4 coniferous) : OA 86%
- Sheeren et al. (2015), Formosat-2, 13 species classification in South West of France : kappa 92 %
- Clark et al. (2018) , Landsat, 16 species classification in California : kappa 67 %

Use of SITS to analyze phenology
High potential but most of the studies are based on MODIS (or Landsat)

- Fisher & Mustard (2007) : Landsat and Modis, $r^2 = 0.60$
- Liang et al. (2010) : identify phenology with less than 2 days error with MODIS
Due to increased information on phenology, dense series of multitemporal, multispectral Landsat-8 and Sentinel-2 data can serve as a good basis for the mapping of forest composition at national scales, considering major tree species typically occurring in temperate and boreal ecosystems.

Fassnacht et al., 2016¹

Research questions

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

- Is spectral and temporal reflectance of S2 strong enough to identify species?
Study site

- Historical extent of a Formosat-2 tile (25x25km)
- Most of the site is composed of crops and small private forests
- Forest represents less than 10% (54km²) of the landcover
Data / Images

Sentinel-2 Time Series, T31TCJ tile, 16 dates:
- from 29th August 2017 to 21st May 2018

Less 50% clouds, Level 2A\(^1\), from Theia.

\(^1\)Hagolle et al. 2015
### Data / 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>252</td>
<td>13</td>
</tr>
<tr>
<td>Red Oak (<em>Quercus rubra</em>)</td>
<td>211</td>
<td>7</td>
</tr>
<tr>
<td>European ash (<em>Fraxinus excelsior</em>)</td>
<td>135</td>
<td>3</td>
</tr>
<tr>
<td>Aspen (<em>Populus tremula</em>)</td>
<td>205</td>
<td>6</td>
</tr>
<tr>
<td>Black Locust (<em>Robinia pseudoacacia</em>)</td>
<td>96</td>
<td>8</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>146</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>215</td>
<td>5</td>
</tr>
<tr>
<td>Maritime Pine (<em>Pinus pinaster</em>)</td>
<td>196</td>
<td>8</td>
</tr>
<tr>
<td>Black Pine (<em>Pinus nigra</em>)</td>
<td>53</td>
<td>2</td>
</tr>
<tr>
<td>Silver fir (<em>Abies alba</em>)</td>
<td>71</td>
<td>6</td>
</tr>
<tr>
<td>Douglas fir (<em>Pseudotsuga menziesii</em>)</td>
<td>67</td>
<td>8</td>
</tr>
<tr>
<td>Cypress (<em>Cupressus</em>)</td>
<td>46</td>
<td>1</td>
</tr>
</tbody>
</table>

Total: 1809 pixels
Data / Phenological survey

Since septembre 2017 : 10-days revisit of 14 plots (2 per deciduous 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
- State of the substory vegetation

\(^1\) Badeau et al. 2017
\(^2\) Tichy L, Collins B. 2016
**Stage 0**
Awakening

**Stage 1**
Leaves coming out

**Stage 9**
Leaves colouring/falling

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**BBCH 00**: sleep

**BBCH 05**: bud swell

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**Stage 0**
Awakening

**Stage 1**
Leaves coming out

**Stage 9**
Leaves colouring/falling

---

**BBCH 09**: bud burst

**BBCH 12**: 20%

**BBCH 17**: 70%

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**BBCH 92**: 20%

**BBCH 97**: 70%

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**BBCH 32**: 20% full size

**BBCH 37**: 70%
November 11, 2017

April 20, 2018

Quercus palustris

BBCH = 15

Quercus pubescens

BBCH = 18

May 5, 2018
Methodology / 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 autocorrelation

- SLOO compared with Random selection (RS\(^50\)) for training/validating (50/50)

\(^1\) 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.
Methodology / Sampling references for classification

Spatial Leave-One-Out¹ sampling.

Using Moran’s Index to compute autocorrelation distance

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

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

Validation pixel

Spatially correlated pixels

Using Moran’s Index to compute autocorrelation distance

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

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

\(\text{Validation pixel} \quad \text{Spatially correlated pixels} \)

Using Moran’s Index to compute autocorrelation distance

\(^1\) 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\textsuperscript{1} sampling.

\textsuperscript{1} Le Rest et al. 2014.
Methodology / Classification

Hierarchical Classification on 3 levels

1. Broadleaf
   - Deciduous
     - Oak, Aspen, Willow, European ash
   - Eucalyptus

2. Conifer
   - Evergreen
     - Corsican Pine, Maritime Pine, Black Pine
   - Pine
   - Others
     - Douglas fir, Silver fir, Cypress
Results
95% ±1 kappa when using standard random sampling (RS50)
55% ±12 kappa when using Spatial Leave-One-Out (SLOO)
Results / SLOO + Hierarchical Classification

Kappa (%)

93 (+/- 25)
95 (+/- 21)
82 (+/- 38)
68 (+/- 17)
100
95 (+/- 14)
88 (+/- 23)

Level 1

Trees

Broadleaf

Conifer

Deciduous

Evergreen

Pine

Others

Oak  Aspen  Willow  European ash
Black locust  Silver birch  Red oak
Eucalyptus
Corsican Pine  Maritime Pine  Black Pine
Douglas fir  Silver fir  Cypress
Results / SLOO + HC / level 1

93% ±25

kappa

when using
Spatial Leave-One-Out (SLOO) +
Hierarchical classification
Results / SLOO + HC / level 1 (explained with species)

93% ± 25 kappa
when using Spatial Leave-One-Out (SLOO) + Hierarchical classification
Results / SLOO + HC / level 3

76% kappa when using Spatial Leave-One-Out (SLOO) + Hierarchical classification
Hierarchical Classification
Spatial Leave-One-Out
Level 3

- Oak
- Red oak
- Silver birch
- European ash
- Black locust
- Aspen
- Willow
- Eucalyptus
- Corsican pine
- Maritime pine
- Black pine
- Douglas fir
- Silver fir
- Cypress
Hierarchical Classification
Spatial Leave-One-Out
Level 3

- Oak
- Red oak
- Silver birch
- European ash
- Black locust
- Aspen
- Willow
- Eucalyptus
- Corsican pine
- Maritime pine
- Black pine
- Douglas fir
- Silver fir
- Cypress
Hierarchical Classification
Spatial Leave-One-Out
Level 3

- Silver birch
- Black pine
- Douglas fir
- Silver fir
- Silver birch
- European ash
- Black locust
- Aspen
- Willow
- Eucalyptus

IGN - ORTHO-SAT ® SPOT 6/7 2017
Hierarchical Classification
Spatial Leave-One-Out
Level 3

- Silver birch
- Black pine
- Douglas fir
- Silver fir

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

150m scale
Results / Phenology / Silver birch

- **NDVI**
  - Beginning of leaf falling or colouring
  - 90% of leaves still on tree

- **CACO (Canopy Cover)**
  - Still 20% leaves on tree
  - No more leaves
  - All leaves are out

- Budburst
  - Start Of Season

<table>
<thead>
<tr>
<th>Year</th>
<th>NDVI</th>
<th>CACO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-09</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2017-10</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2017-11</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2017-12</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2018-01</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2018-02</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2018-03</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2018-04</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2018-05</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2018-06</td>
<td>0.8</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Results / Phenology / Silver birch

- **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)**
Results / Phenology / Silver birch

- **NDVI:**
  - Beginning of leaf falling or colouring
  - 90% of leaves still on tree

- **Caco (Canopy Cover):**
  - Still 20% leaves on tree
  - No more leaves

- **Results / Phenology:**
  - Silver birch
  - CACO / Leaves fall / Leaves out (%)

- **Graph:**
  - NDVI and Caco (Canopy Cover) over time from 2017-09 to 2018.
NDVI

Budburst
Start Of Season

CACO / Leavesfall / Leaves out (%)

Results

Still 20% leaves on tree
No more leaves

40
20
0


0.0 0.2 0.4 0.6

NDVI
Results / Phenology / Black locust

- **Beginning of leaf falling or colouring**: 90% of leaves still on tree
- **No more leaves**: Still 20% leaves on tree
- **NDVI**
- **CACO**

- **Budburst**: Start Of Season
- **All leaves are out**

The graph shows the progression of leaf fall and the NDVI and CACO readings over time from 2017-09 to 2018-06.
Results / Phenology / Black locust

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

### Graph Details

- **NDVI**
- **CACO**

**Axes**:
- **NDVI**
- **CACO / Leaves fall / Leaves out (%)**

**Time Periods**:
- **2017-09** to **2018-06**
Results / Phenology / Black locust

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

- **CACO**
  - Start Of Season
  - Leaves out (%)

- **Results**
  - Black locust phenology
NDVI / CACO

- Beginning of leaf falling or colouring
- 90% of leaves still on tree

Budburst

Start Of Season

CACO / Leaves fall / Leaves out (%)

- All leaves are out

NDVI

- 2017-09: 0.0
- 2017-10: 0.0
- 2017-11: 0.0
- 2017-12: 0.0
- 2018-01: 0.0
- 2018-02: 0.0
- 2018-03: 0.0
- 2018-04: 0.0
- 2018-05: 0.0
- 2018-06: 0.0

C

A

C

O / Leaves fall / Leaves out (%)
Conclusion… and beyond

Classification:
- Importance of the spatial cross-validation method
- **Spatial autocorrelation** can really **overestimate quality** (because of sampling bias)
- Better results and comprehension of mistakes with Hierarchical Classification

Phenology:
- Need to finish year 2018... with less clouds please !
- Need to study **substory vegetation effect** (e.g. in identification of SOS/EOS)
Presented by Nicolas Karasiak
Thanks for listening

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