Wall-to-wall NFI Products of Switzerland: Forest Cover and Forest Type Maps

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Our remote sensing group works on countrywide products for the Swiss NFI

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Remote Sensing Laboratories University of Zurich
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- Background, user demands, state-of-the-art

- Countrywide products of the Swiss NFI
  - Remote sensing and reference data
  - Approaches, products, challenges
    - => Forest Cover
    - => Forest Type

- Conclusions
High demand on countrywide map products

**Forestry sector:**
- Management
- Renewable energy source
- Protection etc.

**Beyond forestry sector:**
- Biodiversity
- Nature conservation
- Topographic maps etc.

What is expected by the user?

- **High expectations** on countrywide maps
- **What input data** are available? (remote sensing data, reference data)
- **Continuity** of these data sets (regular updating?)
- **What level of detail?** (individual tree, plot, stand level)
- **What maps are required** (forest cover, tree type, biomass etc.)?

=> Need of spatial products for operational NFI applications
What is given by the researcher?

- In the last 40 years, **advances in remote sensing technologies** (new sensors, 3D point clouds, machine & deep learning etc.)
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- However, (only) recently from case study to countrywide level
What is given by the researcher?

- In the last 40 years **advances in remote sensing technologies** (sensors, 3D point clouds, machine & deep learning etc.)
- However, (only) recently from case study to countrywide level
- **Gap** between research and practice: optimal conditions versus operational constraints => difficult to implement

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Is countrywide mapping of forest attributes feasible?

Typical for mountain areas

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Countrywide mapping approaches for Switzerland (41'285 km²)

**Concept**
- Focus on open / free remote sensing data
- Existing training / reference data
- Open software (R)
- High degree of automation
- Maps public available

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Remote sensing data of Switzerland

- ADS80/120 sensor with 10-20 cm RGBI aerial imagery – updated every 6 years by Swiss Federal Office of Topography
- LiDAR with ~0.5–40 points/m² (2001-15), since 2017 full-wave

- Sentinel-2 (1C/2A, 10 bands), 10-20 m, 5-7 days
- Sentinel-1 C-band SAR ~10 m, 2-3 days
Training / reference data

- **Swiss National Forest Inventory (NFI)**
  2-phases sample-based survey, continuously visited (9 year cycle) on a 1.4km regular grid
  - Aerial stereo-image interpretation (tree height, forest decision, land cover)
  - Terrestrial surveys

- Individual mapping (field surveys, forest stand maps)

- Other existing inventories / programs in Switzerland
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Products / wall-to-wall maps

1) Vegetation height model
2) Forest cover map
3) Forest cover change map
4) Tree type map
5) Above ground tree biomass map

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1) Vegetation Height Model (VHM)*

- 1 m spatial resolution, continuous updating
- DSM: Image-based point clouds from ADS80/120 RGBI stereo-images
- LiDAR DTM
- nDSM = DSM – DTM
- Buildings removed

2) Forest cover map*

- Highly automated workflow, 1 m spatial resolution

- **Full implementation of Swiss NFI forest definition** (4 criteria):
  - Minimum tree height (>3m)
  - Crown coverage (20%)
  - Width (25m)
  - Land use

⇒ Land use criterion difficult to obtain from mono-temporal remotely sensed data (time series needed)

*Waser, L.T. et al., 2015. Wall-to-wall forest mapping based on DSMs from image-based point clouds and a NFI forest definition. Forests 6: 4510-4528
Forest cover map: Workflow

*Waser, L.T. et al., 2015. Wall-to-wall forest mapping based on DSMs from image-based point clouds and a NFI forest definition. Forests 6: 4510-4528

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Land use criterion

Temporary unstocked area within the forest

Vegetation height < 3m

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Accuracy assessment

- Validation with NFI sample plot data (n = 9984):
  - Switzerland: 0.97 (OA); 3.8% (EO); 10.1% (EC)
- Problems: Theoretical vs. expected forest edge

*Waser, L.T. et al., 2015. Wall-to-wall forest mapping based on DSMs from image-based point clouds and a NFI forest definition. Forests 6: 4510-4528

**Errors of omission (EO) commission (EC)
3) Forest cover change map*

- Adaptive multi-scale approach using image-based point clouds from ADS80 stereo-imagery of different years*

4) Tree type maps*

- Distinction of broadleaved / coniferous trees at 3-10m
- Training data: digitized tree crowns, validated with (independent) NFI plot data
- Highly automated workflow using Random Forest (RF) in R

Workflow with 5 main steps

1. RS data
   - Pre-processing
   - Variables
   - Layer stack

2. Reference data
   - Checking Δ time

3. Sentinel-1
4. Sentinel-2
5. ALS DTM
6. VHM

Processing steps:
1) Remote sensing data collection
2) Reference data collection
3) Classification algorithm selection
4) Validation process
5) Tree species classification

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Workflow with 5 main steps

2. Reference data

Pixel values to Reference data

Splitting into subsets

Variable selection

RF, SVM, LRM

Deep learning

Cross-validation

Cross-validation

Final classification

Independent validation

Tree species map

Processing steps:
1) Remote sensing data collection
2) Reference data collection
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Workflow with 5 main steps

1. Reference data
   - Sentinel-1
   - Sentinel-2
   - ALS DTM
   - VHM
   - ADS80/100
   - Pre-processing
     - Variables
     - DTM variables
     - Height classes
   - Layer stack
   - Pixel values to Reference data
     - Splitting into subsets
     - Variable selection
     - RF, SVM, LRM
     - Deep learning
       - Cross-validation
       - Final classification
     - Independent validation

2. Countrywide tree type mapping

3. Classification

Processing steps:
1) Remote sensing data collection
2) Reference data collection
3) Classification algorithm selection
4) Validation process
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Testing in 5 representative regions

- Derivation of variables (ADS, Sentinel-1 / 2, ALS, Indices)
- Classification algorithms
Workflow with 5 main steps

1. Reference data
   - Sentinel-1
   - Sentinel-2
   - ALS DTM
   - VHM

2. Pre-processing
   - Variables
   - Variables
   - DTM variables
   - Height classes

3. Layer stack
   - Pixel values to Reference data
   - Splitting into subsets
   - Variable selection

4. Validation
   - Independent validation
   - Tree species map
   - Testing

5. Final Map
   - Countrywide tree type mapping
1st Approach: broadleaved / coniferous trees

- Based on RGBI ADS80 aerial images, ALS DTM, Random Forest, 3m spatial resolution

  - Model accuracies: 98%, Kappa 0.95 (5 *10-fold CV)
  - Independent validation of the predictions


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2nd Approach: broadleaved / coniferous trees

- Based on summer/winter Sentinel-2 images, Random Forest, 10m spatial resolution

Model accuracies: 93%, Kappa 0.85 (5 * 10-fold CV)

- Less overestimation of coniferous trees
- Partly satisfactory
2nd Approach: Improvements

- Additional use of Sentinel-1 C-band SAR data (VH, VV)
- ALS DTM: slope & aspect classes to train models, RF, 10m

Model accuracies: **96%, Kappa 0.9 (5 *10-fold CV)**

=> Minimized overestimation of coniferous trees

=> Requirements met

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Waser et al. 2019, in prep.

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2nd Approach: Independent validation with NFI data

<table>
<thead>
<tr>
<th>Deviation of broadleaf fraction (%)</th>
<th>Validation based on</th>
<th>IAs (n)</th>
<th>M (%)</th>
<th>$M_{abs}$ (%)</th>
<th>NMAD (%)</th>
<th>RMSE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All IAs</td>
<td>3389</td>
<td>0</td>
<td>10.00</td>
<td>14.83</td>
<td>27.86</td>
<td></td>
</tr>
</tbody>
</table>

=> Averaged out, no general overestimation of coniferous tree fraction
3rd Approach: Tree species classification (Test phase)

- Focus on 9 tree species (95% coverage of all Swiss tree species)
- Sentinel-2 time series (March-October), Sentinel-1 winter / summer data to benefit from phenological differences among tree species

=> First tests with RF promising ~80% OA for 5 tree species

=> Countrywide feasible to separate larches from other conifers

- Ongoing collection (2016- today) of multi-temporal Sentinel-2 imagery (missing 40% of monthly coverage for March-October)
- Ongoing collection of adequate training data from forest stand maps

=> Proposed plan: 1-2 PhD students
5) Above ground tree biomass*

- Based on ALS data, image based-point clouds and NFI plots


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Is countrywide mapping of forest attributes feasible?

YES, but…

Typical for mountain areas
Conclusions

✓ Countrywide mapping is nowadays feasible for forest cover (and change), tree types, tree biomass, not yet for tree species

   -> Remaining increasing demand on countrywide products

✓ Providing spatial explicit information which is not given by NFI plots

✓ Open data and software, high degree of automation

   => broad impact (practice, users, researcher)

   – Restrictions: remote sensing data (acquisition date, phenology, differently acquired, etc.), costs, reference data

Ongoing / future research:

▪ Dense series of Sentinel-1/-2 data
▪ New full-waveform ALS data
▪ Deep learning
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Thank you for your attention!