Monitoring snowmelt area by means of Sentinel-1 Interferometric Wide Swath SAR

Thomas Nagler, Helmut Rott, Elisabeth Ripper and Gabriele Schwaizer
• Algorithm for Snow Mapping by Sentinel-1 SAR IW mode data
• Examples and Validation of Algorithm in Alps and Northern Latitudes
• Prototype snow extent algorithm for Sentinel-3 optical sensors
• Combination of S1 and S3 snow products
• Conclusions
Observational requirements for satellite-based snow extent products for operational hydrology and climate research (IGOS Cryosphere Theme Report):

- Spatial resolution: 100 m
- Revisit time: 1 day (during melting period)

Product type of the current satellite-based C-band SAR Systems:

- **Extent of snow melt area** → based on backscatter sensitivity to wet snow
- C-band SAR backscatter is not suitable for operational monitoring of **dry snow areas** → very limited sensitivity to dry snow.
Groundbased Backscatter Signatures – Leutasch/Alps

C-Band
Co-pol.

σ° [dB]
-50  -40  -30  -20  -10   0   10

incidence angle [deg]
0  20  40  60  80

meadow
dry snow
wet snow

Ambiguity
snow/no-snow
at low θ_i

Good discrimination at all θ_i
Sentinel-1 Backscatter Ratios
High Alpine Test site Ötztal

Backscatter ratio (median, Mdn, 1st and 3rd quartile) for Sentinel-1 VV- and VH- polarized channels in dependence of the local incidence angle, $\theta$, for test area Ötztal.

\[ R_{VV} \]

\[ R_{Vh} \]
Sentinel-1 Dual Pol Wet Snow Mapping Method

Relation for merging $R_{vv}$ and $R_{vh}$ in order to create a combined single channel $R_c$

$$R_c = W R_{vh} + (1 - W) R_{vv}.$$  

With:

- $IF (\theta < \theta_1) \rightarrow \{W = 1.0\}$
- $IF (\theta_1 \leq \theta \leq \theta_2) \rightarrow \{W = k \left[1 + \frac{(\theta_2 - \theta)}{(\theta_2 - \theta_1)}\right]\}$
- $IF (\theta > \theta_2) \rightarrow \{W = k\}$

$k=0.5, \ \theta_1=20^\circ, \ \theta_2=45^\circ$

Wet Snow for: $R_c < \text{THR, \ with \ THR = -2dB}$

### Sentinel-1 and Sentinel-3 Sensor Overview

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polarisation</td>
<td>Dual (HH + HV, VV + VH)</td>
</tr>
<tr>
<td>Access (incidence angles)</td>
<td>31° – 46°</td>
</tr>
<tr>
<td>Azimuth resolution</td>
<td>&lt; 20 m</td>
</tr>
<tr>
<td>Ground range resolution</td>
<td>&lt; 5 m</td>
</tr>
<tr>
<td>Azimuth and range looks</td>
<td>Single</td>
</tr>
<tr>
<td>Swath</td>
<td>&gt; 250 km</td>
</tr>
<tr>
<td>Maximum NESZ</td>
<td>−22 dB</td>
</tr>
<tr>
<td>Radiometric stability</td>
<td>0.5 dB (3σ)</td>
</tr>
<tr>
<td>Radiometric accuracy</td>
<td>1 dB (3σ)</td>
</tr>
</tbody>
</table>

**Global Land (Status):** 12 days repeat coverage with IW mode; some regions 6-days

**SLST** (Sea and Land Surface Temperature)
- Swath width: dual view scan, 1675 km (nadir) / 750 Km (backwards)
- Spatial sampling: 500 m (VIS, SWIR), 1 km (MWIR, TIR)
- Spectrum: 9 bands [0.55-12] μm

**OLCI** (Ocean and Land Colour Instrument)
- Swath width: 1270 km, with 5 tilted cameras
- Spatial sampling: 300 m @ SSP
- Spectrum: 21 bands [0.4-1.02] μm

Optionally for S3: Metop- SG VII
Sentinel-1 IW Swath Product

Track 88 22 April 2015, VV
Example of S1 Snow Melt and Landsat TM Snow Extent – Ötzter Alps

Landsat-7, 5 June 2015;

Sentinel-1, 2 June 2015;

Confusion matrix for the classes snow (S) and snow-free (F) in Ötzter test site, for snow classification based on Landsat (LS) and Sentinel-1 (S1) data. $AR$ — overall agreement rate ($0.0 \leq AR \leq 1.0$).
Validation site for S1 Snow melt product
Swiss Alps

Landsat-7, 3 June 2015;

Sentinel-1, 7 June 2015;

Confusion matrix for the classes snow (S) and snow-free, for snow classification based on Landsat (LS) and Sentinel-1 (S1) data. $AR$ — overall agreement rate ($0.0 \leq AR \leq 1.0$).

<table>
<thead>
<tr>
<th></th>
<th>$R_{VV}$</th>
<th>$R_{VH}$</th>
<th>$R_{HH}$</th>
<th>$AR$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS-S</td>
<td>80.7</td>
<td>94.5</td>
<td>94.7</td>
<td>0.882</td>
</tr>
<tr>
<td>LS-F</td>
<td>4.2</td>
<td>5.3</td>
<td>3.2</td>
<td>0.946</td>
</tr>
<tr>
<td></td>
<td>0.962</td>
<td>0.962</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sentinel-1A Wet Snow Maps - Dual Pol Algorithm

Derived from 4 tracks
Validation Site for S1 Snow Melt and Landsat TM Snow Extent – Tröllaskagi Peninsula, Iceland

Landsat-8, 27 June 2015; Sentinel-1, 26 June 2015;

Confusion matrix for the classes snow (S) and snow-free, for snow classification based on Landsat (LS) and Sentinel-1 (S1) data. $AR$ — overall agreement rate (0.0 ≤ $AR$ ≤ 1.0).
Monitoring melting snow using Sentinel-1 SAR

Nagler et al., Remote Sensing, 2016
**Sentinel-3:**

SLSTR (follow on of AATSR):
- 0.5 – 1.6, -3.7 μm + TIR
- 500 m / 1 km

OLCI (follow on of MERIS):
- 0.4–1.2 μm; 300 m

Daily Global Coverage

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Fractional Snow Extent estimated using multi-spectral algorithm
Combining fractional snow extent maps with melting snow area maps

Snow Product by S1 and S3 Synergy

- S1 Wet Snow Map 100 m
- S3 FSC Map 300 m
- Aggregation to 300 m grid
- S1 Fractional Wet Snow Map

Combined Snow Product (Total Snow Extent, Dry / Wet Snow Area)
Conclusions

- A dual pol (Co-, Cross) Snow Melt Algorithm for Sentinel-1 IW was developed and validated in Alps and Northern Latitudes, shows a very high agreement with snow maps from high resolution optical data.
- Due to the high spatial resolution and frequent repeat coverage, Sentinel-1A & 1B time series of snowmelt area are of great interest for applications in hydrology and water management.
- Synergy of Sentinel-1 and -3 sensors is a powerful approach for comprehensive snow monitoring in terms of repeat coverage and snow pack state.
S1-4SCI SNOW - DEVELOPMENT OF PAN-EUROPEAN MULTI-SENSOR SNOW MAPPING METHODS EXPLOITING S1

ESA SEOM Study - Dec 2016 – Nov 2018

PRIMARY OBJECTIVES

• Develop, implement and validate methods for generating maps of snowmelt area based on SAR data of the S-1 mission
• Combination of S-1 wet snow products with snow products from optical sensors of S-2 and S-3
• Use developed algorithm to generate pan-European snow maps from S-1 and S-3

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