Nora Jennifer Schneevoigt, Geir Moholdt and Andreas Kääb

Mapping glacial and periglacial environments with optical and radar data

At all latitudes, field research in glacial and periglacial regions encounters limitations in terms of accessibility, expenses and repeatability.

Remote sensing techniques represent a valuable additional dimension for feature monitoring. They
• operate at global scales
• use globally uniform data sets and methods
• provide long-term, comparable measurements.

The Reintal in southern Germany and Austfonna on Svalbard are considered here (Fig. 1). Located at similar longitudes, they represent two extremes in terms of (peri-)glacial environments: a high alpine, steep rugged valley versus a smooth ice cap with low optical contrast.

Two independent methods are assessed to handle the gradients involved with respect to topography and climate:
A. an object-oriented approach for alpine landform detection
B. a combination of optical and radar data for subpolar glacier mapping

Fig. 1: Study areas in the Bavarian Alps (Reintal valley) and on Svalbard archipelago (Austfonna ice cap). Source: Google Earth

A — Object-oriented approach

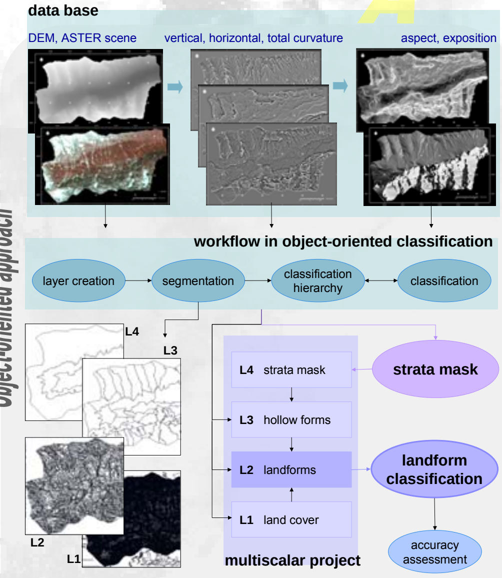


Fig. 2: Object-oriented classification. Top: Input data: an ASTER satellite scene (29.05.2001, 15m resolution), a digital elevation model (DEM; 5m resolution) generated in Topogrid from data by the Bavarian Land Survey, and five DEM derivatives generated in ArcInfo. Bottom left: Segmentation on four hierarchical levels L1 to L4. Bottom right: Classification process flow.

In the segmentation on four levels (Fig. 2),
…a small scale parameter conveys the spectral ground information of the Reintal (L1, Fig. 2)
…the mask of three altitudinal subsystems (L4) requires a very high scale parameter
…a high scale parameter is needed for cirques and hanging valleys (L3)
…an intermediate level serves as final level L2 (for details, see Schneevoigt et al., 2008).

In a second, separate step, classification is done on level L1, L4 and L3 individually. All information then merges into the final classification on L2, mostly based on fuzzy membership functions.

Level L1 classification renders ground land cover, level L4 the strata mask, level L3 eastern and western walls of cirques and hanging valleys (see Schneevoigt & Schrott, 2006).

This leads to a sound L2 landform classification (Fig. 3); a kappa coefficient of 0.915 in eCognition confirms the good fit of the results to ground truth.

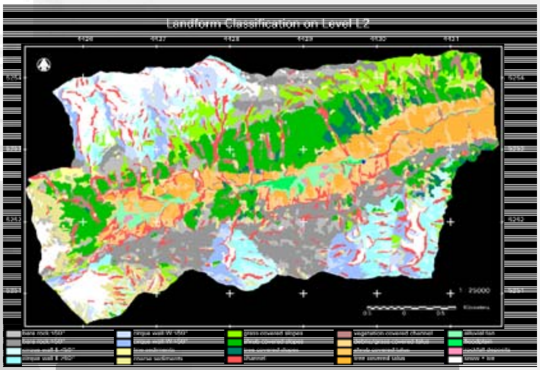


Fig. 3: Object-oriented classification result (17km², relative relief of 1700m)

B — Combination of SAR and optical data

Synthetic aperture radar (SAR) has the following advantages over optical data (e.g. ASTER used in A)
• independence of cloud cover and daylight (Fig. 5)
• the radar signal penetrates the ground to a certain extent; it's amplitudinal backscatter depends on humidity amongst others
  > information on ice melting conditions retrievable
• coherence between the phases of two or more satellite passes flying on the same orbit can be used for SAR interferometry (InSAR) and differential InSAR (Fig. 4)
  > DEMs and movements can thereby be derived even from areas with poor optical contrast like Austfonna ice cap (Figs. 5, 6, poster background).

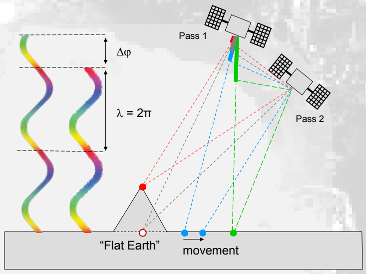


Fig. 4: InSAR principles. Left: coloured fringes with 2π wave-length and phase difference Δφ between the two passes. Right: InSAR geometry, "flat Earth" removal to obtain clear topography signals and the effect of movements.

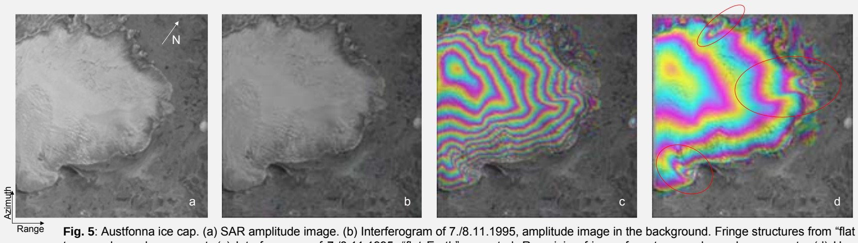
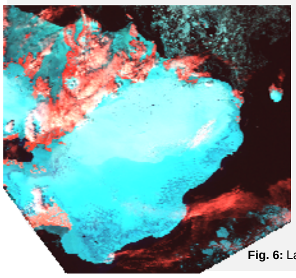


Fig. 5: Austfonna ice cap. (a) SAR amplitude image. (b) Interferogram of 7./8.11.1995, amplitude image in the background. Fringe structures from "flat Earth", topography and movement. (c) Interferogram of 7./8.11.1995, "flat Earth" corrected. Remaining fringes from topography and movements. (d) Unwrapped interferogram where the fringes represent continuous values instead of modulo 2π. Marked areas indicate fringe deformation due to movement influence.



While optical data often lacks spectral contrast in (peri-)glacial environments, it can provide information which is less obvious in SAR data, e.g. the exact glacier outline (Fig. 6) and its variations over time. Besides, the optical spectral mass balance correlates with the volumetric glacier mass balance.

The analysis of combined optical and SAR data applied to glaciers leads to an increased gain of information: optical and radar analyses complement one another with their respective strengths.

Fig. 6: Landsat 7 composite of Austfonna (10.07.2001) in RGB 543; shown in RGB 321 in the poster background.

Conclusions

The result of approach A coherently shows the geomorphic process units in the entire valley up to its inaccessible upper regions, which had not been mapped before.

In the visible spectral range, interpretations appear quite straightforward, because optical data depict the ground as it is perceived by the human eye. This helps understanding and represents an asset for methods to be widely spread.

For further information on the optical, object-oriented remote sensing applications and for geomorphic details, see Schneevoigt et al. (2006, 2008).

Conversely, SAR imagery delivers information beyond the visible: backscatter, polarisation and interferometric phase coherence permit inferences on and below the surface, concerning roughness, melting conditions and snow facies amongst others.

Juxtaposing the two approaches A and B shows that the combination of these two distinct data sources is advantageous. The incorporation of radar data into an object-oriented classification scheme could result in a further yield of information.

References

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Department of Geosciences, University of Oslo, P.B. 1047 Blindern, N-0316 Oslo (contact: njs@geo.uni.no, http://folk.uio.no/njs)