Physically Based Cloud Gap Filling Of Satellite Snow Products

Johanna Nemec[1], Gabriele Schwaizer[1], Thomas Nagler[1], Michael Aspetsberger[2]

1) ENVEO IT GmbH, Fürstenweg 176, 6020 – Innsbruck, Austria,
2) Catalysts GmbH, Huemerstraße 23, 4020 – Linz, Austria
Contact: gabriele.schwaizer@enveo.at

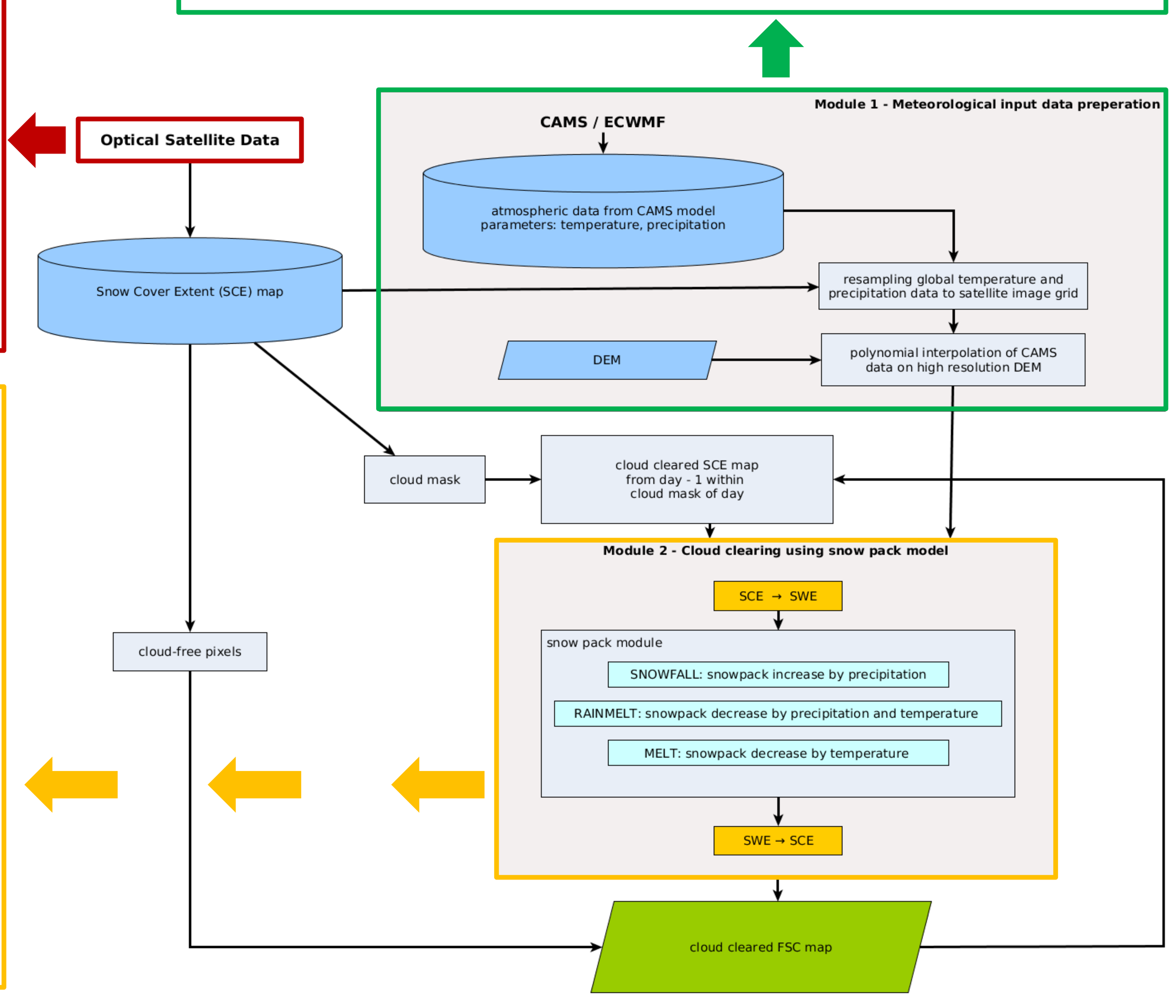
Daily regional to global **snow extent products** from medium optical resolution sensors are essential input to many applications in water management, hydrology, meteorology and climate monitoring. The snow extent products are based on mature algorithms for estimating fractional snow extent and for detection of cloud covered areas. However, clouds have always been considered as one of the major drawbacks of optical sensors for snow monitoring.

Here, we present a **physically based approach** to fill cloud gaps by assimilating satellite snow products with a **snow-pack model** running for each pixel individually. In this approach, a one-layer snow-pack model driven by high resolution, numerical meteorological data (temperature, precipitation) interpolated to the grid of the snow product has been applied. It has been successfully demonstrated and validated for the Alps and the Pan-European domain using gridded meteorological data from the Copernicus Atmosphere Monitoring Service (CAMS).

Concept of the cloud gap filling approach

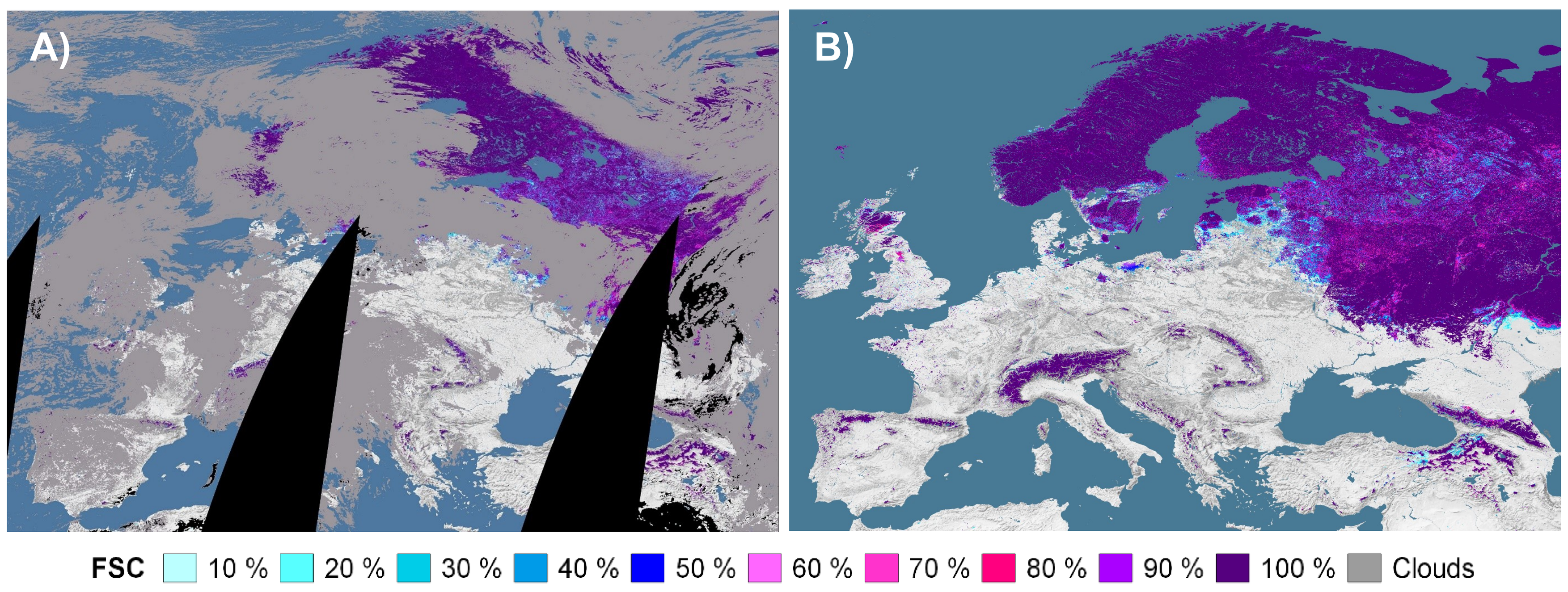
An advanced method for mapping fractional snow cover (Schwaizer, Ripper, and Metsämäki, 2017) has been successfully tested and was applied to Sentinel-3A SLSTR data.
For cloud screening, the Simple Cloud Detection Algorithm (SCDA, V2.0, Metsämäki et al. 2015) was applied.

Meteorological data from CAMS (Copernicus Atmospheric Monitoring Service) were selected for the development and demonstration, but data from any high resolution meteorological gridded dataset can be used.

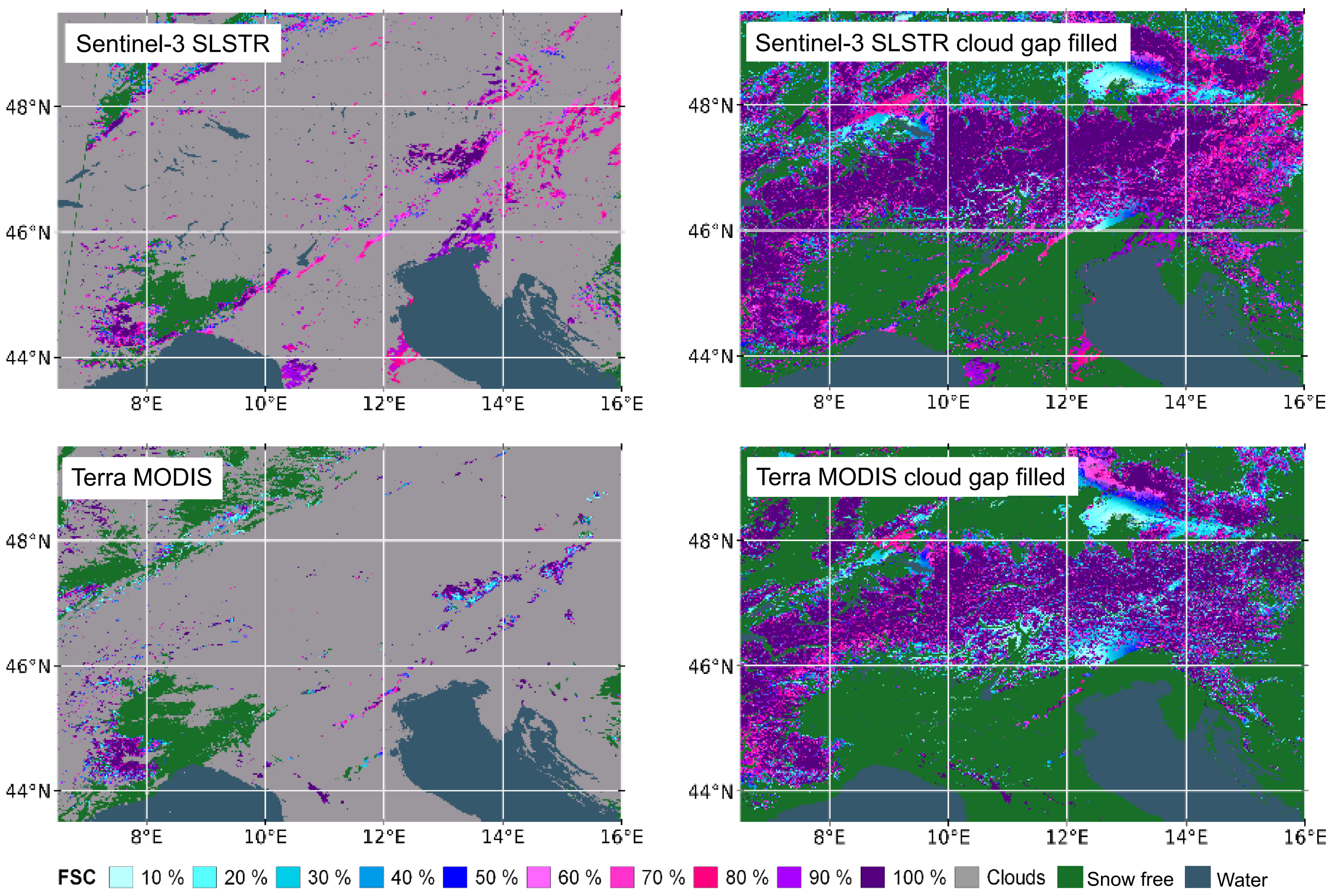


For pixels detected as cloud covered, fractional snow extent is converted into average snow mass. The snow-pack model is running for these pixels with meteorological input data (temperature, precipitation) using a statistical function.
The estimated snow mass for the pixel is converted to fractional snow extent to fill the cloud covered pixel.

Standard vs. Cloud gap filled fractional snow cover products from Sentinel-3A SLSTR and Terra MODIS data



***Fractional snow cover map** of 04/04/2018 **for the Pan-European domain from Sentinel-3A SLSTR data. A)** Standard fractional snow cover product including clouds and input data gaps. **B)** cloud gap filled fractional snow cover map. For the assimilation, input data gaps are handled in the same way as clouds.*



*Examples of **standard (left)** and **cloud gap filled (right) snow cover fraction maps** from **Sentinel-3A SLSTR** and **Terra MODIS** data over the **Alpine domain** of 08/12/2017.*

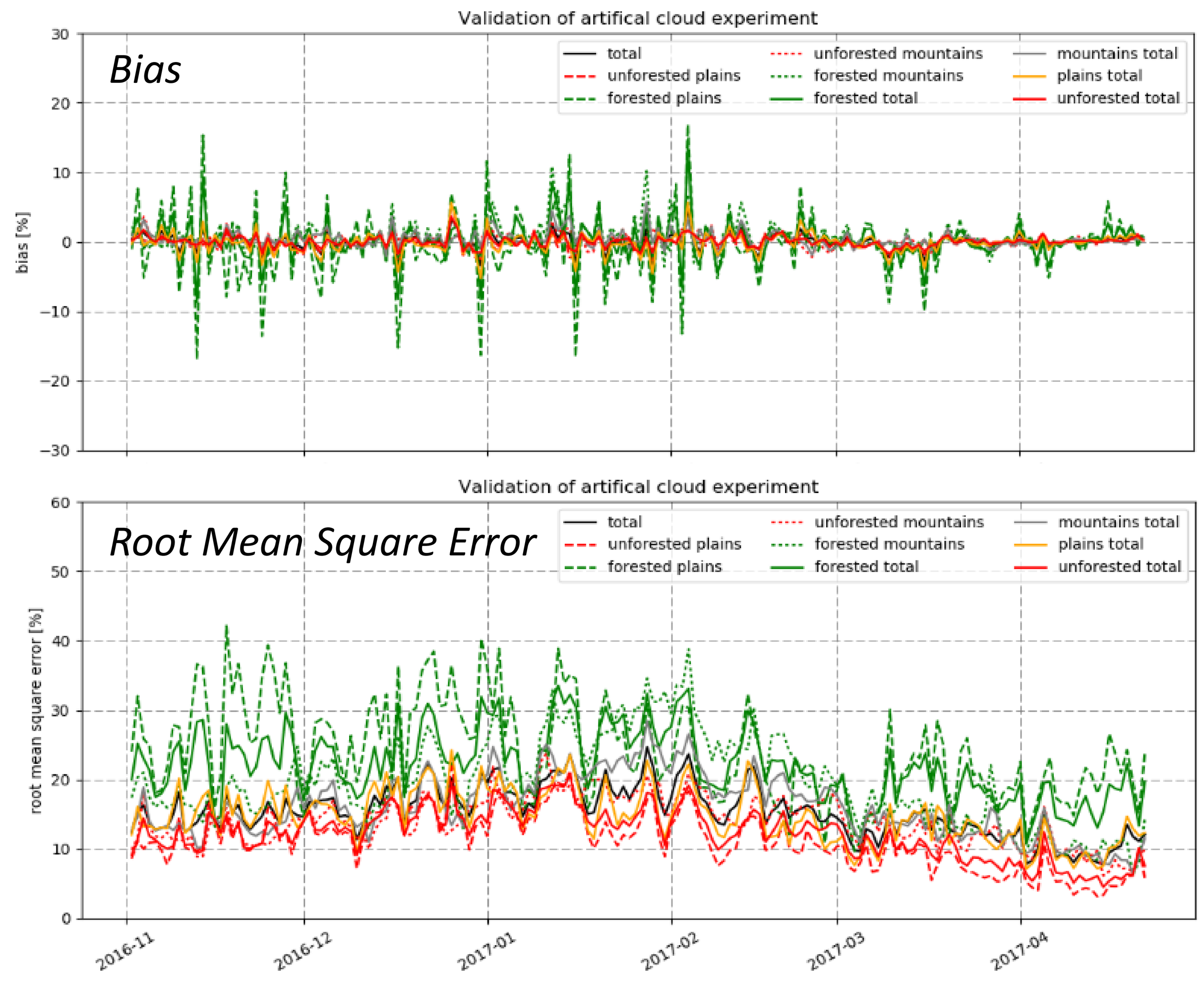
Quality assessment of cloud gap filled snow products

To assess the performance of the cloud gap filled products, regions observed by satellite data during several days at clear sky conditions and with different snow conditions were selected. Then, artificial clouds were added to the snow product over these regions and the cloud gap filling processing chain was started. The results from the cloud gap filling processing were compared with the observed values.

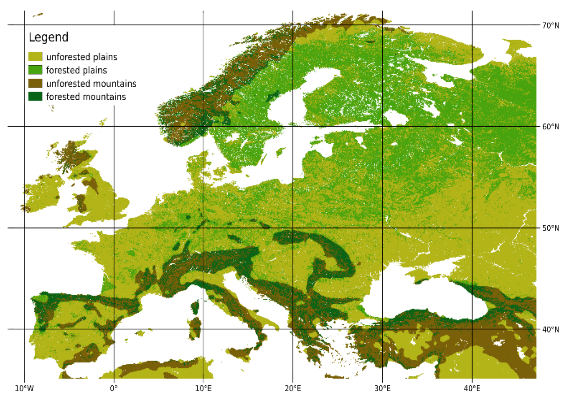
Two evaluation approaches were applied:

A. Single day artificial cloud experiment. The artificial clouds cover the whole Pan-European domain. The experiment was performed daily for the period November 2016 – April 2017.

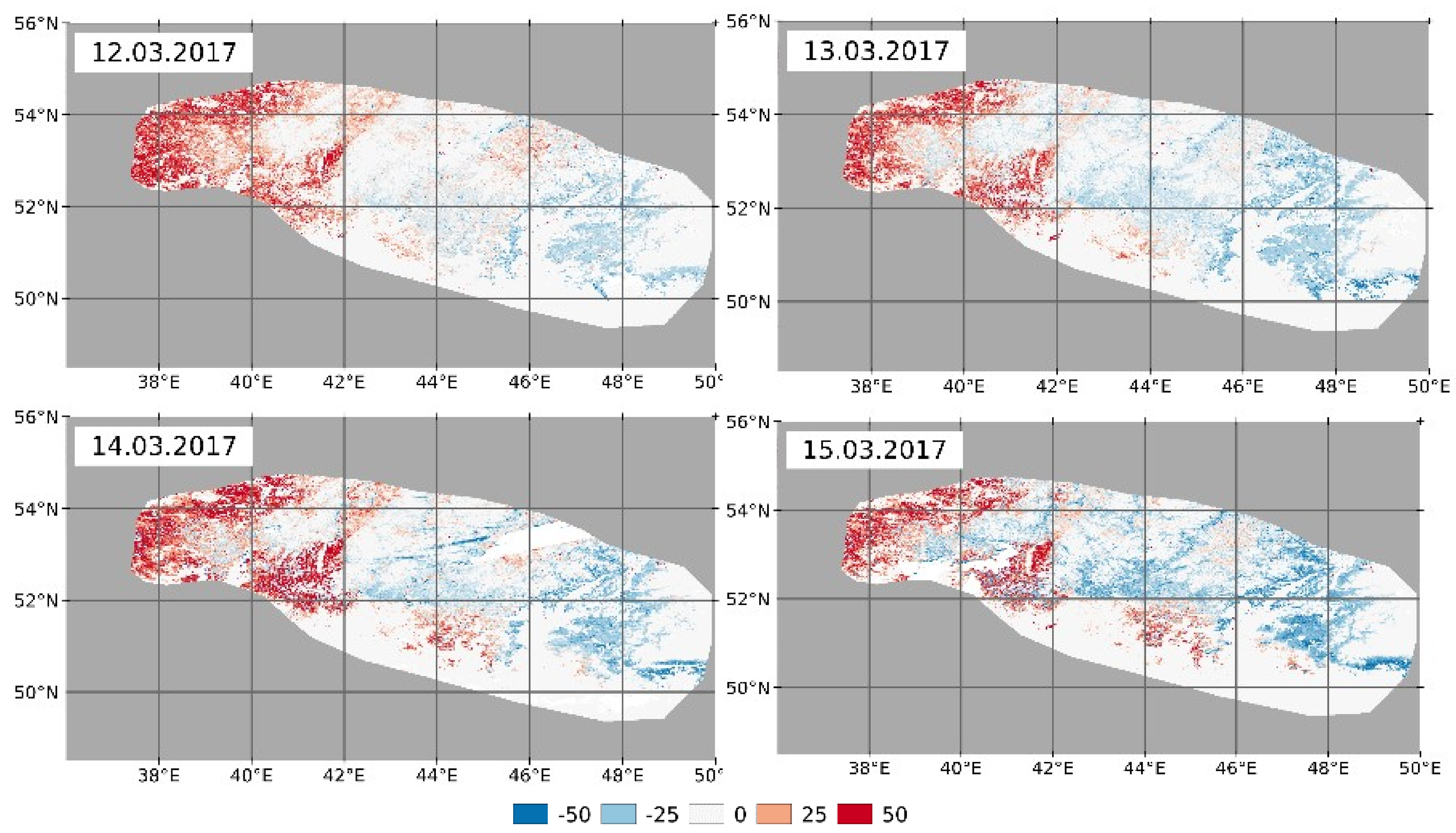
B. Multi-day artificial cloud experiment for selected test sites.



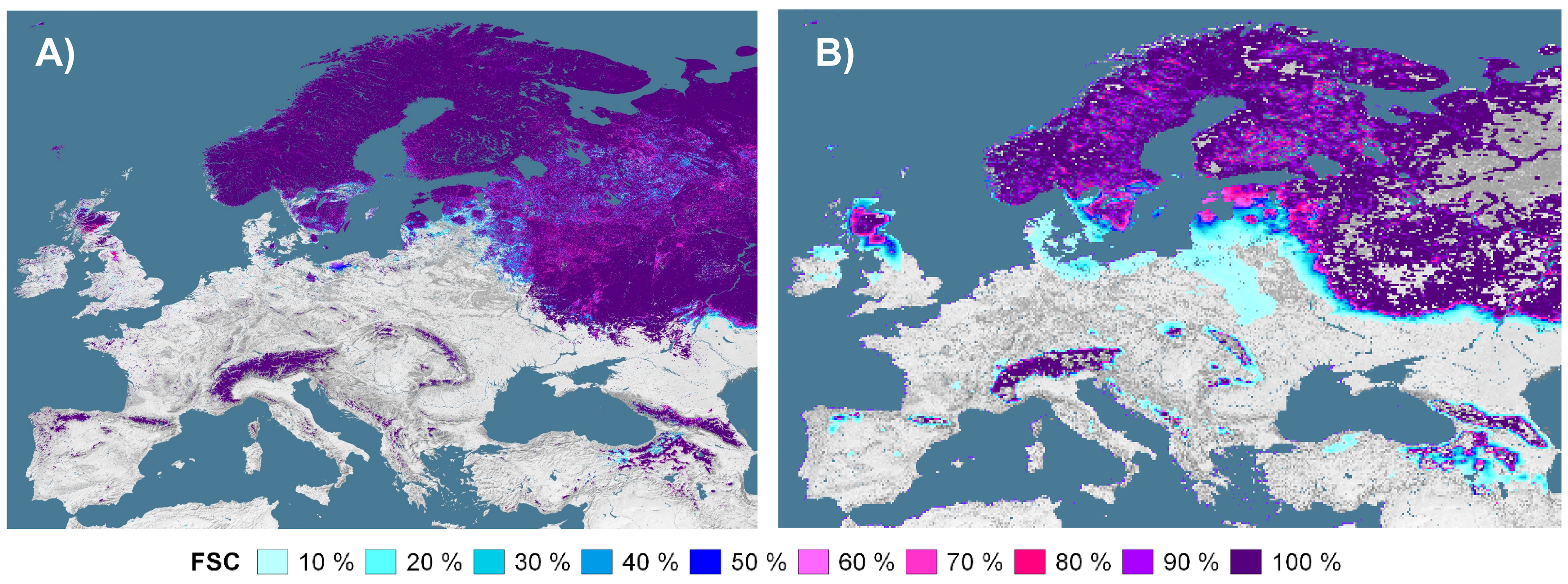
*Statistical measures resulting from the single day artificial cloud experiment **(A)**. Different line types and colors refer to different surface types.*



Forest and mountain mask used for validation and intercomparison of snow maps (generated by ENVEO within the SnowPEx project): http://snowpex.enveo.at



*Difference maps of observed and cloud gap filled fractional snow cover maps resulting from a multi-day artificial cloud experiment **(B)**. An artificial cloud mask over a test site in Russia/Ukraine was inserted for a 4-day period.*



***Fractional snow cover** for the **Pan-European domain** of **04/04/2018.** Comparison of **(A) cloud gap filled product** (~500 m) from **Sentinel-3A SLSTR** data with **(B) ERA-5 Fractional Snow Cover product** (~10 km).*

Conclusions and Outlook

- Physically based cloud gap filling approach was successfully demonstrated for different spatial coverages and with snow products from different optical satellite sensors
- No systematic over- or underestimation of snow is introduced by the cloud gap filling method
- Multi-day experiment shows persistent differences, indicating a stable algorithm for cloud filling.
- **Approach has the potential to be used for the generation of near real-time, cloud gap filled, snow cover maps from optical satellite data tailored to user needs.**

Schwaizer, G., E. Ripper, and S. Metsämäki. 2017. "Copernicus Global Land Operations 'Cryosphere and Water' - Algorithm Theoretical Basis Document for Snow Cover Extent, Collection 500m Continental Europe." V1.0, I1.02 https://land.copernicus.eu/global/.
Metsämäki, S., J. Pulliainen, M. Salminen, K. Luojus, A. Wiesmann, R. Solberg, K. Böttcher, M. Hiltunen, and E. Ripper. 2015. "Introduction to GlobSnow Snow Extent Products with Considerations for Accuracy Assessment." Remote Sensing of Environment 156. Elsevier Inc.: 96–108. doi:10.1016/j.rse.2014.09.018.