EO-HYDRO: Earth Observation data for the hydropower plant management

L. Tampellini [a], , L. Eikvil[b], E. Malnes[c], G. Ober[a], D. Power[d], T. Strozzi[e], F. D. Vescovi[a], P. Vincent[f]
[a] Carlo Gavazzi Space, Milano – Italy, ltampellini@cgspace.it
[b] Norwegian Computing Center, Oslo – Norway
[c.] The Norut Group Ltd., Tromsø – Norway
[d.] C-Core, St. John's NL – Canada
[e.] Gamma Remote Sensing, Bern – Switzerland
[f.] VIASAT Geotechnologies, Montreal - Canada

Abstract – The results presented in this paper were obtained in the framework of EO-HYDRO, a user oriented service which provides hydro power companies with Earth Observation products. Its main focus is the water management and the security of the dams. The results here presented are derived from the application of image processing methods aiming at mapping the snow cover and the snow water equivalent (SWE). The snow cover maps are generated for Norway and the Alps. The used algorithms integrate data from different optical (MODIS, AATSR, MERIS, IKONOS) and radar (ASAR) sensors. Information derived from DEM, vegetation cover and a cloud mask are also added. The SWE maps are generated from RADARSAT and ENVISAT ASAR data. Snow density and land cover data are needed in input as well. A software has been developed (EQeau) for the purpose. Methods and results are accurately discussed.

Keywords: hydropower, snow cover maps, snow water equivalent, EO based service.

1. INTRODUCTION

The EO-Hydro Service is being developed for the hydro power companies in the frame of the ESA Earth Observation Market Development (EOMD) Programme. The service results from the integration of technologies available in research institutes and industries based in the Alpine area, Canada and Norway, where testing activities are currently carried out. Its main focus is the improvement of the water management of the dams through the use of EO data. The results presented in this paper are related to the following provided products:

- snow cover maps at different ground resolutions;
- snow water equivalent (SWE) maps.

All generated maps are based on the processing of SAR and optical data. The snow cover maps are generated by image processing chains which are specific for the area of application. They integrate multi-source SAR and optical data at different resolutions. The SWE maps are derived from RADARSAT and ENVISAT ASAR data. Further technical details on each product can be found under: http://www.eohydro.com.

2. METHODS FOR THE SNOW COVER MAPPING

Two different approaches were developed for the Scandinavian area and the Alps.

2.1 The snow cover method in Scandinavia

The algorithms for the snow cover at regional level integrate multi-source optical and SAR data at different resolutions.

NR (Norwegian Computing Centre) Optical Snow Cover Area method.

The methodology to obtain regional snow cover maps (250 m resolution) makes use of 250m MODIS (MOD02QKM) for snow cover classification and 1 km MODIS (MOD021KM) for cloud classification (Figure 1). The reason for using the 1km MODIS product for the cloud classification is that this product contains more spectral bands than the 250m product. The cloud classification is performed using a multispectral KNN classification scheme. The resulting cloud mask is resampled to 250m.

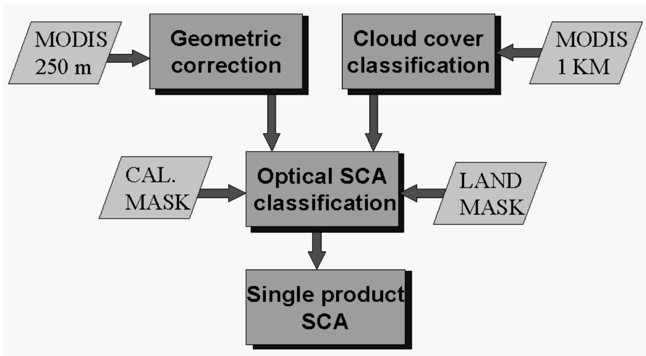

Figure 1. Data control flow of the regional snow cover maps for Scandinavia generated by optical MODIS.

The snow cover classification uses then in input the generated cloud mask in addition to a pre-existing landmask and a calibration mask. The processing is performed on radiometrically calibrated data. A linear relationship between the snow covered area and the pixel radiance is assumed. The resulting snow cover product gives the percentage of snow covered area (0-100%) estimated for each pixel in the image. A confidence map is also produced.

NORUT SAR snow cover area method

This methodology generates regional snow cover maps (250 m resolution) using Envisat ASAR data (fig. 2). The ASAR WS imagery is calibrated to backscatter values in decibel (dB). Then the Nagler algorithm (Nagler and Rott, 1997) is applied using thresholding between the current image and a validated winter image. The output is a classification of the wet snow. Dry snow is subsequently inferred by using wet snow line and the digital elevation model (Malnes et al. 2002). Forest pixels and pixels from lakes are masked. A confidence map id also produced.

Integration

Optical and SAR single products of the snow cover area are integrated. The multisensor fusion algorithm matches both optical and SAR outputs selecting the pixel having the highest confidence. The current map is accumulated over a certain period (typically one week), and the confidence in each pixel is degraded depending on the age.

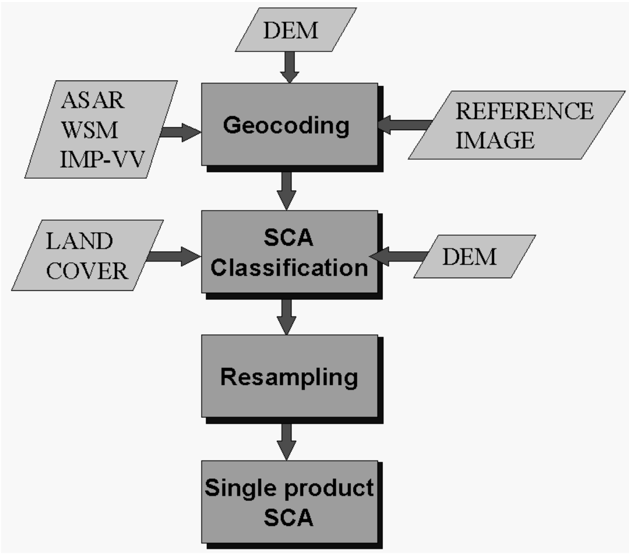

Figure 2. Data control flow of the regional snow cover maps for Scandinavia generated by ASAR.

2.2 The snow cover method on the Alps

Carlo Gavazzi Space developed a method which generates snow cover maps at regional scale (250 m resolution) using MODIS satellite data (Fig. 3).

Regional scale

The surface reflectance MODIS products at 500m and at 250m ground resolution (MOD09GHK and MOD09GQK, respectively) are the inputs for the processing chain. The cloud classification is performed on 500m ground resolution bands and the resulting cloud cover mask is resampled to 250m. The snow classification is performed on the 250m bands and is then corrected for the errors introduced by coniferous forests. The snow cover under those trees is not detectable with optical instruments thus it must be inferred depending on the vegetation map and the elevation.

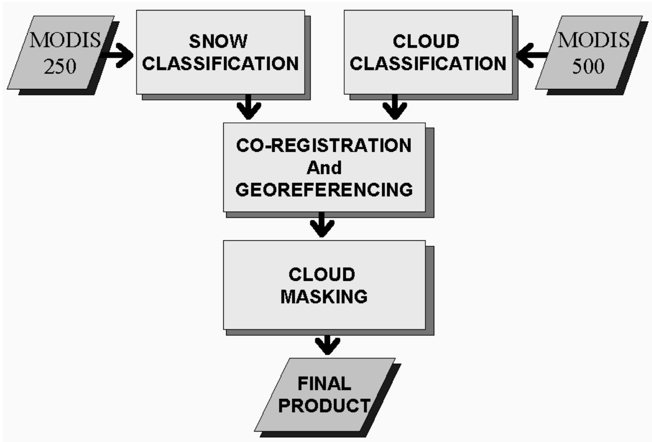

Figure 3. Processing chain for the snow cover mapping at regional scale performed for the Alps.

Local scale

On user request also a snow cover map at local scale (4 m resolution) can be performed using high resolution images (IKONOS or Quick Bird).

After a land campaign in the area training pixels on the image are identified and a maximum likelihood classification process is launched to identify the main classes: snow, ice, bare soil and vegetation. Statistics on the classified areas are calculated and a classification accuracy is then evaluated and delivered with the final product. In Figure 4 the input and the output of the process is shown.

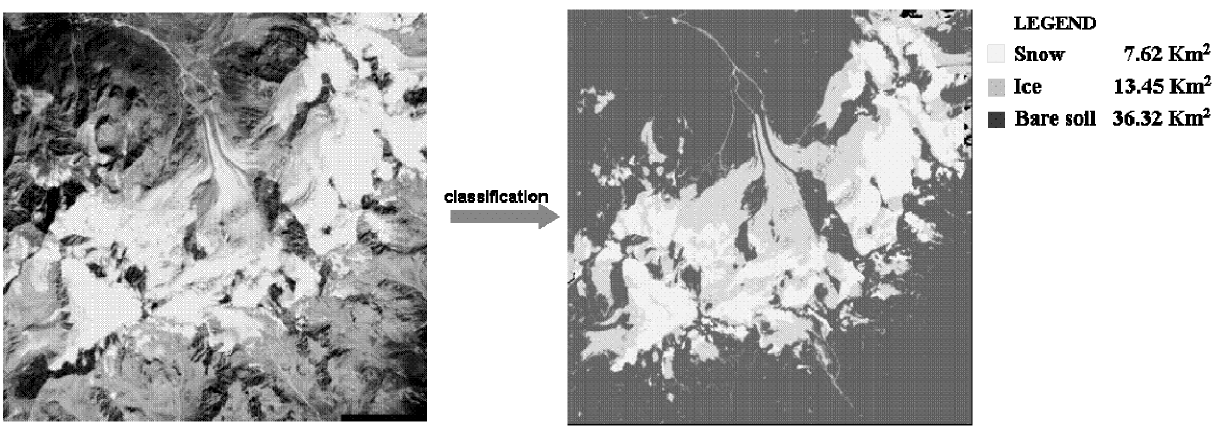

Figure 4. Left: a very high resolution image at 4 m resolution (IKONOS image from 7 August 2003) over Forni Glacier. Right: example of snow cover map resulting from the classification of the previous image.

3. METHOD FOR THE SNOW WATER EQUIVALENT (SWE)

The processing is performed by EQeau Software which was jointly developed by VIASAT Géo-Technologie inc. and the Institut National de la Recherche Scientifique (INRS-Eau) of the Université du Québec, for the Hydro-Quebec Society. The input images are RADARSAT and ENVISAT ASAR data.
EQeau software needs the following inputs:

- a reference image (preferably acquired in fall when the soil is frozen and snow free);
- a winter image (acquired at the time of SWE investigation);
- the mean snow density (obtained from surveys, modeling or historical data);
- the land cover (from a Landsat-TM classification).

The physical principle for shallow snow covers is based on two equations (Bernier, 1991; Bernier, M., J.P. Fortin, 1998; Romanov et al. 2000):

1) The first equation relates a backscattering ratio between two images (with snow / snow free) to the snow cover thermal resistance (Fig. 5).

$$Rest = m\ (\sigma h / \sigma a) + b$$

where:
Rest is the snow cover thermal resistance.
σh is the “snow” image to be investigated.
σa is the “snow free” reference image acquired in fall.
m and b: are the slope and intercept of the linear relation between the backscatter ratio and the snow thermal resistance, respectively.

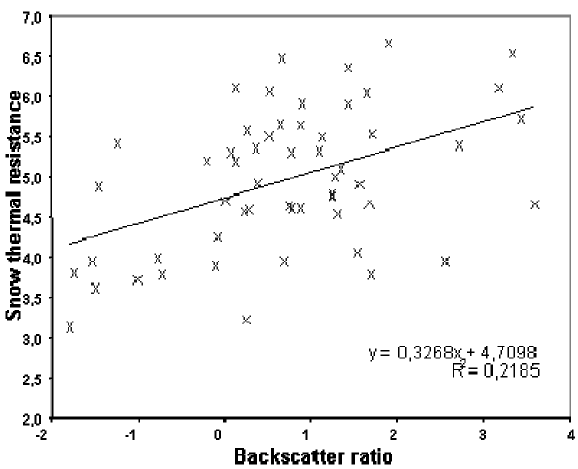

Figure 5. Relationship between the backscatter ratio (snow / no snow) and snow thermal resistance.

2) The second equation is a relation between the SWE and the snow thermal resistance. This relation is linear but the slope of the regression is a function of the snow density (Fig. 6).

$$SWEest = \alpha\ Rest$$

where:
SWEest is the estimated SWE.
α is the snow thermal conductivity: $\alpha = A\rho\ 2 + B\rho + C$ ($A = 2{,}83056 \times 10^{6}$, $B = -9{,}09947 \times 10^{5}$ and $C = 0{,}0319739$)
ρ is the snow density (kg/m3)

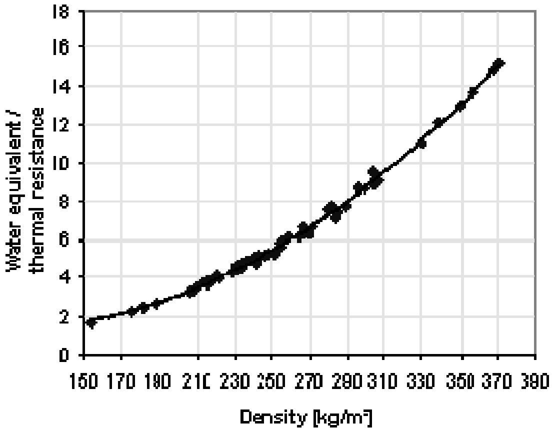

Figure 6. Relation between SWE and the snow thermal resistance.

4. RESULTS

4.1 Outputs of the snow cover method in Scandinavia

In Figure 7 an example of snow cover result at medium resolution (250m) for Norway is shown. This is derived from the integration of different sensors (optical MODIS + radar ASAR) in multiple acquisitions.

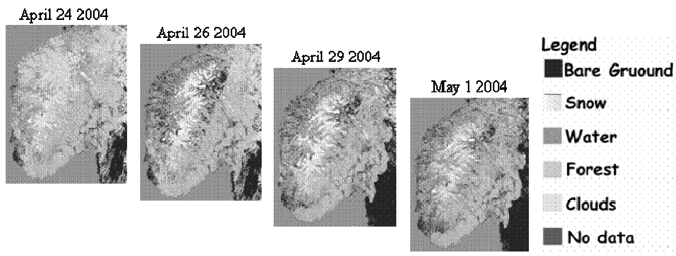

Figure 7. Example of snow cover product at medium resolution (250m). Through integration of different sensor data (optical MODIS + radar ASAR) a multitemporal product is obtained.

4.2 Outputs of the snow cover method on the Alps

Regional scale
In Figure 8 a snow cover map on the Alps at 250 m resolution in shown. This is the so called regional scale product. It is the result of a 7-day acquisition composite, from 1 to 7 January 2005.The accuracy evaluation of these results is performed using a local network of point observation on some basins on the Alps. These ground data are property of the hydropower companies thus can not be published. However, the consistency of the resulted snow maps and the observed data is checked 8 times yearly. The accuracy is considered by the users satisfactorily and the maps are suitable for their use. Further details on the accuracy of these results will be published in further publications.

Regional scale
An example of the local scale snow cover map is shown in Figure 4. The resulting map is validated visually by comparison with pictures taken locally for ground truth.

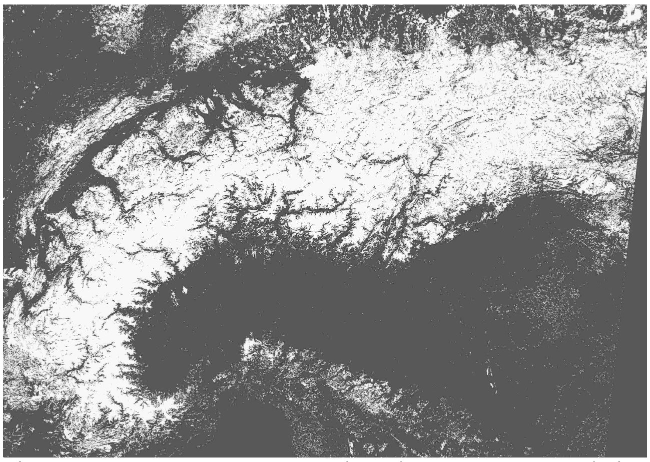

Figure 8. Snow cover map on the Alps at 250 m resolution (composite 1-7 January 2005). White is snow, grey is snow free.

4.3 Outputs of the SWE

The resulting SWE estimation maps (see example in Figure 9) are in raster format with a pixel size of 375 m x 375 m, coded in 8 bits. Each pixel represents a range in mm of SWE values. Each class ranges 50 mm. This method is currently developed by VIASAT in Québec and has recently been tested in Norway too.

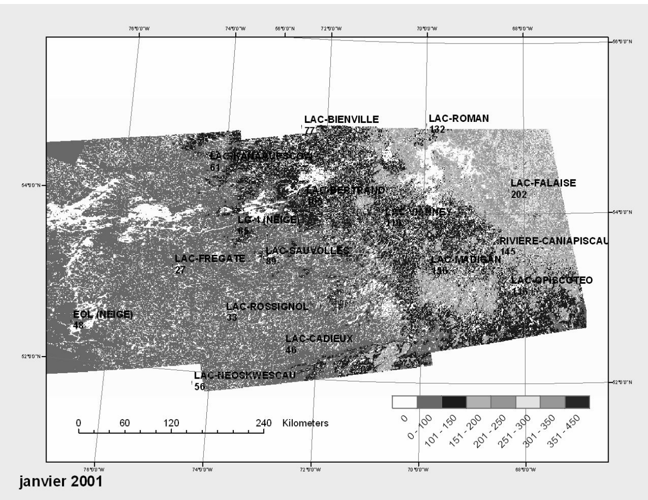

Figure 9. Example of SWE estimation map derived from RADARSAT images acquired in January 2001. The area of about 150.000 km^2 shows the large La Grande River Watershed located in the Province of Québec, Canada.

5. CONCLUSIONS

The applied methods are successful to produce snow cover maps and SWE maps. Howerver, some improvements in the accuracy of the results are needed and planned. EO-Hydro service has been proven by the hydropower producers to be a useful tool for forecasting and managing the water reservoirs in the studied basins. All products are accessible online for the users and are provided in GIS compatible format. This service allows an efficient and sustainable use of the available water resources for power generation. Further developments of the methods are planned and will be tested outside the current areas of application.

6. REFERENCES

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