EO-HYDRO: AN EARTH OBSERVATION SERVICE FOR HYDROPOWER PLANT MANAGEMENT

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ABSTRACT

EO-Hydro Service has been developed in the frame of the ESA EOMD Programme, with the aim of providing Hydropower Companies with innovative products based on the processing of Earth Observation data. These are derived from both SAR and optical satellite sensors. The service results from the integration of different technologies available in research institutes and industries based in the Alpine area, Canada and Norway. Its main focus is the water management and the security of the dams. The provided services are snow cover monitoring service, snow water equivalent service, water runoff forecast service and land displacement service. Different products (maps, plots, reports, etc.) are provided at different scales and frequencies. In this paper some study cases of practical applications are presented and discussed.

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

1. INTRODUCTION

The EO-Hydro Service has been developed for the hydro power companies in the frame of the ESA Earth Observation Market Development (EOMD) Programme. EO-Hydro offers different services and products which integrate the available technologies in research institutes and industries based in the Alpine area, Canada and Norway. Its main focus is the improvement of the dam water management and the dam security conditions through the use of EO (Earth Observation) data. The services presented in this paper are related to the following products:

- snow cover maps at different ground resolutions;
- Snow Water Equivalent (SWE) maps;
- water runoff forecast products;
- land displacement products.

All generated maps are based on the processing of optical and/or SAR data.

Further technical details on each product can be found under: http://www.eohydro.com.

2. ALGORITHMS AND APPLIED METHODS

2.1 The snow cover service

Two different approaches were developed for the snow cover monitoring service:
- 1) service in Scandinavian area;
- 2) service in the Alps.

1) The algorithms for the snow cover at regional level integrate multi-source optical and SAR data at different resolutions. The Optical Snow Cover Area method to obtain regional snow cover maps at 250 m resolution [4] makes use of 250m MODIS (MOD02QKM) for snow cover classification and 1 km MODIS (MOD021KM) for cloud classification (Fig. 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.](image)

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.

The *SAR snow cover area method* is applied by NORUT (Norway). 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 [3] 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 [4]. Forest pixels and pixels from lakes are masked. A confidence map is 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 cumulated over a certain period (typically one week). 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.](image)

2) The snow cover monitoring service for the Alps is available by Carlo Gavazzi Space. The processing chain generates snow cover maps at regional scale (250 m resolution) using MODIS satellite data (Fig. 3). 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 and broadleaf forests. In fact, 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.](image)

2.2 The snow water equivalent service

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 [1, 2, 5]:

1) The first equation relates a backscattering ratio between two images (with snow / snow free) to the snow cover thermal resistance (Fig. 4).

\[
Rest = m \left( \sigma_s / \sigma_a \right) + b \quad (1)
\]

where:
- Rest is the snow cover thermal resistance.
- \( \sigma_s \) is the “snow” image to be investigated.
- \( \sigma_a \) 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.
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. 5).

\[ \text{SWE}_{\text{est}} = a \text{ Rest} \quad (2) \]

where:

- \( \text{SWE}_{\text{est}} \) is the estimated SWE.
- \( a \) is the snow thermal conductivity: \( a = A_2 + B_3 + C \) (\( A = 2.83056 \times 10^7 \), \( B = -9.09947 \times 10^3 \) and \( C = 0.0319739 \))
- \( \rho \) is the snow density (kg/m\(^3\))

2.3 Water Runoff Forecast Service

A versatile and robust system for operational runoff modeling and forecasting in alpine basins with substantial snow and glacier melt, developed and operated by ENVÉO, was applied to the basins Zillertal and Ötztal in the Austrian Alps. The semi-distributed hydrological model requires hydro-meteorological data from stations or numerical weather models and spatially detailed snow information from satellite data as input. Assimilation and preprocessing of the different types of data includes downsampling of meteorological data by taking the elevation dependence into account and generation of snow maps from satellite data. Each of the basins consists of several sub-basins, for which real time forecasts of the daily runoff up to 6 days in advance for the melting periods 2005 and 2006 were calculated and provided to the customers AHP-Verbund and the Hydrological Service Tirol. Real-time data links were established to provide hydromet data and satellite images via Internet. Snow maps were automatically generated from ENVISAT ASAR WSM and MODIS satellite images, available within 24h after image acquisition. Meteorological forecasts were provided by the ECMWF deterministic model and from the ECMWF Ensemble Prediction System (EPS), which consists of 51 meteorological forecasts for each time steps. The EPS products allow accounting for the uncertainty of meteorological forecasts in runoff prediction. Quality control of the runoff forecasts was carried out daily by comparing predicted runoff with measurements of the previous days.

2.4 Land Displacement Service

The land displacement service concerns the computation of the temporal displacement of significant points of dams and of landslides around dams with differential SAR Interferometry (InSAR) and SAR Interferometric Point Target Analysis (IPTA). Pre-commercial projects performed in the Alps and Southern Italy showed that the current use of SAR interferometry for land displacement monitoring, in general, and of IPTA for dam monitoring, in particular, is still suffering from limitations due to the impossibility to identify the exact nature and position of the radar scatterers, the frequency of the radar observations, and decorrelation because of vegetation cover and rapid displacements.

3. PRODUCTS AND SERVICES

3.1 Outputs of the snow cover service in Scandinavia and in the Alpine Region.

In Fig. 6 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.
3.2 Outputs of the SWE

The resulting SWE estimation maps (see example in Fig. 8) 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.

3.3 Outputs of the water runoff forecast service

Fig. 9 shows the Squirrel Plot of the real-time runoff forecast for the basin Tumpen. An example of the EPS runoff forecast for the 2 June 2006 is shown in fig.10. The comparison between runoff forecasts and measurements showed in general very good agreement, with some uncertainties mainly due to errors in precipitation forecasts.

Figure 6. Example of snow cover product at medium resolution (250m) of 28 May 2006.

In Fig. 7 a snow cover map on the Alps at 250 m resolution is shown. This is the so called regional scale product. It is the result of a 7-day acquisition composite, from 26 February to 4 March 2007. 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.

Figure 7. Snow cover map on the Alps at 250 m resolution (composite of the week 26 February - 4 March 2007). White is snow, green is snow free.

Figure 8. Example of SWE estimation map derived from RADARSAT images acquired in January 2001. The area of about 150,000 km² shows the large La Grande River Watershed located in the Province of Quebec, Canada.

Figure 9: Squirrel plot of the real time forecasts of the daily runoff for the Basin Tumpen, Ötztal, Austrian Alps. Black line – measured runoff, colored lines – runoff forecasts of 1 – to 6 days in advance.
3.3 Outputs of the Land Displacement service

In Fig. 11 the result of the applied technique is illustrated. After discussion with the user an evaluation of the product was provided. The current use of SAR interferometry for land displacement monitoring, in general, and of IPTA for dam monitoring, in particular, is still suffering from limitations due to following reasons:

- impossibility of identifying the exact nature and position of the radar scatterers;
- frequency of the radar observations;
- decorrelation due to vegetation and rapid displacements.

4. CONCLUSIONS

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. The snow cover monitoring service, snow water equivalent service, water runoff forecast service are already operative and are brought to a marketable level. Some limitations have been reported for the land displacement service. EO-Hydro allows an efficient and sustainable use of the available water resources for power generation.

5. REFERENCES


