Remote sensing snow cover monitoring for hydro-electric power generation at Tavanasa and Sedrun

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Abstract

Seasonal accumulation of snow and the subsequent snowmelt runoff are dominant features of alpine basins. Direct measurements of snow reserves are hampered by the difficult access and avalanche hazards in the remote parts of a mountain basin. During the snowmelt period, the snow covered area is gradually decreasing which affects the meltwater production. Satellite monitoring of snow cover enables the snow reserves to be indirectly evaluated. It provides data on the changing areal extent of snow cover which facilitates runoff forecasts.

All available satellite recordings have been evaluated for the high alpine regions Tavanasa and Sedrun and depletion curves have been derived for the runoff season 1985.

Interest is focused on getting remote sensing information from very different sensors such as Landsat-MSS, SPOT-XS, and NOAA/AVHRR by quasi real-time access. The data has to be integrated into a multitemporal dataset for the analyses and in order to use them for operational discharge forecasts for a hydroelectric scheme.

Monitoring of seasonal snow cover by satellites

Earth observation satellites allow to monitor the seasonal changes of the snow coverage in alpine regions. The seasonal accumulation of snow and the gradual decrease of the snow covered area during the snow melt season is a typical feature. Methods are being developed to quantify this process by periodical snow cover mapping.

As an example, Fig. 1 shows the basin of the upper Rhine in the Swiss Alps (Rhein-Felsberg 3250 km², 560-3614 m a.s.l.). The snow cover is shown as it has been evaluated from Landsat-MSS data (Baumgartner, 1987). The areal extent of the snow coverage in different elevation zones can be evaluated for different regions of interest or subbasins. If consecutive snow cover maps resulting from different satellite overflights are available, depletion curves can be derived as shown in Fig. 3. In the figure the depletion curves of two smaller subbasins Sedrun (108 km², 1840- 3210 m a.s.l.) and Tavanasa (215 km², 1277-3210 m a.s.l.) are given for comparison. The curves are referring to the runoff season of 1985. The two hydroelectric stations Sedrun and Tavanasa are located within the subbasin Illanz (Fig. 1).

As mentioned, remote sensing capabilities enable us to map the snow cover. Advanced digital image processing techniques are used and with the aid of a digital terrain model (DTM) the snow cover analyses are computed in different elevation zones. A rather complex procedure
Fig. 1  Basin of the upper Rhine in Switzerland (*Felsberg*) with the snow cover evaluated from the Landsat overflight on 18-MAY-1982. Partial test areas are labeled: 6 = Tavanasa  7 = Sedrun  1+6+7 = Ilanz

Fig. 2  Flowchart of the procedure of snowmelt runoff simulations based on remote sensing satellite data
has been applied as can be seen from Fig. 2. By that means, the snow cover depletion curves have been plotted from the sequence of satellite recordings.

The depletion curves reflect the seasonal decrease of the snow cover as it is influenced by temperature and precipitation on a daily basis.

**Fig. 3** Depletion curves of elevation zones (B, C, D, and E) of the sub-basins a) *Sedrun* and b) *Tavanasa* for the snowmelt season 1985.

- B  1100-1600 m a.s.l.
- C  1600-2100 m a.s.l.
- D  2100-2600 m a.s.l.
- E  2600-3614 m a.s.l.

**Modelling of the snowmelt runoff for hydropower and flood control**

The seasonal snow cover is a dominant runoff factor in mountain basins. Recently, the attention has been focused on snowmelt runoff models by a project of the World Meteorological Organization (WMO, 1986). Of the models tested, the SRM model (Martinec et al., 1983) exploits the increasing availability of snow cover mapping from satellites. Besides

**Fig. 4** a) Computed and measured discharge from the catchment area of the hydroelectric station *Sedrun*

**Fig. 4** b) Computed and measured discharge from the catchment area of the hydroelectric station *Tavanasa*. 
the air temperature and precipitation, the snow covered area from conventional depletion curves (Fig. 3) is the essential input variable used.

The deterministic snowmelt runoff model (SRM) is designed to simulate or to forecast the daily discharge in mountain basins, resulting mainly from snowmelt but also from precipitation.

Based on the above mentioned satellite snow cover mappings, the daily flows from April to September 1985 have been computed for the previously mentioned hydroelectric stations Sedrun and Tavanasa. As shown in Fig. 4, the daily runoff values have been simulated for both stations. The model accuracy is characterized by the coefficient of determination

\[ R^2 = 1 - \frac{\sum_{i=1}^{n}(Q_i - Q'_i)^2}{\sum_{i=1}^{n}(Q_i - \overline{Q})^2} \]

where 
- \( Q_i \) is the measured daily discharge
- \( Q'_i \) is the computed daily discharge
- \( \overline{Q} \) is the average measured discharge
- \( n \) is the number of daily discharge values
  (\( n = 183 \) in the given case)

and by the volume deviation

\[ D_V [\%] = \frac{V - V'}{V} \times 100 \]

where 
- \( V \) is the measured runoff volume
- \( V' \) is the computed runoff volume

No updating or calibration was used, that is to say the model parameters were predetermined and the simulation proceeded on the basis of previously computed discharge. It was thus possible to use snow cover mapping from Landsat data in two relatively small catchment areas.

If such computations can be carried out in real time (using temperature and precipitation forecasts), hydroelectricity production can be increased (Kawata and Kusaka, 1988) and flood control improved. In alpine conditions, floods from snowmelt only are improbable. They occur when the runoff from heavy rainfalls is superimposed on the snowmelt runoff, as illustrated in Fig. 4 by several sharp peaks.

**Forecasting on the basis of multisensor satellite recordings**

In order to be able to use these techniques for (operational) forecasting purposes, one needs "guaranteed information". In the past, usable Landsat-MSS data was not always available for the specified area and the time period under consideration. Based solely on Landsat imagery a runoff forecast cannot be guaranteed.

An obvious consideration is to integrate remote sensing information from other satellite sensors into the snow cover determination scheme as well. It has been discussed by Baumgartner et al. (1988) under what circumstances data from the weather satellite system...
NOAA/AVHRR can be used for snow cover mapping. It has been reported that due to the spatial resolution of about 1000m x 1000m of NOAA a minimum basin size of about 600-1000 km² is necessary for digital analyses.

In the meantime data became available from the SPOT-1 satellite and data will become available rather soon from the Japanese MOS-1 system. No major problems have to be expected for the analyses of those data. Due to the fact that they have about the same spatial resolution or even better than Landsat-MSS the resulting snow cover maps will be of adequate quality.

The SPOT system offers in the multispectral mode a ground resolution of 20m x 20m and the ability of its sensors to point up to 27° East and West of the local vertical axis. This latter feature gives interesting possibilities to increase the number of opportunities to obtain views of a given area. Exactly this property in addition with any further active sensor in orbit prepares the way for an operational procedure for snowmelt runoff forecast.

Conclusions

Remote sensing Landsat-MSS data enabled us to map snow coverages even in rather small catchment areas (as requested by a hydroelectric company) in order to serve the requirements of snowmelt runoff forecasting.

The paper deals only with Landsat-MSS data, but with the advanced capabilities of the SPOT sensor system and any further earth observation satellite a sufficient frequency of overflights seems to be guaranteed.

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References


