Snow Mapping Technique at Subpixel Level for Small Basins

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ABSTRACT

Snow cover mapping is often carried out using optical satellite imagery. In this paper we address the problem of snow mapping of small basins with areas only 10 times the spatial resolution of the sensor using subpixel analysis. This technique is currently being used in several basins in the Spanish Pyrenees and has been developed as part of a snow cover mapping and snowmelt runoff forecasting system which uses snow cover as an input for the Snowmelt Runoff Model (SRM). Spanish hydropower companies receive the snowmelt forecasts and use them as criteria in decision making for reservoir management. The accuracy of the forecast strongly depends on the snow cover accuracy.

INTRODUCTION

Spatial distribution of snow is an important input to several hydrological models. This work has been developed as part of a snow cover mapping and snowmelt runoff forecasting system which uses the Advanced Very Hight Resolution Radiometer (AVHRR) on board the National Oceanic and Atmospheric Administration (NOAA) satellites. AVHRR data is processed to obtain the snow covered area as an input for the Snowmelt Runoff Model (SRM) [2]. SRM is being applied to several basins in the Spanish Pyrenees to simulate and forecast the daily discharge of each basin. The techniques presented in this paper constitute a sub-pixel approach to obtain the percent of snow covered area in each AVHRR pixel, using channels 1 and 2. The procedure can be applied to instruments other than AVHRR, as long as a visible and a near infrared channels are used. When several consecutive images of the studied basin are available, an algorithm can be applied to improve the snow map, using the different versions of the snow patches that each image provides. The main difficulty in developing a method to improve the determination of snow distribution within a pixel is to verify the result without knowing the real shape of the snow patch but only the overall pixel response. In this study two patterns of snow were created to test the method, one simulating a compact snow distribution and another simulating a diffuse distribution. For each pattern, a series of training images were obtained to simulate satellite images, each one generated with a random displacement of the pixel grid.

SNOW MAPS

This method is currently being used with NOAA-AVHRR scenes and it has been designed to be applied to albedo images of two channels; one visible and another near infrared (channels 1 and 2, respectively, in the NOAA-AVHRR case). Especially NOAA-14 has been used, due to its noon orbit over the Pyrenees area. Combination of three or more channels were also tested, giving slightly less accurate results.

The basic idea of this approach is to consider the spectral response of a target as a composition of elementary spectral responses corresponding to each of the cover types included in the target. As in the Linear Mixture Models (LMM), the spectral proportion of each cover type is equal to its cover proportion. The goal is to obtain an image in which every pixel has a digital value proportional to its snow cover percent, assuming the target as a mixture of bare ground and snow. We can write our linear combination as $a_1C_1 + a_2C_2$, where an C_1 and C_2 are the pixel values (albedoes) of channels 1 and 2, respectively. To obtain the combination coefficients a_1 and a_2, the following equation is used:

$$a_1\begin{pmatrix}S_1\\G_1\end{pmatrix}+a_2\begin{pmatrix}S_2\\G_2\end{pmatrix}=\begin{pmatrix}255\\0\end{pmatrix} \qquad (1)$$

Where S_1 is the snow threshold of channel 1, S_2 the snow threshold of channel 2, G_1 is the ground threshold of channel 1 and G_2 is the ground threshold of channel 2. The snow threshold of each channel is defined as the minimum digital value of a pixel fully covered of snow. It can be obtained from snow classification and with the help of a snow histogram of frequencies, either graphically or numerically. The ground threshold is defined as the maximum digital value of a pixel corresponding to bare ground (no forested areas are considered). It also can be obtained from a ground

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classification on a monthly and weekly basis. Details of this method can be consulted in [1].

ALGORITHM

The basic idea of these algorithm is to use the different versions of the snow patches that each snow map provides. One major concern is that the shape of snow patches might change during the time lapse from one image to the next. This might be a particular problem for snow patches in low altitude zones after a recent snowfall and during periods of high temperature (late April and May). Therefore, to test this method in a real case, three NOAA images were chosen during the middle of February 1998 and two weeks after the last snowfall. The time lapse between the first and the third image was 5 days, which is reasonably short considering the slow changes of the snow patches one might expect during a cold month such as February.

A flow chart of the algorithm can be seen in Fig. 1, in which two snow maps are combined. The resulting snow map can be combined with a third one, allowing a combination of any number of snowmaps. Decisions are based on the surroundings of each pixel. A total of 18 values are considered for each decision, 9 for each input pixel; one value corresponding to the examined location and 8 neighbors around that location. The neighbor values considered are: u1, u2 (upwards, decreasing rows); d1, d2 (downwards, increasing rows); r1, r2 (right-sided, increasing columns) and l1, l2 (left-sided, decreasing columns). The criterion to identify the first neighbor is to obtain a different value from the input value. The second neighbor must have a different value from the first one, but can be equal to the input value. Only when the two first neighbors are found is the search completed for a particular direction.

The distance of a neighbor from the examined location is associated with a factor 2^{-n}, where n is the number of positions (or image pixels) between the neighbor and the examined location. This weight factor is used together with the neighbor values and the input values to compute the value of the output pixel. Other weight functions can be used. The search for each neighbor is set to a maximum n=20 positions. Once the routine reaches this distance the search stops and the neighbor is considered not to exist. Considering values beyond 20 positions would be useless since a weight factor 2^{-20} would eliminate any neighbor influence and the computed result would be the arithmetic average of the input values.

RESULTS AND DISCUSSION

To test the algorithm, simulated satellite images were used, obtained from different snow patterns. Correlation coefficients ρ between the snow patterns and the algorithm output increase with the number of input snow maps. For a compact snow pattern, ρ improves from 0.975 (one snow map) to 0.998 (five snow maps), and it only increases slightly when more than five inputs are used. For a scattered snow pattern, ρ improves from 0.955 (one snow map) to 0.988 (three snow maps) and inproves poorly beyond three inputs. Therefore, the reasonable number of snow maps to be combined should be between three and five. To apply this algorithm to a real case, three NOAA-14 AVHRR images of the Valira basin (Pyrenees) where selected on February 15, 17 and 19, 1998 (see Fig. 2). The snow distribution obtained from the algorithm output was compared with the snow distribution derived from the single images. The algortihm output shows less snow in low elevation zones and more in high elevation ones.

A treatment of the pixel response using the Point Spread Function (PSF) distribution implies a completely different method and more complex algorithms [3] beyond the objetives of this paper. Some works [4] use PSF functions to deconvolve the albedoes with statistical techniques, demonstrating the possibility to obtain a better spatial resolution from repeated non coincident images of the same area.

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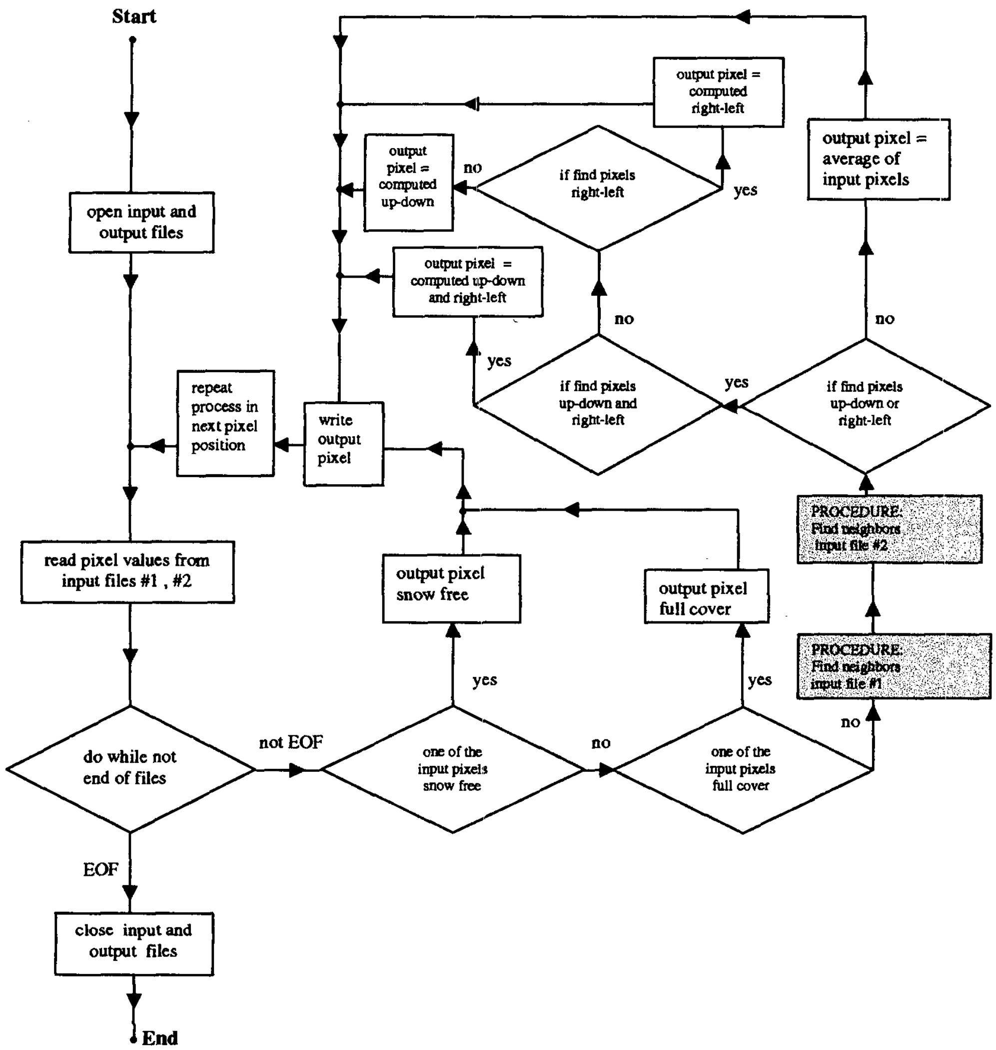

Fig.1. Algortihm for combining consecutive images of one target.

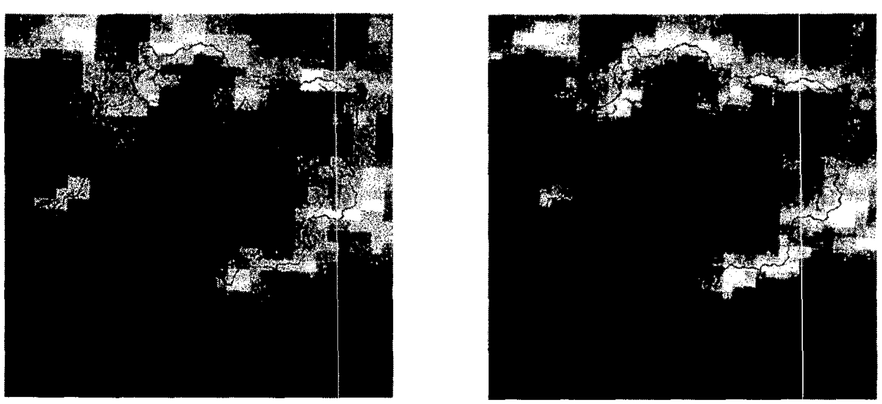

Fig. 2. Left: Snow map of Valira Basin (544.6 km^2, Central Pyrenees) on 19 February 1998. Right: algoritm output from three images.