ASSIMILATION OF MODIS SNOW COVER AND REAL TIME SNOW DEPTH POINT DATA IN A SNOW DYNAMIC MODEL

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1. Introduction

Snow plays an important role in mountain regions hydrology, as accurate estimates of the amount of water contained within the snowpack are important for water supply, soil and groundwater recharge and floods. Estimates of snow water equivalent (SWE) are required, e.g., as inputs to snowmelt models to forecast the river runoff in the snowmelt season, but the estimation of distributed SWE is very difficult due to its high variability also over small distances. This variability makes it often impossible to obtain a sufficiently accurate estimate of the water volume available in the snowpack at the watershed scale. All sources of information to evaluate SWE distribution are then to be considered: point measurements, satellite data and snow modelling, each one affected by intrinsic uncertainty. The methodology outlined in this work consists of combining several sources of information to provide the best estimate of the snowpack state as possible. We use satellite snow cover area (SCA) from MODIS and real time point measurements to drive a simple spatially distributed snow hydrological model in a data assimilation framework.

2. Methodology

The objective of this work is to evaluate the SWE field at a watershed scale combining all the sources of information available in a (near-)real time operational framework. The estimation of the SWE follows the steps illustrated in Figure 1. A spatially distributed snow model gives a prior estimate of SWE driven by meteorological input data (precipitation, temperature, incoming short wave radiation). The spatial resolution of the model for the case study is 100 x 100 meters and the temporal resolution is one hour. Once a day an observation map of SWE is obtained interpolating snow gauges measurements on the satellite-based SCA. After automatic quality control, this map is assimilated into the snow model using a nudging scheme. The result is an a posterior estimation of the SWE.

The snow dynamic model used in this experiment simply resolves the conservation of mass equation and uses a hybrid approach to compute snow melting (Kustas et al., 1994). The nudging equation used for updating the state variable (SWE) of the model is:

$$\frac{dSWE(j)}{dt} = F(SWE(j),t) + \frac{1}{N}\sum_{i=1}^{N} w(i,j)\left[SWE^{interp}(j) - SWE(j)\right] \quad (1)$$

in which F represent the model, i is the coordinate of the measure point, j is the coordinate of the modelling point and w is the weighting function defined as:

$$w(i,j) = \max\left(0, \frac{R^2 - d_{i,j}^2}{R^2 + d_{i,j}^2}\right) \tag{2}$$

with *d* distance between *i* and *j* and *R* radius of influence (set equal to 150 km in the present case study).

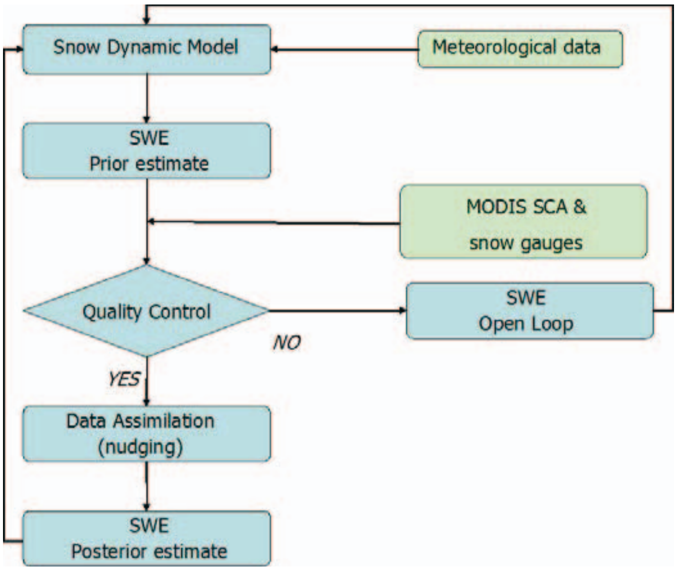

Figure 1 Flow chart of the assimilation scheme

The snow covered area are daily map obtained from MODIS (NASA's Moderate-Resolution Spectroradiometer) by using an original unsupervised approach illustrated in Macchiavello et al. (2009). The snow gauges measures are interpolated by using a multiple linear regression on slope, aspect, radiation index, elevation gradients in south and north direction and the wind index introduced by Winstral et al. (2002).

3. Case Study and Ground Data

The basin chosen for the application of the technique is a mountainous Italian region named Valle d'Aosta (Figure 2). The real time telemetry networks consist of 38 snow gauges, 80 rainfall gauges, 92 thermometers and 34 pyranometers that collect data with a hourly temporal resolution.

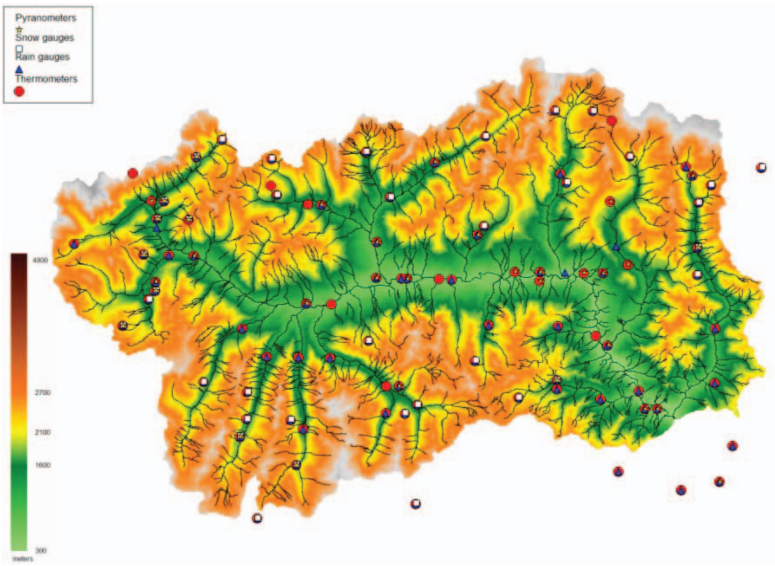

Figure 2 Digital elevation map of the Valle d'Aosta, the resolution is 100 m. The locations of the real-time measurement stations are also included.

4. Data Assimilation Experiment

The procedure of nudging assimilation ran on the period between the 1st of September 2008 and the 1st of June 2009. The Figure 3 reports the comparison between SWE maps obtained from the Open Loop run (without assimilating snow interpolated maps) and from the Nudging run (with the assimilation of snow interpolated maps). The correction performed by the algorithm are quite strong and reflects the weakness of input data in the Open Loop configuration.

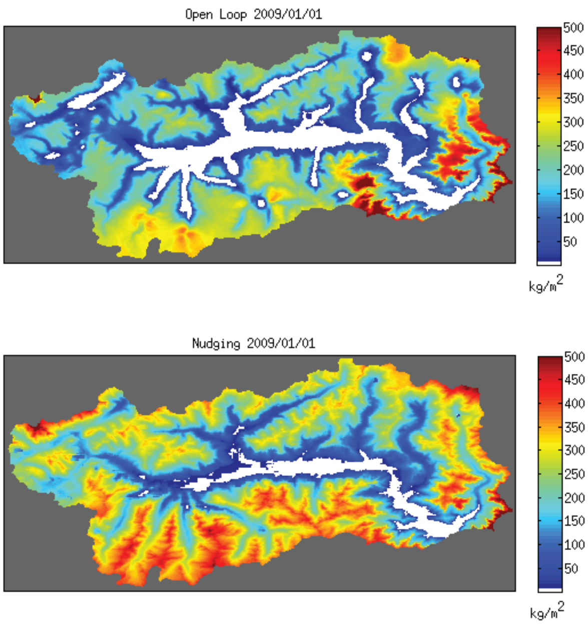

Figure 3 Comparison between SWE maps obtained from the Open Loop run (without assimilation) and the Nudging run (with assimilation of satellite and in-situ data)

A validation of the procedure has been performed excluding 8 snow gauges measurement stations form the assimilation procedure. These 8 stations are not used in the generation of the interpolated map with MLR and MODIS. The excluded snow gauges are reported in Figure 4 together with the results of the validation. Point validation shows again a high level of correction from the assimilation procedure. In general this independent validation shows an evident gain that derives form the combination of the three sources of information. Model refinements can be guided by the assimilation procedure to reduce the update kick so that the added value of satellite and in situ data can be exploited at a more refined level.

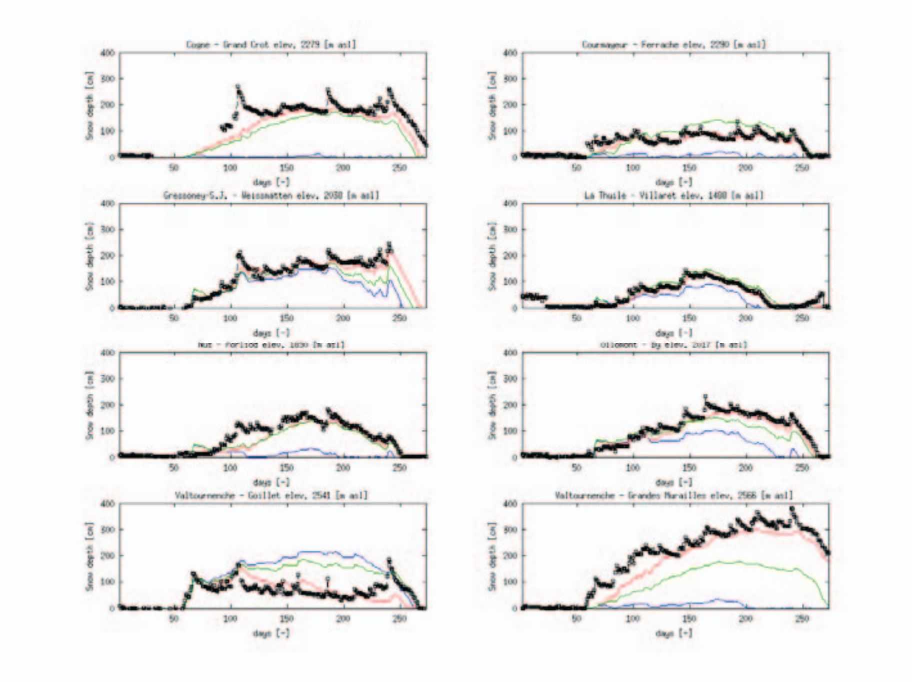

Figure 4 Punctual results from the validation: the black line represents the snow gauges observations, the blue line is open loop simulation, the red line is the nudging run considering all the snow gauges observations, the green line is the nudging run excluding the 8 snow gauges.

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