Calibration of distributed snow dynamic model from satellite images in are with complex topography

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ABSTRACT: This paper presents a simplified numerical model of snow dynamic implemented into a continuous distributed hydrological model for hydrograph simulations at basin scale. This snow model is based on air temperature thresholds that rule the snow melt and the accumulation processes.

A simple procedure to calibrate these temperature thresholds from NOAA satellite snow cover maps is discussed. We show that, in area with complex topography, for an accurate model calibration, it is necessary to correct snow coverage to fill in falsely uncovered pixels due to the presence of shaded area.

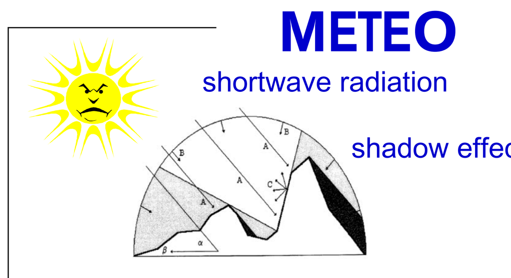
Snow model performance is tested both at local and basin scale on Alpine catchment. At local scale a good agreement between modelled snow dynamic and observed snow depth data at snow gauge stations in the Toce river basin (Italy) is shown; at basin scale agreement between observed and simulated hydrographs at the discharge station of the Toce river is reported.

MODEL DESCRIPTION

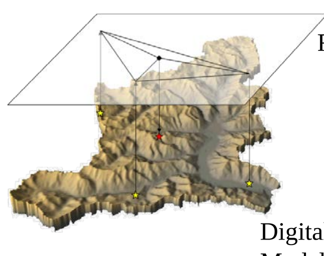
METEO

shortwave radiation

shadow effect



temperature



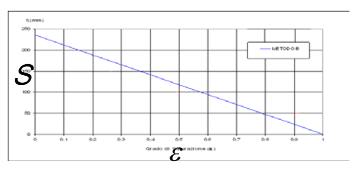
SURFACE RUNOFF

EXTENDED SCS-CN

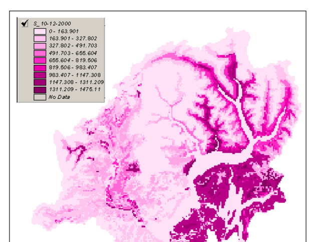
$$R = \frac{(P_{lorda} - Ia)^2}{P - Ia + S}$$

$$S_t = S_1 \cdot (1 - \varepsilon_t)$$

$$\varepsilon_t = \frac{\theta_t - \theta_{res}}{\theta_{sat} - \theta_{res}}$$

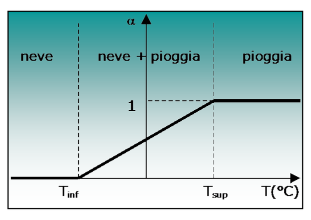


S map before a flood event



SNOW

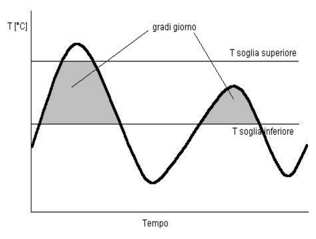
SNOW ACCUMULATION



$$\begin{cases} P_L = \alpha P \\ P_S = (1-\alpha)P \end{cases}$$

$$\alpha_p = \begin{cases} 0 & if \quad T_a \le T_{low} \\ 1 & if \quad T_a \ge T_{up} \\ \frac{T_a - T_{low}}{T_{up} - T_{low}} & if \quad T_{low} < T_a < T_{up} \end{cases}$$

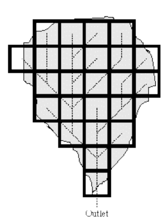
SNOW MELT

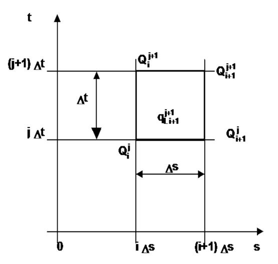


degree-day

$$M_s = C_m(T_a - T_b)$$

ROUTING





Variable celerity Muskingum-Cunge

$$Q_{i+1}^{j+1} = C_1 \cdot Q_i^{j+1} + C_2 \cdot Q_i^j + C_3 \cdot Q_{i+1}^j$$

$$C_1 = \frac{\Delta t - 2 \cdot k \cdot \varepsilon}{2 \cdot k \cdot (1-\varepsilon) + \Delta t}$$

$$C_2 = \frac{\Delta t + 2 \cdot k \cdot \varepsilon}{2 \cdot k \cdot (1-\varepsilon) + \Delta t}$$

$$C_3 = \frac{2 \cdot k \cdot (1-\varepsilon) - \Delta t}{2 \cdot k \cdot (1-\varepsilon) + \Delta t}$$

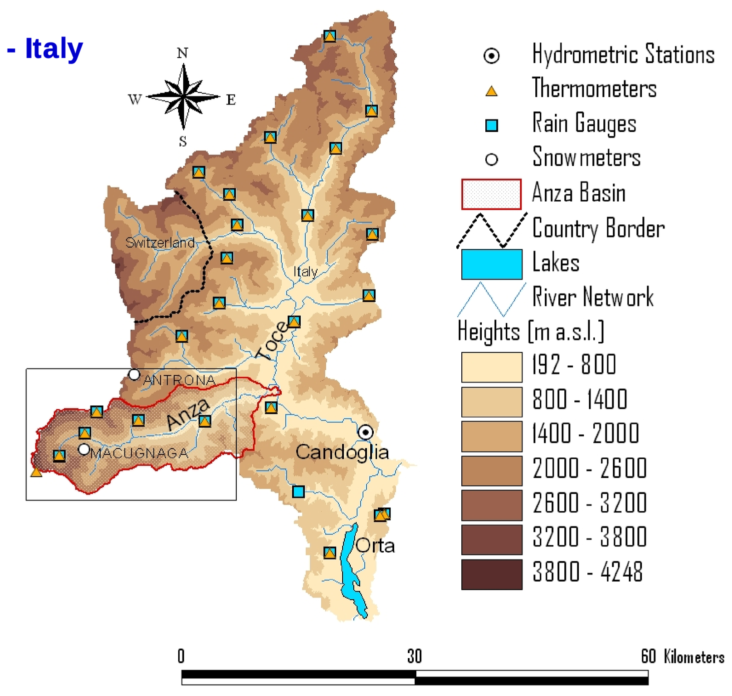
$$k = \frac{\Delta x}{\omega} \qquad \varepsilon = \frac{1}{2} \cdot \left(1 - \frac{Q}{B \cdot \omega \cdot S_0 \cdot \Delta x}\right)$$

$\omega i,j\ (t) = 5/3\ Vi,j\ (t)$

$$V = \left(k_s \left(\frac{r_f}{r_f + 2}\right)^{\frac{2}{3}} \cdot i^{0.5}\right)^{0.75} \cdot \left(\frac{Q}{r_f}\right)^{0.25}$$

CASE STUDY

River Toce Basin - Italy

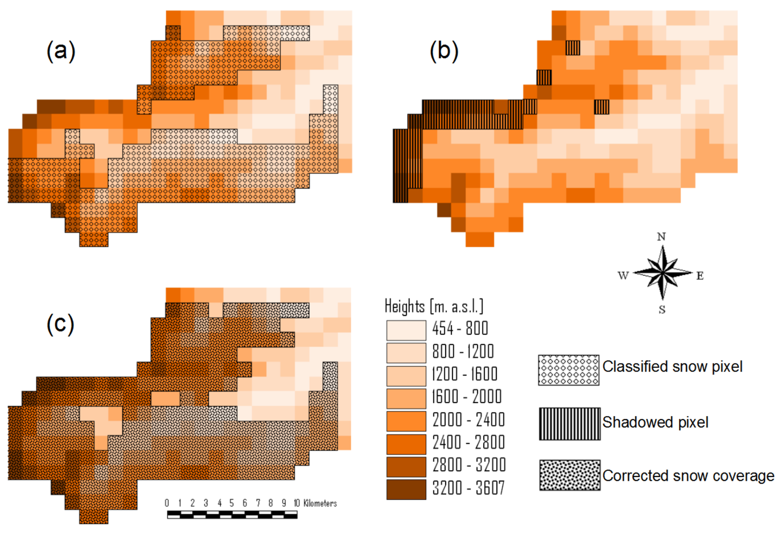


The Toce watershed extracted from the digital elevation model showing locations of the rain gauges, thermometers for air temperature measurements and hydrometric stations.

The subject area is the river Toce basin, a typical alpine basin with a total drainage area of about 1534 km², with nearly 32% of the total area above 2000 m a.s.l.. It is located in the north of the Piedmont region in Italy (Fig. 1). Climate conditions are typically humid, characterized by higher precipitations in autumn and spring. The annual average precipitation exceeds 2000 mm. Climatic characteristics, together with morphology and soil texture, frequently induced flood events in the past years. Most of the presented results are related to the Anza river basin, a tributary of the river Toce, with a total drainage area of about 261 km².

Available digital cartographic data include: the Digital Elevation Model (DEM) available in raster format at 100 m x 100 m resolution; CORINE land cover maps (CEC, 1994, EEA, 2000) updated in the year 2000 available in vector format; pedologic characteristics for soils available in vector format.

SNOW COVER FROM NOAA IMAGES



Maps of the pixels classified as snow covered (a), higher crests induced shadowed pixels (b) and resulting snow coverage after elevation based correction (c). Maps are related to the 10 February 2001 NOAA-AVHRR image.

Influence of shadow on pixel classification.

A zoom of the entire basin, characterized by very high elevations, is presented. Digital elevation model was resampled at the same spatial resolution of NOAA images (1100 m). A map of shadowed pixels was produced, related to the time when the satellite image was taken. A module taking into account the shadow effect induced by topography was developed. The algorithm calculates the angle □ between the point with maximum elevation in the direction of the solar beam, and the examined cell.

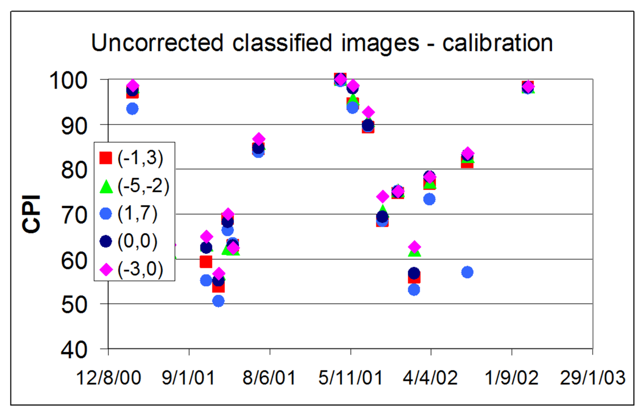
If the angle is higher then the sun elevation, the cell is shadowed.

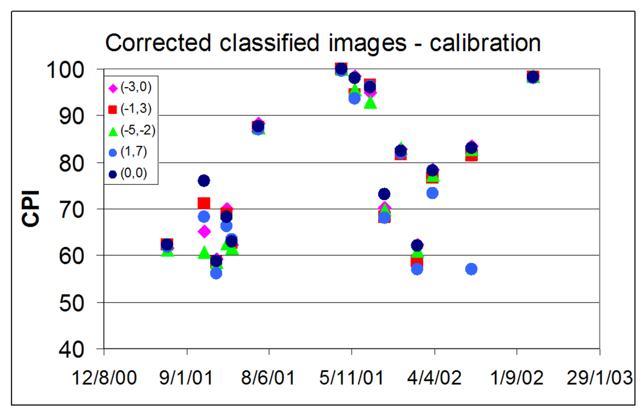
In order to reduce shadow induced error, an elevation based correction was applied. Beyond this method all pixels above a reference altitude were considered as snow covered. Reference altitude is fixed as the mean altitude of snow on the satellite image. The basic assumption is that if a pixel is classified as not covered but its elevation is greater than average snow coverage elevation, the correction is applied.

The corrected image was compared to the snow coverage retrieved from pixel classification and a strong correlation is shown between shadowed pixels and pixels falsely classified as not covered by snow.

MODEL CALIBRATION

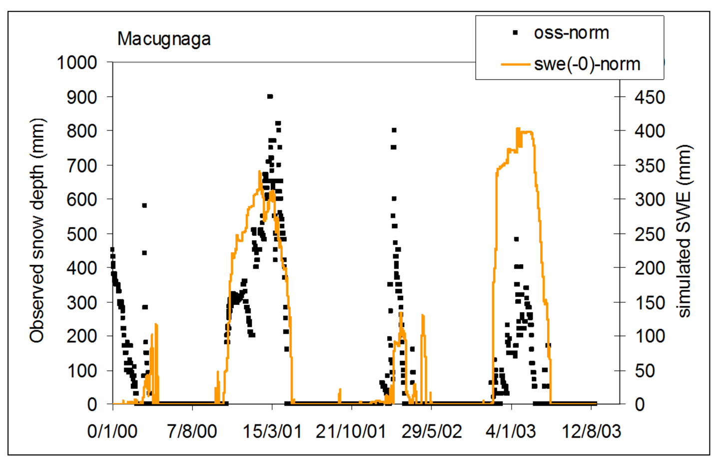
The calibration of snow accumulation temperature parameters, Tlow and Tup, in equation 3, is based on the comparison of simulated snow cover extent with the one retrieved from satellite images. The calibration was based on two objective indices: the minimization of the root mean squared error (RMSE) calculated on the number of snow covered pixels and the maximization of the correct performance index (CPI) (Ravazzani et al., 2007).





Ravazzani, G., Mancini, M., Giudici, I., Amadio, P. (2007), Effects of soil moisture parameterization on a real- time flood forecasting system based on rainfall thresholds. In: Quantification and Reduction of Predictive Uncertainty for Sustainable Water Resources Management (Proceedings of Symposium HS2004 at IUGG2007, Perugia, July 2007), IAHS Publ. 313, 407-416.

LOCAL SCALE VALIDATION



Snow heights measured at Macugnaga station are qualitatively compared to simulated snow water equivalent for the calibrated temperature thresholds Tlow = Tup = 0.

Macugnaga station

Simulated (-3,0)

observed	No snow	Snow
No snow	789	191
Snow	47	433

Simulated (-1,3)

observed	No snow	Snow
No snow	770	209
Snow	37	443

Simulated (-5,-2)

observed	No snow	Snow
No snow	882	98
Snow	115	365

Simulated (0,0)

observed	No snow	Snow
No snow	817	162
Snow	40	440

Simulated (1,7)

observed	No snow	Snow
No snow	700	280
Snow	35	445

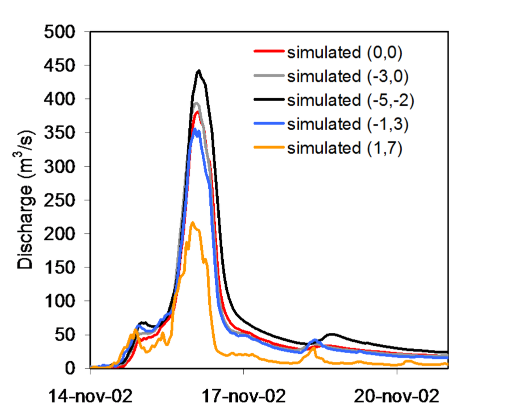
Contingency tables of binary comparison between measured snow heights and simulated results in Macugnaga station for different values of Tlow and Tup (in brackets). Results are expressed in days.

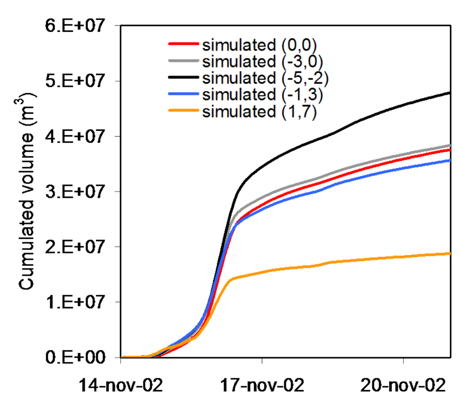
Only a qualitative comparison of the temporal dynamic between the measured snow depth and the modelled snow water equivalent (Tlow = Tup = 0) is reported for the Macugnaga station in the Anza basin and for the Antrona Lago station in the Toce basin.

So for a direct comparison of the temporal dynamic of the snow, from the "snow"-"no snow" binary series, contingency tables are build up including simulated snow data for different combination of Tup and Tlow and observed snow depth.

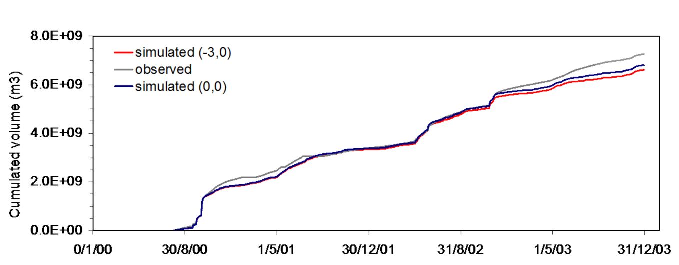
For the Macugnaga station the combination of temperatures that better represents ground cover condition is Tlow = Tup= 0 °C (CPI = 86.2%), with only 202 discrepant days on a total of 1458, confirming the results obtained from calibration of distributed model. The other combinations of temperatures, Tup=3 °C and Tlow=-1 °C and Tup=-2 °C and Tlow=-5 °C, CPI of, respectively, 83.1% and 85.4%. For Tup=0 °C and Tlow=-3 °C CPI is equal to 83.7%, while for Tup=7 °C and Tlow=1 °C CPI is 78.5%.

SIMULATION RESULTS

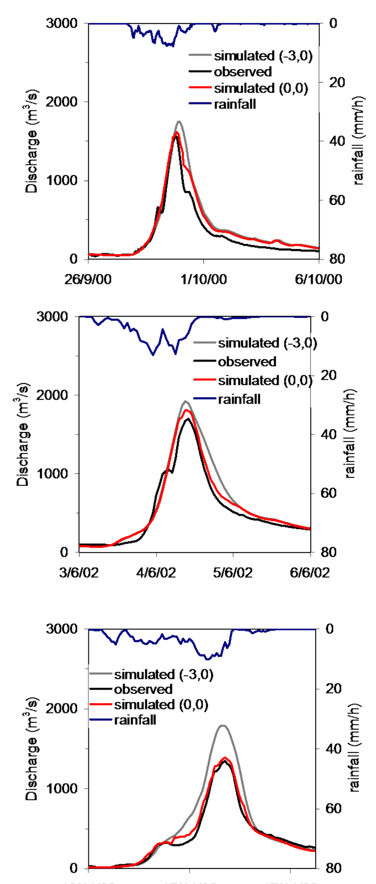




The role of the temperature thresholds at the control section of Piedimulera on the simulated discharges and on the cumulated volumes.



Comparison between the observed and the simulated runoff volume (m3) with the selected temperature threshold with non corrected satellite images (Tlow = -3 and Tup = 0) and after the topographic-shading correction (Tlow = Tup = 0) at the river cross section of Candoglia in the Toce basin.



Comparison between the observed and the simulated runoff (m3) with the selected temperature threshold (Tlow = -3 and Tup = 0) from the calibration with raw satellite images and with the selected the selected temperature threshold (Tlow = Tup = 0) from calibration and validation with corrected satellite images at the river cross section of Candoglia in the Toce basin.

CONCLUSIONS: The paper presents a simple procedure to correct NOAA-AVHRR satellite images respect to shadowed pixels induced from high crest in mountain areas. The correction consists in assigning snow coverage to those pixels with an elevation greater than a value, calculated from observed map as the average snow coverage elevation.

Snow coverage maps retrieved from satellite images were used for the calibration of a snow model, based on air temperature, integrated in a distributed hydrological model. The calibration procedure that uses raw classified images, however, led to the determination of temperature thresholds in a range not accepted by literature. Instead, when using corrected snow coverage maps, the best result was most frequently achieved when both two temperature parameters were set to 0°C. Moreover, simulation of discharge hydrograph at main river section reached best performance when the temperature thresholds calibrated with the use of corrected snow extent were used.

The snow model and the methodology for its calibration were validated at local scale, too. Comparison between simulated snow water equivalent and observed snow depth at two gauges showed that temporal dynamic of snow was better simulated when the two temperature parameters were set to 0 °C.

In order to further validate the topographic-shading correction, observed snow depths were compared to snow coverage retrieved from satellite. We showed that, when using corrected images, discrepancies were completely removed.

The presented procedure is suitable also for application to those river basins where snow depth measurements are not available.

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