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AWARE

A tool for monitoring and forecasting Available WAter REsource in mountain environment

SPECIFIC TARGETED RESEARCH PROJECT
PRIORITY 4: Aeronautics and Space

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1. **PROJECT OBJECTIVES**

AWARE (A tool for monitoring and forecasting Available WAter REsource in mountain environment) is a research project that aims at providing innovative tools for monitoring and predicting water availability and distribution in those drainage basins where snowmelt is a major component of the annual water balance, such as the Alpine catchments.

AWARE has been motivated by the urgent need to predict medium-term flows from snowmelt for an effective and sustainable water resources management.

The innovations proposed by the project regard:

- the use of Earth Observation (EO) data, in order to model snow-pack related processes in a spatially distributed framework exploiting the enhanced capability of such data to provide continuous information on hydro-meteorological state variables;
- the development of an on-line tool to make runoff models accessible on the web sharing them with interested users by offering the possibility to run hydrological models, by means of specifically designed geo-services capable to select, discover and harmonize ground and EO data needed for the purpose.

2. **CONTRACTORS INVOLVED**

AWARE has been carried out by a team of hydrologists, remote sensing specialists and remote sensing specialists and information system analysts from 5 European countries with a long term experience in modelling and representing environmental phenomena.

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3. WORK PERFORMED AND RESULTS

Following the objectives of the AWARE project an analysis of requirements phase has been performed to cover a number of aspects related to users, catchments characteristics, EO and ground data availability and the functionalities of the geo-service.

On the basis of the EO data requirements, in terms of spectral, spatial and temporal resolution, and products to be assimilated in the models models, EO data acquisition, pre-processing, classification and parameter extraction activity have been defined and implemented.

Four models have been selected for the set up of the assimilation activity: two models for Snow Water Equivalent evaluation, one based on physical approach (Bartelt et al., 2002) and the other on statistical one (Carrol and Cressie, 1997); two models for the Snow melt Dynamic quantification, both conceptual and semi-distributed, the SRM (Martinec and Rango, 1983) and the modified HBV (Blöschl, 1991) models for the Snow melt Dynamics quantification. A model for the analysis of groundwater impact on runoff formation has been also investigated to study the influence of snowmelt on groundwater dynamics (Martinec et al., 1982). Model calibration, validation and demonstration is performed for representative catchments of different geographic conditions in the European Alps.

Runoff models have been implemented in a geo-portal allowing the tailoring of data and models to different environments under an integrated approach capable of effectively addressing the specific problems raising from different stakeholders, these including water policy makers, economic and social stakeholders. The geo-services designed are fully compliant with the architecture of the INSPIRE (INfrastructure for SPatial InfoRmation in Europe) initiative, and capable of coupling global and local data to compute, archive, upgrade and distribute model results.

3.1 EO data processing

Each remote sensing application has specific demands as regards the amount of area to be covered, the frequency with which measurements will be made, and the type of energy that will be detected.

Thus, a sensor must provide the spatial, temporal, spectral and radiometric characteristics necessary to meet the needs of the application. Sensors on-board satellite platforms are defined by four main technical characteristics (resolutions) that represent key information about the kind of imagery acquired by the sensor and their general suitability for the different applications.

In the AWARE project framework modelling is primarily aimed to estimate two quantities: Snow Water Equivalent (SWE) - both under statistically and physically based perspectives, and, water discharge from snow melt dynamics (SMD) modelling, by both a general hydrological and a snow melt runoff model, also taking into account the impact of ground water.

Starting from the analysis of requirements phase related to users, catchments characteristics, EO and ground data availability to users, a set of parameters has been defined to test the assimiliation of EO data in the selected models:

- Snow Cover Area (SCA): snow cover distribution is the main information that can be derived from satellite observations to be assimilated in all the models proposed.
- Air temperature: an experiment to evaluate and validate empirical relationships between air and land surface temperature (LST) as well as between instant temperature and daily mean values has been also conducted exploiting MODIS LST products.
- Albedo maps have been derived by TM images acquired on a well equipped Swiss basin to experiment the assimilation of albedo information in the physical model for the estimation of snow water equivalent.
- Snow Water Equivalent: an experiment of deriving snow water equivalent information from SAR data has been conducted. Targeted field measurements have been planned and performed contemporary to the acquisition of ALOS-PALSAR data in the framework of an ESA project aimed to demonstrate the feasibility of ALOS-PALSAR data for hydrological purposes, in particular for mapping and quantify Snow Covered and Water Equivalent. Unfortunately the satellite acquisitions planned have not been performed and a back up solution using RS data has been conducted.

3.1.1 Snow Cover Area

Snow Cover Area (SCA): snow cover distribution is the main information that can be derived from satellite observations to be assimilated in all the models proposed.

Analysing suitable EO sensors, in terms of their technical characteristics (temporal resolution and coverage) and of some indications of feasibility (cost per scene, maximum processing level provided, real time availability), MODIS products could be considered the most suitable EO data to be utilised.

Several approaches have been applied to derive SCA from these types of images:

— A procedure to extract snow cover area from MOD02 NASA products has been applied, including, radiometric correction, application of a Normalized Snow Index (NDSI), identification of water bodies and cloud masking.

— Due to the small extension of some Alpine basins, fractional snow cover techniques have been experimented. Soft classification techniques based on fuzzy set theory have been applied on a set of 6 images on a small basin in Lombardia Region (Mallero basin).

— To overcome the main problem given by the presence of cloud cover, spatio-temporal interpolation algorithms have been developed.

3.1.1.1 NDSI for snow cover mapping

In the AWARE project framework, Snow Covered Area products based on the Normalized Difference Snow Index (NDSI) used and assimilated in hydrological and snowpack models are of two kinds:

1. NASA standard products as provided by the MODIS Snow and Sea ice Global Mapping Project on the base of the SNOMAP algorithm [14];
2. Snow cover maps obtained by a segmentation approach similar to the SNOMAP algorithm (D. Hall et al., 2002) but customized on the Alpine region.

Both kinds of products - MODIS standard product (fig. 3.1.1a) and project product (fig.3.1.1b) - have been used in the assimilation of SCA in the AWARE project models.

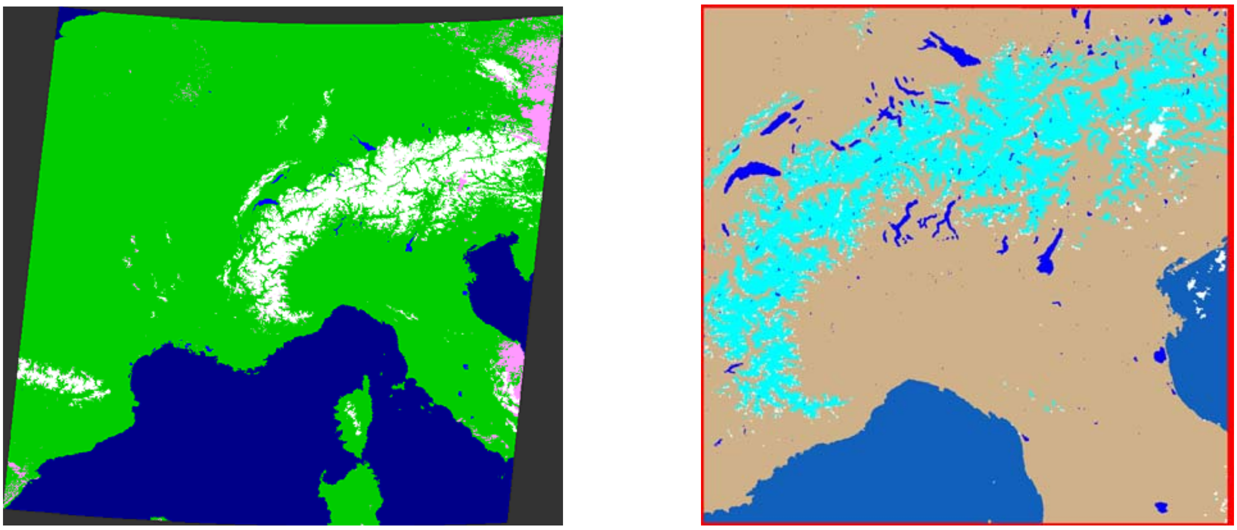

(a) (b)

Figure 3.1.1 - SCA products for 2003-03-19: (a) MOD10A1 product (snow:white; no_snow:green; clouds:magenta; water:blue) (b) AWARE SCA_r3(snow:cyan; no_snow:brown; clouds:white; water:blue)

As regards the use of SCA data in the framework of the AWARE geo-service, thanks to a MODIS Snow and Sea ice Global Mapping Project agreement, both kind of products are available in the Catalogue Service (CSW), and Web Map Service (WMS) for the AWARE users'.

While project products are available for the Alps, the MOD10 daily products (tile 18:04) are available also over the eastern Pyrenees.

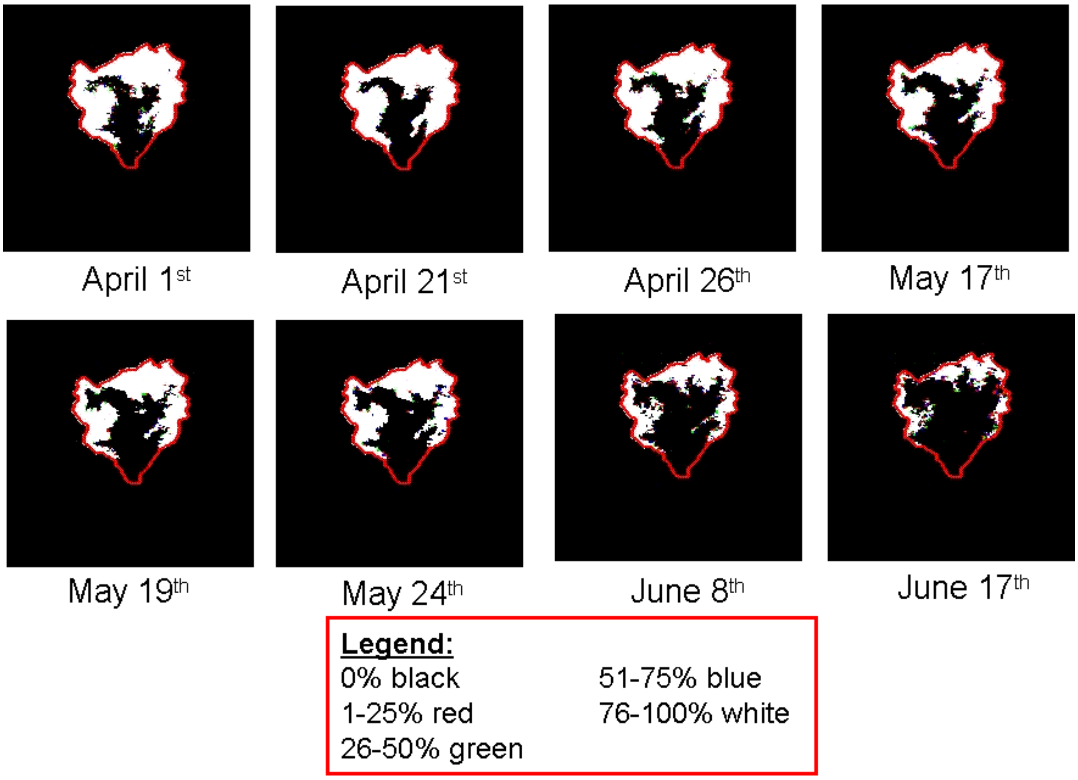
3.1.1.2 Fractional snow cover procedure

The choice of using the MODIS sensor for SCA mapping in the project framework has been constrained by the need for high temporal resolution, adequate spectral resolution (shortwave infrared presence), together with the coverage of at least the whole Alps. Though this choice is adequate for most applications, sometimes spatial resolution is not sufficient: it is the case of small basins of few hundred km^2.

In this case it has been proposed a procedure based on fractional snow cover determination by means of a supervised soft classification paradigm. The use of an expert supervision makes the procedure semi-automatic and hence practical only in particular case studies.

A way to improve spatial resolution is offered by both the use of an un-mixing technique for classification and of MODIS bands at 250m pixel size.

The classification is based on the fuzzy statistics method proposed by Wang (1990). This method does not classify pixels simply as belonging to a certain class, but for each pixel a membership function to each class is calculated (soft result) which can be considered an indicator of the fractional snow cover within the pixel (fig. 3.1.2). This technique leads to an increased geometric resolution of the results: although it is only possible to infer the percentage of snow in a pixeland not the snow mosaic within the mixed pixel, this last is not always necessary for assimilating SCA in models. For instance using the soft result in runoff models making use of altitude ranges the information is sufficient, since it provides the required percentage of snow area Vs no-snow in each altitude belt.


April 1st
April 21st
April 26th
May 17th
May 19th
May 24th
June 8th
June 17th

Legend:
0% black
1-25% red
26-50% green
51-75% blue
76-100% white

Figure 3.1.2 – Fractional Snow Cover maps on the Mallero river basin (borders highlighted in red) for the year 2004; the legend associates colours to the percentage of snow

3.1.1.3 Spatio-temporal interpolation

One of the major sources of inconvenience in the use of SCA data as derived by optical remote sensing in hydrology is the presence of cloud coverage, especially in mountains regions. Since modelling works usually on a daily basis, a daily information about snow covered area is required. While theoretically this temporal resolution is provided by satellite sensors such as the MODIS, practically in the mountain regions the frequency is largely lower, and particularly in the Alps the cloud coverage incidence remains an open issue.

In the literature two main approaches are referred to the problem of cloud coverage in snow mapping from remotely sensed images: extrapolation methods and the coupled use of radar sensors.

The use of radar imagery for snow cover mapping has been investigated but still presents two main constraints: 1) the discrimination of dry snow and snow-free areas that cannot be accomplished at the active microwave C-Band (4-8 GHz), in which most of the Synthetic Aperture Radar (SAR) sensors (ERS-SAR, RADARSAT, ASAR) operate (Strozzi and Mätzler, 1998 Strozzi et al., 1999) 2) the significant amount of missing coverage occurring in SAR images due to geometric effects, particularly in mountain regions (Caves et al. , 2000).

Extrapolation methods can be designed either on spatially or temporally based image reconstruction methods to restore information under cloud obscured pixels.

In the project framework four extrapolation methods were adopted and tested on different study areas; all methodologies are based on quite simple approaches to provide operative tools useful in the project context.

The first three extrapolation methods are simple re-mapping methods based on spatial and temporal combination of MODIS images (Parajka and Blöschl, 2008). The reduction of cloud coverage is achieved by using information from neighbouring non-cloud covered pixels in time or space, and by combining MODIS data from the Terra and Aqua satellites.

The first approach, termed the combination of Terra and Aqua, merges the two MODIS snow cover products on a pixel basis. The pixels classified as clouds in the Aqua images are updated by the Terra pixel value of the same location if the Terra pixel is snow or land. This approach combines observations on the same day, shifted by several hours.

The second approach, termed the spatial filter, replaces pixels classified as clouds by the class (land or snow) of the majority of non-cloud pixels in an eight pixel neighbourhood. When there is a tie, the particular pixel is assigned as snow covered. The spatial filter procedure was applied to the combined Aqua-Terra images of the first approach.

The third approach, termed the temporal filter, replaces cloud pixels by the most recent preceding non-cloud observations at the same pixel within a predefined temporal window. Temporal windows of 1, 3, 5 and 7 days were tested. This procedure was, again, applied to the combined Aqua-Terra images of the first approach.

The accuracy of all filter methods is evaluated over Austria, using daily snow depth observations at 754 climate stations and daily MODIS images in the period 2003-2005.

The results indicated that the three filtering techniques are remarkably efficient in cloud reduction, and the resulting snow maps are still in good agreement with the ground snow observations.

The fourth extrapolation approach is based on the recognition in the same image of cloud-free pixels with comparable snow conditions of cloud-obscured ones (Pepe et al., 2005). The methodology approximates the snow line altitude in different morphological conditions on the base of statistical distribution of cloud-free pixels.

The basic assumption for this extrapolation method is that a certain catchment area can be considered as meteorologically homogeneous (Seidel et al., 1983) and that the main features controlling snow accumulation and depletion in each catchment area are the altitude and the aspect. Slope, which was initially considered, proved to be statistically not significant for achieving better extrapolation results.

The snow cover map, including the cloud cover mask, the Digital Elevation Model (DEM), the aspect map, and a map representing main catchments are integrated by an automatic procedure to produce a snow cover map improved by reconstructed snow covered surfaces.

The methodology has been applied to the Terra daily snow cover product in the period 2002-2006 over Austria and accuracies have been evaluated using daily snow depth observations at 754 climate stations.

The results indicated that the extrapolation technique is very effective in reducing cloud obscuration, and the extrapolated snow maps still present a good accuracy level when compared with ground snow observations.

An average of 66% cloud coverage of the Terra products is reduced to 40% in the extrapolated snow products.

3.1.2 Air temperature

Air temperature: an experiment to evaluate and validate empirical relationships between air and land surface temperature (LST) as well as between instant temperature and daily mean values has been also conducted exploiting MODIS LST products.

The determination of spatially distributed temperature information from point observations in mountainous areas is often a delicate task, dependent on many influencing factors which cannot be taken into account by a simple interpolation based only on the vertical lapse rate. When the scale of observation passes from local to regional one, a spatial interpolation would be necessary, but the irregular characteristics of the Alpine landscape, in terms of different land cover types and topography, add uncertainties to the final spatial estimations. In this context, remote sensing from satellites can offer a contribution since it regularly provides spatially distributed information also about ungauged areas (Ignatov and Gutman, 1998). Radiometers onboard satellites cannot directly measure the air temperature, but estimations of the Land Surface Temperature (LST) can be obtained by means of specific algorithms from Thermal Infra-Red (TIR) channels satellite data [26]. Coarse/medium spatial resolution sensors like the Advanced Very High Resolution Radiometer (AVHRR) and, more recently, the Moderate-resolution Imaging Spectroradiometer (MODIS) have already been extensively used and tested for the LST retrieval.

In particular, MODIS furnishes twice a day a LST product at 1 km spatial resolution covering all the Earth's surface.

A methodology to estimate the daily mean air temperature in Alpine areas from EO derived Land Surface Temperature (LST) MODIS products has been designed and implemented; it has been tested on a region in Italian central Alps, and compared with a standard spatialization method (i.e. Inverse Distance Weighting).

Initially, the satellite-derived LST is linked to the instantaneous air temperature, at the time of the satellite overpass, as collected at meteorological stations, through a simple linear regression.

Then, the daily mean air temperature is obtained from the instantaneous air temperature by means of another linear regression and taking into account the air temperature diurnal cycle.

The methodology to estimate the daily mean air temperature from MODIS satellite imagery was applied to a study area (3,500 km^2) located in the Italian Alps, Lombardia district, where Terra satellite overpasses every day between 10 and 11 AM and between 9 and 10 PM.

The methodology proved to be useful in heterogeneous landscapes with low density of meteorological stations, like Alpine areas. Generally, in environmental hydrological and climate modelling, the daily mean air temperature in an ungauged site is estimated using the spatial interpolation of point measurements. But the results of the study proved that the proposed methodology based on EO data performs better than a standard deterministic interpolation technique such as the Inverse Distance Weighted (IDW) interpolation in areas where the density of meteorological stations is generally low, overcoming problems common in environmental modelling in mountain areas.

3.1.3 Albedo

Albedo maps have been derived by TM images acquired on a well equipped Swiss basin to experiment the assimilation of albedo information in the physical model for the estimation of snow water equivalent.

The total energy reflected by the surface is a key factor in the understanding of the mass/energy balance of the snowpack. This is the reason why this variable was useful to be assimilated in the ALPINE 3D snowpack physical model.

Depending on the grid size of the model as well as the spectral information required, the Landsat Thematic Mapper (TM) imagery proved to be the more suitable EO data set.

In this study, the Landsat-5 TM data acquired on 24th April 1996 over the Dischma Valley (Switzerland) was used to derive albedo values. The final aim was the subsequent assimilation of this kind of EO-based products in the ALPINE3D snowpack physically based model to predict the SWE in mesoscale catchments.

The retrieval of surface albedo from satellite data using physically based models requires different steps, mainly involving the following four processing steps:

- the calibration of the satellite sensors,
- the correction for atmospheric effects,
- the calculation of the spectrally integrated albedo from values measured in sensor spectral bands, and
- the correction of anisotropic reflection at the surface (Greuell and Ruyter de Wildt, 1999)

In this study, the conversion of raw digits into at-the-sensor radiances was based on the calibration coefficients provided by Chander and Markham (Chander and Markham, 2003), who critically have been revising the status of TM sensor performances during the years.

The correction for the atmospheric effects was computed using the radiative transfer code 6S (Vermote et al., 1997). The code was run with high visibility range (100 km), continental model for aerosols and an average ground altitude of 2000m. In the atmospheric correction and for the albedo computation, the surface was assumed to be Lambertian. This is an approximation since in nature very few surfaces act on incident radiation as a Lambertian reflector that scatters the energy equally well in all directions irrespective of solar illumination angle. Nevertheless, accurate knowledge of the bi-directional distribution functions of the investigated targets is needed for understanding the impact of Sun angle illumination and sensor viewing geometry (Giardino and Brivio, 2003).

The broad-band albedo (BBa) from TM data was determined as a function of atmospherically corrected TM reflectance in bands 2, 4 and 7, according to literature data (Knap et al., 1999). Highest albedo values were observed at the top of the mountains, while a decreasing of albedo was observed for lower altitudes. Unfortunately, no ground truth measurements of the albedo were available at the time of Landsat overpass for validation. Anyway a comparison between the albedo from EO data and the one computed within the model ALPINE3D, as well as an analysis of respective influences on model results were performed.

The results presented in this study showed the capabilities of Landsat to map albedo, an important parameter in SWE retrieval. The computation of albedo from satellite is anyway affected by several factors, including the anisotropic reflectance properties of investigated surfaces. The methodology could be further exploited according to the following items:

- The atmospheric corrections should be parameterised according to different elevation zones and detected values of aerosol concentrations. If such data are not available like in this study, the iterations of 6S runs should be accomplished using a larger ground-truth dataset. Also the effect of topography should be taken in account in applying the atmospheric correction;

- the assumption that snowy surfaces are close to be *Lambertian* for the nadir viewing geometry of Landsat should be verified;
- the albedo map seems reliable but, in general, the albedo map should be validated using in-situ observations.

Anyway the analysis of BBa values obtained from TM data was useful in the understanding of ALPINE3D sensitivity to its determination method and offers the basis for further analysis.

3.2 **Assimilation of EO data into snow water equivalent models**

3.2.1 Statistical approach to snow water equivalent evaluation

Snow accumulation and ablation rule the temporal dynamics of water availability in mountain areas and cold regions. In these environments, the evaluation of the snow water amount is a key issue. The spatial distribution of snow water equivalent (SWE) over a mountain area, at the end of the snow accumulation season, is estimated using a simple statistical method (SWE-SEM). This combines ground measurements collected at snow gauges and MODIS data of snow covered area (SCA). SWE-SEM calculates firstly local SWE estimates at snow gauges, then the spatial distribution of SWE over a certain area using an interpolation method: linear regressions of the first two order moments of SWE with altitude. The spatial interpolation is conditioned by the SCA retrieved via MODIS data. SWE-SEM is applied to Mallero basin, mountain part of Lombardia region, Davos area.

3.2.1.1 Method

SWE-SEM is a two-step procedure: *i*) local SWE estimates are obtained at snow-gauged sites, then *ii*) the spatial distribution of SWE over a certain area is derived from local SWE estimates via an interpolation method based on linear regressions of the first two order moments of SWE with altitude.

Local SWE estimates at snow gauges

The snow water equivalent, $S \geq 0$, is defined as

$$S = \frac{\rho_s}{\rho_w} H_s, \tag{1}$$

where H_s is the snow depth, ρ_s is the snow density, and ρ_w is the water density. ρ_s is generally in the range 200÷650 kg/m^3, ρ_w is assumed 1000 kg/m^3. Eq.(1) gives SWE in the same unit of snow depth, commonly in cm. Here, H_s and ρ_s are referred to the end of the accumulation season, in our case April 1st. If snow gauges provide both snow depth and snow density observations, Eq.(1) gives a direct measurement of SWE at snow gauges. Alternatively, if snow gauges provide only snow depth measurements, as often happens in the Italian context, snow density estimates are necessary. These are obtained through empirical formulas, see e.g., Elder et al. (1991); Onuchin and Burenina (1996), Ranzi et al. (1999), Martinelli et al. (2004). Thus combining snow depth measurements and snow density estimates in Eq.(1), it is possible to obtain SWE estimates at snow gauges.

Spatial distribution of SWE from SWE estimates at snow gauges

Let S(**u**) denote the r.v. snow water equivalent, at the end of accumulation season, parameterized by the vector $\mathbf{u} \equiv (x, y, z)$ in the domain $\mathbf{A} \subset \mathbf{R}^3$. The domain **A** is a non-planar surface representing a river basin or a geographic region**.** The variable S describes a random field over the domain **A**. Let

E[S(**u**)] and σ[S(**u**)] be respectively the mean and standard deviation of S at the point **u** (on a certain Julian date, in our case April 1st). In mountain basins, the orography influences the spatial distribution of precipitation: along a slope the precipitation tends to increase with the altitude. Also the snow depth at ground is a function of the altitude z (Carroll 1995). This means that, for $\mathbf{u}_1 \neq \mathbf{u}_2 \in \mathbf{A}$, $E[S(\mathbf{u}_1)] \neq E[S(\mathbf{u}_2)]$ and $\sigma[S(\mathbf{u}_1)] \neq \sigma[S(\mathbf{u}_2)]$. Consequently, the random field is non homogeneous in the mean and standard deviation (e.g., Carroll and Cressie, 1997). In order to transform the non homogeneous random field in a homogeneous one in terms of mean and standard deviation, the following normalization is considered:

$$S^*(\mathbf{u}) = \frac{S(\mathbf{u}) - E[S(\mathbf{u})]}{\sigma[S(\mathbf{u})]}, \tag{2}$$

where $S^*(\mathbf{u})$ is the standardized snow water equivalent at location $\mathbf{u} \in \mathbf{A}$. $S^*(\mathbf{u})$, $\forall \mathbf{u} \in \mathbf{A}$, is characterized by zero mean and unitary standard deviation. Since S(**u**) is referred to April 1st, i.e., it represents the water under snow form accumulated during the winter season, S(**u**) is distributed as a Normal distribution, according to Central limit theorem, and consequently, $S^*(\mathbf{u})$ as a standard Normal distribution, i.e., $S^*(\mathbf{u}) \sim N(0,1)$. In addition, according to the data (see next section), the realizations of $S^*(\mathbf{u})$ are assumed independent in time, and fully (positive) dependent in space. This means that for a single realization S^* is the same $\forall \mathbf{u} \in \mathbf{A}$.

The variability of E[S(**u**)] and σ[S(**u**)] is explained by geomorphologic variables like altitude (z), aspect (P), and slope (I). In particular, the altitude z explains the great part of E[S(**u**)] and σ[S(**u**)] variability, because the altitude controls the temperature patterns (Lopez-Moreno and Nogues-Bravo, 2006). Simple linear regressions with altitude are then used to estimate E[S(**u**)] and σ[S(**u**)] in ungauged sites:

$$\hat{E}[S(\mathbf{u})] = \alpha z + \beta \tag{3.1}$$

$$\hat{\sigma}[S(\mathbf{u})] = \gamma z + \delta \tag{3.2}$$

where α, β, γ, δ are the coefficients of regressions.

Consequently, an estimate of S(**u**), for the year j, is

$$\hat{S}_j(\mathbf{u}) = \hat{E}[S(\mathbf{u})] + \hat{S}_j^*(\mathbf{u})\hat{\sigma}[S(\mathbf{u})] \tag{4}$$

where $\hat{E}[S(\mathbf{u})]$ and $\hat{\sigma}[S(\mathbf{u})]$ are derived from Eq.(3). An estimate of $\hat{S}_j^*(\mathbf{u})$ can be obtained as follows. If observed data are available in the domain for the year j, $\hat{S}_j^*(\mathbf{u})$ is calculated as sample mean of the standardized snow water equivalent collected at *n* snow gauges ($\mathbf{u}_i$, i=1,…,n) for the considered year, i.e., $\hat{S}_j^*(\mathbf{u}) = \sum_{i=1}^{n} \hat{S}_j^*(\mathbf{u}_i)/n \ \forall \mathbf{u} \in \mathbf{A}$.

Let $\mathbf{B} \subseteq \mathbf{A}$, a portion of the domain **A**, the mean snow water equivalent over (the non-planar surface) B, is defined as

$$S_B = \frac{1}{B} \int_{\mathbf{B}} S(\mathbf{u}) d\mathbf{u} \tag{5}$$

where B is the area of the (non-planar) surface **B**. If **B** is the portion of the domain **A** characterized by S>0, Eq.(5) represents the conditional mean of snow water equivalent by S>0.

The volume of the snow water equivalent, V_{S_B}, is simply the product $S_B B$.

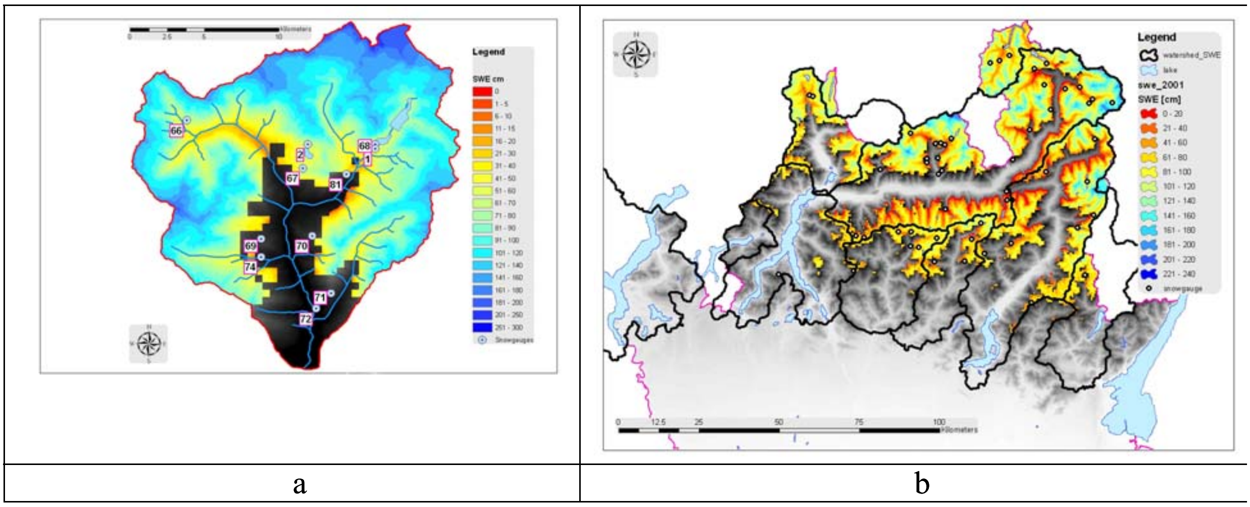
An estimate of S_B, for the year j, can be obtained integrating Eq.(4) over the domain **B** as

$$\hat{S}_{jB} = \frac{1}{B}\int_{\mathbf{B}} \hat{S}_j(\mathbf{u})\,d\mathbf{u}\,. \tag{6}$$

3.2.1.2 Study areas: SWE map production

We have applied SWE-SEM to Mallero basin and Lombardia Region.
Figure 3.2.1 gives the spatial distribution of SWE for Mallero basin and Lombardia Region for 2001. Figure 3.2.2 shows the same information for Davos area for 2001 and the comparison with ALPINE3D physically based model.

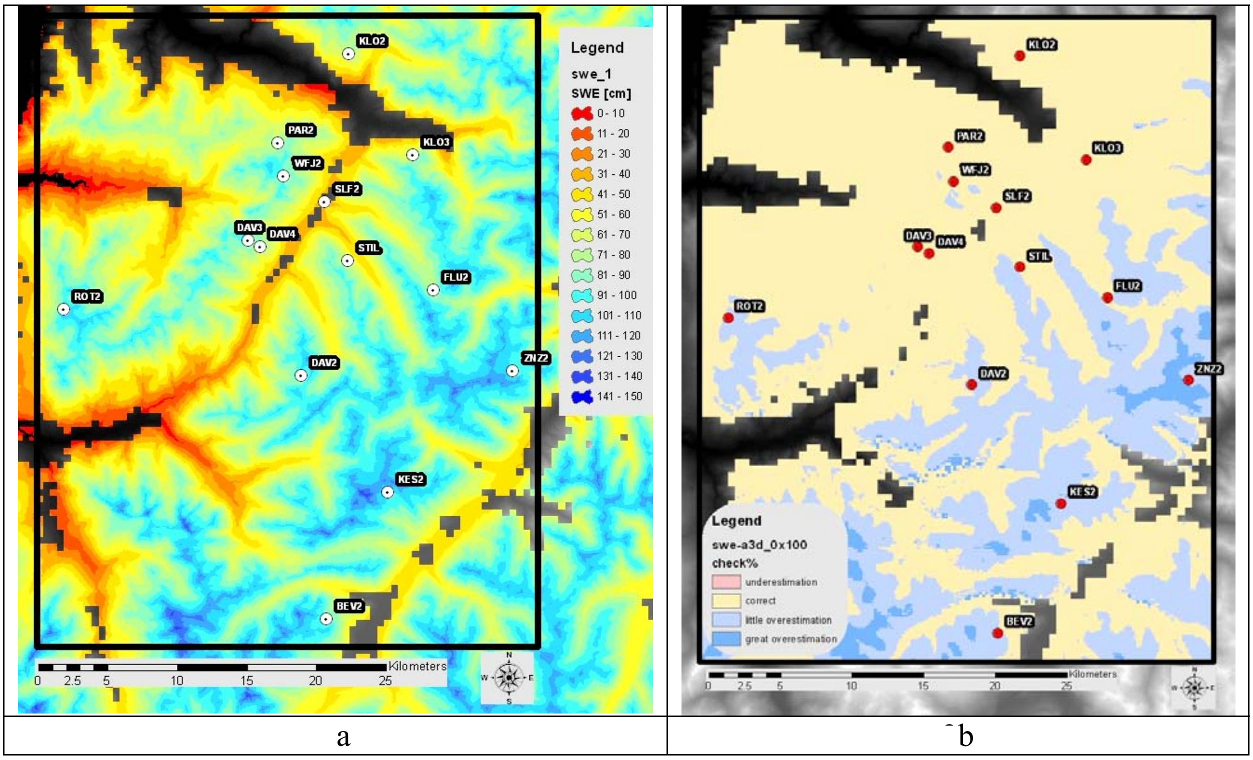
More over in Davos area (CH), we have carried out comparisons between SWE-SEM model and other models, namely, SNOWPACK and ALPINE3D, developed by the Swiss Federal Institute for Snow and Avalanche Research, achieving quite good agreement.



a

b

Fig. 3.2.1: Spatial distribution of SWE for Mallero basin and Lombardia Region for 2001.



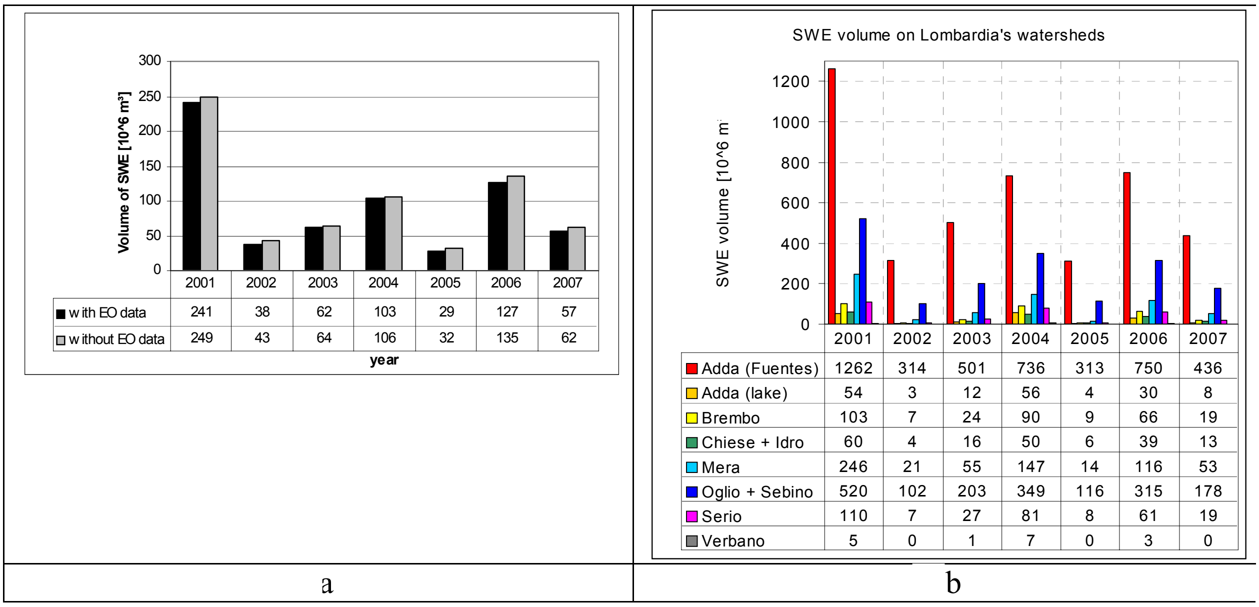
a

b

Fig.3.2.2: Spatial distribution of SWE in Davos area for 2001(2a) and comparison with ALPINE3D (2b).

3.2.1.3 Results

Figure 3.2.3 illustrates SWE volumes for the period 2001-2007, respectively for Mallero basin (a), and Lombardia Region basins (b). Figure 3.2.4 gives the same information for Davos area.



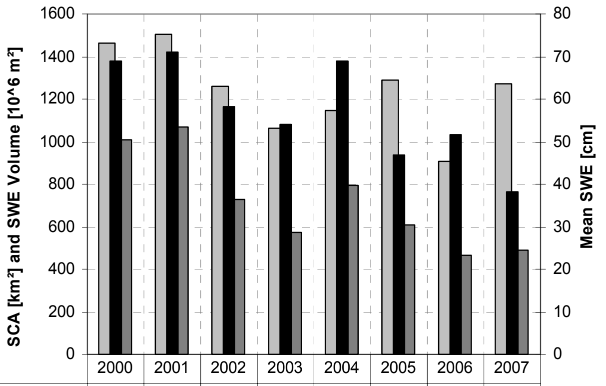
	2001	2002	2003	2004	2005	2006	2007
■ with EO data	241	38	62	103	29	127	57
▨ without EO data	249	43	64	106	32	135	62

	2001	2002	2003	2004	2005	2006	2007
🟥 Adda (Fuentes)	1262	314	501	736	313	750	436
🟧 Adda (lake)	54	3	12	56	4	30	8
🟨 Brembo	103	7	24	90	9	66	19
🟩 Chiese + Idro	60	4	16	50	6	39	13
🟦 Mera	246	21	55	147	14	116	53
🟦 Oglio + Sebino	520	102	203	349	116	315	178
🟪 Serio	110	7	27	81	8	61	19
⬛ Verbano	5	0	1	7	0	3	0

a

b

Fig. 3.2.3: SWE volumes on Mallero river basin and on Lombardia Region basins.



	2000	2001	2002	2003	2004	2005	2006	2007
□ SCA [km²]	1460	1505	1258	1060	1149	1292	909	1272
▨ SWE Volume [10^6 m³]	1006	1070	731	572	794	607	468	488
■ Mean SWE [cm]	69	71	58	54	69	47	51	38

Fig 3.2.4: SCA and SWE estimated on the Davos area

3.2.1.4 Conclusions

A simple statistical method, SWE-SEM, for the determination of spatial distribution of SWE over a small mountain basin, at the end of the snow accumulation season, is presented. This couples ground measurements collected at snow gauges and MODIS data of snow covered area. SWE-SEM is a two-step procedure: firstly local SWE estimates are obtained at snow gauges, secondly a spatial distribution of SWE over a certain area is derived through an interpolation method which uses linear regressions of the first two order moments of SWE with altitude. SWE-SEM is applied to different areas: Mallero basin, mountain part of Lombardia region, and Davos area, during the period 2001-2007.

3.2.2 Physical approach to snow water equivalent evaluation

The estimation of snow water equivalent distribution by means of physical models has been the focus of WP232. To this end, Alpine3D, a physical model of Alpine surface processes has been used. Alpine3D consists of several modules (Fig 3.2.5). For the AWARE application, we relied on input from meteorological stations and used spatial meteorological interpolation for creating input fields for Alpine3D. We used the model in the way described by Lehning et al., (2006), i.e. without the drifting snow and full meteorological simulation. The main features of the model are thus a three-dimensional radiation energy balance model, a distributed snow cover model and a conceptual runoff model. The one-dimensional snow cover model includes a soil column of arbitrary depth and a vegetation model. The model has been adapted to allow data assimilation. In particular, snow depth could be adjusted to match observed snow cover from MODIS snow cover area (SCA) products derived within the project. Also, tests have been made with a satellite albedo product, which has been derived from the Thematic Mapper (TM) data on Landsat5.

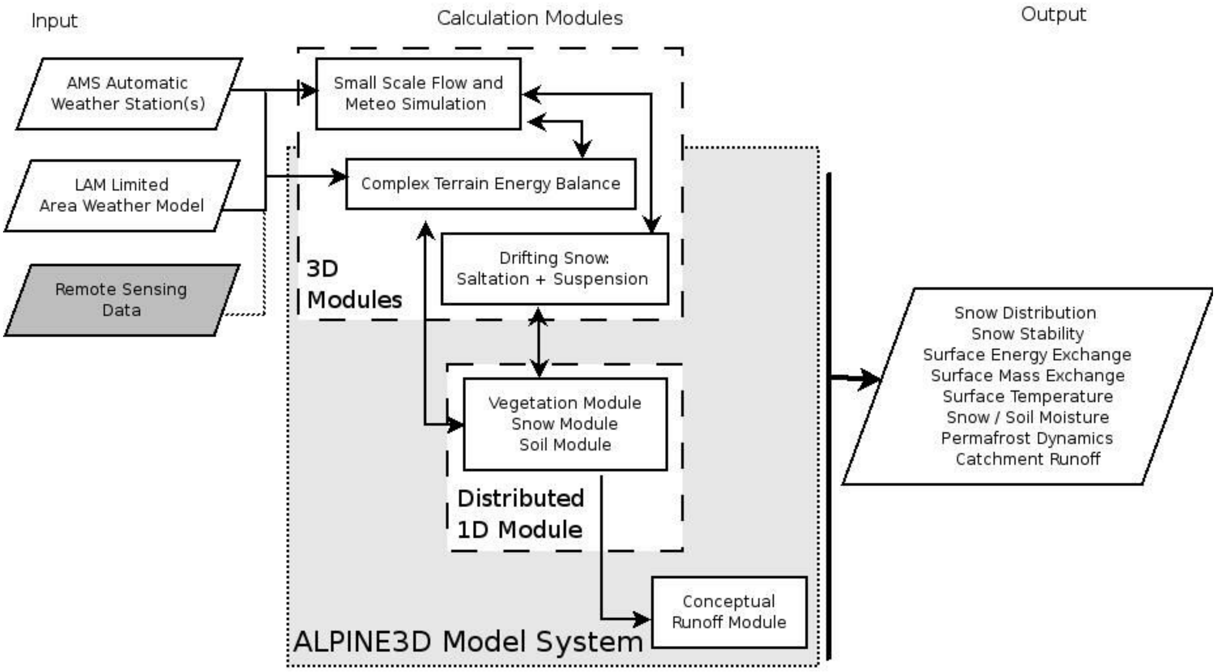


Figure 3.2.5: Flow chart of the model system Alpine3D (from Lehning et al., 2006).

3.2.2.1 Study Areas

The first catchment simulated is Dischma, located in eastern Switzerland. It ranges in elevation from 1530 to 3218 meters above sea level and covers an area of 43.3 km^2. The rectangular simulation domain encompassing the catchment covers a wider area of 12.8 km by 15.4 km (197 km^2). The catchment has already been described in detail in Zappa et al. (2003). Surface cover is 70 % rock and meadow, the rest being minor contributions from forest and bushes. Glaciers do not play a significant role but are present in the simulated area (5 % of the total area). The domain is meshed by 100 x 100 meters square cells.

The Inn catchment in the Engadin occupies 1945 km^2 within a 66.5 km by 71.75 km rectangular simulation domain (4771 km^2). This domain also encompasses the Dischma catchment, which is not part of the Inn catchment, however. The domain has an altitude range from 658 to 3868 meters above sea level. A few glaciers are part of the simulated area (4 %) but again, most of the surface is rock and sub-alpine meadow (50 %) with coniferous forests (15 %) occupying a significant fraction. One of the better known Swiss glaciers, the Morteratsch, is part of the simulated area. The cells are 250 x 250 meters. An overview of the catchments can be found in Fig. 3.2.6.

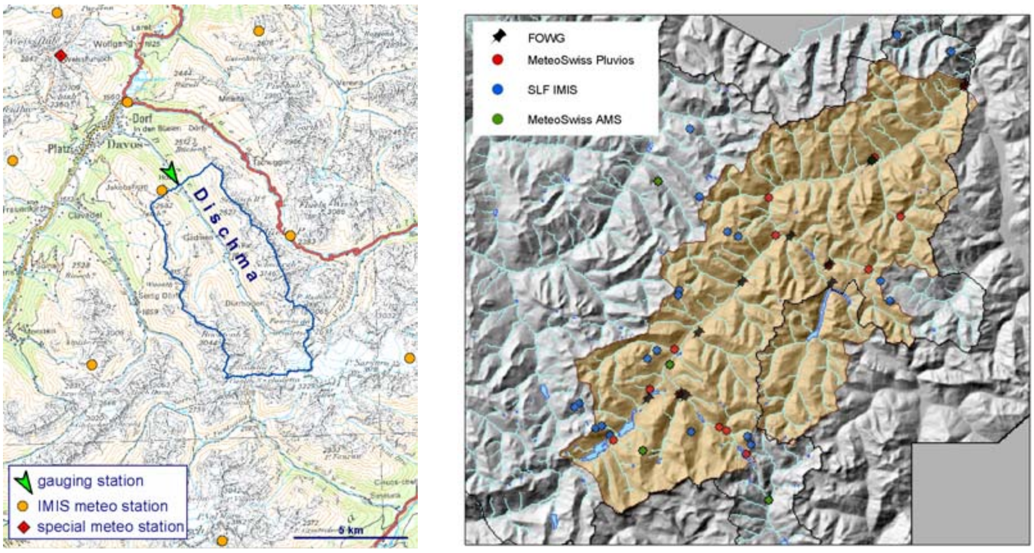


Figure 3.2.6: Catchments with meteorological stations, Dischma (left) and Inn (right).

3.2.2.2 Results

Assimilation of SCA

Potential benefits from assimilating SCA into Alpine3D have been investigated. To this end, quality controlled MODIS maps have been used to update the amount of snow present in Alpine3D. A simple data assimilation procedure was introduced, which added snow or removed snow at Alpine3D pixels based on the MODIS SCA information. Overall, the effect of this type of assimilation was rather small. The Inn catchment showed a more pronounced response probably to larger model errors in this simulation, which has been run with a coarser resolution. Figure 3.2.7 shows the comparison between a selected SCA product and the corresponding model simulation in the Inn catchment.

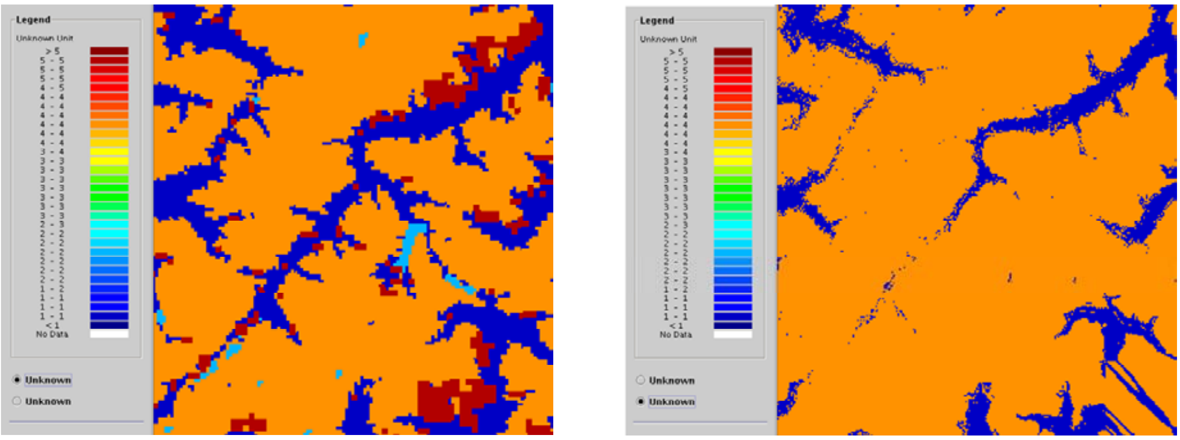


Figure 3.2.7: Comparison between MODIS derived (left) and simulated SCA in the Inn catchment on the 13 April 2003. Colors denote different classes (No snow: dark blue, Snow: orange, Clouds: Red, Water: light blue)

Figure 3.2.8 shows the runoff simulation with and without assimilation. It can be seen that Alpine3D typically overestimates runoff peaks which is probably due to an overestimate of snow water equivalent at higher altitudes.

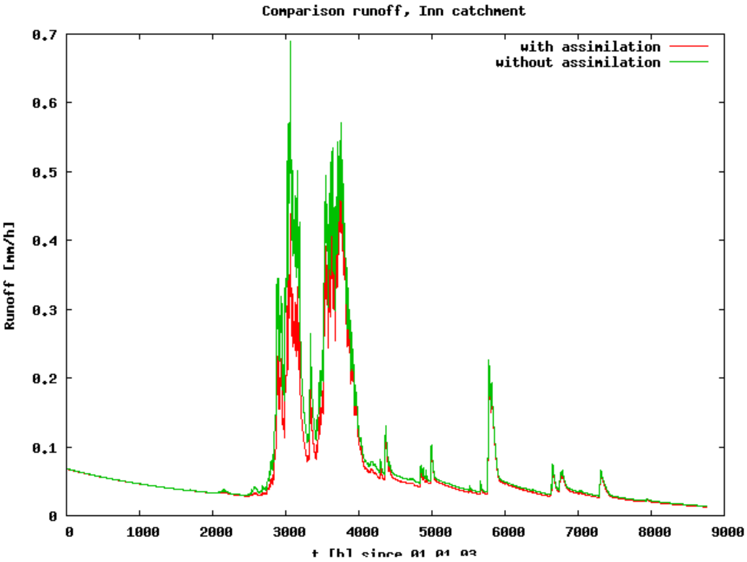


Figure 3.2.8: Comparison of simulated runoff in the Inn Catchment in 2003 between simulations with and without assimilation of SCA.

3.2.2.3 Assimilation of Albedo

From TM on Landsat5, an albedo map can be derived and can be assimilated in Alpine3D. Alpine3D in standard mode calculates albedo based on land use maps for bare surfaces and based on snow type and age for snow covered surfaces. Altogether, a first comparison shows that the Alpine3D albedo is much higher than the corresponding TM albedo. This may contribute to the observation that SWE is overestimated in Alpine3D. Running the model with the albedo from Landsat5 then creates a very significant difference in the snow and runoff simulation. In particular, the snow melt runoff peaks are much less pronounced in the model run with assimilated albedo. However, the true albedo is probably somewhere between the Alpine3D and the Landsat5 estimates, since satellite based measurements usually underestimate local albedo due to the mountain topography. In contrast, Alpine3D usually overestimates overall albedo over snow since it assumes a continuous snow cover at higher altitudes, while the snow cover over steep and rugged terrain is typically discontinuous. An in depth analysis of this effect will be available from Löwe et al., (in preparation).

3.2.2.4 Conclusions

For the overall goal to estimate water resources in Alpine regions, this investigation has produced the following results.

1) The availability and timeliness of typical SCA and other satellite products is such that a fully operational product of available snow water resources is difficult to realize.
2) The performance of physical models to estimate snow water equivalent in mountains is promising and operational products based on local meteorological measurements and physical models appear to be feasible and useful, provided that sufficient local observations are available. Satellite information is very useful to validate such products and to find systematic model errors.
3) With the improvements of meteorological forecast and analysis models, local measurements may be replaced by weather models and satellite information.

Furthermore, having reliable physical models of SWE helps to downscale climate change scenarios and to predict future snow cover and hydrology. An example in the context of AWARE is presented in Bavay et al., submitted. There it could be shown that runoff from snow melt, which contributes to stream-flow during much of the summer under the current climate, will be concentrated on a small and narrow peak in spring under a climate change scenario for the end of the century. It is also important to note that this study has assumed uniform snow deposition and effects of very steep terrain as described in Lehning et al., (2008) have been neglected for the larger scales considered in this study. Overall, the knowledge and experience created in AWARE have also already been successfully applied to glacier mass balance studies (Mott et al., in press; Michlmayr et al., in press).

3.3 Assimilation of EO data into snowmelt dynamics models

3.3.1 Hydrological Model to estimate Snow Water Discharge

The main goal of the research was to develop an integrated conceptual scheme that allows us to improve the water balance simulations using satellite Earth Observation (EO) snow cover data. The main intention was to improve the snow state representation of the hydrologic simulation scheme and to assess the added value of EO snow cover for the water balance estimation. The specific research objectives were:

a) to validate a typical snowmelt simulation concept using EO and ground based snow measurements,

b) to assimilate the snow EO data into the calibration of the hydrologic system and to evaluate the assimilation efficiency against runoff and snow observations,

c) to assimilate EO data into the snow state representation of a hydrologic simulation scheme and to quantify the assimilation efficiency in snowmelt runoff simulation and forecasting.

3.3.1.1 Methods

The development of an integrated modeling concept was based upon a semi-distributed conceptual rainfall-runoff simulation scheme, which follows the structure of the HBV. The system simulates the daily water balance in different elevation zones of a watershed. Snow accumulation and melt are represented by the concepts of threshold air temperatures and a degree-day melting approach. The amount of water stored in the snow pack is the snow water equivalent (SWE), which is one of the state variable of the system. The soil moisture state is estimated from the rain, snowmelt and evapotranspiration and determines the type of runoff generation process. Runoff routing on the hillslopes is represented by an upper and a lower soil reservoir, where the outflow from both reservoirs is described by a triangular transfer function.

The development of an integrated simulation system is based on an indirect comparison of the simulated amount of water stored in the snow (SWE) and satellite observations of areas covered by snow. The definition of appropriate measures for the EO snow cover integration and snow accuracy assessment was based on sensitivity and uncertainty evaluations.

3.3.1.2 Data

The integration of EO snow data into a conceptual hydrologic system is tested and evaluated for 148 catchments in Austria (Figure 3.3.1). These catchments are located in different physiographic and climatic zones and have different sizes, ranging from 25 km² to 9770 km² with a median size of 369 km². Elevations of the study region range from 115 m a.s.l. to 3797 m a.s.l.. Mean annual precipitation ranges from less than 400 mm/year in the East to almost 3000 mm/year in the West. Land use is mainly agricultural in the lowlands and forest in the medium elevation ranges. Alpine vegetation and rocks prevail in the highest mountain regions. The hydrologic data set includes daily precipitation at 1091 stations, daily air temperature at 240 climatic stations and daily runoff data of 148 catchments. The water balance simulations were performed in different periods; the data from the periods 2002-2005 and 1987-1997 were used for the calibration and verification, respectively. Such diverse physiographic and landscape characteristics suggest that the study region is representative of a wider spatial domain and the results may be applicable in catchments with similar characteristics. The snow cover maps used in the research have been acquired by the MODIS instrument mounted on the Terra and Aqua satellites. The spatial resolution of the snow cover maps is 500m and the dataset includes daily maps in the period 2002-2005.

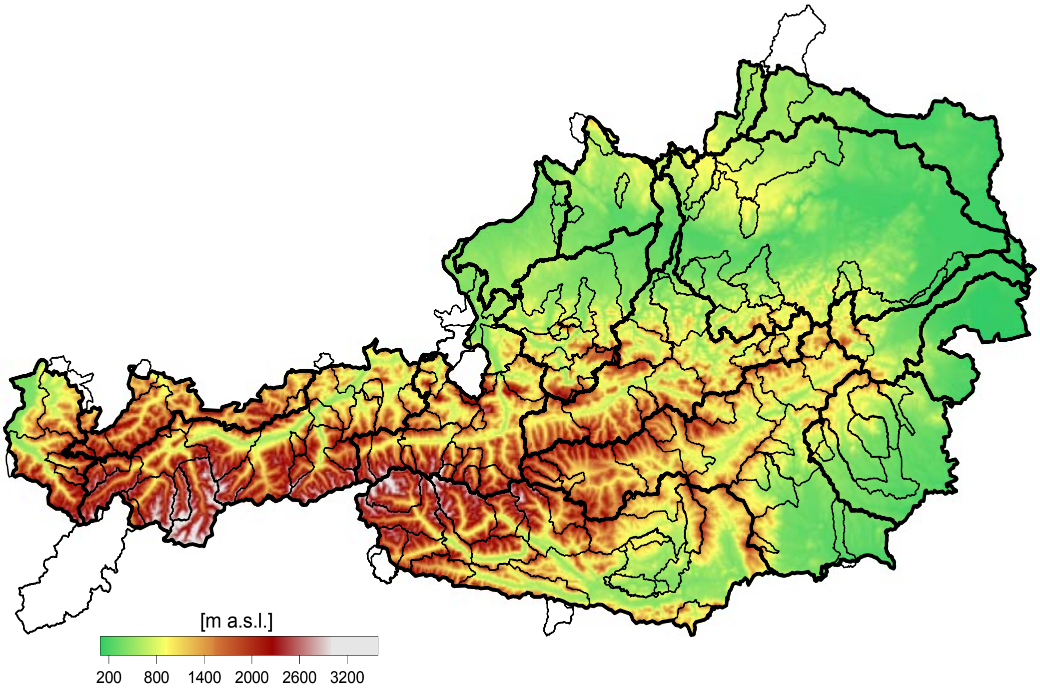


Figure 3.3.1. Topography of the study region and boundaries of the 148 catchments analyzed in the research.

3.3.1.3 Results

The improvement in runoff performance (ME) is defined as the difference between the errors obtained by the typical single-objective (using only runoff data) calibration and the calibration based on the runoff and EO snow cover data integration. In figure 3.3.2 the improvement measure is plotted with respect to the number of climate stations in a catchment in the calibration (2002-2005, left) and verification (1987-1997, right) periods. The value of EO Data is particularly large in the verification case if only a few ground based stations are available.

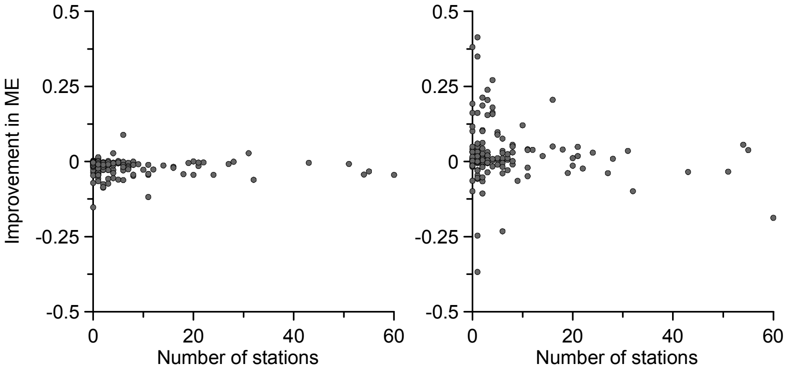


Figure 3.3.2. The added value of EO snow cover data for runoff estimation.

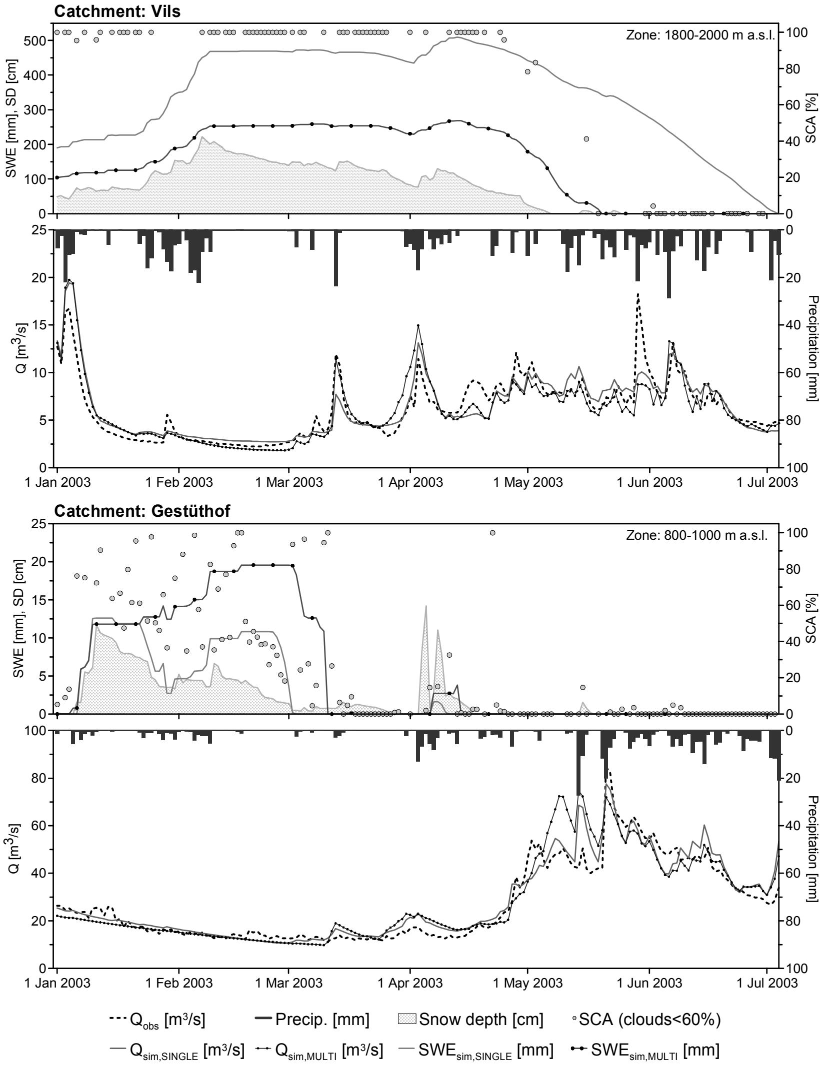
Improvement in the snow simulations gained by the proposed integrated simulation concept. In figure 3.3.3, panels compare observed runoff and EO snow cover data with hydrologic simulations. The simulations are based on the typical (single) and EO data integrated (multi) simulation concept. Top and bottom panels show examples for the Vils and Gestüthof catchments, respectively.

3.3.1.4 Conclusions

The objective of this research was to test the potential of EO (MODIS) snow cover images for validation and calibration of a conceptual hydrologic scheme. The cornerstone of the investigation was based on an indirect comparison of snow water equivalent (SWE) simulated by a hydrologic system and snow covered area (SCA) estimated using different satellite EO snow cover products.

The integration of EO snow cover data was tested in a calibration mode, where the hydrologic simulation system is adjusted by both the runoff and satellite snow cover data. Evaluation of the runoff and snow simulation efficiencies demonstrated that the multiple-objective calibration framework enables a robust estimation of hydrologic parameters of the system (calibration). The runoff performance obtained in the calibration period was similar or only slightly poorer than obtained by calibration to runoff only (single-objective calibration). However, the snow efficiency was improved. This finding is important especially for the operational estimation of SWE and change assessment studies where the constraining of the simulation system to runoff only may not adequately represent the state of snow variables.

Various data assimilation alternatives were tested for the correction of snow state variables of the hydrologic simulation system. Overall, the data assimilation reduced only slightly the runoff simulation efficiency, but improved the snow simulations. The results showed a clear trade off, where the improvement in snow efficiency is at the cost of a reduction in runoff simulation accuracy. The assessment of the forecasting efficiency indicated that the forecast of runoff tends to be somewhat poorer than control runs without the assimilation, but the snow state variable is noticeably improved. Evaluation of the forecast performance for different lead times showed no significant change in the runoff efficiency. The most noticeable change was observed for the updating of snow underestimation errors, where the extent of improvement is significant only for the date of updating and one day ahead.



3.3.3 Comparison among observed runoff and EO snow cover data with hydrologic simulations

A detailed evaluation of the factors that are related to the added value of EO data indicates that they are particularly useful to improve the snow simulations in small catchments with no or only a few ground based observations. These results and more general analyses of snow simulations suggest that the data availability is the major factor that controls the snow simulation accuracy. The magnitude of the improvement is also likely related to the quality and availability of the EO data. Although, overall, the EO data can be considered rather accurate it is clear that, with increased spatial and temporal resolutions of the satellite sensors and more accurate snow cover classification, the added value in hydrologic simulations would also increase.

The uncertainty and sensitivity assessments indicate that the magnitude of the snow simulation efficiency is sensitive to the choice of the threshold of snow covered area used in estimating the snow underestimation errors, and the cloud cover threshold used in deciding whether a satellite snow cover image can be used for integration. Evaluation of the system performance against different EO snow products shows that the combination and filtering of different satellite products does not significantly affect the runoff and snow simulation efficiency

3.3.2 The Snowmelt Runoff Model

The snowmelt runoff model (SRM) (Martinec, 1975; Martinec and Rango, 1986) is a deterministic lumped temperature index model which takes into consideration the precipitation and air temperature, along with other predetermined catchments specific parameters to simulate and forecast daily stream flows in mountain basins where snowmelt is a major runoff factor.

This model uses a degree day approach for melting snow in a basin. An advantage of the degree day method is that it is easy to use operationally, because a limited amount of data is required for calibration and forecasting, i.e. usually precipitation and temperatures.

The SRM improves upon the traditional degree day approaches by using remotely sensed observations of the Snow Covered Area (SCA). Satellite remote sensing offers the advantage of providing low-cost, repetitive, multi-spectral, synoptic and uniform observations over large areas: these spatially distributed observations are in principle more directly linked to snowmelt because melting is extremely variable either in time and space, when it occurrs in areas where the topography is complex, as in mountain range.

The basin is subdivided into altitude belts (elevation zones), and the remote observations are used to determine the portion of each elevation zone where the snow cover remains and the degree-day approach should be applied to estimate melting of the existing snow pack.

The model needs in input a set of variable values, derived from ground measurements and satellite observations, together with the calibration of a set of parameters, describing geomorphologic and hydrological characteristics of the watershed.

In the SRM model the following expression calculates the average daily river discharge Q_n [m^3/s] at day n, for a watershed subdivided in i elevation zones each having an area A_i:

$$Q_{n+1} = \left(\sum_{i=1}^{I} \left[DDF_{in} \left(T_{in} + \Delta T_i \right) \cdot Cs_{in} S_{in} + Cr_{in} P_{in} \right] \frac{A_i \cdot 10^{-2}}{86400} \right) \times \left(1 - k_{n+1} \right) + Q_n \cdot k_{n+1}$$

The values of the model variables are given in input with daily frequency for each of the elevation zones: they are T mean daily air temperature [C°], P rain precipitation [cm day^{-1}], and S snow cover as percentage of each elevation zone area [%].

Model parameters include the degree-day factor DDF [cm °C^{-1}day $^{-1}$], the runoff coefficients for snow (C_s) and rain (C_r) which account for the basin losses, and the recession coefficient k that has to be obtained by the analysis of historical discharges. The conversion from [cm m^{-2} day^{-1}] to discharge units [m^3 s^{-1}] is made by the factor $(10^{-2}/86400)$.

Remote sensing satellite images are processed to produce snow cover maps and their seasonal variations to derive the snow cover depletion curves (SDC). SDCs represent the day-by-day decreasing of snow cover extent during the melting season.

Mean value of daily temperature derived from meteorological station measurements are corrected for the temperature lapse rate in order to represent the temperature of the mean elevation for each zone.

Precipitations recorded at meteorological stations include both snow and rain, whose contributions are separated by means of a critical temperature.

While model parameters are determined during the calibration phase, for real time forecast the values of input variables, i.e. precipitation, temperature and snow cover area, have to be updated daily. Temperature and precipitation values must be forecasted for the hydrological basin; snow cover is assessed through the SDCs defined during the calibration. Howver, whenever a new satellite image is acquired and processed, the derived snow cover area allows to update the percentage values of snow cover for each elevation zone that are used in the model for the next period prediction (days until next image acquisition). This update is realized through the so-called modified depletion curves (MDCs).

3.3.2.1 Calibration of the model

The first step of the calibration activity is the definition of the basin boundary and the elevation zones. The basin boundary is defined by the location of the stream-gauge and the watershed divide must include all the rivers contributing to the discharge at the stream-gauge.

Recession coefficient, critical temperature and vertical lapse rate are SRM model parameters derived from the literature and/or measurements.

In particular the recession coefficient has to be evaluated by analysing historical series of discharge considering only discharges of days when neither snowmelt nor precipitation occurred. These data are used to define the variability of recession coefficient in relation to the discharge (Q) at day (n) by determining the constants x, y in the equation [2]:

$$k_{n+1} = xQ_n^{-y} \qquad (2)$$

x and y are approximated by a geometric power regression.

In AWARE, the SRM has been implemented in calibration and simulation mode using Interactive Data Language (IDL) in order to deploy such routines as Web Processing Services (WPS) in the framework of the AWARE geo-service. The IDL code was hence written in its object oriented environment to establish a connection with the AWARE geo-portal within a Java environment, by means of the IDL Export Bridge technology.

The AWARE geo-service contains WPSs for the approximation of x and y by a geometric power regression, and methods for: the creation of depletion curves, the automatic calibration, the simulation and the accuracy assessment.

The geo-service drives a procedure for the automatic calibration that was designed in order to allow a non expert user to perform the calibration of parameters.

The automatic calibration procedure is based on the Levenberg-Marquardt algorithm (Press et al., 1992), which combines the steepest descent and inverse-Hessian function fitting methods to perform a non-linear least squares fit to a function with an arbitrary number of parameters. Iterations are performed until three consecutive iterations fail to change the χ^2 value by more than a specified tolerance.

3.3.2.2 Application

The model has been applied to two basins in Italy: the Mallero river basin, i.e. a small catchment in the central Italian Alps, and the Dora Baltea river basin, a large catchment located in the western Italian Alps.

Test site: Mallero River Basin

In order to simulate river discharge within the Mallero watershed, variable values and parameters were collected and estimated during three snowmelt seasons: 2002, 2003 and 2004. Since in SRM the basin is subdivided into altitude belts, the model's variable values were collected and spatially distributed for each elevation zone. In particular, point values of daily rainfall precipitation (P) and daily air temperature (T) collected by the ARPA (Regional Agency for the Environmental Protection) Lombardia ground stations network were processed in order to obtain the average value for each elevation zone. Daily snow cover area (S) was estimated by analyzing, processing and classifying satellite images from NASA (National Aeronautics and Space Administration) MODIS (Moderate Resolution Imaging Spectroradiometer) sensor. In this report all the procedures followed for the retrieval of snow cover areas, for the calibration of the model's parameters and for obtaining the recession coefficient by the analysis of historical ground data are presented.

Mallero river is a tributary of the Adda river. This basin, located in the central Italian Alps, covers an area of about 323 km^2 ; the stream-gauge is sited in the city of Sondrio, where it joins the Adda. By analysing the DEM we have obtained an elevation range between 290 and 4019 m.

Many experiments have been conducted using Mallero basin example in order both to verify the sensitivity of SRM to spatial resolution of EO data and develop the automatic procedure for the calibration phase.

The following experiments have been performed:

- Use of MODIS SCA products and automatic calibration of parameters
- Use of fractional snow cover maps derived by fuzzy classification of MODIS images and both manual and automatic calibration of parameters
- Refinement of automatic calibration procedure through a sensitivity analysis
- Use of MODIS SCA products and refined automatic calibration of parameters
- Use of fractional snow cover maps derived by fuzzy classification of MODIS images and refined automatic calibration of parameters

In figure 3.3.4 the results of calibration using fractional snow cover maps derived by fuzzy classification of MODIS images and automatic calibration of parameters in the years 2002, 2003 and 2004 are shown.

Test site: Dora Baltea Basin

The study area concerns the upper part of the Dora Baltea River basin, located in North-Western Italian Alps (Valle d'Aosta). The area of the basin is about 1290 km^2 and the elevation range is between 609 m. and 4655 m. a.s.l., with an average elevation of 2300 m.

Runoff measurements used are collected at Aymavilles gauging station, and were provided by Regione Valle d'Aosta (Dipartimento Territorio e Ambiente) together with meteorological data.

Five meteorological stations measuring data on air temperature and precipitation were available at the sites of Villeneuve, Morgex, La Thuile, Cogne and Valsavarenche. The highest location of meteorological station is Valsavarenche (1951 m.): it is lower than the average elevation of the basin.

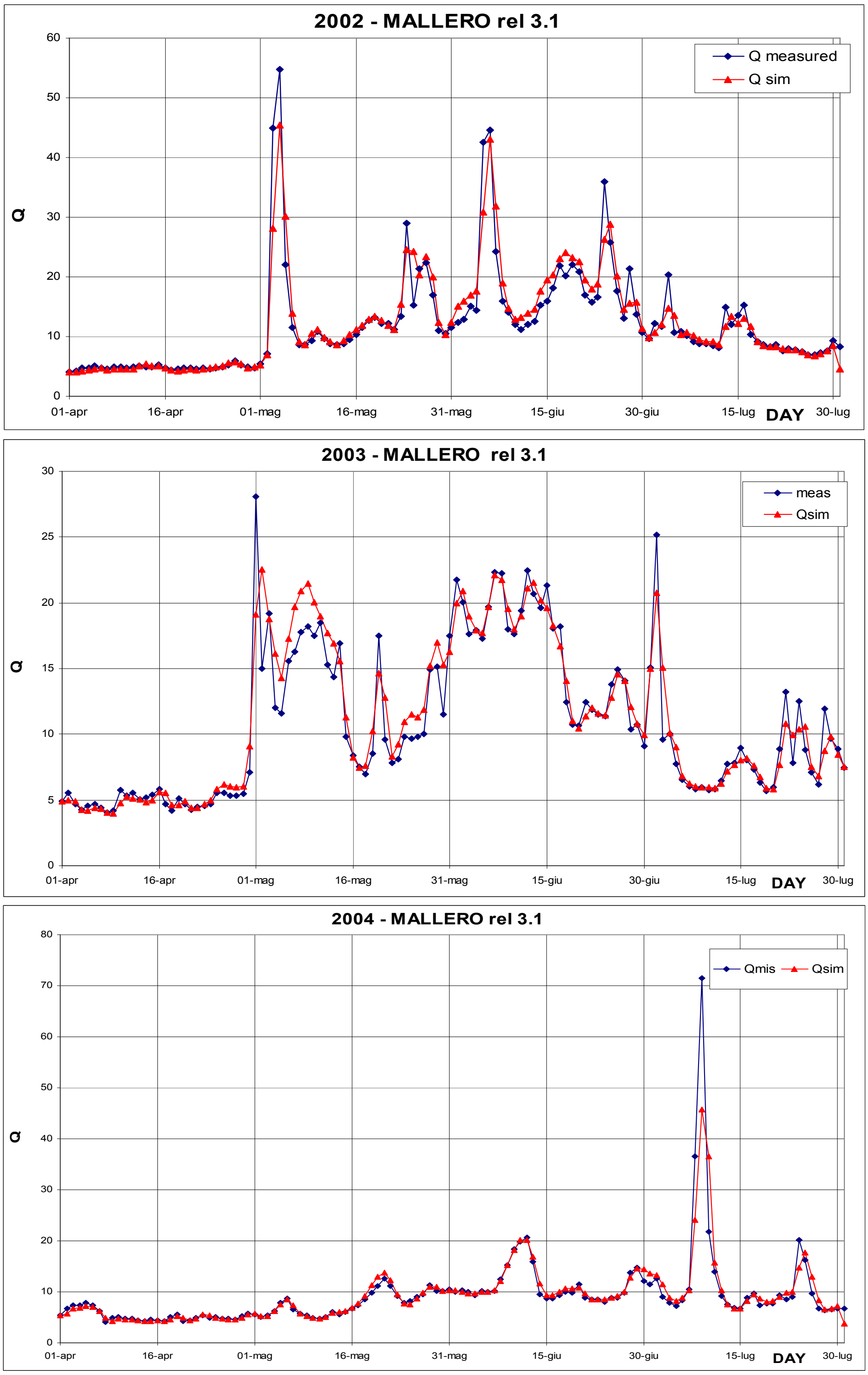


Figure 3.3.4: Simulated (Qsim) and observed (Qmeas) runoff [m3/sec] for the Mallero catchment from 1st April to 31st July of years 2002, 2003, 2004 (from top to bottom graphs)

3.3.2.3 Conclusions

The implementation of SRM in the framework of the AWARE project included the calibration and simulation phases. Experiments conducted on the basin test sites were performed from the point of view of designing the model routines as a user-friendly tool to any user – either expert or untrained – of the AWARE geo-service.

This is the reason why an automatic calibration procedure based on a Levenberg-Marquardt optimization, as well as other model related routines (depletion curves' creation; recession coefficient approximation), have been implemented in IDL to be deployed as processing services, and have been tested and refined during the application to Mallero River basin. Once the procedures reached a good level of efficiency were applied also to the Dora Baltea River basin.

Manual expert-guided calibrations have driven the analysis of automatic calibration results as well as some sensitivity tests.

The snow covered area information has been derived by different procedure applied to MODIS imagery at different spatial resolutions: i.e. MODIS standard products at 500m and fractional snow cover maps at 250m (see section 3.1 for product details).

The experiments performed over a total amount of 4 melting seasons in the two different test basins – 2002, 2003 and 2004 for the Mallero, 2003 for Dora Baltea – demonstrated a good reliability of the automatic calibration, as well as its limitations due to some residual compensation effects among parameters causing a level of time-consistency which is not optimal. Anyway, in absence of a good knowledge of the basin by an expert, the implemented model provides a reliable tool for parameter determination and could also offer a starting parameter set for manual tuning during simulation.

3.4 **The groundwater impact on runoff formation**

The study concerns the effect of the groundwater on the runoff formation.

A groundwater model have been developed and applied for this aim in two main study areas: LJUBLJANSKO POLJE and SAVA RIVER. The focus is on wintertime, to better understand the contribute and the effect of snowmelt, not included in the model simulations.

For this reason snowmelt events have been investigated accurately observing differences year by year. Moreover simulations and comparison with SNOWPACK modeling have been carried out in collaboration with SLF.

The contribute of EO data in this investigation was not very helpful because of the persistent cloud coverage in these regions during winter time. Moreover large forests induced misclassification in EO data analysis.

A machine learning method have been applied to generate regression trees models to connect climate features (e.g. snowmelt, temperature, etc.) with discharge dynamics obtaining no particularly robust result.

3.4.1 Material and methods

The model of Ljubljansko Polje aquifer was developed in 1980 and set as a three-dimensional non-stationary model. Later it was updated several times, the last update being done in 2003 when the model was transferred in the PMWIN (Processing Modflow for Windows) environment. In 2007 we updated the model with data for 3 more years (the model is now made for the period 1/1/1978–30/5/2006). The data of groundwater and surface water regime from 1978 to 2006 were collected and the model was run and calibrated. We collected the data for groundwater level from 25 piezometers, three well fields and one lyzimeter.

Snowmelt events

Data about snow cover for the Ljubljana weather station were analysed. Water balance in winter seasons of 1978/1979–2005/2006 was analysed and the impact of snowmelt on groundwater recharge was estimated. For seasons that had at least a 0.5-m thick snow cover and the seasons from 2000/2001 to 2005/2006 the impact of snow melt and spring precipitation was analysed in detail. The groundwater level data from two different wells on Ljubljansko Polje and precipitation data (snow and rain) were compared.

Machine learning method

The HBV model has been used for modelling in the Sava river watershed in Slovenia and the results of snow cover modelling are used as the input in the machine learning model of the Sava Dolinka watershed in the head part of the Sava River.

The M5 Machine learning method as it is implemented in the WEKA system, developed at the University of Waikato, New Zealand, was used in the Sava Dolinka watershed to generate regression and model tree models connecting snow-melt and temperature characteristics with flow increase at the Sava Dolinka River – Jesenice gauging station.

Mean daily flow data for the Jesenice gauging station (on Sava Dolinka River), snow cover height and mean daily air temperature data for the Kredarica temperature station and mean daily air temperature data for the Ratece temperature station were available (1961/2003).

Events when the snow cover height was continiously falling or staying at the same level, when there was no or almost no rainfall and when the mean daily flow at the Jesenice gauging station was continously rising for at least 4 days were selected; 94 events were identified. Three models were built; first one by using all of the 94 recorded snowmelt events, the second one by using only the selected 26 snowmelt events and the third one (simpler model than second one - with only one leaf) also by using only the selected 26 snowmelt events.

Snowpack modelling

Snow pack modelling has been applied to a Slovenian area. Simulations of four winter seasons have been performed with the data from Kredarica, the highest meteorological station in the Julian Alps, with an altitude of 2500 m.a.s., operated by the Environmental Agency of the Republic of Slovenia (ARSO). The long term average of the annual precipitation on Kredarica amounts to 2012 mm, while the average number of days with snowcover is 267. The maximum snow height ever measured on Kredarica occured in spring 2001 – 700 cm.

The four simulated winter seasons were: 1997/1998, 1998/1999, 2000/2001 and 2002/2003. The seasons were chosen according to the quality of the provided data. For instance, the meteorological hourly data series were incomplete, particularly the hourly precipitation data, which was omitted from the simulations. The snow height data was available only on daily base.

EO data

Due to the GIS vector data processing used to achieve high accuracy of calculation at large scales (1 : 5000 and 1 : 25,000) and compatibility with available existing vector data, the raster content of SCA3 had to be vectorized. The conversion to vector was performed with the vectorizer tool called "Vextractor" for automatic conversion to the vector format. Upon vectorization, we obtained the vector contours of snow cover.

The SCA3 polygons were obtained for 8 dates. 4 images showed the lack of snow cover in the area of Slovenia. In July, June, August and September of 2003 there was no snow, however, in February 2003 there was considerably more snow.

The obtained vector polygons contained several patches (islands) that needed to be excluded from further processing. A more complex typology had to be elaborated (topology with islands). The nested-in islands (single nested or multi-nested – island within an island) were excluded separately. These were determined based on topological attributes and algorithm, looking at the left and right side of the vectors, helping us to determine whether or not the polygon is an island.
Then we built a new topology. The islands were subtracted to obtain the »Polygon with Islands«, which provided an accurate overlay of the SCA raster content.

3.4.2 Study areas

LJUBLJANSKO POLJE: the groundwater model grid (100 m x 100 m) stretches across 80.79 km^2, mainly in the Ljubljana municipal area, Figure 3.3.5. The average precipitation in Ljubljana is 1430 mm per year. The water that does not constitute runoff, infiltrates. The rainfall infiltration contributes about 42 % water to the groundwater flow, 8 % is contributed by inflow of groundwater from the edge of Ljubljansko polje, sunken streams and the water leaking from water pipes on their way to users. The mean annual infiltration in Ljubljansko polje is estimated at approx. 740 mm, which is an half of annual precipitation.

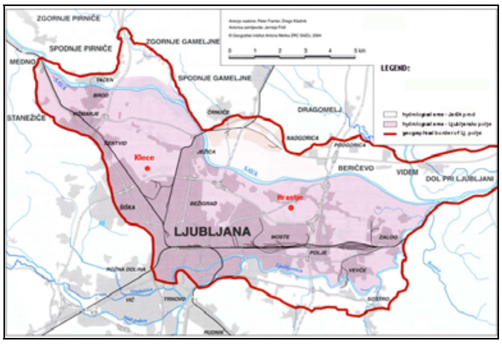


Figure 3.3.5: Area of Ljubljansko Polje aquifer (groundwater level measurement stations at wells Kleče and Hrastje are indicated in red).

SAVA RIVER: the Sava River runs 945 km from northwest to southeast, rising in Slovenia, continuing across Croatia and Bosnia and ending in Serbia at its confluence with the Danube in Belgrade. It contributes approximately 25% of the Danube’s total discharge and has a drainage area of approximately 96 400 km^2. The Sava river basin is the most flood-threatened region in Slovenia. The upper part of the basin is mountainous with altitudes up to 2800 metres. The altitudes of the plain area, in the middle reach of the Savinja, are between 100 and 400 metres. The floods (usually flash floods) are caused by heavy rainfall in headwater mountain areas, especially in autumn. Some tributary flows can rise more than a hundred times in such events.

3.4.3 Results

Ground water model
The model was calibrated and water balance calculated for the period from 1978 to 2006. Special attention was given to the water balance in winter.

Snowmelt events

The conclusions are given for each season that was discussed. In detail, the seasons with snow cover thicker than half a metre and seasons from 2000/2001 to 2005/2006 are described. The last seasons have more available data and can be investigated in greater detail.

The mean snow cover duration in the winter seasons in the period from 1978 to 2006 is 52 days. The variation of snow cover duration is quite high, reaching from 0 to 118 days.

EO data

The visual check indicates that much of the area under investigation is not covered in snow, or that the cover is undetermined. However, based on our knowledge and experience, there should be the presence of snow cover in these areas. Namely, these areas are covered in forest with the snow cover under the tree canopy, which, in all probability, the EO satellites failed to detect. These areas include large forest-covered surface of the hills of *Polhograjsko hribovje* and *Škofjeloško hribovje*, and the plateaus of Pokljuka and Jelovica (Fig.3.3.6).

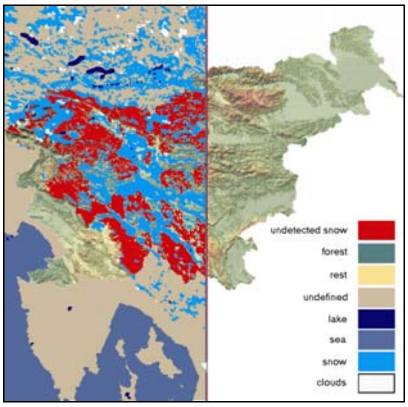


Figure 3.3.6: Vectorized areas under snow, 24 February 2003, Republic of Slovenia.

Snowpack modelling

The simulation results for show height showed major deviations from the measured data during the melt season. The simulated melt rate was too low thus the model simulated snow cover when it was actually already gone. The reason for this could be, that the precipitation data was omitted from the simulations, and thus the contribution of the rainfall during the spring melt is missing in the energy balance.

Machine learning method

MODEL 1: The resulting model forecasts the flow rate increase at the Jesenice Gauging Station as a function of average air temperature at Kredarica temperature station during the snowmelt event, month event and snow cover depth at the start of the snowmelt event.

MODEL 2: The resulting model forecasts the flow rate increase at the Jesenice Gauging Station as a function of only snow cover depth at the start of the snowmelt event.

MODEL 3: The resulting model forecasts the flow rate increase at the Jesenice Gauging Station as a function of only snow cover depth at the start of the snowmelt event, air temperature increase at Kredarica temperature station during the snowmelt event and average air temperature at Kredarica temperature station during the snowmelt event.

3.4.4 Conclusions

Ground water model

The results of the groundwater model showed great fluctuations in the groundwater level (about 4 to 5 m per year). The model calculates the values twice a month – in the beginning and at end of the month. It is seen that the greatest deviation of the calculated values from the observed ones is during peaks. For some months, the deviation could partly also be a consequence of snowmelt, which it is not considered in the model.

Snowmelt events

Surprisingly, the water from snow cover mainly evaporates during the snowmelt period. There was no significant increase in the groundwater level during snowmelt events. Groundwater significantly increases only during winter rainfall events or in events with snowmelt and rainfall (in autumn before the first snowfall and in spring, in events with snowmelt and spring rainfall). Groundwater mainly decreases in the wintertime, however, in some years just a slight increase of the groundwater level was observed.

EO data

Weather conditions in wintertime are unfavourable for satellite data collection by images. Only 30% of time with snow cover, less than 20% of the sky is covered by clouds, which is also the reason why only two images were useful for snow cover analysis. It has been established that with large forest cover the EO (Earth Observation) method for SCA detection fails to give satisfactory results, that is, the actual snow cover cannot be determined in a satisfactory manner.

Snowpack modelling

The comparison showed that the model underestimates the SWE for 10-20%. Other unsolved question is how come the measured peak SWE is much higher than the measured precipitation during the snow accumulation season (the difference for the 1997/1998 winter season is 37%, while it exceeds 90% for the 2000/2001 winter season). The most probable reason for this could be the snowdrift and the solid precipitation losses due to wind turbulence and evaporation from the rain gauge.

Machine learning method

Due to relatively high modelling errors it can be concluded that event characteristics included into the models' development probably do not present enough information to build a satisfying model to forecast the flow rate increase at the Jesenice Gauging Station; it seems that snow characteristics recorded at the Kredarica station are not representative enough for the snow cover situation in the whole Sava Dolinka River basin.

3.5 **Model comparison on test areas (cross-tests on study areas)**

Two experiments aimed to compare the different behaviors and the results of models developed have been conducted.

The first one performs the comparison between the results of the application of the statistical and the physical approach to SWE estimation on an area around Davos in Switzerland; the second is aimed to compare the SWE derived from the statistical approach to SWE modeling and the SWE derived using the SRM model by computing the cumulated melt-water on the melting period considered.

3.5.1 Comparison of statistical and physical models for SWE estimation on Dischma area

The statistical model for SWE estimation described in paragraph 3.2.1 have been applied to a rectangular area around Davos, located in the Eastern part of Switzerland in the canton of Grisons, on the north face of Alps, near the border with Austria. The area includes snow-rich parts in the north and dryer inner-Alpine parts to the south. Because of the high elevation, most of the area is snow covered in the winter. The mean elevation is approximately 2000 m a.s.l. and the higher altitude is 3418 m a.s.l., reached at the P. Kesch. It is well monitored with 14 snow gauges in an area of approximately 1656 km^2 area. In this area moreover many regular manual measurement of snowpack properties are carried out. This area features a relevant snowmelt runoff component in late spring-summer.

For the years from 2000 to 2007 the statistical SWE model has been applied and the local SWE values estimated in each station for all the simulation years.

The SWE estimation in each cell of the considered area have been then computed by applying the regression equation. The negative values not physically meaningful have been removed using the effective Snow Covered Area (SCA) as estimated by EO MODIS data. The combination between the raw SWE map and the SCA map allows providing a SWE map with values only where snow is observed according to the EO data. In figure fig.3.5.1 the results for the year 2001 are shown.

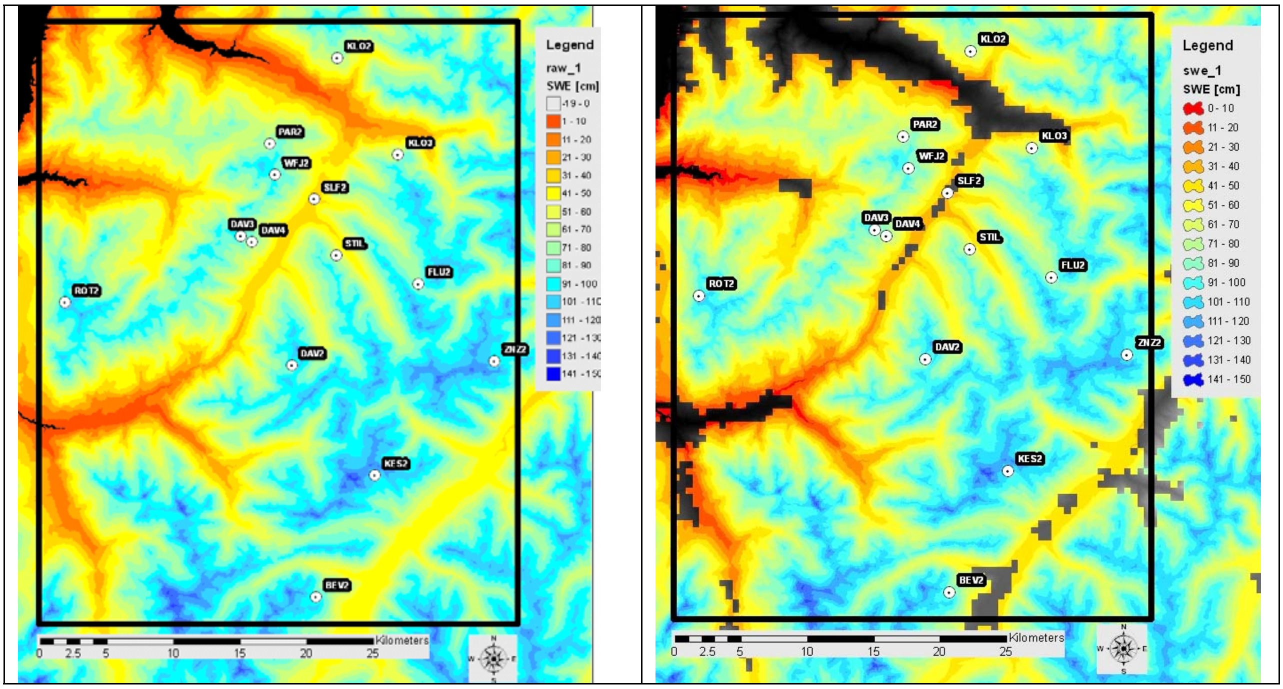


Fig. 3.5.1: Left map: SWE raw map including also negative Right map: final SWE map achieved coupling the raw SWE map and the observed SCA (year 2001)

The physical model for SWE estimation described in paragraph 3.2.2 has been applied to the same area.

SNOWPACK model has been applied to compute the SWE at the snow gauges for the years from 2000 to 2007 and the ALPINE3d module has been used to distribute the SWE in all the area considered. The resulting map for the year 2001 is shown in figure 3.5.2.

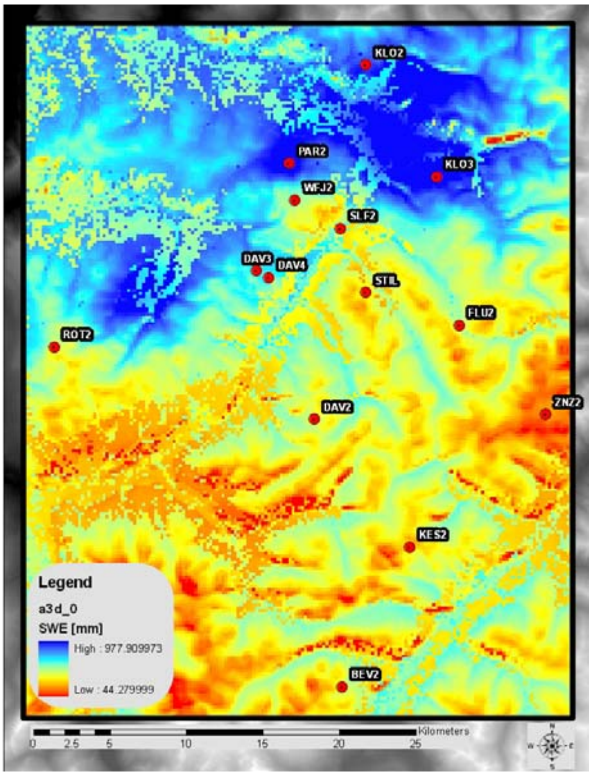


Fig. 3.5.2: SWE [mm] map achieved by ALPINE3D model. In blue the highest estimated values, in red the lowest ones.

The comparison between the 1D results of our SWE statistical model and SNOWPACK at the snow-gauges provide information about the quality of the snow density estimation equation. In fact no information about spatial interpolation is included at this level and the snow depth data, coming from the same snow gauges, are exactly the same for the two models.

The comparison show a very good fit: only few values are strongly different between the two models (tab. 3.5.1). There are a lot of data with a difference lower than 5 cm of SWE and the difference on the average values between the two models is 2.5 cm that correspond to about 4.4 %. The snow density equation of statistical model hence overestimates somewhat, on average, SNOWPACK output results.

Tab. 3.5.1: Comparison between SNOWPACK and the statistical SWE model

Difference of SWE between two models [cm]														
name	**BEV2**	**DAV2**	**DAV3**	**DAV4**	**FLU2**	**KES2**	**KLO2**	**KLO3**	**PAR2**	**SLF2**	**WFJ2**	**ZNZ2**	**STIL**	**ROT2**
cod	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
18/04/00	20.2	7.3	6.0			14.5	2.7	-3.0	-1.3		6.5			
22/04/01	1.0	17.2	14.8			-7.8	12.4	18.8	14.9	-0.2	16.9			
04/05/02	20.2	17.9	14.9			20.9	-1.6	4.0	0.2	-0.6	16.3			
27/04/03	-12.7	-6.5	-9.7	-7.7		-25.9	-9.8	-8.5	-11.7	0.0	-6.4	7.6		
10/05/04	13.3	1.6	5.6	7.8	0.9	4.5	-6.8	-1.1	-4.1	0.0	0.9	14.3		
26/04/05	8.7	4.4	6.7	3.8	-0.8	8.7	-6.4	0.8	-0.1	0.0	7.7	12.2		14.2
29/04/06	5.7	2.2	2.2	3.6	5.4	3.7	-5.7	0.6	0.7	0.4	2.2	10.4		10.4
04/04/07	6.5	5.1	3.3	3.8	5.1	5.5	-2.4	5.0	2.6	-1.4	3.0	7.9		8.3

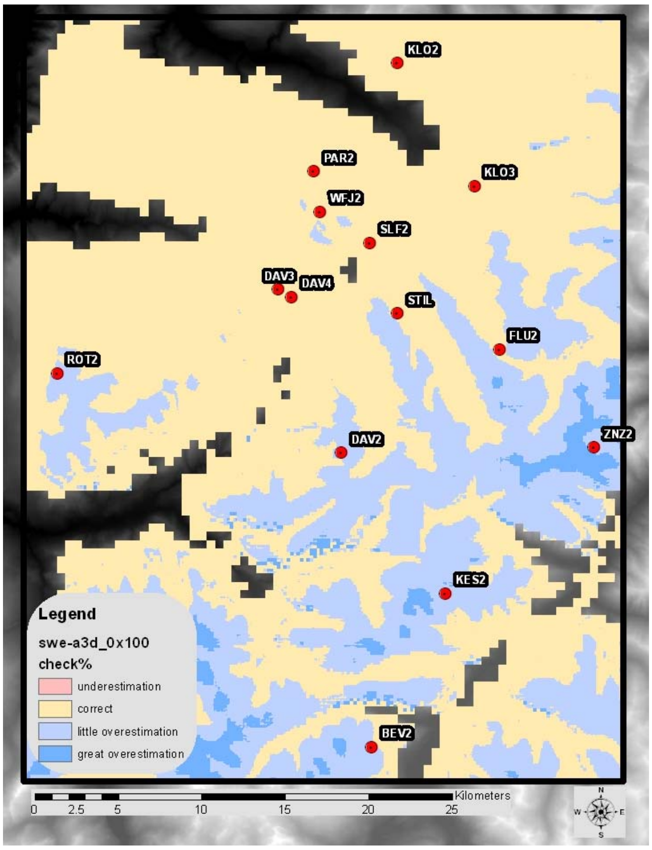


Fig. 3.5.3: Comparisons map for the year 2000 between SWE statistical model and ALPINE3D model. There are little areas where our model provide great overestimation of the ALPINE3D values (threshold 25 %) but there is a wide area in Engadina where it features a little overestimation leading to a great difference in total SWE volume. This issue is a consequence of the low number of gauges available in Engadina region.

The SWE map provided by the statistical SWE model and by ALPINE3D model for the year 2000 are quite different in snow cover patterns and distribution. Firstly notice that ALPINE3D map of the selected date provides a positive values of SWE on the whole studied area, but in many pixel, at the lowest altitudes, the SWE simulated values are extremely small and practically negligible. This happens because the selected date was just after a snowfall as confirmed by snowgauges data (e.g. 40 cm of new snow registered at WFJ station during the week before 18/4/2000). For this reason the comparison have been performed only in the areas where snow cover has been detected using EO data (fig. 3.5.3).

Selecting the same difference threshold of 25 % there are small areas featuring high overestimation but, if we assume a smaller threshold (10 %), there are wide areas where SWE is overestimated. Moreover, because of the clipping by SCA, there are no underestimation zones. SWE statistical model hence provide a greater average SWE value and a greater total water volume available on the area.

Nevertheless most of the overestimation zones are spread in the Engadina region, where both the ALPINE3D model and the statistical SWE model feature the lowest reliability because of the low data availability (see section 5.6.2).

On the other hand in the Davos – Weissflujoch area, where both the model are more reliable thanks to the great data availability, the agreement is very good, with differences lower than 10 % for each cell. These similar results are achieved in spite of completely different approaches followed by the two models.

3.5.2 Comparison of SWE estimation with SWE statistical model and SRM model

A comparison has been performed between the results obtained by the application of the statistical SWE model and the ones obtained by using the SRM model on the Mallero River basin.

Since the SRM model output is the daily discharge, the total SWE available at the start of the melting season has been simulated by cumulating all the daily snow melted amount during the whole season.

The total melted volume is derived in the SRM model by the cumulated meltwater depth (M) on the melting period considered (Martinec et al., 1994), where daily M, for each elevation zone, is equal to:

$$M_{in} = \left(DDF_{in} \cdot \left(T_{in} + \Delta T_{in}\right) \cdot SCA_{in} \cdot A_i\right) \tag{2}$$

where
M = melt water depth [cm]
T = air temperature [°C*day]
ΔT = temperature vertical lapse rate
SCA = snow covered area [-]
DDF = degree day factor [cm/°C*D]
A = surface area [km²]
n = daily time step
i = altitude zone

The SWE for the melting period can be calculated as follows:

$$SWE = \sum_{in} \left(DDF_{in} \cdot \left(T_{in} + \Delta T_{in} \right) \cdot SCA_{in} \cdot A_i \right) \tag{3}$$

An expert-based calibration of parameters was performed to achieve good simulation of runoff for melting seasons – considered from 1st April to 31st July – on 2003 and 2004.
In Figure 3.5.4 and 3.5.5 the results of the calibration of the SRM model for 2003 and 2004 years are shown. The parameter set, hence also the degree day factor (*DDF*), is the same for the 2 years.

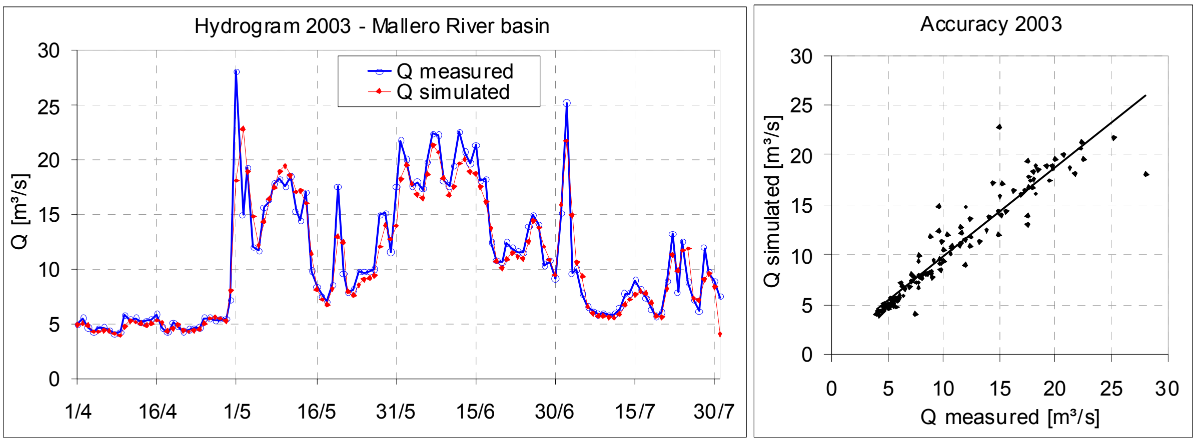


Figure 3.5.4 - Measured and simulated hydrograph and accuracy scatter plot for the 2003 melting season.

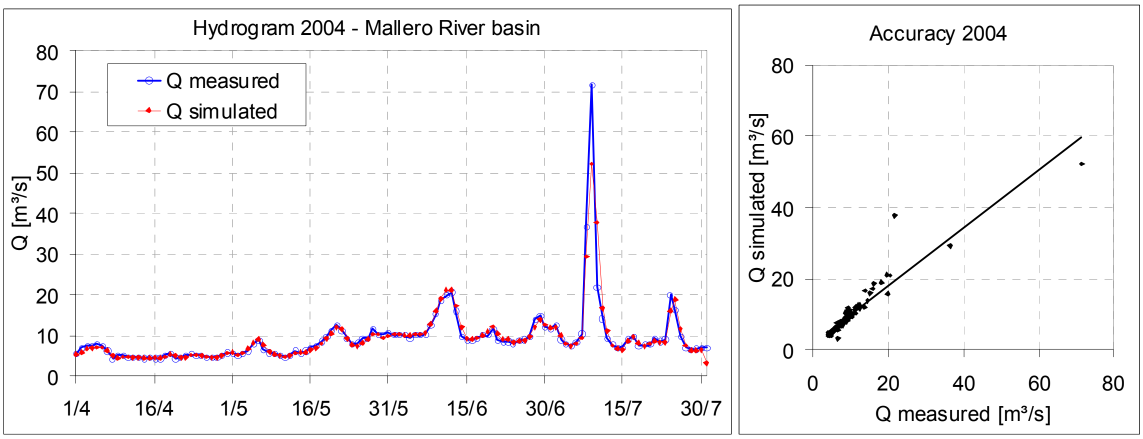


Figure 3.5.5 - Measured and simulated hydrograph and accuracy scatter plot for the 2004 melting season.

On 2003 the SRM achieved good simulation results (fig. 3.5.4), with a Nash-Sutcliffe coefficient equal to 0.90 and a deviation in volume equal to 2.8%. Using the DDF determined from calibration the SRM provided a SWE melted total volume of about 66.7 millions of m³ (see table 3.5.2). This is pretty close to the estimated value with the statistical SWE model applied on April 1st. This parameter set produced manually allows to provide a good simulation of runoff and a correct separation of the snowmelt contribution as well.
Appling the same set of parameters to the year 2004, SRM provides similarly good simulation results as can be seen in the hydrograph (3.5.5) and proved by a Nash-Sutcliffe coefficient of 0.88 and a deviation in volume equal to 1.6 %.

In table 3.5.2 the comparison shows that for the 2004 year the SWE volume seems to feature a worst fitting, in fact the SRM snow melted volume is equal to 66.9 millions of m³, sensibly lower than the SWE volume estimated with the statistical model.

Table 3.5.2 - SWE estimated volumes comparison between statistical SWE model and SRM auto-calibrated fixing the DDF values according to the data of Funivia Bernina station.

Year	SWE statistical model	SRM	Remarks
2003	60.3 millions m³	66.7 millions m³	Almost all the snow is melted at the end of July
2004	97.3 millions m³	66.9 millions m³	About 50 % of the zone 4 is still covered with snow at the end of July

This can be explained by considering that at the end of July, the highest elevation zone is still covered of snow for 50% of its extent. A longer simulation period would be needed to achieve a complete evaluation of the snow melt and to reach the melting of the whole snowpack on the ground. For this reason the SRM underestimation seems justified because part of the snow volume is not melted yet. Moreover it has to be noticed that some snow can remain on the ground after the end of the ablation season till the beginning of the following accumulation one. This happened for example in the past times, during glaciers growing. In this sense the two models are conceptually different because the statistical SWE model provides an evaluation of the water availability at the beginning of melting, while the SRM provides the estimation of the presently melted snow volume.

In conclusion, taking into account the conceptual differences outlined above, there is a good agreement between the two models results. It has to be stressed out also how the inter-comparison of the two models was useful as a test bench for the evaluation, testing and refinement of the automatic procedure for parameter calibration within the geo-service application.

3.6 The AWARE geo-service

The AWARE Application is a distributed, web-based information system that allows access to and execution of hydrological models through a set of integrated components such as user interfaces, web data processing services, databases, problem-solving wizards, and online help to guide users through model calibrations on new catchments.

The approach for the implementation of the AWARE Application involved the following steps:

- Collection of functional requirements in order to understand properly the characteristics and data needs of the environmental models supported by the AWARE Application.
- Design of a conceptual architecture to support the functional requirements in terms of abstract layers, components and their relationships.
- A study of the state of the art in current open source components and technologies in the topics related to the AWARE project, in order to avoid effort duplication in terms of implementation and maximize as much as possible software reuse.
- Bottom-up implementation approach of components, services, user interfaces and other software components needed to support the requirements of the SRM model.
- Bottom-up implementation approach of components, services, user interfaces and other software components needed to support the requirements of the HBV model.

- Integration of the independent software components in order to assemble a coherent application to support environmental models. Isolated, distributed components are put together forming workflows that respond to complex tasks in the environmental models.
- Creation of a web geoportal to provide online access to the various components.
- Testing and demonstration, among AWARE partners and in international conferences and seminars.

The AWARE Application includes several existing open source components and various technologies depending on the abstract layer where the AWARE components are placed. The server and middleware sides integrate technologies such as Java 1.5.0.12 (http://java.sun.com), Apache HTTP Server 2.4 (http://httpd.apache.org), Apache Tomcat 5.5 (http://tomcat.apache.org), JK Connector 1.2.25 (http://tomcat.apache.org/connectorsdoc/index.html), Apache Struts 1.2.7 (http://struts.apache.org), 52N WPS Implementation 0.4.0 (http://52north.org), Database MySQL 5.0.45 (http://www.mysql.com/), GeoTools 2.3.1 (http://geotools.codehaus.org/), JFreeChart 1.0.5 (http://www.jfree.org/jfreechart/), Minnesota Web Map Service (http://mapserver.gis.umn.edu/), Geonetwork (http://geonetwork-opensource.org/), IDL-Java (http://www.ittvis.com/idl/)

Multiple technologies have been interrelated (mashed-up) to compose the user interface (presentation) of the AWARE Application. First we have used server-side technologies (e.g. JSP) for retrieving information and generating content dynamically for HTML forms. A JSP page normally combines static information (HTML tags) and dynamic information by using a set of JSP tag libraries that allow developers to access to the application model. These technologies are closely related with the service and data integration components in the middleware layer. For data visualization, we have used the Google Maps API 2.x (http://map.google.com) for building the user-interface part of the mapping mashup in our Geoportal. Client-side technologies such as XML, XSLT, JavaScript and AJAX (Asynchronous JavaScript and XML) have been also used in the AWARE Application for enabling user interaction, as well as other technologies focused on the specification of data and visual encodings for data input to mapping mashups (e.g. KML, GML).

3.6.1 Application architecture

The AWARE Application architecture adapts the principles exposed in the E.U. framework directive (INSPIRE) technical architecture (http://inspire.jrc.it/), in order to establish an open and interoperable architecture based on standard interfaces and reusable components and services. According to INSPIRE all service instances are interfaced by specifying functional service descriptions in a standardised manner (service metadata, as part of the INSPIRE metadata), allowing users and software applications to discover specific service instances by querying catalogue services in the context of SDIs, in order to invoke them typically through a Geoportal. In the AWARE Application we have developed and deployed a service network taking into account this requirement by which available services are grouped according to the INSPIRE service types or categories:

- *Discovery Services* allow searching for spatial data sets and services on the basis of the content of the corresponding metadata and to display the resulting spatial data and services' metadata.
- *View Services* make it possible, at a minimum, to display, navigate, zoom in and out, pan or overlay viewable spatial data sets and to display legend information and any relevant content of metadata.

- *Download Services* enable copies of spatial data sets, or parts of such sets, to be downloaded and accessed directly.
- *Transformation Services* enable spatial data sets to be transformed with a view to achieving interoperability".
- *Invoke Spatial Service Services* which are those services that allow geospatial services to be invoked.

Figure 3.6.1 illustrates an overview of the layered AWARE architecture based on the INSPIRE (SDI) technical architecture. The Presentation layer involves user interfaces and interaction. In the AWARE Application the Geoportal enables users to interact with hydrological models and visually explore the modelling results. The Horizontal Service layer allows the description and implementation of concrete components, the business logic, and includes service chaining control as it is necessary for running the hydrological models, and then allows the instantiation and invocation of services instances. As described previously, the Service layer combines a set of service instances grouped into the INSPIRE service types needed to solve the concrete user requirements for hydrological models. Processing services are not yet defined in the INSPIRE Network Services, because the INSPIRE technical architecture identifies invoke services as the service type able to invoke and process services. In the AWARE Application this type is identified as a processing service, while the invocation service type is implemented as a concrete software component within the Horizontal Service layer. Finally, at the bottom, the Data layer contains spatial data sets and metadata.

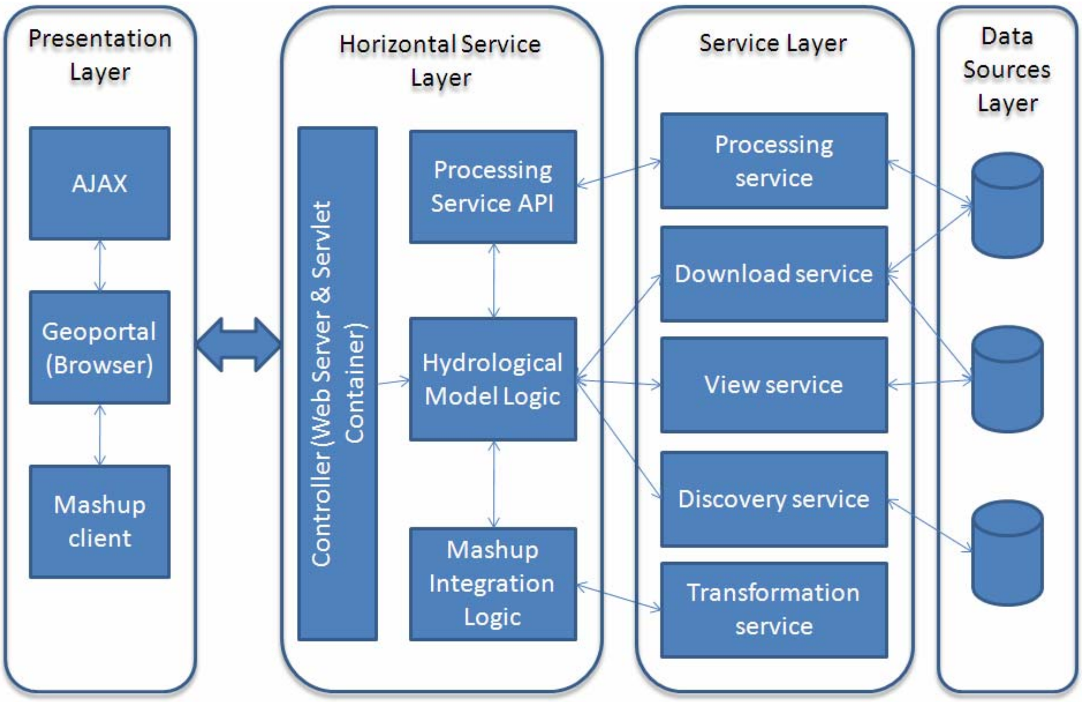


Figure 3.6.1: AWARE Application architecture

3.6.2 Results

The results obtained in the AWARE project in terms of software tools are mainly two: first, a set of distributed geoprocessing services available outside (independent of) the AWARE Application context, which performs general-purpose and thematic functionalities. These services may be reused in other applications and contexts. Second, the AWARE Application itself, a web-based application composed of many components such as the Geoportal, middleware components, user interfaces, databases, and services interrelated with each other in order to support and interact with the environmental models proposed in the AWARE project.

3.6.3 Set of distributed services

The following table summarizes the distributed services implemented in the context of the AWARE project. Some of them, in particular the processing services, are available on an independent basis at link http://www.geoinfo.uji.es/wps.html, where anyone can test them using his/her own data inputs.

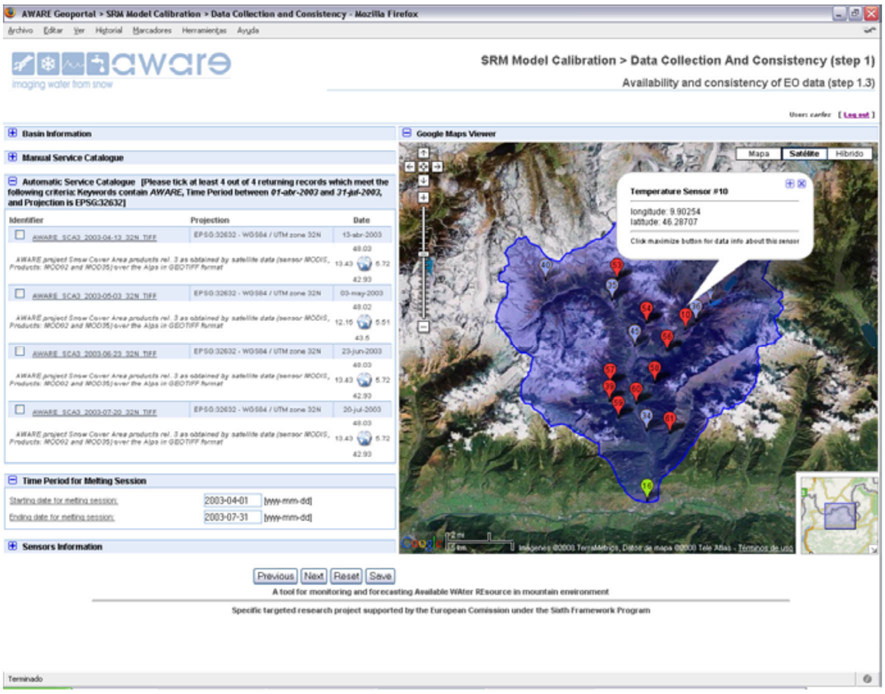
AWARE Service	***Type* / Specification**	**Service processes**	**Description**
Catalogue	*Discovery* / OGC Catalogue Service for Web (CSW)	N/A	It offers the functionality to search and provide all earth observation data catalogued of the study areas in the AWARE project.
Web Map	*View* / OGC Web Map Service (WMS)	N/A	It provides the user with some graphical maps of datasets over the study area.
Chart	*View* / OGC Web Processing Service (WPS)	Depletion Curves Plot Discharge Plot, HBV Runoff Plot, HBV SWE Plot, Sensor Data Chart	It provides diagrams (e.g. line plots) to represent some of the useful information, not as maps, but as descriptive plots showing some information in a graphical way.
Web Feature	*Download* / OGC Web Feature Service (WFS)	N/A	It provides users with some vector data (GML) over the study areas.
Coordinate Transformation	*Transformation* / OGC Web Processing Service (WPS)	TransCoordGMLPoint, TransCoordPoint, TransCoordPoint7P	It converts coordinates from a source reference system to a target one
Data Conversion	*Transformation* / OGC Web Processing Service (WPS)	Shp2GML	It converts from shapefile format to GML format.
Topology	*Processing* / OGC Web Processing Service (WPS)	Area, Intersection, Buffer, Max Extent, Snow Percentage, Get Feature By Attribute, Thiessen	Topological operations and interpolation algorithms.
Sextante	*Processing* / OGC Web Processing Service (WPS)	Coordinate Elevation, Stations Elevation, Elevation Curves, Elevation Zones, Hypsometric Elevation, Reclassify, Vectorize	Image processing algorithms, raster computations

IDL	*Processing* / OGC Web Processing Service (WPS)	Snow Interpolation, Calibration, Simulation, K Coefficient Computation	It wraps polynomial interpolations and routines in IDL.

Table 3.6.1: AWARE services

3.6.4 AWARE Application for environmental models

The AWARE Application integrates and combines the services listed in Table 3.6.1 by means of various software components located at the Presentation and Horizontal Service layers. The Presentation layer provides the entry point (user interfaces, map viewer, etc.) for users and decision makers to access the data and services provided by the AWARE Application. The Horizontal Service layer enables the communication between the Service and the Presentation layers. Accessing transparently to service instances from the user interface implies mainly the integration of heterogeneous services and data in order to provide proper results in response to user requests. These components integrate, compose, instantiate, and invoke services instances in the Service layer.



SRM Model Calibration > Data Collection And Consistency (step 1)

Availability and consistency of EO data (step 1.3)

User: carlos [Log out]

Automatic Service Catalogue [Please tick at least 4 out of 4 returning records which meet the following criteria: Keywords contain *AWARE*, Time Period between *01-abr-2003* and *31-jul-2003*, and Projection is EPSG:32632]

Identifier	Projection	Date
☐ AWARE_SCA3_2003-04-13_32N_TIFF	EPSG:32632 - WGS84 / UTM zone 32N	13-abr-2003
AWARE project Snow Cover Area products rel. 3 as obtained by satellite data (sensor MODIS, Products: MOD02 and MOD35) over the Alps in GEOTIFF format		48.03 13.43 6.72 42.93
☐ AWARE_SCA3_2003-05-03_32N_TIFF	EPSG:32632 - WGS84 / UTM zone 32N	03-may-2003
AWARE project Snow Cover Area products rel. 3 as obtained by satellite data (sensor MODIS, Products: MOD02 and MOD35) over the Alps in GEOTIFF format		48.02 12.15 5.51 43.5
☐ AWARE_SCA3_2003-06-23_32N_TIFF	EPSG:32632 - WGS84 / UTM zone 32N	23-jun-2003
AWARE project Snow Cover Area products rel. 3 as obtained by satellite data (sensor MODIS, Products: MOD02 and MOD35) over the Alps in GEOTIFF format		48.03 13.43 6.72 42.93
☐ AWARE_SCA3_2003-07-20_32N_TIFF	EPSG:32632 - WGS84 / UTM zone 32N	20-jul-2003
AWARE project Snow Cover Area products rel. 3 as obtained by satellite data (sensor MODIS, Products: MOD02 and MOD35) over the Alps in GEOTIFF format		48.03 13.43 6.72 42.93

Temperature Sensor #10

longitude: 9.90254
latitude: 46.28707

Click maximize button for data info about this sensor

Time Period for Melting Session

Starting date for melting session: 2003-04-01 [yyyy-mm-dd]
Ending date for melting session: 2003-07-31 [yyyy-mm-dd]

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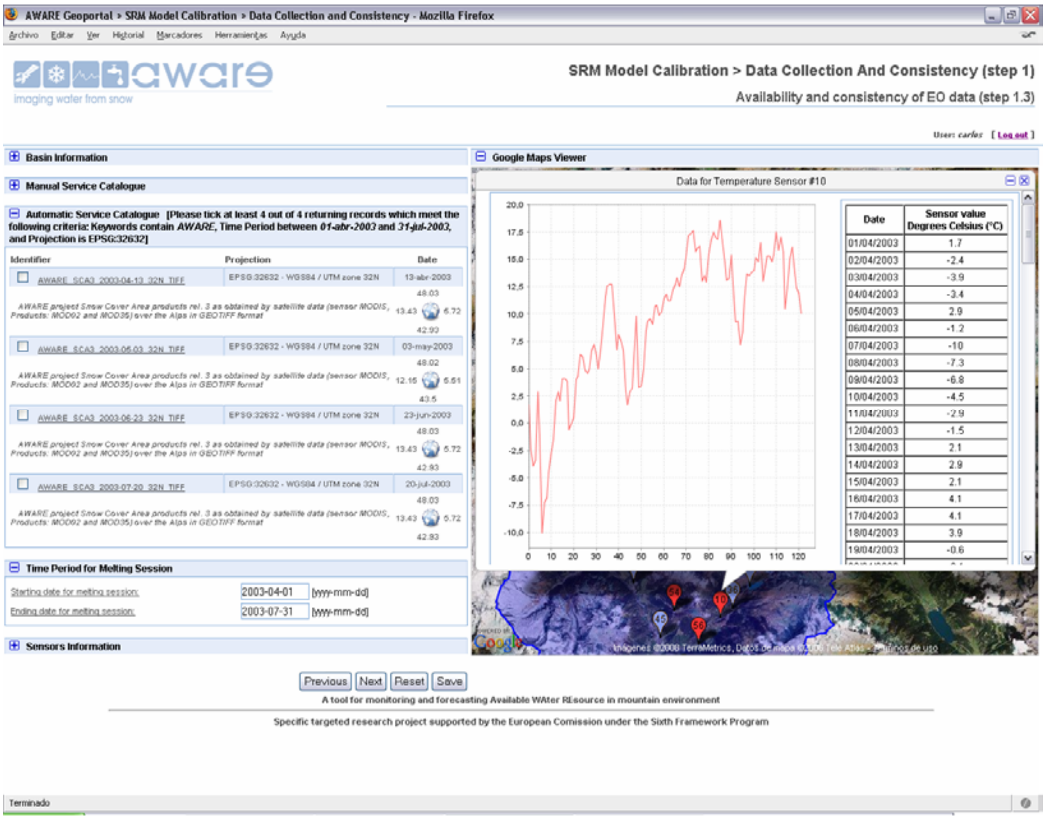
Figure 3.6.2:. User interface for selecting SCA products in the list provided by retrieving metadata records from a catalogue service.

Figure 3.6.22 shows an example of the AWARE Application running the first step of the SRM model. AWARE Application integrates a Catalogue service client, which connects to the AWARE Discovery Service offering the discovery capability and providing the user the available data. The right side of Figure 2 shows the map viewer displaying the basin boundary together with the location of meteorological sensors. Each sensor icon is numbered with its identifier and classified according to the fill colour (red-temperature; blue-precipitation, and green-stream gauge).



SRM Model Calibration > Data Collection And Consistency (step 1)

Availability and consistency of EO data (step 1.3)

User: carlos [Log out]

Automatic Service Catalogue [Please tick at least 4 out of 4 returning records which meet the following criteria: Keywords contain *AWARE*, Time Period between *01-abr-2003* and *31-jul-2003*, and Projection is EPSG:32632]

Identifier	Projection	Date
☐ AWARE_SCA3_2003-04-13_32N_TIFF	EPSG:32632 - WGS84 / UTM zone 32N	13-abr-2003
AWARE project Snow Cover Area products rel. 3 as obtained by satellite data (sensor MODIS, Products: MOD02 and MOD35) over the Alps in GEOTIFF format		48.03 13.43 6.72 42.93
☐ AWARE_SCA3_2003-05-03_32N_TIFF	EPSG:32632 - WGS84 / UTM zone 32N	03-may-2003
AWARE project Snow Cover Area products rel. 3 as obtained by satellite data (sensor MODIS, Products: MOD02 and MOD35) over the Alps in GEOTIFF format		48.02 12.15 6.61 43.5
☐ AWARE_SCA3_2003-06-23_32N_TIFF	EPSG:32632 - WGS84 / UTM zone 32N	23-jun-2003
AWARE project Snow Cover Area products rel. 3 as obtained by satellite data (sensor MODIS, Products: MOD02 and MOD35) over the Alps in GEOTIFF format		48.03 13.43 5.72 42.93
☐ AWARE_SCA3_2003-07-20_32N_TIFF	EPSG:32632 - WGS84 / UTM zone 32N	20-jul-2003
AWARE project Snow Cover Area products rel. 3 as obtained by satellite data (sensor MODIS, Products: MOD02 and MOD35) over the Alps in GEOTIFF format		48.03 13.43 5.72 42.93

Time Period for Melting Session

Starting date for melting session: 2003-04-01 [yyyy-mm-dd]
Ending date for melting session: 2003-07-31 [yyyy-mm-dd]

Date	Sensor value Degrees Celsius (°C)
01/04/2003	1.7
02/04/2003	-2.4
03/04/2003	-3.9
04/04/2003	-3.4
05/04/2003	2.9
06/04/2003	-1.2
07/04/2003	-10
08/04/2003	-7.3
09/04/2003	-6.8
10/04/2003	-4.5
11/04/2003	-2.9
12/04/2003	-1.5
13/04/2003	2.1
14/04/2003	2.9
15/04/2003	2.1
16/04/2003	4.1
17/04/2003	4.1
18/04/2003	3.9
19/04/2003	-0.6

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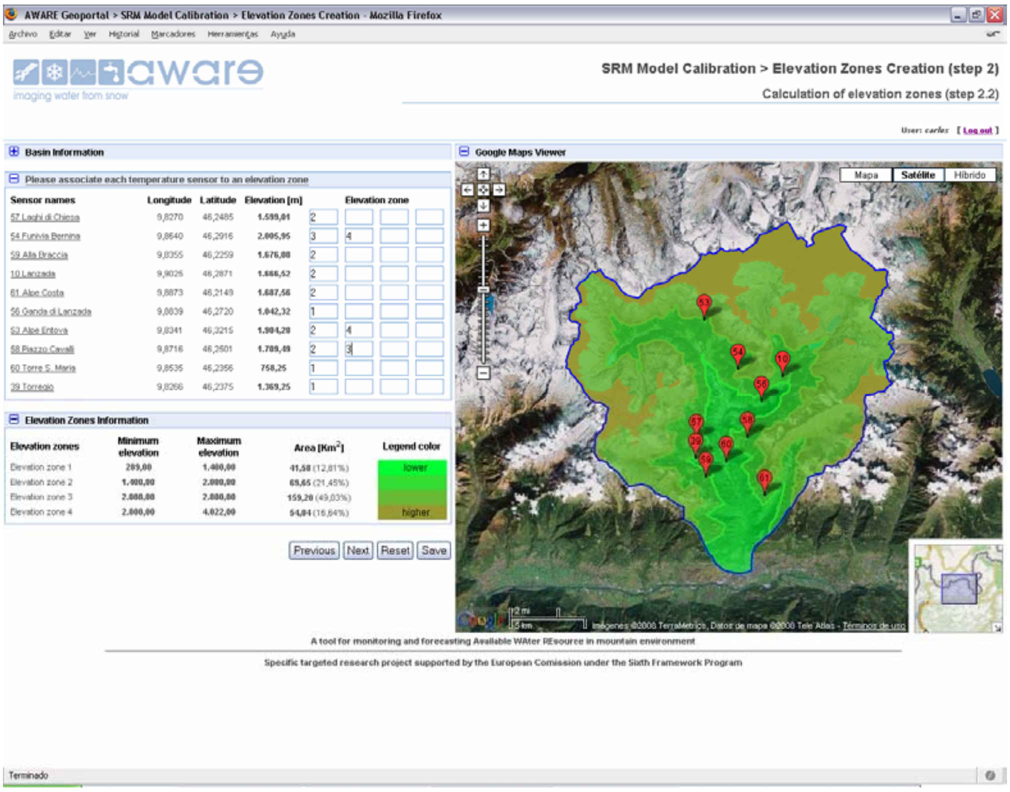
Figure 3.6.3: User interface to inspect visually temperature sensor data.

Figure 3.6.3 shows an example of the possibilities offered by the AWARE Application for data visualization and exploration. Users may click on a sensor icon to obtain more information about the sensor data. This action is executed on the server side via requests to the Chart Service, one of the AWARE View Services in the Service layer, which provides the capability of showing this kind of data in a graphical way as needed by hydrologists.



SRM Model Calibration > Elevation Zones Creation (step 2)
Calculation of elevation zones (step 2.2)

User: carlos [Log out]

Please associate each temperature sensor to an elevation zone

Sensor names	Longitude	Latitude	Elevation [m]	Elevation zone			
57 Laghi di Chiesa	9,8270	46,2485	1.599,01	2			
54 Funivia Bernina	9,8640	46,2916	2.005,95	3	4		
59 Alla Braccia	9,8355	46,2259	1.676,00	2			
10 Lanzada	9,9026	46,2871	1.666,52	2			
61 Alpe Costa	9,8873	46,2149	1.687,56	2			
56 Ganda di Lanzada	9,8039	46,2720	1.042,32	1			
53 Alpe Entova	9,8341	46,3215	1.904,20	2	4		
58 Piazzo Cavalli	9,8716	46,2501	1.709,49	2	3		
60 Torre S. Maria	9,8535	46,2356	758,25	1			
39 Torregio	9,8266	46,2375	1.369,25	1			

Elevation Zones Information

Elevation zones	Minimum elevation	Maximum elevation	Area [Km^2]	Legend color
Elevation zone 1	209,00	1.400,00	41,58 (12,81%)	lower
Elevation zone 2	1.400,00	2.000,00	69,65 (21,45%)	
Elevation zone 3	2.000,00	2.800,00	159,20 (49,03%)	
Elevation zone 4	2.800,00	4.022,00	54,04 (16,64%)	higher

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Figure 3.6.4:User interface for displaying the elevation curves for the watershed

Figure 3.6.4 shows the result of calculating elevation zones for a watershed by orchestrating various processing services (raster analysis computations, spatial intersections, and coordinate transformations), and visualizing the generated elevation zones in the web mapping viewer.

3.6.5 Conclusions

The AWARE Application guides expert users in running hydrological models by executing remotely a set of distributed geospatial services. The layered AWARE architecture adapts the principles exposed in the INSPIRE technical architecture, in order to establish an open and interoperable architecture based on standard interfaces and reusable components. The AWARE Services are also implemented according to standard interfaces in order to ensure service interoperability and reuse. The AWARE Application offers the capability to AWARE users, on one hand, of discovering data and services and, on the other hand, accessing and invoking discovery, view, download, transformation and processing services to successfully interact with environmental models to support decision making.

3.7 **Demonstration**

For the demonstration phase, a set of different tools, hereafter called *AWARE-Demonstrator*, has been provided to allow users to access the demonstration at different level of interaction.
AWARE-Demonstrator is accessible from the AWARE geo-portal or directly at the address http://geoportal.dlsi.uji.es/aware/. The login web-page is shown in figure 3.7.1.

The geo-portal functions is an ‘orchestring’ application able to activate different OGC services compliant with the INSPIRE directive. In particular, it lets users run some Web Processing Services.

AWARE Geoportal

Login to AWARE Geoportal

You are not logged in

☐ Please enter the login information below

User:

Password:

New user? Register

AWARE (A tool for monitoring and forecasting available water resource in mountain environment) is a research project that aims at providing innovative tools for monitoring and predicting water availability and distribution in those drainage basins where snowmelt is a major component of the annual water balance, such as Alpine catchments. More info at http://www.aware-eu.info

A tool for monitoring and forecasting Available WAter REsource in mountain environment
Programme: FP6-AEROSPACE Project Reference: SST4-CT-2004-012257

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Fig. 3.7.1: AWARE login page

The functionality of the *AWARE-Demonstrator* is to give access to the users that expressed an interest in data and products resulting from AWARE activities, to various OGC standard services, i.e. the catalogue of metadata, a Web Map Service and a Web Feature Service distributing all the data produced during the life of the project. All provided OGC services have been realized following the implementation rules and the guidelines of INSPIRE.

The AWARE-Demonstrator allows the following different actions:

1. Access to the catalogue of AWARE products
   Accessing to the catalogue of AWARE activates a link to the CNR-IREA geo-portal developed in the framework of the IDE-Univers project, funded within the INTERREG MEDOCC programme aiming at creating a Spatial Data Infrastructure (SDI) to encourage access, exchange and interoperability of the huge quantity of information with a geographic reference produced by Universities and Research Centers in their projects and activities.
   The Geo-portal collects geographic information related to some past or ongoing CNR-IREA projects including all the AWARE products.

The metadata of 222 maps has been archived related to different tasks of AWARE project:

- 22 maps of snow cover (SCA) as obtained by satellite data (sensor MODIS, Products: MOD02 and MOD35) over the Alps in GEOTIFF format with the procedure developed by RSDE: in figure 3 an example of the related metadata
- 177 maps of MODIS snow cover products: in figure 4 an example of the related metadata
- 14 maps of SWE on Lombardia Region produced by POLIMI (figure 5)
- 8 maps of SWE on Davos area produced by POLIMI (figure 6)

Alla above maps can be inspected by a OGC Web Map Server hosted at CNR-IREA, too.

2. Access to the tutorial demonstration of models

   In order to allow users to learn the use of SRM and HBV models, 2 tutorial have been provided that automatically illustrate the sequences of actions to be performed when running the models.

3. Run of models with local data provided by AWARE archives

   Two sample sets are downloadable to allow users to train the models using real data; once downloaded the files, the user can access the models and run them.

4. Run with local data directly provided by users on their own basins.

   Once the user has got the feel with the provided tools he can run the models using her/his own data.

   By selecting "Run SRM and HBV models" the access to a summary of the characteristics of the two different models and the requirements of their use is given as well as data specifications.

   Each action and request of data are supported by help windows; error messages on top of page are also provided in case of inconsistency of data provided.

4. INTENTION FOR USE AND IMPACT

The availability of a general framework to monitor and assess water availability in mountainous areas is of strategic importance to Europe.

A reliable, near real-time approach for monitoring the water quantity is a first and essential step to build the basis of an alert network regarding water availability for anthropic use and riverine ecosystems, thus helping in defining and maintaining management policies.

The target user community where the AWARE project results have been disseminated is a quite specific community with a background in hydrology. User targets are water policy makers, water supply and hydropower companies, irrigation consortia, authorities at different levels (basin, municipal, regional), scientists and university teachers.

All the aforementioned user categories are represented among the 21 organisations which expressed their interest in AWARE results so far as end users.

The end users expressed their interest for the following project results:

- the EO data produced as input for modelling, providing continuous information on hydro-meteorological state variables;
- the runoff simulations and forecasts resulting from the application of the models;
- the Snow Water Equivalent products;
- the geo-portal and related geo-services.

5. PUBLISHABLE RESULTS

Through the AWARE geo-portal, some validated products resulting from the application of models are freely downloadable and all the Web Processing Services implemented are accessible (www.aware-eu.info) (Table 5.1).

Table 5.1: Publishable results

Result	Description	Stage of development
Geo-service prototype	The Geo-service includes the SRM runoff model, HBV model and sets of downloadable EO products	concluded
AWARE Final report	It describes in details all the technical solutions adopted in the assimilation of EO data in the SWE and SRM models and the design and implementation of the geo-service	concluded
SWE maps	Maps of Snow Water Equivalent	concluded
SCA maps	Maps of snow cover derived from MODIS data with different procedures	concluded

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