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Snow cover area estimate and analysis in the alpine range using moderate resolution satellites

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ABSTRACT: The environmental importance of medium and high latitudes snow cover is well established. Snow melt dynamics generate a complex set of interactions, which dictates a need for long-term monitoring of snow cover in conjunction with other climatological variables. Suitable data can be derived from satellite observations. Moderate satellite sensors help in the survey of the variations of snow coverages because they provide synoptic information over large territories, have low costs and adequate spectral resolution, even if the low spatial resolution it is still a problem. Previous works have been focused on the monitoring of American northern regions and the procedures involved have been tuned to large areas. In particular NASA mission on Moderate Resolution Imaging Spectroradiometer (MODIS) have been tailored to monitor spatial phenomena all over large areas. The work here presented has been performed in the AWARE project funded by EC. This project aims at providing innovative tools for monitoring and predicting water availability and distribution in snowmelt regime Alpine catchments using hydrological models and Earth Observation data integrated. Among the available EO sensors, MODIS has been chosen as the most suitable for producing the required parameters, according to factors identified in the analysis of requirements, such as temporal coverage and resolution, spectral and spatial resolution. Snow Cover Area (SCA) has been estimated on the Alpine range. The raw images has been converted in radiance; then water and clouds cover has been masked and a snow index has been calculated. Alpine basins considered have a dimension that not allow the application of NASA MODIS mission elaboration methodology so the procedure has been modified and a new approach, tailored on Alpine basins, has been settled.

1 INTRODUCTION

The activity here presented has been performed in the framework of AWARE project (A tool for monitoring and forecasting Available WAter REsource in mountain environment), in the Sixth program of the EC. This is a Research Project that aims at providing innovative tools for monitoring and predicting water availability and distribution in snowmelt regime Alpine catchments using Earth Observation (EO) data. Different hydrological models will be applied to basins situated all over the Alps to estimate the amount of water availability from snow variations in the melting season (April – July). The duration of the project is of 3 years starting from July 2005. This project has eight partners coming from different European countries (Italy: CNR-IREA, RSDE, POLIMI; Austria: TUW; Spain: ICC, UJI; Switzerland: SLF; Slovenia: ULFGG) and a big number of users interested on data and information produced (Web: http://www.aware-eu.info).

A big amount of the project work, object of this paper, regards the elaboration of EO data to be used as inputs in the hydrological models. This data will be used for the extraction of parameters of hydrological models to be integrated with traditional measurements, however snow drifted and snow depth are not considered as inputs in the analysed models.

Due to the high number of images to be processed (for the high temporal resolution required by the hydrological models) some procedures have been set up and implemented to automatically identify, download, geocode and calibrate images as well as to extract snow parameters (Engman & Gurney, 1991).

As the main information used by all project models is the Snow Covered Area (SCA), different images classification procedures for producing snow cover maps have been compared in order to identify the most suitable for the purpose taking into account the need for repeatability and automation. The comparison resulted in a modification of the Normalised Difference Snow Index (NDSI) in order to customize it on the Alpine characteristics. While basins requiring a more detailed spatial resolution and fractional cover information (Switzerland and Austrian ones), a set of classified images has also be planned by using the fuzzy statistical classifier.

A set of procedures *ad hoc* will be implemented for the extraction of parameters from EO data. This information regards the distribution of snow-cover, the albedo and the temperature and could be an improvement of the data retrieved in situ. The novelty of the presented approach consists in the tailoring of the NASA snow cover monitoring method changing the conventional steps of the procedure.

2 METHODS

2.1 *EO data acquisition*

The selection of the suitable EO data depends on many factors:

- Historical and revisit times (temporal coverage and resolution) requirements;
- Spatial requirements;
- Spectral bands measured by the sensor (spectral resolution);
- Cost vs. value of the information;
- Data processing requirements.

Different kind of EO data has been taken into consideration: NOAA-AVHRR, MODIS, Landsat TM sensor and ASTER. The MODIS images are the selected one. The major advantages of MODIS are that it provides a sufficiently high repetition rate and cover an area as larger as the Alps. The MODIS sensor is well suited for snow cover monitoring. Its repetition cycle of less one day allows to map the change of snow cover extent with a sufficiently high temporal resolution.

The last, but not less important characteristics of a sensor is the availability and the cost. In this case the MODIS images are free and very easily available on the NASA's Server. It is possible to order the images by internet and the day after you can pull down them.

The web site is: *http://edcimswww.cr.usgs.gov/pub/imswelcome/*.

Two kind of MODIS data are available: the not classified ones (MOD02) and the processed ones (products). Among these products we can find maps regarding the cloud coverage (MOD35), surface temperature (MOD11), vegetation indexes (MOD13), snow coverage (MOD10) (*http://modis.gsfc.nasa.gov/*). As said before, these products are not generally suitable for each part of the world and it should be necessary a tuning phase to obtain correct information on the studied zones. A variety of snow and ice products (see Figure 1) is produced from the MODIS sensors, and the products are available at a variety of spatial and temporal resolutions (Maurer *et al.* 2003).

The dimensions of the considered Alpine basins do not allow the application of NASA MODIS mission elaboration methodology. A new approach tailored on Alpine basins has been settled.

Different procedures have been considered. Unsupervised classification (ISODATA e K-means), where it is not necessary to train the classifier giving the information of ground truth. Methodologies of threshold and indexing (like NDVI and NDSI) can be also considered unsupervised and they have been tested.

Then supervised classification approach has been analysed where the contribution of the user is very high. Among these the maximum likelihood and the fuzzy classification.

After an analysis cost/benefits, considering the high number of images to be processed and to guarantee a service all over the entire Alpine range, the Normalised Difference Snow Index (NDSI) has been chosen as the more appropriated approach to be used in the project. However, the computing of this index has been modified in the consecutive releases for tuning it to the particular zones considered. Topography effects have not been considered in the snow mapping because of the spatial resolution of the product.

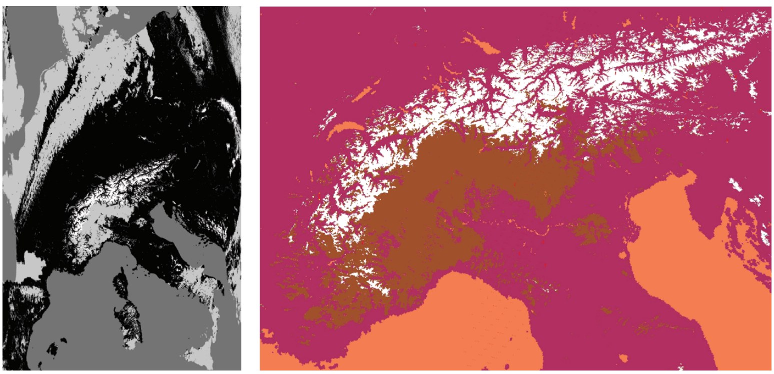


Figure 1. The MOD10 for Europe and the product after the reprojection for the Alpine area. Snow coverage in white.

2.2 *Procedure of elaboration of MODIS imagery*

The procedure for the extraction of the Snow Cover Area has passed through a complex phase of improving. Different releases have been produced to reach the best SCA product.

The hydrological year selected as first test analysis was the 2002/2003.

Here the steps of the procedure of classification applied to MODIS data to produce the first release.

1. Choice of images and filling the MetaData information
2. Geometrical correction of images
3. Reflectance conversion of the DNs
4. Water masking
5. Computing of NDSI and its slicing
6. Cloud cover masking
7. Quality flag production

2.2.1 *Choice of images and filling the MetaData information*

The choice of the images suitable for the project purposes starts from the downloading of cloud mask file from the NASA server (MOD35, Oct.2002 – Oct.2003). The reason is that these files are easier to be treated for their dimension.

Then, this procedure produces a selection of images that guarantees a total coverage of the Alpine range and with a little cloud coverage. A spatial coverage analysis (panoramic corrections that guarantee a minimum distance of the external boundaries from the interest zone) has been finally conducted.

During the acquisition and the choice of images to be used in the process, also information regarding images has been archived reading automatically the metafiles (in xml format). This allows the creation of a descriptive catalogue of the images and their characteristics according the normative ***INSPIRE*** and ***ISO9115***.

2.2.2 *Geometrical correction of Images*

After the selection of the useful images, they have been georeferenced using the geolocation infomation available by the NASA. Considering the position of the entire Alpine range (a big area), geographical considerations about different projection has been necessary.

We arrived to choose an appropriate CRS based on the datum **WGS84,** while the coordinates system we decided to use is **UTM Universal Transverse Mercator**.

The reason for this choice in AWARE project is also due to the wide use of it between the partners of the project, but even for the extreme facility of passing from another coordinate system to this, using a great variety of GIS Software.

A quality check of the geocoding process has been provided using the images in the EU project CORINE2000, obtained by Joint Research Centre.

2.2.3 *Conversion in reflectance*

The values of the pixels on the images (MOD02) available at NASA are Digital Numbers not atmospherically corrected. It has been decided to use a unique value of reflectance for each band (equal till the fourth places of decimals) to convert in reflectance value.

2.2.4 *NDSI index for snow identification*

The Normalised Difference Snow Index (NDSI) has been performed and improved by D. Hall on 2001 (Hall *et al.* 2002). This index, similar to the well known NDVI for vegetation studies, from the MODIS bands 4 and 6 allows identifying snow cover area using an adequate threshold.

$$\mathbf{NDSI} = \frac{\mathrm{SWIR} - \mathrm{NIR}}{\mathrm{SWIR} + \mathrm{NIR}} \quad \Longrightarrow \quad \mathbf{NDSI} = \frac{\mathrm{MODIS\ 4} - \mathrm{MODIS\ 6}}{\mathrm{MODIS\ 4} + \mathrm{MODIS\ 6}}$$

Snow detection is achieved through the use of two groups of grouped criteria tests for snow reflectance characteristics in the visible and near-infrared regions.

When computed this map of NDSI, to obtain the snow cover information it is necessary to consider values bigger than a threshold retrieved from literature or image analysis. The key phase is the decision of this threshold that should be representative for all the snow covered area in the images. It has been decided the fixed value 0.55. In the next releases it will be considered its dependence by seasons and zones (specification for test basins).

2.2.5 *Water masking procedure*

The NASA approach use for providing MOD10 product (a slicing applied on the band 2 of MOD02) is incorrect because of misclassification of shadowed zones as water. So, a water masking.has been applied.

28 Landsat images have been selected from the server of Joint Research Council (JRC: http://image2000.jrc.it/). The Corine Landsat images (25m of resolution) have been mosaicked using the projections UTM32 and UTM33 WGS84. The procedure has been performed twice: one for each projection. Only a cut zone has been considered for every projection. The mosaic has been classified with an unsupervised procedure (10 classes and 10 iterations).

Then, the vector obtained from the unsupervised classification need a procedure of "cleaning" because of the numerous shapes wrongly classified. This procedure had to be performed manually. However, not all the lakes classified has to be used in the water mask because they are not comparable with the pixel size of the MODIS image.

The definition of sea water and coastal zones boundaries, to eliminate problems with classification of water as undetermined, has been performed using MOD02 band 2 of a dry image without clouds (with a threshold not from literature) with a resolution of 250m and using the MODIS product MOD10 at 500 m.

There is a zone of uncertainty around the lakes where pixel could be classified wrongly. So, a buffer has been applied in and out the lake boundaries. The buffer zone depends on the dimension of the object: if the lake is big it is possible to use a big buffer, if it is small, we consider a smaller buffer zone. This buffer is of 250 m if the lake is small and 500/

750 m if it is big. For the sea boundary 500 and 750 buffers has been used. These buffered pixel will be use to create a quality flag in the next releases.

2.2.6 *Cloud cover masking*

The cloud coverage of the images has been eliminated (masked) from the SCA result using MOD35 product (1000m resolution). The procedure provides the creation of a cloud mask from the interpretation of the product. It is a conservative cloud mask that is independent by the kind of clouds.

2.2.7 *Quality flag production*

Due to the errors in the different steps of the procedure (raw images, georeferencing, water classification, cloud masking), has been produced a quality flag map. This is a matrix that allows to know for each pixel how is the quality of the process that produced it.

3 RESULTS: SCA PRODUCTION

The result of the first release of the SCA is a 2 classes product where snow and no-snow have been distinguished and classified as a mask.

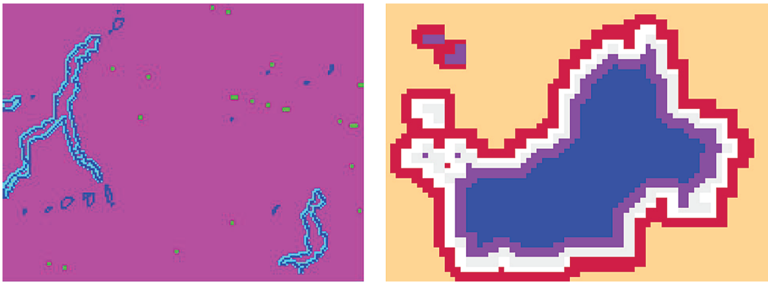
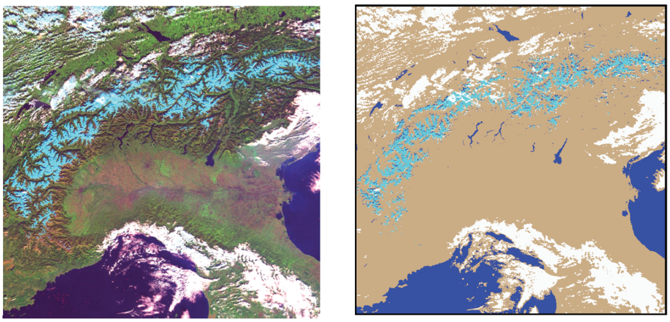


Figure 2. Quality maps: Every colour corresponds to a different quality.



Row	Class Names	Color
0	unclassified	
1	water	
2	undetermined	
3	snow	
4	clouds	

Figure 3. The 18 September 2002 MODIS image (RGB723) and the SCA map.

This is a problem for users that want to know if in a zone the class no-snow is due to the cloud coverage or to a bare soil. So, in the following releases, it has been decided to produce a 4 classes product where water (inland and sea water), clouds, snow and undetermined (bare soil, vegetation, urban, etc.) are specified.

The SCA product is then exported in the format that users want (*.tif, *.raw, *.img, etc).

4 DISCUSSION: FUTURE IMPROVEMENTS

The resulting SCA maps have been validated using the NASA product MOD10 (1000 m resolution) and comparing the snow information obtained from in situ measurements of weather stations: some discordances have been found. Because of interpretation and classification errors in the SCA product, that not allowed the partners to completely use the product, it will be necessary to improve the results with new steps in the procedure or changing the information retrieved by a single step. Here the next step to be performed to produce the new releases.

Possible future improvements will be:

- Reflection conversion
- Cloud masking
- Increase of frequency
- Fuzzy classification

5 CONCLUSIONS

The AWARE project is an important test to define the potentiality of using medium resolution satellite data as input in hydrological model applied to the Alpine basin. The main application of EO data is snow mapping because of the importance of the spatially distributed observations for snowmelt modeling. Model innovation stems with the enhanced capability of Earth Observation data to provide continuous information on the state variables, that can be poorly accounted for, when using the traditional approach based on input-output control. The EO data procedure applied has been tested over different Alpine basins and demonstrates the completely usefulness for the purposes proposed.

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REFERENCES

Andreadis, K.M., Lettenmaier, D.P. 2005. Assimilating Remotely Sensed Snow Observations into a Macroscale Hydrology Model, *Preprint submitted to Advances in Water Resources*.

Engman, E. T., Gurney, R. J. 1991. *Remote Sensing in Hydrology* (London: Chapman and Hall).
Grody, N.C. & Basist, A.N. 1996. Global identification of snowcover using SSM/I measurements, *IEEE Transaction on Geoscience Remote Sensing* 34 (1) 237–249.
Hall, D.K., Riggs G.A., Salomonson V.V., DiGirolamo N.E. & Bayr K.J. (2002). MODIS snow-cover products, *Remote Sensing Environment* 83, 181–194.
Maurer, E.P., Rhoads, J.D., Dubayah, R.O. & Lettenmaier, D.P. 2003. Evaluation of the snow-covered area data product from MODIS, *Hydrological Processes* 17, 59–71.
Rango A., Martinec J., Foster, J. & Marks D. 1983: Resolution in operational remote sensing of snow cover, *IAHS Publ* 145, 371–381.
Schmugge T. J., Kustas W. P., Ritchie J. C., Jackson T. J. & Rango A. 2002. Remote sensing in hydrology, *Advances in Water Resources* (Elsevier) 25, 1367–1385.
Swamy A. N., Brivio, P.A. 1997. Modelling runoff using optical satellite remote sensing data in high mountainous alpine catchment of Italy, *Hydrological Processes* 11, 1475–1491.