

Utilization of BEAM and NEST open source toolboxes in education and research

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Abstract

European Space Agency (ESA) provides several open source toolboxes for visualization, processing and analyzing satellite images acquired both in optical and microwave domains. Basic ERS & Envisat (A)ATSR and MERIS Toolbox (BEAM) was originally developed for easier handling ENVISAT optical data. Today this toolbox supports several raster data formats and datasets collected with other EO instruments such as MODIS, AVHRR, CHRIS/Proba. The NEXT ESA SAR Toolbox (NEST) has been created for processing radar data acquired from different satellites such as ERS 1&2, ENVISAT, RADARSAT or TerraSAR X. Both toolboxes are suitable for the education of the basic principles of data processing (geometric and radiometric corrections, classification, filtering of radar data) but also for research. Possibilities for utilization of these toolboxes in remote sensing courses based on two examples of practical exercises are described. Use of the NEST toolbox is demonstrated on a research project dealing with snow cover detection from SAR imagery.

Introduction

European Space Agency (ESA) has been focused on development of open source toolboxes for professional processing of remote sensing data for more than a decade. At the same time the agency pays attention to educational activities such as Eduspace that offers students and teachers of secondary schools examples of Earth Observation (EO) data and simple software tools for image processing (LEOWorks, [1]). Nowadays, 29 toolboxes are available from the ESA homepage [2]. In the first place, they have been developed to help users to read, process and manage data of ESA EO missions but recently some products of so called "third party

missions” can be processed with these software tools as well. From the point of view of teachers and researchers dealing with optical and microwave remote sensing, the following toolboxes may be found most interesting and useful (ESA toolboxes [2]):

- BEAM (Basic ERS & Envisat (A)ATSR and Meris Toolbox) is primarily suited for viewing and processing of ENVISAT optical data.
- NEST (Next ESA SAR Toolbox) enables viewing and processing of SAR data such as ERS or ENVISAT/ASAR but also new sensors as TerraSAR-X and RADARSAT-2.
- POLSARPRO offers tools for manipulating SAR polarimetric data. It also includes educational material about SAR polarimetry.
- Enviview contains visualization tools for ENVISAT data.
- ESOV (Earth Observation Swath and Orbit Visualization tool) gives an overview on instrument swaths of all ESA Earth Observation Satellites, e.g. where and when satellite data capture takes place and where and when ground contact is possible.

In addition to the mentioned software tools, there are two others that are very useful for searching data from ESA EO missions and some third party missions (both archive data and planned acquisition), namely EOLISA [3] and Descw [4]. While the former can also be used for ordering data, the later is suited for SAR acquisitions and finding interferometric pairs with proper geometric and temporal parameters.

The purpose of this paper is to show a possibility for using the BEAM and NEST toolboxes for the education of remote sensing on the university level and in research. First, a short characteristic of both toolboxes is given. Examples of two practical exercises dealing with spectral characteristics of vegetation and mapping snow cover area from ENVISAT optical data (MERIS and AATSR) follow. Use of the NEST toolbox is demonstrated on a research project focused on snow cover monitoring from SAR imagery.

BEAM and NEST toolboxes

BEAM

Basic ERS & Envisat (A)ATSR and MERIS Toolbox (BEAM) was originally developed for viewing and processing of Envisat optical data. Based on an ESA project, the software development has been carried out by the private company Brockmann Consult. Since the start of the project in 2002, several versions have been released (v. 4.8 in July 2010). BEAM is programmed in Java which enables its use on different platforms. There are versions for Windows, Linux, Mac OS and Solaris operation systems. The users can develop and implement their own modules. The user community is rather wide; it has a lively user forum. BEAM consists of three main components [5]:

- VISAT, a visualization, analyzing and processing desktop application comprising functions for
 - data import and export (formats Envisat N1, CEOS, HDF, GeoTIFF, BEAM-DIMAP),

- displaying images including navigation window, layer manager and enhancement tools,
 - basic image analysis: histogram, scatter plots, band transect profile, definition of points of interest (so called PINs), spectrum view in PIN positions, geometric corrections
 - Generation of image products: reprojection, orthorectification, connecting images to a mosaic, band arithmetic, band filtering,
 - advanced processing: cluster analysis, spectral unmixing and special functions suited for processing MERIS data (SMILE and SMAC correction, radiance to reflectance processor, NDVI processor, cloud probability processor). All these modules are accessible both from VISAT and from a command line,
- convertor from the internal BEAM-DIMAP format to GeoTIFF, HDF-5 or RGB images,
 - Java API for development of new, user defined modules.

Based on our experience, the VISAT graphical interface is user friendly. It also has the ability to display GIS data (shapefiles) and other datasets available via WMS. Basic image processing tools can be easily implemented into introductory remote sensing courses. The advanced tools are mostly used for research or in master degree courses in remote sensing and image processing.

NEST

The purpose of the Next ESA SAR Toolbox (NEST) is to provide functions for viewing, analyzing and processing synthetic aperture radar (SAR) data from ESA satellites (ERS 1 & 2, ENVISAT and future Sentinel). It also supports data of other SAR sensors such as RADARSAT 1 & 2, TerraSAR-X or ALOS PALSAR. The user interface of NEST is based on BEAM VISAT but it comprises a set of functions for SAR data processing that are also a part of the Basic Envisat SAR toolbox (BEST). NEST is being developed under an ESA project by a Canadian company Array Systems Computing, Inc. The latest version NEST 4A-1.5 (October 2010) comprises among others following SAR processing functions [6]:

- radiometric calibration,
- speckle filtering,
- multilooking,
- coregistration,
- terrain correction,
- transformation from slant range to ground range.

The newest version also enables InSAR processing (coherence estimation, generating interferogram) and it is therefore an alternative to the DORIS software package (DORIS InSAR [7]) developed for the Linux operating system. Moreover, a set of functions for ocean applications have been implemented such as object and oil spill detection.

ESA toolboxes in RS courses

At the Department of Applied Geoinformatics and Cartography of Charles University in Prague, BEAM and NEST software packages have recently started to be utilized in the remote sensing courses to give students some alternatives to commercial (and costly) software packages. The BEAM toolbox is mostly used for processing of ENVISAT/MERIS (Full Resolution Level 1 [8]) and AATSR (Level 1 [9]) images that are continually collected at the Department via a receiving station established in cooperation with ESA. The basic functions of the BEAM toolbox are explained during a practical exercise of the course Application of Geoinformatics that is compulsory for students on the master level specialized in cartography and geoinformatics. From the academic year 2010/2011, students will get more familiar with optical ENVISAT data and the BEAM toolbox by solving two tasks in the scope of the course Extraction of information from Remote Sensing data. Both tasks are based on results of diploma theses recently defended at the Department and they are at the same time a part of ongoing research activities.

Spectral signatures of selected vegetation species

The main advantage of MERIS data in monitoring of vegetation is in their high spectral and temporal resolution. The area of the Czech Republic is covered each three days; the only problem is the cloud cover that can be rather dense in some months of the year. The goal of the described practical is to compare spectral curves of different kind of crops (e.g. rapeseed, maize, sugar beet, hops) and other types of vegetation (e.g. coniferous and deciduous forests) within the year and in connection to different geographical and climatic conditions (altitude, orientation, average temperatures). A data set including images with minimal cloud cover (less than 20%) from the vegetation season (monthly scenes from April to September 2009) and a map of land cover (including crops) derived from MERIS data by classification and verified using in situ data is available. As a data set comprises multitemporal data, one of the goals is to teach the students how to deal with a radiometric correction and how to verify its result. The geolocation is based on orbital parameters but it should be checked by the students as well (mutual shifts of images should not exceed 1 pixel). The original scenes are already trimmed to the area of the Czech Republic according to the previously produced land cover map. Ancillary data about altitude and slope orientation were calculated in GIS software from SRTM data. Moreover, a map of climatic regions of the country will be used [10]. The exercise in BEAM consists of following steps:

- radiometric corrections of MERIS data (spectral shift – SMILE correction, atmospheric correction – SMAC [11]),
- creating spectral curves for selected crops and other vegetation according to the legend of the land cover map using BEAM functions "pin manager" and "spectrum view" at the selected positions that differ with respect to altitude, slope orientation and climatic region.

Figures 1 and 2 show one of possible outputs from the exercise. Students will produce and compare reflectance curves of different types of vegetation, evaluate an influence of geographic and climatic conditions on spectral characteristics of vegetation and draw some conclusions and recommendations for classification of MERIS images for the purpose of crop or forest

monitoring. The students will learn how to work with multitemporal data and they will get better understanding of spectral behavior of vegetation in relation to different natural conditions.

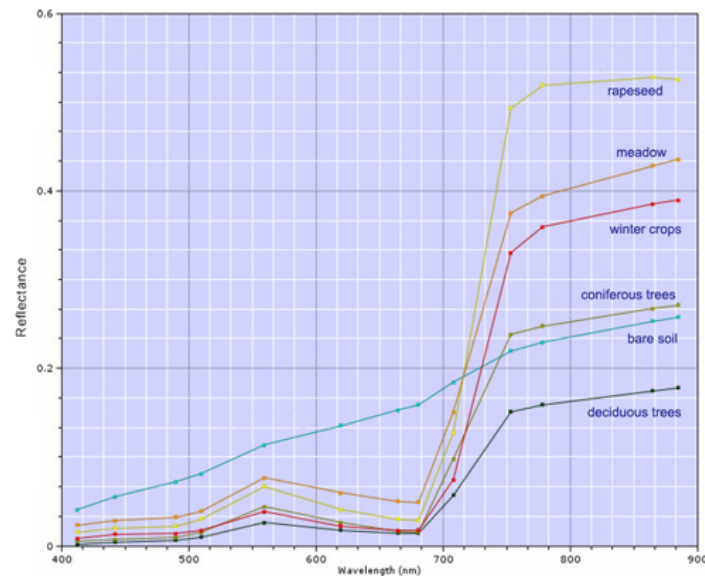


Figure 1: Reflectance curves of different vegetation types derived from MERIS data on 21st April 2009 (source: [12])

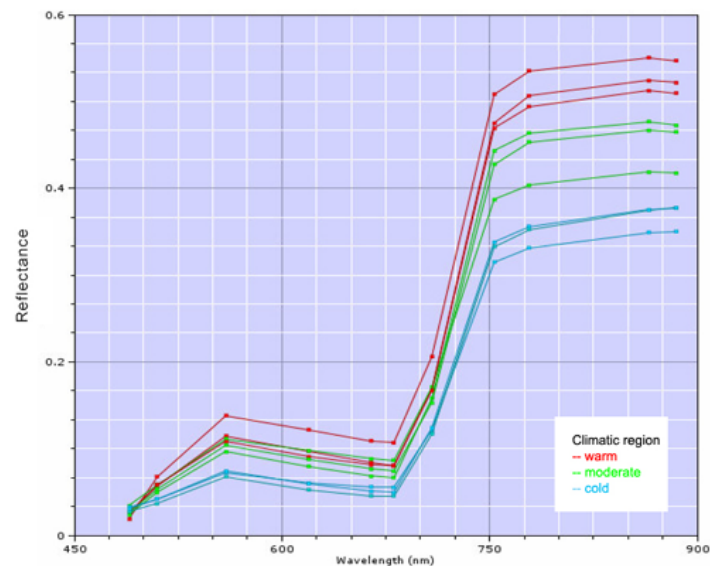


Figure 2: Reflectance curves of rapeseed in different climatic regions derived from MERIS data on 3rd May 2009 (source: [12])

Snow cover determination using MERIS and AATSR data

Reflectance of snow and ice is very high in visible (VIS) and near infra red (NIR) part of the spectrum. Similar spectral behavior is typical for clouds. That is why it is not possible

to distinguish between snow and cloud cover in VIS and NIR images. Reflectance of snow decreases considerably in the short wave infrared (SWIR) part of the spectrum (intervals $1.55 \mu m$ to $1.75 \mu m$ and $2.1 \mu m$ to $2.3 \mu m$) while the reflectance of clouds does not change considerably in comparison to shorter wavelengths [13]. The sensor MERIS acquires data in 15 spectral bands in the range from 390 nm to 1040 with approximately 300 m spatial resolution and it is not therefore suitable for snow detection in case of a partial cloud cover. The AATSR sensor has a lower spatial resolution (1 km) but it includes also a spectral band in the SWIR part of the spectrum ($1.6 \mu m$). The goal of the proposed exercise is to teach students how to combine these two sources of data and how to derive a snow product from them. The exercise contains following steps:

- creating a sub-scenes of original data covering the area of the Czech Republic,
- radiometric corrections of MERIS data (spectral shift – SMILE correction, atmospheric correction – SMAC [11]),
- coregistration of MERIS and AATSR images (function "Collocation"); an image from the MERIS sensor is chosen as a "master" and an AATSR image is resampled into it,
- visualization of a coregistered product,
- derivation of a snow and cloud mask based on thresholds,
- evaluation of the created snow mask based on comparison with other snow products (e.g. based on MODIS data) or in situ measurements.

Visualization of a coregistered product

Practical examples show the advantage of the AATSR SWIR band for discrimination between clouds and snow as depicted in Figure 3. BEAM visualization tools can be used for this purpose.

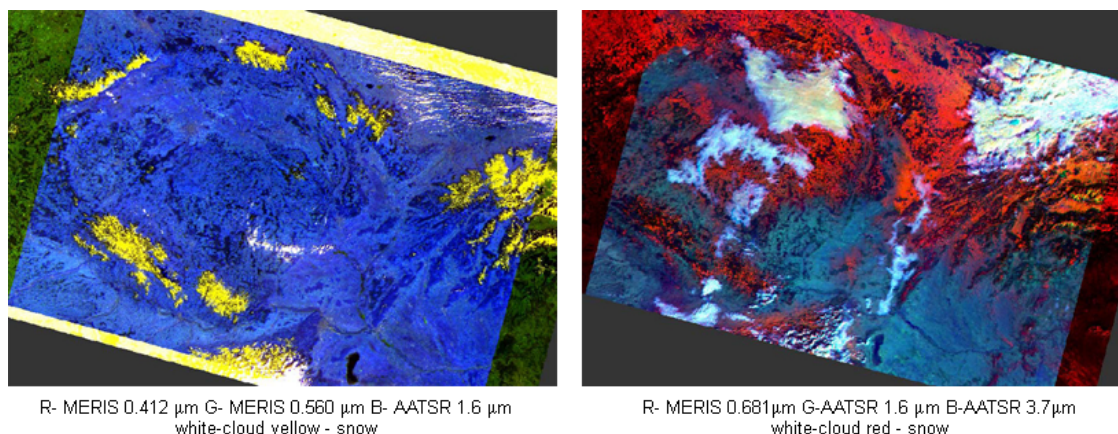


Figure 3: Example of color composition of MERIS and AATSR data for visualization of snow and cloud cover (source: [14])

Derivation of snow and cloud mask based on thresholds

Using band arithmetic, following indexes can be calculated:

- Cloud index [15] $CI = (AATSR\ 3.7 - AATSR\ 11) / (AATSR\ 3.7 + AATSR\ 11)$

- MERIS normalized differential snow index [16] $MNDSI\ 1 = (MER\ 0.865 - MER\ 0.885) / (MER\ 0.865 + MER\ 0.885)$
- Normalized differential snow index [14] $NDSI = (MER\ 0.665 - AATSR\ 1.6) / (MER\ 0.665 + AATSR\ 1.6)$
- Normalized differential vegetation index $NDVI = (MER\ NIR - MER\ R) / ((MER\ NIR + MER\ R))$

The number behind the sensor abbreviation corresponds to the spectral band central wavelength in μm . Several MERIS spectral bands can be used for the calculation of NDVI. In the algorithm presented below bands 7 and 10 (0.665 μm and 0,753 μm) are used [14].

The goal of the exercise is to evaluate suitability of the above listed indexes in combination with reflectance (R) and bright temperature values for snow and cloud determination and to empirically derive thresholds for discrimination of both of these features. Relevant literature, e.g. [15], is available. An example of derived masks and an applied classification algorithm are shown in Figure 4.

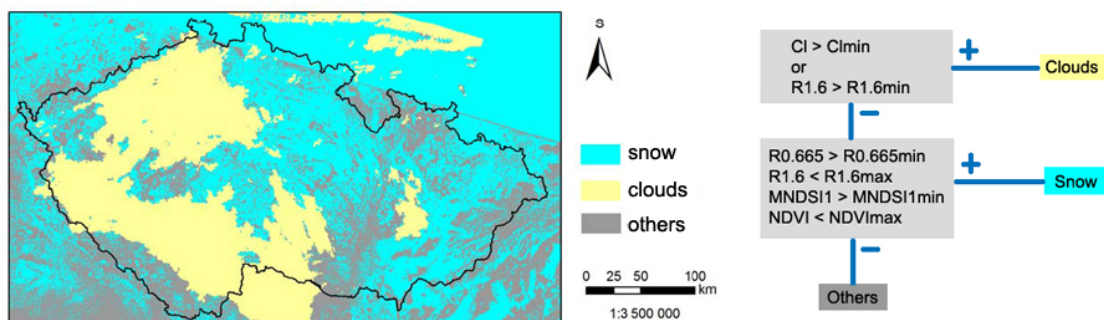


Figure 4: Result of snow classification from MERIS and AATSR data on 9th January 2009. The classification is based on combination of thresholds on cloud index, AATSR reflectance values at the spectral band 1.6 μm , MERIS normalized differential snow index and NDVI. (source: [14])

Snow detection from ENVISAT/ASAR data

The extent of snow cover area (SCA) is important for hydrological models, especially for flood prediction due to snow melt. Discrimination of SCA from optical and radar images is one of tasks of the project "Demonstration of ESA environments in support to FLOOD Risk Earth Observation monitoring" (FLOREO). Within this project, SCA determination based on observations from both optical and radar sensors were tested. Utilization of optical images is problematic due to cloud cover that is rather frequent in winter period (e.g. average cloud cover in February 2009 was 93%). Our research therefore focused on the determination of SCA from ENVISAT ASAR images. With the exception of the final classification and visualization of the results, all processing steps were carried out in the NEST software package.

The influence of snow on radar backscattering in the C band has been known for many years (e.g. [17]). While the impact of volume scattering in dry snow is negligible and the nominating

backscatter comes from ground surface, presence of liquid water in the snow pack causes a significant decrease of backscatter in comparison to snow free or dry snow conditions. Thus, wet snow can be discriminated if an image acquired in snow melt period is compared with an image collected before or after this period [18]. Our investigations on the ASAR wide swath mode, single polarized product showed that it was the best to choose images with dry snow or frozen, snow free earth as a reference. Image processing steps for wet snow discrimination are depicted in Figure 5. With the exception of the last classification, NEST functions were utilized in the implementation of proposed methodology.

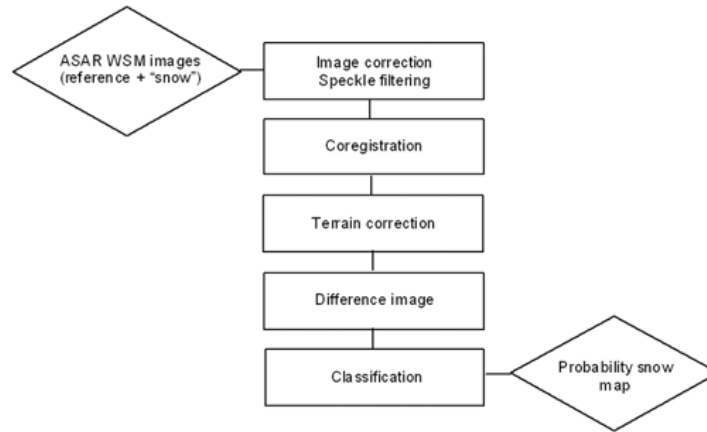


Figure 5: Main processing steps of classification of wet snow from a pair of SAR images.

Intensity values are recalculated to backscatter coefficient σ^0 in the image correction step according to the formula [6]:

$$\sigma^0 = \frac{DN_{i,j}^2}{K} \sin(\alpha_{i,j})$$

where

$DN_{i,j}^2$ is the pixel intensity for pixel i, j

K is the absolute calibration constant

$\alpha_{i,j}$ is an incidence angle

In order to minimize the speckle effect, the gamma filter using the window of 7x7 pixels was applied on the data. In the following step, a NEST function enabling automated coregistration of images was applied. At the beginning of the FLOREO project (2008), this function was not available. Coregistration was therefore performed based on manual measurement of control points (mostly water bodies) followed with a polynomial transformation in the PCI software. An implementation of the coregistration function into NEST created a possibility for a complete automation of all processing steps.

The terrain correction function creates an orthorectified image in the WGS 84 geographic coordinates. It requires orbital parameters and DEM as input values. Orbital parameters are included in the original data file. NEST contains a link to the SRTM DEM.

A difference image is created using the NEST band arithmetic function. Differences in backscatter are calculated as $\Delta\sigma^0 = \sigma_{snow}^0 - \sigma_{ref}^0$. A final classification is based on setting a threshold for $\Delta\sigma^0$ values. In literature a threshold of -3 dB is recommended [18], [19].

Our investigations showed that this threshold is reliable in mountainous areas with sparse vegetation. For the purpose of SCA mapping over the whole country the threshold value was derived for each pair of snow and reference images based on $\Delta\sigma^0$ in the surrounding of meteorological stations where snow height and air temperature are measured or based on snow maps derived from optical images [20]. Although this solution brought some improvements, in the heterogeneous landscape of the Czech Republic a necessity of finding threshold values according to different land cover classes is obvious. After setting a threshold for $\Delta\sigma^0$, a probability snow map (see Figure 6) is created using a sigmoid function $F(x)=50-50\tanh[a(x+3)]$. Parameters a (slope) and x (50% snow probability) are derived from a histogram of differences between a reference image and an image with snow.

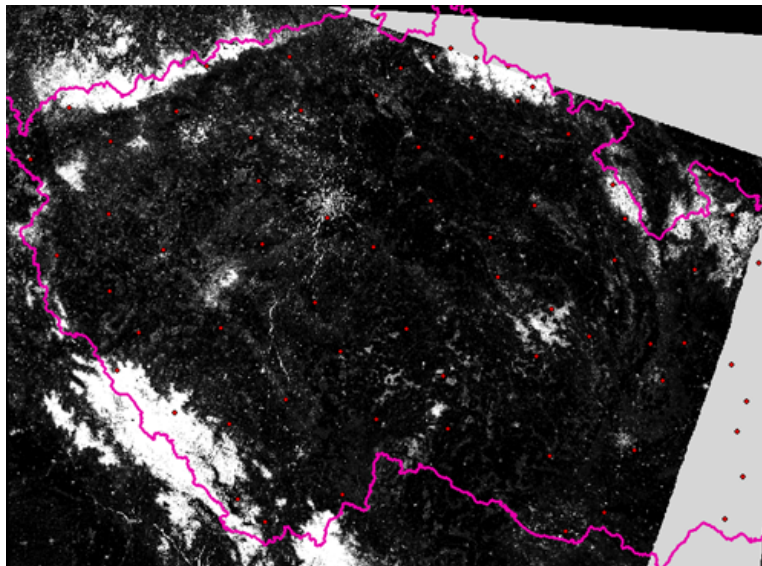


Figure 6: Result of wet snow mapping from ASAR image on 24th March 2009 (black 0% snow, white 100 %). The red dots show positions of meteorological stations. Urban areas are not masked out and appear in bright tones.

Quality assessment of snow maps from ASAR data was performed by a comparison with snow maps derived from MODIS images with resolution of 250 m. The total accuracy of classification was 92% in the image from 24th March 2009 (Figure 7). The values in contingency tables in this and other two tested datasets showed that the classification result from ASAR images underestimated the snow cover area. This result is probably influenced by the fact that all snow pixels from optical data were taken into calculation regardless of wetness of snow. A possible solution to this problem gives post-processing of radar data. The presented classification step of the processing was done in MATLAB, visualization of images in ArcGIS. As it was mentioned before, the whole previous processing was carried out in NEST. The first three processes were chained into one function (using the NEST "graph builder") that can run in a batch mode. Terrain correction was not added to this function due to problems with the size of original scenes. Images have to be cut to the area of interest first. This step is done manually so far but its automation is in progress.

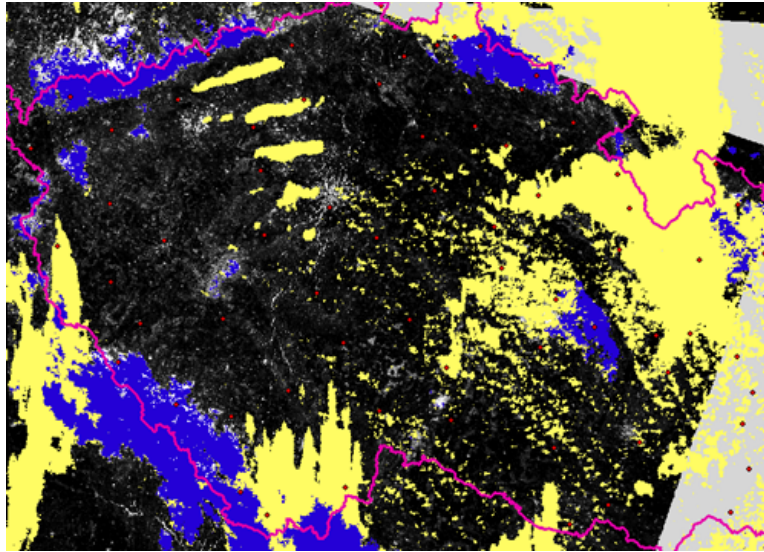


Figure 7: Overlay of classification result of ASAR data from Figure 6 and a snow (blue) and cloud (yellow) mask derived from MODIS image.

Conclusion

The described examples demonstrated only three possibilities of the utilization of the BEAM and NEST open source ESA toolboxes in research projects and in remote sensing courses. The availability of software solutions as well as an opportunity to develop new modules and share ideas and problems in user forums gives a good base for further development of the presented tools. The main advantage and at the same time disadvantage of the software packages is the JAVA platform. It makes it easy to create and implement new modules and it is suitable for educational purposes (not only in remote sensing applications but also for software development). On the other hand processing time is rather long in case of larger data sets which is not very convenient especially in case of operationally oriented projects. Nevertheless, this "weakness" is minor especially in educational applications and experimental work when smaller datasets are usually sufficient. In combination with an easy accessibility of ESA EO data, the mentioned image processing tools create a valuable and solid base for research and education in remote sensing.

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