Global Snow Monitoring for Climate Research

Technical note 2

Cloud Detection Algorithm SCDA

EUROPEAN SPACE AGENCY STUDY CONTRACT REPORT
ESRIN Contract 21703/08/I-EC

PREPARED BY

SARI METSÄMÄKI (SYKE) ROMAN SANDNER, THOMAS NAGLER (ENVEO) RUNE SOLBERG, BJÖRN WANGENSTEEN (NR); KARI LUOJUS, JOUNI PULLIAINEN (FMI)

GLOBSNOW CONSORTIUM

Finnish Meteorological institute (FMI) - Prime contractor

ENVEO IT GmbH (ENVEO)

Environment Canada (EC)

Finnish Environment Institute (SYKE)

GAMMA Remote Sensing Research and Consulting AG (GAMMA)

Norwegian Computing Center (NR)

ESA TECHNICAL OFFICER: Bojan BOJKOV

DATE: 2 May 2011

VERSION / REVISION: 1.0 / 02

Table of Contents

1 INTRODUCTION

ESA GlobSnow project produces climatic data records on snow cover in global scale. The product portfolio includes daily (and weekly/monthly aggregated) maps on Northern Hemisphere Snow Extent. These products exploit the daily data provided by Envisat/AATSR instrument scanning the Earth at visible and infrared wavelengths. The drawback in using optical imagery for snow mapping is the possible cloudiness preventing the view to the earth's surface. The clouds may also lead to false commitments of snow if not identified and masked out. Various cloud masking algorithms has been developed for different satellite sensors; their success depending on sensor characteristics and local conditions at (and above) the geographical target area. Since cloud physical properties and underneath surface properties have large variation, a most intelligent algorithm would adapt to local conditions by involving complicated mathematical calculations. This would not be feasible in GlobSnow due to the massive amount of data and near real-time approach. In order to yield an algorithm simple enough to provide low computational cost but still viable in global scale, a development work was started at the Finnish Environment Institute (SYKE). The cloud masking algorithm was to work for AATSR (and ATSR-2) imagery to serve the Snow extent product of GlobSnow. After several phases of innovations and testing, the SCDA (Simple Cloud Detection Algorithm) was developed by S. Metsämäki, SYKE, in co-operation with R. Sandner, ENVEO, who validated the cloud masks and gave valuable feedback during the work.

The development work started with AATSR Pan-European data set acquired at different stages of snow melt and with altering cloud cover. After finding a well-working (by visual judgement) algorithm, it was tested more globally. Very soon the validation indicated that the algorithm needed refinement in order to perform in global scale, taking into account the climatic and overground characteristics. The AATSR data set was extended with imagery from North America, Greenland, Middle Asia and East Asia, aiming at a single algorithm that would work equally well for all the areas. The work was conducted with empirical approach, based on trials with different features (e.g. band ratios) extracted from AATSR data, followed by immediate testing and feedback. Finally, version 1.4.2 of SCDA was accepted into operational SE processing. The gained algorithm is computationally simple, easy to implement and works reasonably well. The novelty of the algorithm is based on its ability to slightly adapt into local conditions, which is essential in generation of global cloud masks.

2 METHODOLOGY

Authors: Sari Metsämäki (SYKE), Roman Sandner and Thomas Nagler (ENVEO)

The Simple Cloud Detection Algorithm was first proposed by S. Metsämäki (SYKE). The basis of the SCDA algorithm is the brightness-temperature (BT) difference between 11 µm and 3.7 µm (BT11−BT3.7), which shows large negative values for clouds (strong reflection of solar energy at 3.7 µm). So if *BT11−BT3.7 < diff_threshold, then CLOUD*. The development work was mainly focused on deriving a feasible value for this threshold, complemented by few (mostly restrictive) additional rules. The first versions of SCDA were based on using a fixed threshold which was empirically determined, with major drawback of failing in discrimination between cloud and snow over very cold snow surfaces. Therefore, an approach more adaptive to local conditions was invented. After having this, the further development concerned fine-tuning the additional rules which are of minor importance but still necessary.

In current version 1.4.2 *diff_threshold* is defined by local brightness temperature BT12, so that the colder the target, the lower the threshold is set: *diff_threshold = 0.5·BT12−131 (Kelvin)*. However, *diff_threshold* cannot exceed a value of -6 (empirically derived value). The varying threshold was found necessary in order to avoid false identification of clouds over very cold snow surfaces.

In general, using only difference BT11−BT3.7 detects all clouds but would yield to false commitments if not restricted by exclusive rules. Non-opaque clouds are difficult to detect since the surface underneath affect the reflectance and brightness temperatures. Therefore, larger differences of BT11−BT3.7 have to be accepted, accompanied by slightly different exclusive rules than those for opaque clouds.

The SCDA algorithm version 1.4.2 applied in the SE product version 1.0 is fully described in Figure 1. Note that reflectance is given in % units [0-100].

```
diff = BT11-BT3.7
diff_threshold = 0.5*BT12-131 (Kelvins); IF diff_threshold > -6 THEN
diff_threshold = -6

IF (diff<=diff_threshold && BT12<287 && ndsi<0.69 && ndsi>-0.20 && r0550>20)
mask1 = 1
       -  opaque clouds
       -  BT12 < 287 to exclude high reflectivity warm areas like desert
       -  NDSI < 0.69 to exclude relatively warm snow-covered areas
       -  r0550> 20 to exclude snow-free surfaces with low reflectances
       -  ndsi>-0.20 to exclude confident clear-sky snow-free areas

IF ((diff < -3) && (diff > diff_threshold) && BT12<287 && ndsi<0.6 && NDSI>-0.05
&& r0550>20 && ndsi*100<1.1*r0550)
mask2 = 1;
       -  non-opaque clouds
       -  BT1200 < 287 to exclude high reflectivity warm areas like desert
       -  ndsi <= 0.6 to exclude relatively warm snow-covered areas
       -  ndsi >-0.05 to exclude confident clear-sky snow-free areas
       -  r0550> 20 to exclude snow-free surfaces with low reflectances
       -  ndsi*100<1.1*r0550, very important in excluding cloud-free areas with
          full or partial snow cover particularly in forests

IF mask1=1 OR mask2=1 THEN CLOUD
```

Figure 1: The SCDA version 1.4.2 algorithm.

It should be noted that especially in southern latitudes the thermal AATSR bands are saturated over large areas. Figure 2 shows as example the image of the 3.7 µm AATSR band overlaid on an AATSR colour composite. Areas where the 3.7 µm AATSR band is saturated are made transparent, and the colour composite becomes visible. The area with saturated bands at 11 µm and 12µm is considerable smaller. By masking areas where at least one band is saturated as areas where no information can be provided would lead to a significant loss of information, increasing towards north during the year.

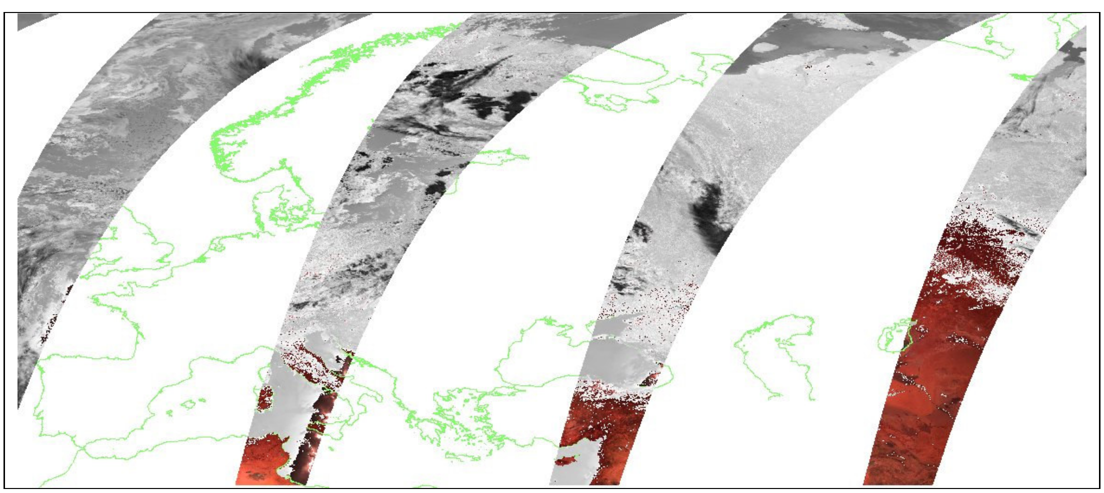


Figure 2: AATSR 3.7 µm brightness temperature on 2004/07/06. RGB colour composite (1600 - 670 - 550 nm) combination in the background. Where the RGB image is shown, the 3.7 µm channel is saturated

In order to enable cloud detection also over areas where the thermal channels at 3.7, 11 and 12 µm are saturated, we have used the defined maximum brightness temperature values in the case of saturation:

- Band 3.7 µm → 311.78K
- Band 11 µm → 321.0K
- Band 12 µm → 318.0K

3 VALIDATION RESULTS

Authors: Roman Sandner and Thomas Nagler (ENVEO)

For evaluating the performance of the SCDA v.1.4.2 in different environments and different periods of the year, we performed two investigations:

- *Statistical properties of the main SCDA conditions:* calculation of the fraction of the two main if conditions for cloud detection on the global domain (see Section 3.1.1.1). This is carried out in order to support the understanding of different SCDA conditions in larger areas.
- *Evaluation of SCDA performance by visual comparison of cloud mask and multispectral AATSR image:* Visual inspection of the cloud mask and comparison with RGB composites of suitable AATSR spectral bands. Visual inspection was carried out in selected test areas, located in different environmental and climate regions in the pan-European domain. It includes different surface types, like mountain regions, flat and hilly forested areas, meadows, bare soil areas, etc. In order to support the cloud algorithm evaluation we calculated and visualized the conditions and the bands and band combinations used for cloud testing.

3.1 AATSR data set for evaluation of cloud masking using SCDA 1.4.2

For cloud evaluation on a global scale we used 3 days with different atmospheric conditions and solar zenith angle. The selected days are:

- 28 February 2003
- 28 April 2003
- 25 May 2003

Figure 3 shows RGB colour composites of the selected days. For cloud evaluation the global mosaic of daily AATSR data was subdivided into four sub regions:

- NA (North America)
- GR (Greenland)
- EW (pan-European domain)
- EA (East Asia)

In this investigation the Greenland subset is not investigated, as most parts of Greenland are masked out by a glacier mask.

For detailed visual evaluation of the SCDA v.1.4.2 cloud masking procedure we defined several evaluation sites in different environments and climate zones and with different surface types. The evaluation sites are listed in Table 1, and the location of the sites are shown as red boxes in Figure 3.

Table 1: Evaluation sites for cloud masking procedure

ID	Area
1	Northwest Territories, Nunavut (CA)
2	Alberta, British Colombia (CA)
3	Buryatia, Irkutsk (RUS)
4	Spain
5	Georgia
6	Kazakhstan, Russia
7	Magadan, Chukotka (RUS)
8	Algeria
9	Pakistan, China and Tibet

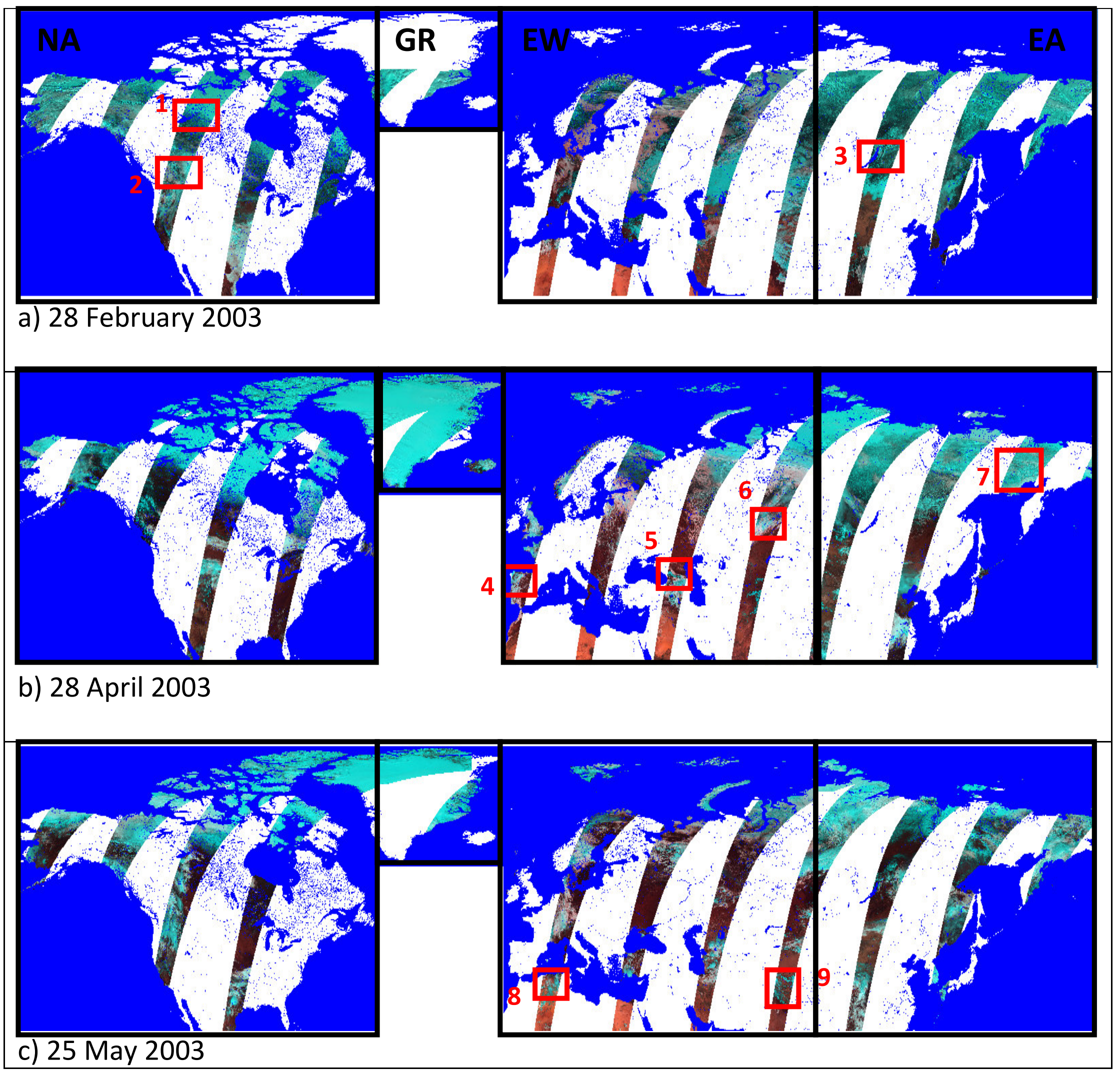


Figure 3.: RGB colour composite of a) 28 February 2003, b) 28 April 2003 and c) 25 May 2003. The visual evaluation regions for detailed cloud analysis are indicated by red boxes and are listed in the Table1.

3.2 Performance of main conditions for cloud detection

The SCDA v.1.4.2 algorithm consists of two main if conditions for cloud detection. In the cloud processing the two conditions are combined by a logical OR. In this section we investigate the contribution of the two conditions for the overall cloud mask.

Table 2: Fraction of cloud coverage on the imaged area and the contribution of the first and second if condition to the overall cloud mask

Region	***Date***	***Cloud-Mask: FIC + SIC [%]***	***Classified by FIC [%]***	***Classified by SIC [%]***
NA	*25.05.2003*	*51,65*	*51,52*	*0,13*
NA	*28.04.2003*	*25,22*	*25,10*	*0,12*
NA	*28.02.2003*	*56,60*	*53,59*	*3,01*
EW	*25.05.2003*	*47,93*	*47,87*	*0,05*
EW	*28.04.2003*	*52,84*	*52,83*	*0,01*
EW	*28.02.2003*	*57,90*	*57,51*	*0,39*
EA	*25.05.2003*	*62,27*	*61,89*	*0,38*
EA	*28.04.2003*	*55,49*	*55,48*	*0,02*
EA	*28.02.2003*	*33,54*	*28,53*	*5,01*

Clouds could either be detected by the First If Condition (FIC) or by the Second If Condition (SIC). The detection of the clouds by both if conditions, is not possible as they are applied mutually exclusive (see Figure 1). The analysis of this limited data set shows:

- The FIC is the main contributor to the SCDA v.1.4.2 cloud mask
- The SIC is more effective during winter periods than during spring and early summer

3.3 Visual evaluation of cloud mapping performance

In this section we summarize the results of the visual evaluation of the SCDA cloud mapping algorithm. The SCDA v.1.4.2 is a slightly modified version of the SCDA v.1.4.1 (the threshold for the NDSI has increased to 0.69 in the v.1.4.2). For 28 February 2003 we also compare the SCDA algorithms with the cloud product of MODIS, which was acquired close in time to the AATSR data. For the other evaluation dates MODIS was acquired with a time difference of about 1.5 hours, and a direct comparison seemed therefore not to be suitable.

28 February 2003

The following sites are evaluated for 28 February 2003:

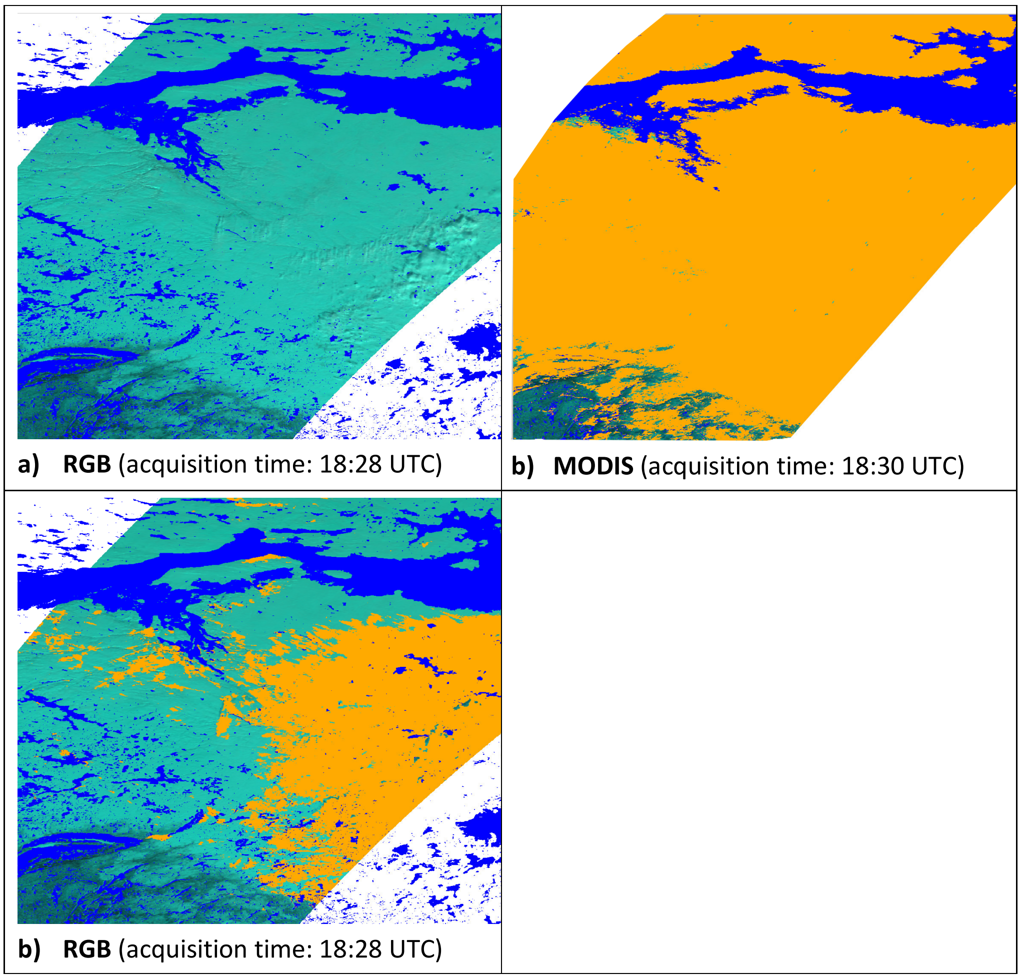
- Northwest Territories, Nunavut (CA) (1)
- Alberta, British Colombia (CA) (2)
- Buryatia, Irkutsk (RU) (3)

Northwest Territories, Nunavut (CA)

The evaluation site is located at 61°N to 70°N latitude and covers parts of the North West Territories and Nunavut, Canada. The elevation ranges from sea level up to approximately 500 m. The site is covered by boreal areas in the southern part and shows sparsely vegetated surfaces in the northern part. The AATSR scene shows the presence of a few cumuli clouds in the eastern part of the image. Most probably thin cirrus clouds are stretching over the scene, but they can hardly be detected in the RGB AATSR image.

Figure 4 shows the multispectral AATSR image, the cloud mask product from SCDA v.1.4.2 and the corresponding MODIS cloud product. The figure shows that

- MODIS overestimates cloud cover
- Cloud shadows are not detected by the SCDA v.1.4.2



a) RGB (acquisition time: 18:28 UTC)

b) MODIS (acquisition time: 18:30 UTC)

b) RGB (acquisition time: 18:28 UTC)

Figure 4: Comparison of different cloud masks for Northwest Territories, Nunavut (CA) on 28 February 2003. a) AATSR RGB composite (1600 – 670 – 550), b) MODIS cloud mask, c) SCDA v.1.4.2

Figure 5 shows a comparison of the SCDA v.1.4.2 and v.1.4.1. The difference between the two algorithms is an adapted threshold for the NDSI test in the FIC. For v.1.4.2 the NDSI threshold was increased to a value of 0.69. This has the effect that the cloud detection over snow-covered areas is improved.

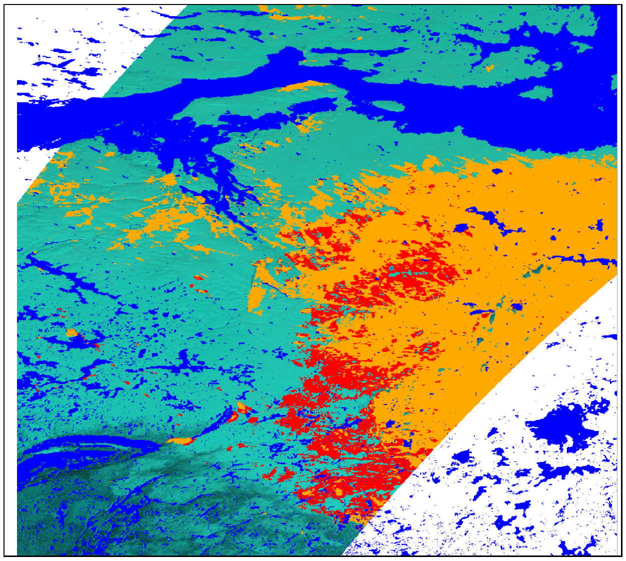


Figure 5: a) Northwest Territories, Nunavut (CA) on 28 February 2003. SCDA v.1.4.1 (orange) and SCDA v.1.4.2 (red and orange)

Changing the NDSI threshold from 0.65 to 0.69, leads to an increase of the cloud mask. This adaptation was made to improve the detection of cold cloud tops which might also occur at high elevations in southern regions. The resulting cloud mask product is better suited for snow mapping than creating a patchy cloud mask in the south where snow will be classified.

Alberta, British Columbia (CA)

This site covers parts of Alberta and British Colombia located at 47°N–56°N latitude. The elevation ranges from 300 m in the northeast to over 2500 m in the Rocky Mountains. The area is predominately covered by mountains and forested areas. The AATSR scene shows a mixture of lower cumulus clouds, mid altitude stratus and higher cirrus clouds.

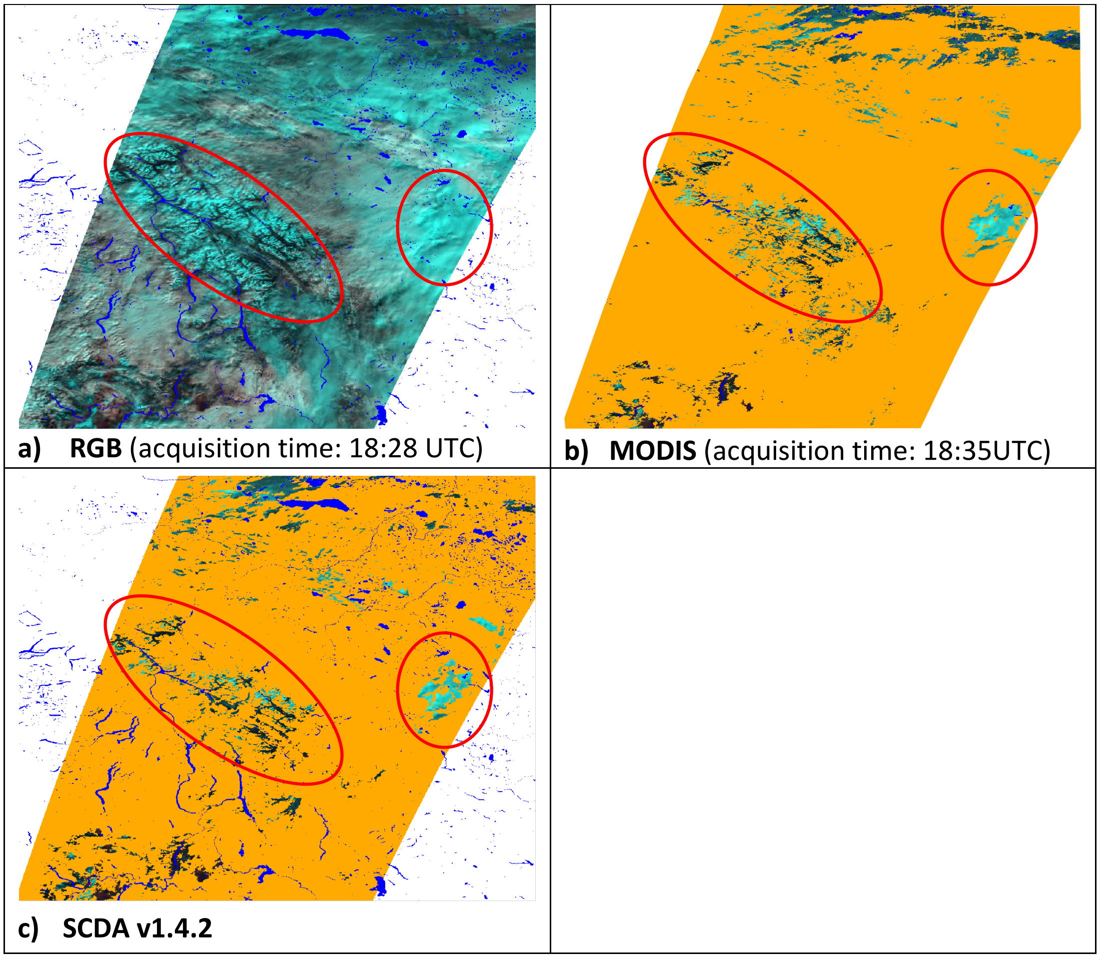


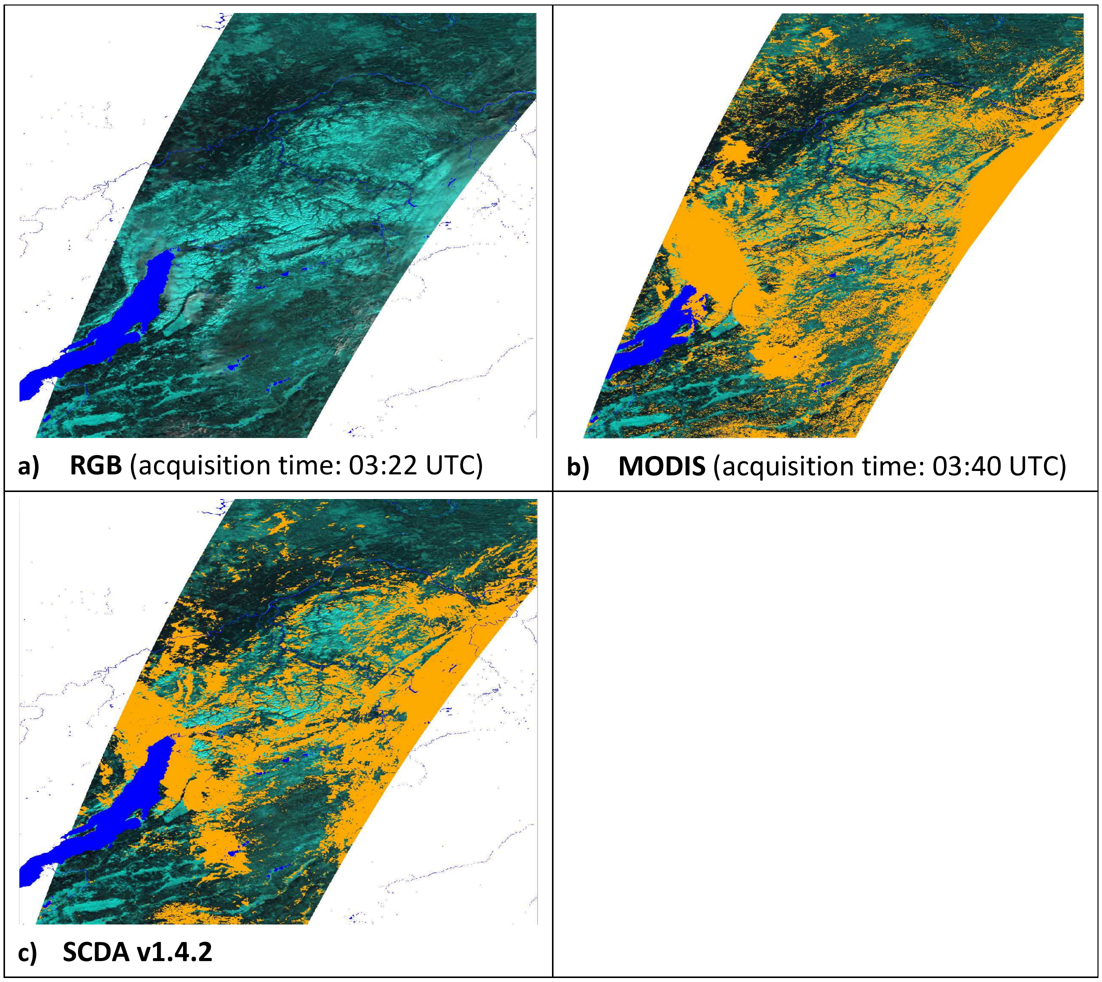
Figure 6: Comparison of different cloud masks for Alberta, British Columbia on 28 February 2003. a) AATSR RGB composite (1600 – 670 – 550), b) MODIS cloud mask, c) SCDA v.1.4.2

From Figure 6 it is concluded:

- Cloud cover is overestimated by SCDA algorithms and MODIS algorithms
- Mixed pixels are classified as clouds by all three algorithms
- Cold cloud tops are not well detected
- Cloud shadows are mostly not classified as clouds, especially by the SCDA v.1.4.2 and the MODIS cloud product

Buryatia, Irkutsk (RU)

This evaluation site covers parts of Siberia (50°N–62°N). Mountains up to an elevation of over 2000 m are stretching from the Baikal Sea to the east. North and south of these mountains the site is covered by boreal forests. This scene is partly covered by thin cirrus clouds.



a) RGB (acquisition time: 03:22 UTC)

b) MODIS (acquisition time: 03:40 UTC)

c) SCDA v1.4.2

Figure 7: Comparison of different cloud masks for Buryatia, Irkutsk (RU) on 28 February 2003. a) AATSR RGB composite (1600 – 670 – 550), b) MODIS cloud mask, c) SCDA v.1.4.2

Figure 7 shows:

- Overestimation of the cloud cover
- MODIS cloud product and the SCDA v.1.4.2 cloud mask are similar. The MODIS cloud product detects only slightly more clouds over snow-covered mountainous regions.

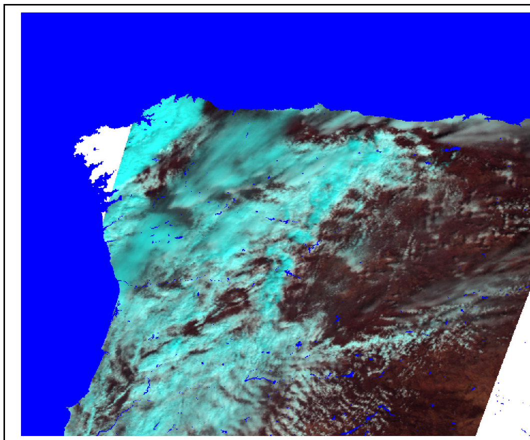
28 April 2003

The 28 April 2003 scene was selected as it represents a typical spring condition in mid latitudes, while at northern latitudes winter is still dominating. The following sites, located in southern, mid and higher latitudes, are used for the evaluation:

- Spain (4)
- Georgia (5)
- Kazakhstan, Russia (6)
- Magadan, Chukotka (RUS) (7)

Spain

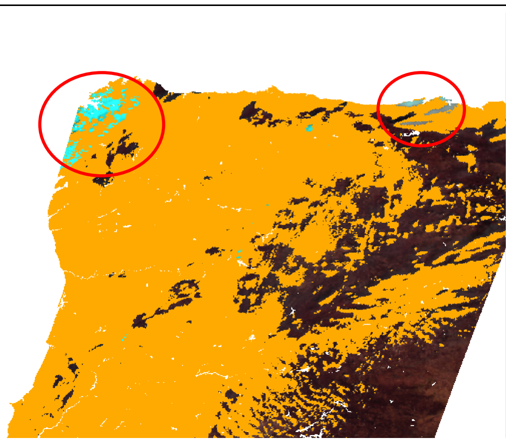
This area shows parts of Spain and Portugal (38°N–44°N). The vegetation in Spain varies from rich grassy meadows in the north to rocky desert or barren steppes in the central part of the test site. Cirrus cumulus is visible in the southern parts and cumulus clouds with a lower cloud base in the north-western part of the scene.



a) RGB

No MODIS data at the same time available

b) MODIS



c) SCDA v1.4.2

Figure 8: Comparison of different cloud masks Spain on 28 April 2003. a) AATSR RGB composite, b) MODIS cloud mask, c) SCDA v.1.4.2

Figure 8 compares the cloud masks from the algorithms. The performance of SCDA v.1.4.2 is quite good. Differences between the two algorithms are found in small areas, predominately related to cloud tops with cold temperatures. The comparison and the investigation of the tests show:

- Cold clouds in the western part of the image are not detected as clouds in the SCDA v.1.4.2.
- SCDA v.1.4.2 fails to detect cold cloud tops. The SCDA v.1.4.2 due to the considerable high NDSI index (> 0.69) in the FIC.
- The SCDA v.1.4.2 generates a cloud mask where also some pixels with considerable low NDSI values were not classified as cloudy pixels (in the north-eastern part of the scene). On closer inspection, this failure is found to be caused by the 12 µm channel. The brightness temperature in this channel was set to its maximum value of 318 K due to the given value of '-1' that denotes a saturated pixel. In this case we recognized that all neighboured pixels show a very low value in the 12 µm channel (around 207 K) indicating that the '-1' value is because of no data in this channel caused by too low brightness temperature. This leads to failure in the test (BT_12 < 287 K) in the FIC.

Georgia

The site is located between 35°N and 44°N. It is mainly dominated by forests, crop land and mountainous areas, where deciduous forests dominate at lower elevations and coniferous forests are predominately found at higher altitudes. The scene shows a mixture of lower cumulus clouds and higher cirrus clouds.

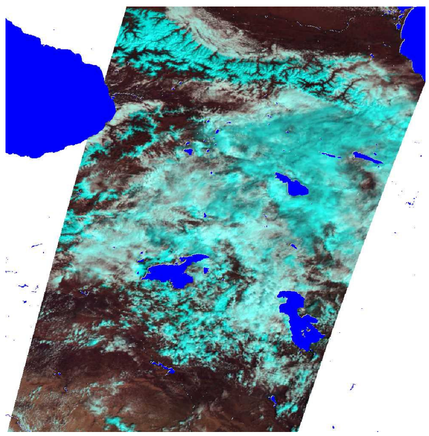
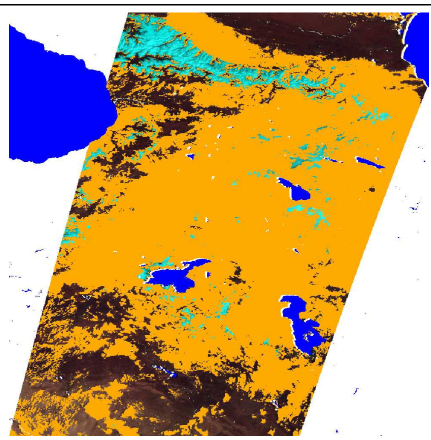
 a) **RGB**	No MODIS data at the same time available b) **MODIS**
 c) **SCDA v1.4.2**	

Figure 9: Comparison of different cloud masks for Georgia on 28 February 2003. a) AATSR RGB composite (1600 – 670 – 550), b) MODIS cloud mask, c) SCDA v.1.4.2

For this site SCDA v.1.4.2 shows good results (Figure 9). Looking closer it seems that SCDA v.1.4.2 shows a slightly better performance.

Kazakhstan and Russia

This site is located between 48°N and 59°N. It is mainly dominated by crop land with some patches of forests. The test site is flat terrain with elevations not exceeding approximately 200 m. The scene shows a mixture of lower cumulus clouds in the south west and higher cirrus clouds in the north-eastern part of the image.

The SCDA v.1.4.2 performs well and shows a good cloud mask.

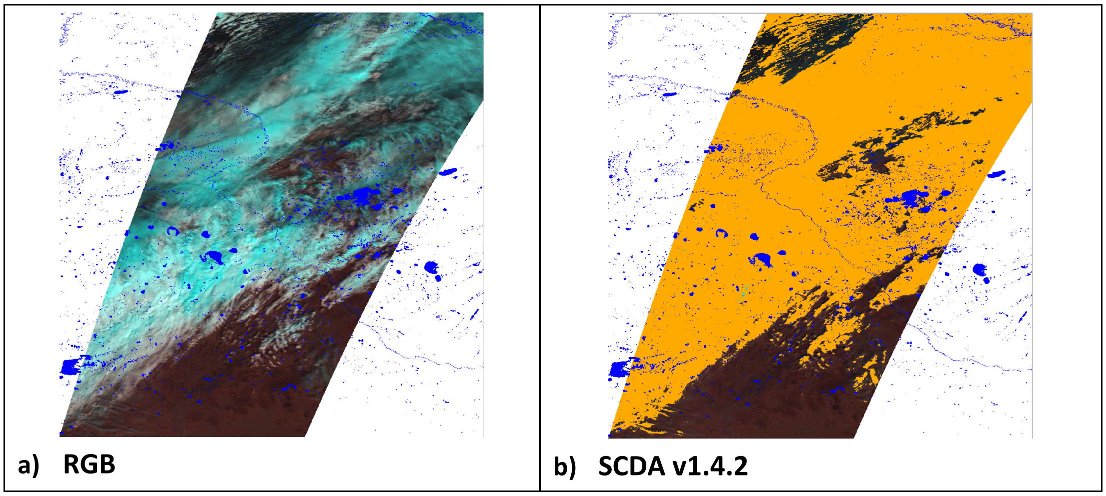


Figure 10: a) AATSR RGB composite (1600 – 670 – 550), and b) SCDA v.1.4.2 cloud mask for Kazakhstan and Russia on 28 April 2003

Magadan and Chukotka (Russia)

This test site is located between 58°N and 71°N. It consists mainly of mountain deserts, tundra and taiga. Large areas in the northern part of this scene are covered by higher cirrus clouds whereas in the southern part additional lower elevated cumuli clouds are present.

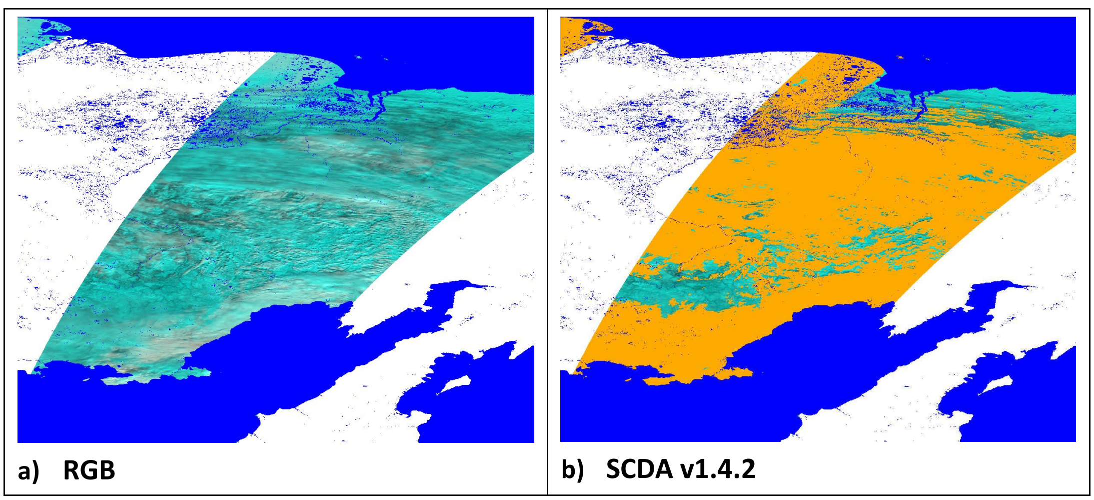


Figure 11: a) AATSR RGB composite (1600 – 670 – 550) and b) SCDA 1.4.2 cloud mask for Magadan and Chukotka (Russia) on 28 April 2003

The distinction between cloud-free snow-covered areas and clouds is very well performed by the SCDA v.1.4.2.

25 May 2003

Following sites are evaluated for 25 May 2003:

- Algeria (8)
- Pakistan, Tibet and China (9)

Algeria

The test site Algeria covers mountainous regions predominately without vegetation south of the Mediterranean coast, and parts of the Sahara desert on the southern slope of the mountain range.

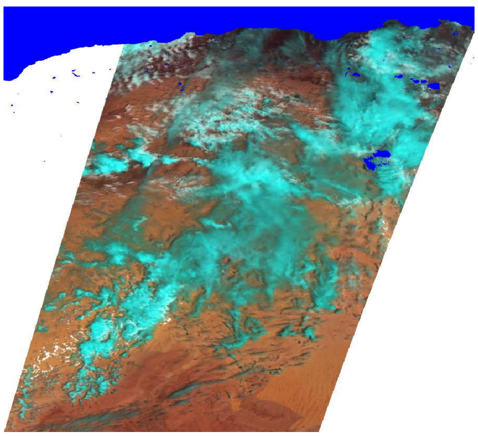
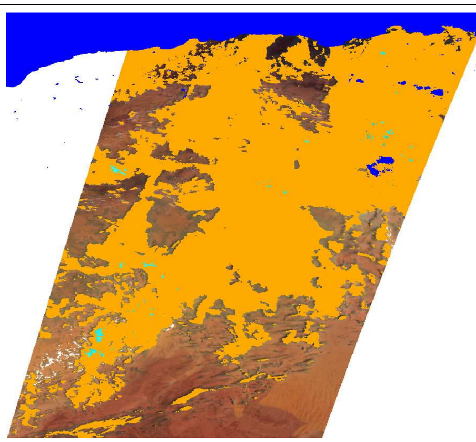
 **a) RGB**	No MODIS data at the same time available **b) MODIS**
 **c) SCDA v1.4.2**	

Figure 12: Comparison of different cloud masks for Algeria on 25 May 2003. a) AATSR RGB composite (1600 – 670 – 550), b) MODIS cloud mask, c) SCDA v.1.4.2

Pakistan, Tibet and China

This evaluation site covers parts of Pakistan, Tibet and China (28°N–38°N). The surface is sparsely vegetated, caused by the high elevations. Elevation in this scene varies from 200 m up to over 8000 m in the Himalayan Mountains. Lower cumulus clouds are visible in the south and cirrus clouds over the mountains. Apart from that the scene is nearly cloud-free.

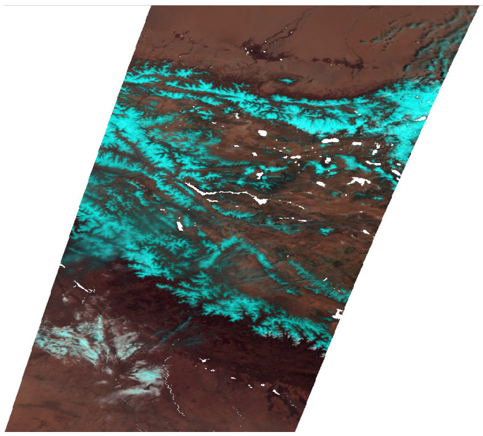
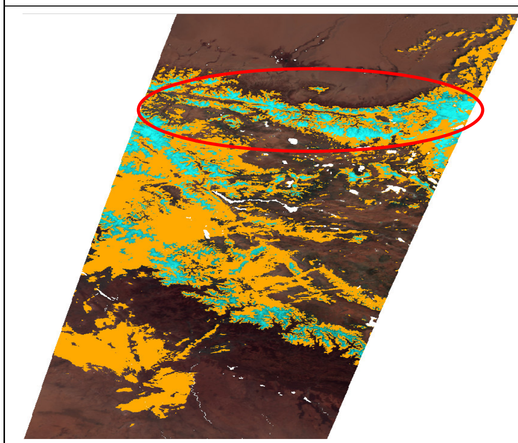
 **a) RGB**	No MODIS data at the same time available **b) MODIS**
 **c) SCDA v1.4.2**	

Figure 13: Comparison of different cloud masks for Pakistan, Tibet and China on 25 May 2003. a) AATSR RGB composite (1600 – 670 – 550), b) MODIS cloud mask, c) SCDA v.1.4.2

The main problem visible here is that mixed pixels along the snow line are detected as clouds. Apart from this, the clouds including cirrus clouds are well detected by the SCDA algorithm.

4 SUMMARY AND CONCLUSIONS

A simple cloud detection algorithm for AATSR (and ATSR-2) data was developed for snow extent mapping purposes in GlobSnow project. The global scale of GlobSnow target area covering different climatic/vegetation zones and at the same time, the demand of low computational costs constricted the approach to a simple feature-based thresholding. The principle rule for cloud/no cloud judgement, however, is locally adaptive: the threshold for difference BT11−BT3.7 varies according to local temperature. The varying threshold was found necessary in order to avoid false identification of clouds over very cold snow surfaces.

Based on the visual comparison of the SCDA cloud mask v.1.4.2 with colour composite AATSR images on a global domain, the main findings can be summarized as:

- The FIC (first if condition) of the SCDA v.1.4.2 is the main cloud classifier in the SCDA v.1.4.2:
  - The dynamical threshold for the difference between the brightness temperatures in the 11 µm and the 3.7 µm channel is an effective way to reduce cloud cover over very cold snow-covered surfaces
  - The adjustment of the NDSI thresholds in SCDA v.1.4.2 in comparison to previous SCDA versions improves the cold cloud-top detection
  - In order to get better detection of high and cold cloud tops, data from other sources could be used, e.g. surface temperature maps as provided by numerical weather models or satellite data (like 8-day mosaics from MODIS data)
  - The use of the maximum value for a band in the case of saturation proved to be a good solution to extend the area covered (these areas were masked out previously)
- SCDA v.1.4.2 does not completely detect high, cold cloud tops due to different reasons. The FIC fails due to NDSI values higher than 0.69
- In certain cases SCDA version 1.4.2 detects clouds along the snow line, probably caused by mixed pixels.

Overall, the evaluation results reveal that SCDA v.1.4.2 represents an improvement when compared to previous SCDA versions. SCDA v.1.4.2 provides a predominately reasonable cloud mask for most surfaces, and is also suitable for an operational environment due to the low computational costs. The misbehaviour described above will cause some false detection in the cloud mask only for small areas.

5 OUTLOOK

For global snow mapping a robust algorithm for discriminating clouds and snow is essential. The current algorithm is a reasonable approach which was implemented and validated within the GlobSnow project. In order to improve the algorithm a few items have been identified. Possible improvements are:

- Use of texture information in cloud detection which is based on the fact that clouds show less spatial variation in albedo than snow covered areas. Texture information could help to reduce the problem of cloud misclassification along the snow boundaries (to be tested). (Figure 14.)

- Improving the detection of cold cloud tops using the brightness temperature at TB(12 µm) by applying a seasonal and regional dependent threshold.

- Improvement the detection of clouds over very cold surfaces by using surface temperatures from other sources (e.g. numerical weather models).

- Spatial filtering of cloud mask, targeting at covering the mixed pixels (cloud edges) not identified by actual cloud detection rules. In practice this mean filling the small holes and expanding the edges of cloud masks.

It was decided to apply the current AATSR SCDA 1.4.2 Algorithm for GlobSnow-1, as it provides reasonable results over most regions. Additionally the CCI CLOUD project was contacted in order to present the requirements for an advanced algorithm detection of clouds especially in snow covered areas. Dr. Hollmann (German Weather Service) was informed by the GlobSnow team on the requirements for a global cloud mapping algorithm for application in snow mapping. The advancements and experiences achieved especially in cloud snow discrimination using AATSR data are shared with the CCI CLOUD team.

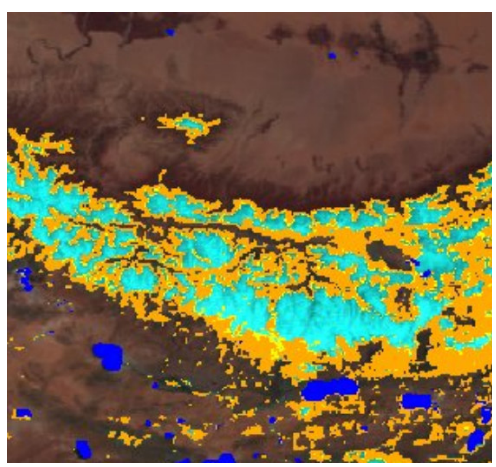


Figure 14: Cloud masks (SCDA v.1.4.2) for Pakistan, Tibet and China on 25 May 2003. Cloud misclassification along the snowline is visible.