A NEW GLOBAL SNOW EXTENT PRODUCT

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ABSTRACT

One of the goals of the ESA project GlobSnow is to develop a global product and a near-real-time service for Snow Extent (SE) and carry out snow mapping of the whole seasonally snow-covered Earth for the years 1995–2010 based on the optical sensors ERS-2 ATSR-2 and Envisat AATSR data. A laboratory processing chain has been developed for testing and improving SE products in an iterative process based on a dialogue with a user group. The final version of the laboratory processing chain will function as a reference system for the implementation of an operational system for production of the full time series of products as well as near-real-time products produced on a daily basis. The first version of the global SE product set spanning 15 years is expected to be ready by the end of 2010 and will be made freely available.

1. INTRODUCTION

The snow cover has a substantial impact on the interaction processes between the atmosphere and the surface, thus the knowledge of snow variables is important in climatology, weather forecasting and hydrology. In mountainous areas and at high latitudes, snowfall is a substantial part of the overall precipitation. However, the seasonal snow cover is practically limited to the northern hemisphere with an average extent during the winter months ranging from 30 to 40 million km^2. Variations of the snow cover at daily-to-seasonal time scales are superimposed on long-term trends which have been observed during the last decades and are attributed to climate change [1, 2].

The European Space Agency (ESA) Data User Element (DUE) GlobSnow project develops time series of Snow Extent (SE) and Snow Water Equivalent (SWE) products. The project started in late 2008 and is to be completed by the end of 2011.

The goal of the GlobSnow project is eventually to produce SE products for the whole seasonally snow covered Earth for the years 1995–2010. The global and final SE product set spanning 15 years is expected to be produced in the autumn of 2010 and will be made freely available.

The SE processing system applies optical measurements in the visual-to-thermal part of the electromagnetic spectrum acquired by the ERS-2 sensor ATSR-2 and the Envisat sensor AATSR. The snow cover information is retrieved by two algorithms, one for high-mountain areas of steep topography above the tree line (NLR) and another developed for forested and open areas (SCAmod). The retrieval results from the two algorithms are merged into one product. Clouds are detected by a cloud-cover retrieval algorithm and masked out. Large water bodies (ocean and lakes) are also masked out. The resulting product is provided in a latitude-longitude grid.

2. ALGORITHMS

2.1. SCAmod

The SCAmod algorithm is based on a semi-empirical reflectance model, where reflectance from a target is expressed as a function of the snow fraction. The average generally applicable reflectance values for wet snow, forest canopy and snow-free-ground serve as model parameters. A transmissivity map provides the amount of reflected sunlight that could be observed from a satellite in forest areas. The transmissivity is an expression of the effect of forest on local reflectance observations. Fractional Snow Cover (FSC) can then be derived from observed reflectance based on the given reflectance constants and the transmissivity values. The method is described in detail in [3]. The algorithm has been developed and is intended for forested and non-forested, non-mountainous regions, particularly for the boreal forest zone and tundra belt.

The SCAmod algorithm requires generation of a prior forest canopy transmissivity map for the whole target area, which has previously been based on the use of clear-sky optical imagery acquired under full (dry) snow cover conditions. The generation of the transmissivity map thus limits the applicability of SCAmod to the regions which have at least few weeks of seasonal snow cover. The model parameters are adjustable and are currently based on image sampling and in situ spectrometer measurements [4]. To mitigate the limitation given by observing the actual transmissivity, an approach using a forest map from the GlobCover project [5] to estimate the transmissivity has been developed in GlobSnow. Currently, band 1 (555 nm) and 4 (1.6 µm) is used in the algorithm. We found that transmissivity for each GlobSnow SE grid cell can be expressed as a linear combination of class-wise statistics and the class-wise occurrence of the finer-resolution GlobCover-classified pixels falling into the SE cell.

2.2. NLR

The NLR algorithm is based on the assumption that there is a linear relationship between snow coverage and measured top-of-atmosphere (TOA) reflectance (or radiance). When this relationship is established, each pixel is classified into fractional snow cover percentage values. The relationship is established by an automatic calibration procedure using calibration targets. Populations of 100% snow covered pixels are identified and determine the reflectance for 100% snow coverage. A corresponding procedure is followed for 0% snow coverage.

The algorithm is often referred to as the Norwegian Linear-Reflectance-to-snow cover (NLR) algorithm, and is actually a two-endmember case of linear spectral unmixing. The algorithm was originally developed for analysis of NOAA AVHRR data [6], and has later been tailored to MODIS data [7]. A special version of the NLR algorithm has been developed for the GlobSnow project. Currently, band 2 is used in the algorithm (670 nm).

2.3. Cloud detection

The cloud detection algorithm is empirically developed within the project and consists of three conditions for detection of clouds. Each of the main conditions includes several tests on spectral bands or combination of spectral bands which have been fulfilled in order to classify a pixel as cloud. All seven bands are utilised.

The two first conditions use the thermal bands (1–3). The third condition includes a combination of VIS, NIR, SWIR and thermal bands, including the Normalised Difference Snow Index (NDSI) and Normalised Difference Vegetation Index (NDVI).

3. PROTOTYPE PROCESSING CHAIN

A prototype SE product processing chain has been implemented by NR into their SnowLab laboratory system based on ENVI/IDL. The prototype processing chain is a test bed for algorithm and processing improvements, and works as a reference for implementation and validation of the operational processing chain, which is currently under implementation.

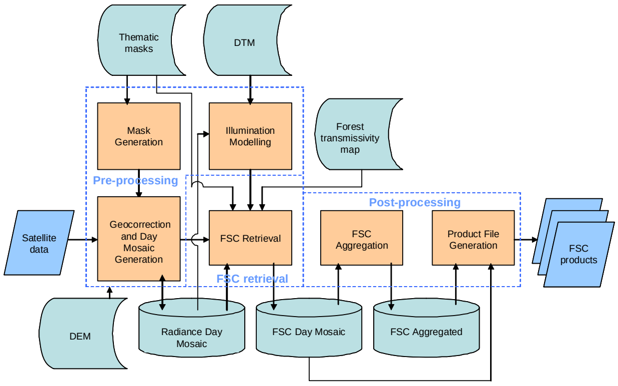

Figure 1. Conceptual model for the SE processing system

A high-level conceptual diagram of the SE processing system is given in Fig. 1. The main data elements and buildings blocks of the system are:

1. Satellite data: ATSR-2 and AATSR data as processed and delivered from the ESA
2. Pre-processing: Geometrical correction (including masking and mosaicking) and radiometrical modelling (estimation of direct solar illumination)
3. DEM: Digital Elevation Model data applied for geometrical and radiometrical correction
4. Fractional Snow Cover (FSC) retrieval: FSC retrieval algorithm including cloud masking. The algorithm chosen for a specific location is steered by logics based upon thematic masks
5. Thematic masks: Providing thematic map information, like forest, mountain, water, etc.
6. Forest transmissivity map: Applied in the SCAmod algorithm
7. Time-series aggregation: Algorithm aggregating satellite data over a period (covering about few days) in order to obtain better spatial coverage
8. Post-processing: Product generation from the FSC map and accuracy data coming from the retrieval algorithms
9. FSC and 4-classes products: Final SE products, including data on accuracy and other metadata

The processing system is tailored to ERS-2 ATSR-2 and Envisat AASTR data. The system should be suited for processing of a combination of Sentinel-3 OLCI and SLSTR data in the future.

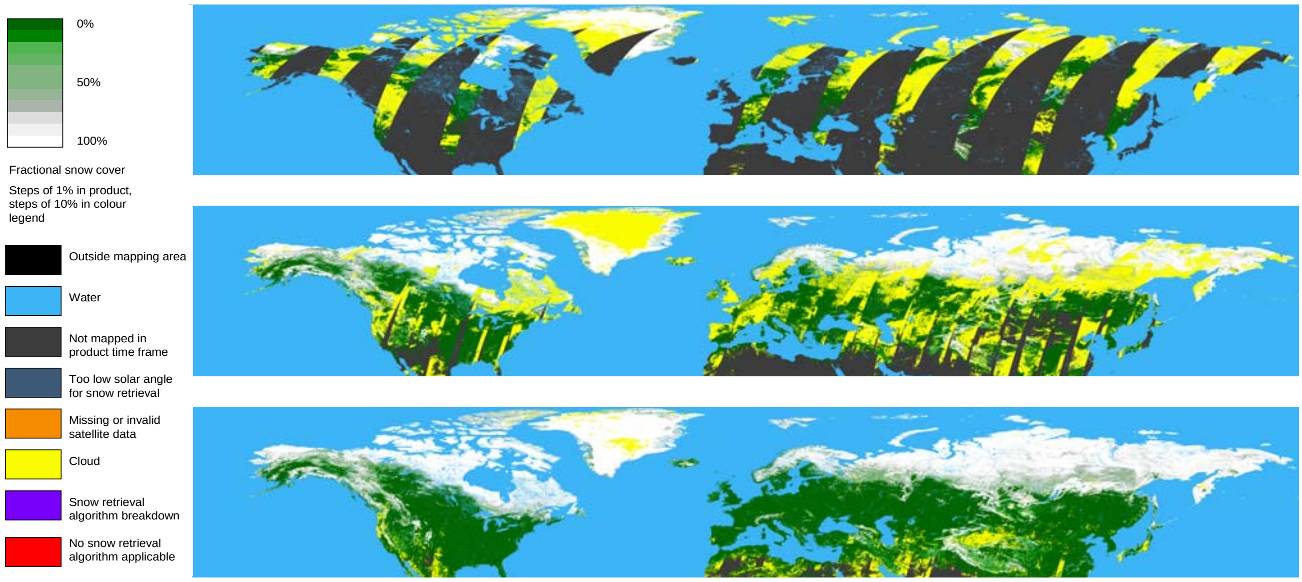

Figure 2. Product examples for the Northern Hemisphere. Top: Daily product for 31 May 2003. Middle: Weekly product covering the period 24–30 April 2003. Bottom: Monthly product for April 2003

4. PRODUCTS

4.1. Product characteristics

There are four types of SE products:

- Daily Fractional Snow Cover (DFSC), snow fraction (%) per grid cell for all satellite overpasses of a given day
- Daily classified snow cover (D4CL), snow cover classified into four categories per grid cell for all satellite overpasses of a given day
- Weekly Aggregated Fractional Snow Cover (WFSC) for all satellite passes within a week. Each snow pixel represents then most resent observation for that pixel within the given week.
- Monthly Aggregated Fractional Snow Cover (MFSC) for all satellite passes within a month. For each pixel, FSC mean, standard deviation, minimum, maximum and number of observations are provided.

The SE product coordinate system is geographical (latitude/longitude) based on the reference ellipsoid WGS 84 and with a grid resolution of 0.01 × 0.01 degrees. Currently, the Northern Hemisphere within the latitude range 25–84° is covered. There is a flag layer in the product providing information like low solar angle and band saturation. Each product is to include an estimate of the uncertainty per pixel, but this is currently not implemented.

4.2. Product examples

Three product examples are provided in Fig. 2. The top example is a day product from 31 May 2003. For this latitude range it takes about ten days to cover the entire area at least once with ATSR-2 or AATSR, so there will be gaps between paths in the day product. The weekly aggregation product (middle) for the period 24–30 April 2003 exhibits significantly better spatial coverage. Since the sensor coverage decreases towards lower latitudes, there will statistically be more clouds at lower latitudes (assuming that the likelihood of cloudiness is the same over the whole area). The 'strange' cloud pattern in the south is due to regions with least satellite coverage within the area (only one acquisition in the period resulting in high cloud frequency). The monthly product for April 2003 (bottom) shows little cloud cover as the whole area has been observed several times (from at least 3 times in the far south to 30 times in the far north).

5. EVALUATION RESULTS

A comprehensive evaluation of the prototype products has been carried out within the Europe and parts of Asia. However, the limited reference data set does not necessarily cover all natural variability worldwide. Therefore, the following results on accuracy are only preliminary. Validation work for the whole Northern Hemisphere is undergoing and will be available when the full product set is released in the autumn.

Spatial ground-truth data are close to impossible to find globally, even for a few selected sites. We have from the past good experience in using high-resolution optical data (like Landsat TM and ETM+) for estimating the actual snow cover and then comparing this with snow products based on moderate-resolution data. We have also found it valuable to compare GlobSnow SE products with products from other services (like NSIDC) on a regional scale.

Comparison with such reference data is carried out for different periods during the snow season. Of particular interest are areas covered also by high-resolution data as this will provide more objective quality information about other snow products as well. For the study using high-resolution data (Landsat TM and ETM+), test sites in different environments and at different latitudes (related to the solar zenith angle) have been selected, and data acquired at different seasons is used.

The cloud detection algorithm has also been evaluated within the same region. The algorithm is visually checked by comparing the cloud mask with the corresponding multi-spectral AATSR image in various regions and periods. Colour composites of the AATSR data is made in order to ease the interpretation. The cloud masks have also been compared with cloud masks in other products (in particular from NSIDC).

The overall results of the FSC retrieval algorithms show that for mountainous terrain in the pan-European region and FSC using the NLR algorithm, the root-mean-squared deviation (RMSD) for the summer months were typically in the interval 10-15%, while 15-25% in the winter (dark months). For forest terrain and FSC using the SCAmod algorithm, the RMSD values were typically around 25%.

The overall performance of the cloud detection is quite good. However, there is misclassification in some cases along snowlines and coastlines (probably a mixed-pixel problem). In other cases cloud detection can be patchy despite a closed cloud cover according to visual interpretation of the colour-composite image. Varying thresholds with latitude or solar zenith angle might to some degree mitigate the problem. Furthermore, cloud shadows on lower elevated clouds are not well detected.

6. CONCLUSIONS AND FURTHER WORK

One of the goals of the ESA project GlobSnow is to develop a global product and near-real-time service for Snow Extent (SE) and carry out snow mapping of the whole seasonally snow covered Earth for the years 1995–2010 based on ERS-2 ATSR-2 and Envisat AATSR data. The global and final SE product set spanning 15 years is expected to be ready by the end of 2010 and will be made freely available.

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A prototype SE product processing chain has been implemented in a laboratory environment. The chain is a test bed for algorithm and processing improvements, and works as a reference for implementation and validation of the operational processing chain, which is currently under implementation.

Prototype products have been produced for the Northern Hemisphere for one full year, 2003, using the laboratory processing chain. The results of comparison with reference data have assisted development and incremental improvement of the multi-algorithm FSC retrieval approach as well as cloud detection.

A preliminary evaluation of the prototype products has been carried out within Europe and parts of Asia. For mountainous terrain using the NLR algorithm, the root-mean-squared deviation (RMSD) of FSC for the summer months were typically in the interval 10-15%, while 15-25% in the winter (dark months). For forested terrain using the SCAmod algorithm, the FSC RMSD values were typically around 25%.

A fully working, stand alone version of the GlobSnow SE Processing System (PS) will be completed this summer. The PS is to go through an on site acceptance test at the Sodankylä ESA site operated by FMI. Following that, the PS is to be run operationally in Sodankylä for near-real-time processing. It will also be run for a period at FMI premises in Helsinki to produce the 15 years product set.

7. REFERENCES

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