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Topics of the Newsletter

Towards the Snow Water Equivalent Version 1.2 product (1979 – 2010)

Towards the Snow Extent Version 1.2 product (1995 – 2010)

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Towards the Snow Water Equivalent Version 1.2 product

The SWE Full Product Set (FPS) v1.0 dataset represents the first daily 30+ year hemispheric time-series of SWE, based primarily on EO-data, and was released by the GlobSnow consortium in October 2010. While the SWE FPS v1.0 can be considered a validated product, it still has issues and can be improved in many ways.

Several aspects concerning the consistency and overall quality of the SWE time series have been investigated after the initial release of the v1.0 dataset. The main efforts that were investigated and are to be improved for the next version of the SWE FPS time-series were:

- Derivation of standard forest cover data from the GlobCover dataset for use in SWE production
- Completion and integration of the weather station snow depth dataset for 1979 - 2010
- Evaluation of SWE time-series production using AMSR-E vs. SSM/I satellite passive microwave data
- Production and evaluation of SWE retrievals for mountainous regions

Utilization of GlobCover derived forest cover data

Based on the evaluations carried out by the GlobSnow team, it is apparent that utilizing the GlobCover derived forest cover data does not have a dramatic effect on SWE retrievals at the hemispheric scale. In general, the SWE retrievals for Eurasia are slightly decreased while for North America they are slightly increased, but in each case the difference in total continental snow mass is lower than 0.5%, as shown in Figure 1.

The assessment with in-situ reference data show similar accuracies when the previous forest cover and the GlobCover derived SWE retrievals are compared. However, utilizing a single source of forest input data for all of Northern Hemisphere improves consistency of the complete SWE time-series as both continents are treated with common forest cover data.

Completion and integration of the weather station snow depth dataset for 1979 - 2010

The consortium acquired the missing weather station-based snow depth data for North America from Dr. David Robinson of Rutgers University (New Jersey, USA). The weather station dataset, to be used for the production of SWE FPS v1.2, now covers the whole Northern Hemisphere from 1979 to 2010.

SWE time-series production using AMSR-E vs. SSMI data

Evaluations of the long-term consistency of SWE production using AMSR-E and SSM/I data showed somewhat unexpected results. There seems to be considerable differences in overall SWE retrievals when determined using input data from different sensors. It is evident that the retrievals utilizing the DMSP F13 SSM/I sensor produce higher overall SWE values when compared with those of Aqua AMSR-E. The retrievals using DMSP F 17 SSM/I sensor, on the other hand, show both higher and lower SWE values than the AMSR-E derived data. The difference is illustrated in Figure 2. The investigation of inter-sensor issues will be continued in future GlobSnow activities. The conclusion reached by the GlobSnow consortium at this stage is that the next SWE FPS (SWE FPS v1.2) will be produced using solely SSM/I data throughout 1987 – 2010. This should improve the overall consistency of the long-term dataset although the impact of the transitions between different SSM/I sensors (i.e. F8 to F11, F11 to F13 and F13 to F17) will need to be assessed. In any case, the consistent use of SSM/I data will improve consistency in sensor characteristics (such as overpass time) that can introduce uncertainties into a combined SSM/I and AMSR-E time series.

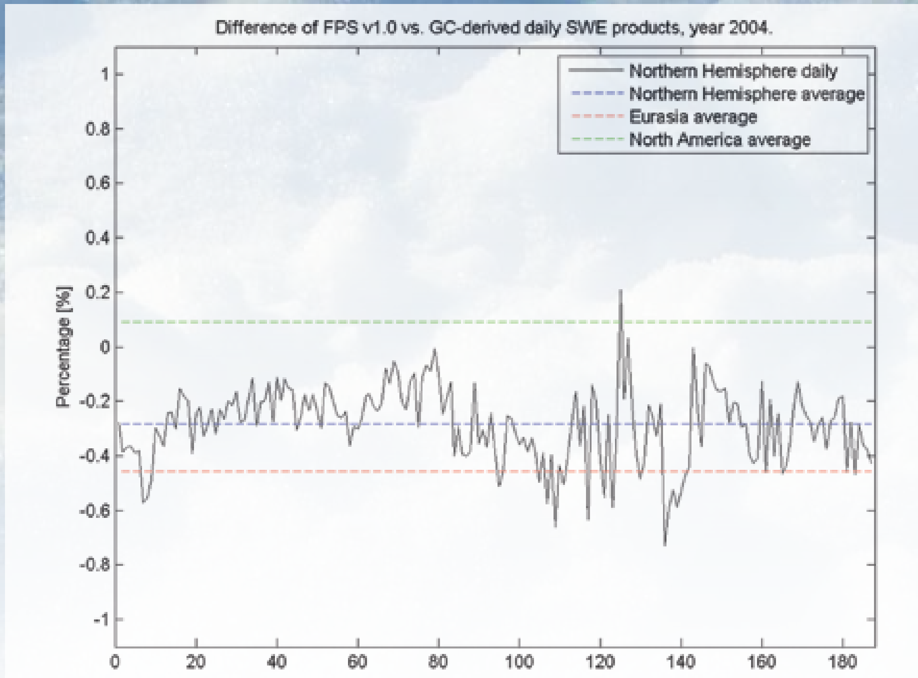

Figure 1: Daily SWE difference for the year 2004 shown between GlobCover-derived SWE and baseline SWE FPS 1.0 data with solid black line. Negative values mean that the GlobCover-derived SWE values are lower than the FPS v1.0 data. In average, the SWE retrievals for Eurasia (red dashed line) show slightly lower values, while for North America (green dashed line) they show slightly higher values, but in either case the difference in average continental snow mass is lower than 0.5 %

Production and evaluation of SWE retrievals for mountainous regions

The investigation of SWE retrievals in mountainous regions identified the challenges in providing an estimate of snow conditions for steep terrain at a coarse spatial resolution. The differences in observed snow depths within a single 25 x 25 km EASE-grid cell vary from tens of millimetres to hundreds of millimetres, as seen in Figure 3. Providing a reasonable estimate of SWE on a coarse scale, even if feasible, does not really provide additional benefit for end-users interested in mountainous regions. On the other hand, utilizing the auxiliary weather station snow depth data from mountainous regions, with typically a high positive bias on measurements when compared with those from low altitudes, would essentially deteriorate the continental scale performance of the dataset where the main focus is on non-mountainous regions. It was agreed that the next SWE FPS (SWE FPS v1.2) will not

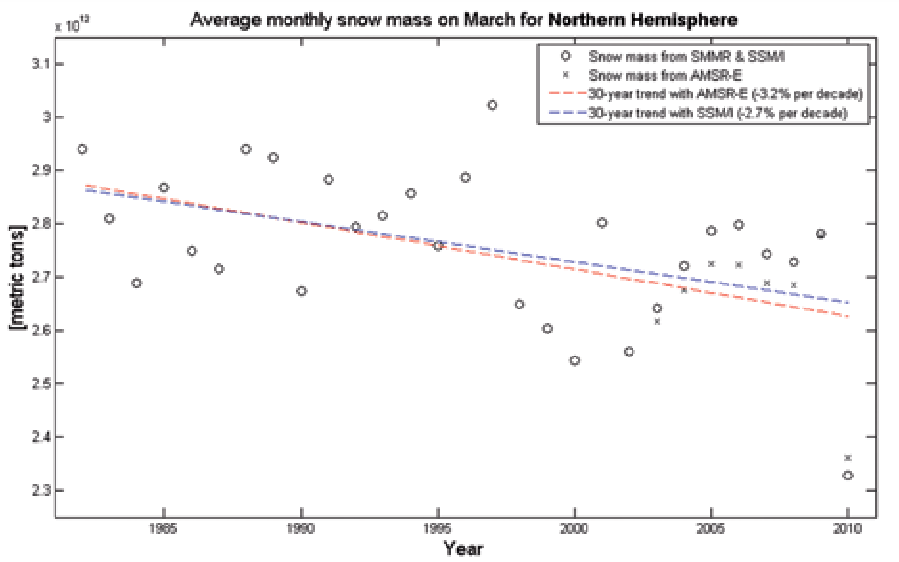

Figure 2: Average March snow mass determined from SSM/I and AMSR-E sensors (note: both time series utilize SMMR and SSM/I data until the end of 2002). The SSM/I-derived retrievals show higher snow masses for the years 2003 – 2009, but lower for the record low year of 2010 than those of AMSR-E. The linear trends derived from SSM/I and AMSR-E data show a decadal decline of -2.7% and -3.2% for average hemispherical snow mass on March.

include SWE estimates for mountains (mountains will be masked out). It was, however, proposed to investigate the creation of two different SWE datasets within the possible GlobSnow continuation project: one which excludes mountains and one which includes them.

Short- and long-term objectives

The key short term objective for the GlobSnow SWE development is the reprocessing of the SWE Full Product Set v1.2. Main modifications are 1) utilizing the DMSP SSM/I series of sensors for the whole period between 1987 to 2010, 2) utilizing the GlobCover derived forest data, 3) utilizing the now complete weather station data for 1979 – 2010. After the reprocessing, a thorough evaluation of the SWE FPS v1.2 dataset will be conducted with the same Canadian and Russian reference datasets employed for the assessment of previous GlobSnow SWE product versions.

The key tasks for long term work are related to inter-sensor investigations, continued retrieval development for mountainous regions, evaluation of the agreement of the GlobSnow SE and SWE snow extents and merging of SWE and SE products on a coarse scale, and implementation of the improved HUT snow emission model for the SWE production.

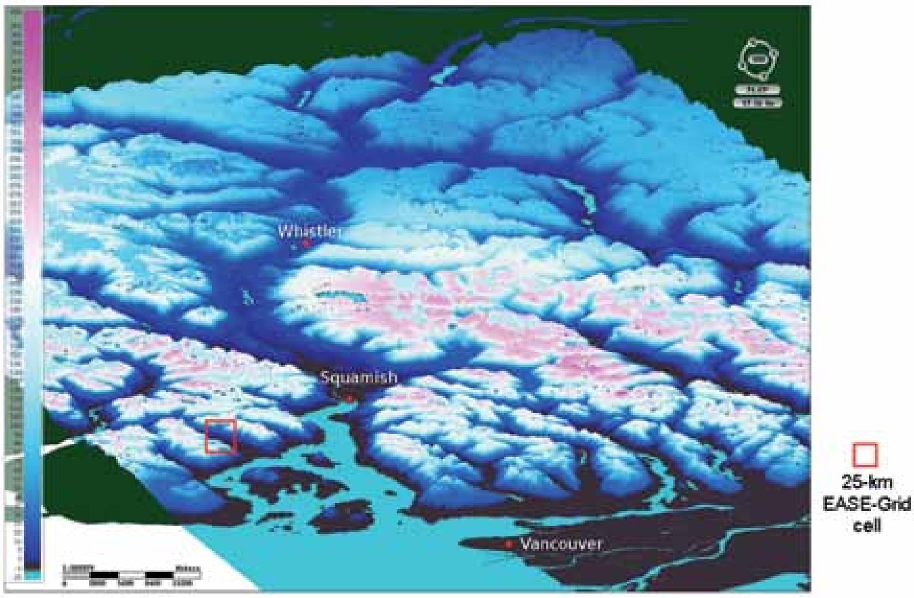

Figure 3: Illustration of the challenge in providing an estimate of snow conditions for steep terrain at a coarse spatial resolution. The differences in observed snow depths within a single 25 x 25 km EASE-grid cell (drawn as a red box on top of an assimilated snow map) vary from tens of millimetres to hundreds of millimetres. The example was acquired from enhanced Environment Canada monitoring and modeling activities during the 2010 Vancouver Olympics (Carrera, M., S. Belair, V. Fortin, B. Bilodeau, D. Charpentier, and I., Dore. 2010. Evaluation of snowpack simulations over the Canadian Rockies with an experimental hydrometeorological modeling system. Journal of Hydrometeorology. 11: 1123-1140.)

Towards the Snow Extent Version 1.2 Product

GlobSnow Phase 2 concluded with the Snow Extent (SE) version 1.0 product. The evaluation results of SE 1.0 revealed that the cloud detection algorithm provided a predominately reasonable cloud mask for most ground surfaces. The snow information in the SE product was evaluated against NSIDC MODIS Fractional Snow Cover (FSC) maps and Landsat TM imagery. SE mapping seems to be quite good in general, but also showed some discrepancies and was recommended for further attention by the SE team.

The GlobSnow Phase 3 work has so far mainly focussed on these overall tasks:

- Visual inspection of the SE 1.0 product time series;
- Experiments and development to improve the snow mapping performance;
- A first version of an approach to estimate the per-pixel uncertainty in the SE product.

Visual inspection of SE Version 1.0

The objective of the visual inspection work (1) was to screen products to find obvious errors and suspicious issues. The original ambition was to inspect all products for 1995, 1999, 2002-2003 and 2008-2009. However, the task showed to be extremely time consuming, so the ambition level had to be reduced. 2009 was fully screened for all product types, while products were sampled from the other years. The result documented a number of issues, many of them originating from partly missing input data (one or more channels missing), or other input data anomalies (see example in Figure 4). The findings are used to determine how to improve the product, in particular with respect to anomalies. The examples found are the basis for inclusion of more tests in the software and more extensive use of "anomaly flagging" in the product.

Mitigation algorithm transition effects

The work to improve the snow mapping performance (2) includes both short-term and long-term focus. For the short-term improvements, in particular to mitigate the sometimes visible transition zone between the two algorithms (SCAmod and NLR) used for FSC retrieval, a set of experiments have been carried out. The SCAmod algorithm ("forest algorithm"), has been tested with and without topographic terrain normalisation (based on the "C-correction" method) for mountainous regions. The results were evaluated against the MODIS FSC product (MOD10_L2) generated by NSIDC, and Landsat TM data. Based on pixel-by-pixel comparison with the MODIS product, statistical parameters like the RMSD (Root Mean Squared Deviation), bias and the correlation coeffi-

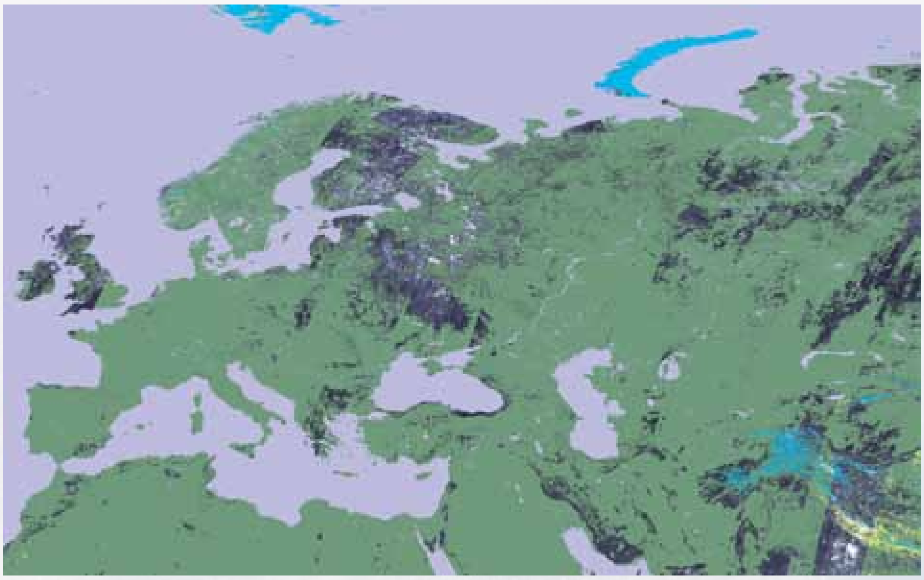

Figure 4: En example of a snow map with no cloud detection. The product is monthly FSC for August 2003. The cloud detection probably failed due to missing data channels. Such cases will be mitigated by the use of an exception class for missing and invalid input data.

cient were calculated.

The overall best results were obtained without the use of the correction. The reason is not yet understood as it is somewhat self-contradictory. It might be related to the fact that the anisotropic behaviour of the reflectance is opposite for snow and forest, while the C coefficient has been optimised for snow surfaces. It might also be related to errors in the MODIS product which has been used for comparison. It was decided to move on with another test where a snow-presence check, based on the Normalised Difference Snow Index (NDSI), is introduced in the NLR algorithm (the "mountain" algorithm) to mitigate the algorithm transition problem. If this is not working, SCAmod without topographic correction will also be used for the mountains regions as a preliminary fix.

Reduced snow retrieval uncertainty by using a bare-ground reflectance map

A more comprehensive effort to improve the SE product quality has been started. The main idea is to improve the FSC retrieval by using variable bare-ground reflectance rather than a constant, which is used today. Analysis of bare-ground reflectance variability shows that it varies from almost 0 % to more than 30 %. A wrong estimate of the bare ground reflectance may result in FSC errors as large as 15-20 %.

An algorithm has been developed for assimilation of per-pixel bare-ground reference reflectance to be used with the algorithms instead of the constant. The reflectance map is to represent conditions just after the snow season (with senescent vegetation). First results of a reflectance map for parts of the Northern Hemisphere have so far been obtained. These look promising, but seem to some degree to be hampered by lack of observations due to low coverage frequency with AATSR and frequent cloud cover in many regions. Next step is to assimilate several years of reflectance observations as to remove remains of clouds in the pixels and other uncertainty issues.

Estimating the per-pixel uncertainty in the SE product

The SE product is at some stage expected to be improved with a layer expressing the per-pixel uncertainty of the FSC estimates. A first approach, based on studies of observed variability in the products, has been carried out. Characterising the errors (or uncertainty) in a remote sensing product is usually challenging. Some algorithms allow an estimate of the uncertainty directly from the algorithm, but this uncertainty is usually based on an idealised situation. Based on this fact and that the algorithms applied for the SE product do not directly allow for uncertainty characterisation, we focused here on an empirical approach where the objective was to estimate the total uncertainty per pixel given the current observation conditions. The approach has so far been to analyse retrieved FSC when we know for certain that the FSC is 0 % or 100 %. That the actual snow cover is full or not present has been determined from visual inspection of the products and the AATSR channels, and combining in information about climatological snow cover and in situ measurements of snow depth (SYNOP).

Two large regions were selected for the analysis, a large part of Russia and a region in Canada. For 100 % FSC it was found that for low values of transmissivity the RMSE is above 25 %, whereas for high transmissivity values the RMSE is about 15 % (see Figure 6). When comparing the confidence interval we observe a high degree of uncertainty in the error estimates for low and high values of transmissivity. Performing the same analysis in the Canadian region we observe the opposite trend in general, i.e. an increasing error for increasing values of transmissivity. The magnitude of RMSE is about the same as for Russia.
Performing a similar analysis for 0 % FSC we observe that the error in general is decreasing as a function of transmissivity. We also observe that the error level is about half the level as for 100 % FSC. Due to the difficulties of finding a region with a certain FSC other than 0 % and 100 %, we propose to apply the uncertainties estimated from the 0 % and 100% certain FSC to establish a model by using interpolation, which is also a function of the FSC. This model should later be tested and refined for the whole monitoring area with seasonal snow cover in the Northern Hemisphere.
Some first analysis was also carried out for mountainous regions. This is significantly more complicated as the uncertainty also depends on the topography and solar elevation. We investigated an area in Norway with rounded mountains as to be sure that we could find observations with close to 100 % FSC. RMSE were as high as 18 % in February to as low as about 1 % in April. There was a clear relationship between the RMSE and solar elevation, which is expected for mountainous terrain. More work is needed to be carried out for mountains before an uncertainty model could be established.

Improved transmissivity map

An improved transmissivity map was developed and tested. The transmissivity map expresses the “transparency” of the forest and is used by the SCAmod algorithm. This map shows some weaknesses, in particular for very dense forest. Improvements were carried out by identifying very dense forests by 1) improving training areas and 2) modifying the methodology of calculation of the class-wise transmissivity statistics (see Figure 5). SCAmod was tested with the new transmissivity map against MODIS snow products. The results show that there is less agreement with MODIS for the new transmissivity map. This is surprising, and might potentially be related to errors in the MODIS product.

Short- and long-term tasks

The short-term objective for the SE product development is to include all feasible improvements in the new SE Version 1.2 product. As the production of this has to be started within weeks, other issues are then included in the longer-term development.

The short term tasks for SE Version 1.2) are to: 1) Mitigate the issues found under the visual inspection of the product time series; 2) Mitigate the transition effect between the two retrieval algorithms in the snow product; and 3) Use the most recent transmissivity map.

For long-term improvements, we expect to focus at: 1) Generating a bare-ground reflectance map representing conditions just after the snow season (with senescent vegetation) for the reduction of SE product uncertainty for sparsely forested, open and mountainous regions; 2) Extend the uncertainty model work to cover the largest possible non-mountainous areas for model calibration, then continue and fulfil the work on a similar model for mountainous regions which also takes into account the effects from the terrain relief and solar elevation; 3) Work towards a fused and advanced GlobSnow SE (GSSE) algorithm building on the original algorithms. This will include the use of one and the same sensor channel for snow, the bare-ground reflectance map, improved terrain normalisation of the reflectance, and smooth and consistent transition between plains and mountains (independent of forest cover).

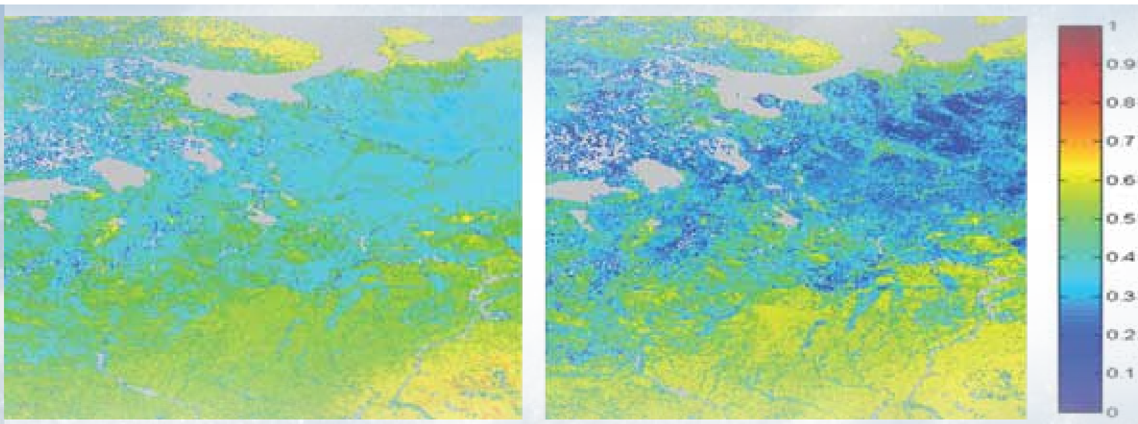

Figure 5: A sub-section of the previous version of the transmissivity map (left) and the new and improved map (right). It is clearly visible that the dense forest in the east Russia is better expressed.

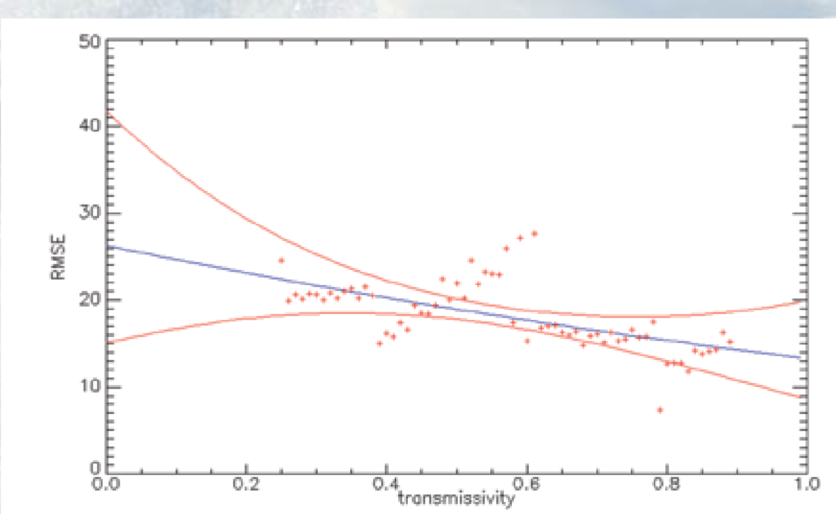

Figure 6: RMSE of the FSC as a function of transmissivity for the Russian region by aggregating March 2003, February and March 2007, and February and March 2009. Red ‘+’ is the estimated error, and the blue line is a smoothed error. Red lines indicate a 95 % CI of the smoothed error.

Project overview

The European Space Agency (ESA) funded GlobSnow project aims at creating a global database of snow parameters for climate research purposes. In addition to a historical data set comprising of 15 to 30 years of snow data an operational near-real time snow information service will be constructed. Information on two essential snow parameters: snow water equivalent (SWE) and areal snow extent (SE) will be provided. The archive and the demonstrated snow service will be based on data acquired from active and passive, optical and microwave-based spaceborne sensors combined

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