INVESTIGATING THE FEASIBILITY OF THE GLOBSNOW SNOW WATER EQUIVALENT DATA FOR CLIMATE RESEARCH PURPOSES

Kari Luojus[1,], Jouni Pulliainen[1], Chris Derksen[2], Helmut Rott[3], Thomas Nagler[3], Rune Solberg[4], Andreas Wiesmann[5], Sari Metsämäki[6], Eirik Malnes[7] and Bojan Bojkov[8]*

[1)] Finnish Meteorological Institute (FMI) Arctic Research, P.O.Box 503, Helsinki, Finland. (*e-mail: kari.luojus@fmi.fi)
[2)] Climate Processes Section, Climate Research Division, Environment Canada, 4905 Dufferin Street, Toronto, Canada
[3)] ENVEO IT GmbH, Technikerstrasse 21a, 6020 Innsbruck, Austria
[4)] Norwegian Computing Center, Gaustadalléen 23, NO-0373 Oslo, Norway
[5)] GAMMA Remote Sensing Research and Consulting AG, Worbstrasse 225, 3073 Gümligen, Switzerland
[6)] Finnish Environment Institute, P.O. Box 140, 00251 Helsinki, Finland.
[7)] NORUT, Northern Research Institute Tromsø, P. O. Box 6434, N - 9294 Tromsø, Norway
[8)] European Space Agency, ESA, ESRIN, Frascati, Italy

Abstract *- This paper presents the efforts for creating two global scale snow dataset covering 15 and 30 years of satellite-based observations. The main emphasis is on describing the validation work carried out for the snow water equivalent (SWE) product that will cover the non-mountainous regions of Northern Hemisphere on a daily basis starting from 1979. The work has been carried out within the ESA GlobSnow project.*

1. INTRODUCTION

The European Space Agency (ESA) Data User Element (DUE) funded GlobSnow project aims at creating a global database of snow parameters for climate research purposes. The main objective is to create a long term time series for two essential snow parameters. The project will provide information concerning the areal extent of snow (SE) on a global scale and snow water equivalent (SWE) for the Northern Hemisphere. Both products will include the end product derived from the satellite data along with accuracy information for each snow parameter. The temporal span of the SE product will be 15 years and the span for the SWE product will be 30 years. A key improvement of the snow products, when compared with the currently available data sets, will be the inclusion of a statistically derived accuracy estimate accompanying each SE or SWE estimate (on a pixel level).

In addition to the SE and SWE time-series, an operational near-real time (NRT) snow information service will be implemented. The service will provide daily snow maps for hydrological, meteorological, and climate research purposes. The snow products will be based on data acquired from optical and passive microwave-based spaceborne sensors combined with ground-based weather station observations. The work was initiated in November 2008, and is being coordinated by the Finnish Meteorological Institute (FMI). Other project partners involved are NR (Norwegian Computing Centre), ENVEO IT GmbH, GAMMA Remote Sensing AG, Finnish Environment Institute (SYKE), Environment Canada (EC) and Northern Research Institute (Norut).

The GlobSnow products will be based on the state-of-the-art algorithms that are thoroughly validated using an extensive ground truth database gathered from Canada, Scandinavia, Russia and the Alps. The snow products will

be generated on a daily, weekly and monthly basis for both SWE and weekly and monthly for SE. Both the historical data sets and the operational products will be made available through the GlobSnow web-based archive.

Extensive algorithm evaluation efforts were carried out for the candidate SWE and SE algorithms during 2008. The acquired evaluation results, described for the SWE product in the following chapter, have enabled the selection of the algorithms to be utilized for the GlobSnow SE and SWE products. The SWE product is derived using the FMI Algorithm and the SE product is a combination of NR and SYKE developed algorithms. Both algorithms showed enhanced estimation characteristics when compared with currently available existing products. Prototype SE and SWE products were released for user evaluation during November 2009 covering the years 2003-2008 for SWE and 2004-2006 for SE. The SWE product covers the Northern Hemisphere and the SE product is provided for Pan-European region. The data are available for all interested parties.

2. THE PRELIMINARY VALIDATION RESULTS FOR THE SWE PRODUCT

The selection of the SWE algorithm for GlobSnow project was the result of an extensive evaluation of several different algorithms for three distinct test regions over three winter seasons. The evaluated algorithms included the FMI algorithm [1], Chang algorithm [2], EC algorithms [3, 4], SPD algorithm [5] the NSIDC operational algorithm [6], and the AMSR-E standard SWE product [7]. The test sites were: 1) Northern Eurasia, including data from the years 1995 to 1997 2) Finland containing ground truth data from the years 2005 to 2008 and 3) central Canada including data from the years 2005 to 2008. The complete algorithm evaluation, including an overview of the algorithms, reference datasets, and results is presented in the GlobSnow Design Justification File [8] available via the GlobSnow website (globsnow.fmi.fi).

2.1. Results for the test region Eurasia

Table 1 shows the results acquired for the large test dataset of more than 20 000 samples for Eurasia.

Table 1. Summary of tested SWE algorithms over Eurasia, dataset of Jan. 1995- Dec. 1997.

Algorithm	***RMSE***	*bias*	*Corelation coefficient*	*Unbiased RMSE*	*Samples*
FMI algorithm	43.2 mm	-3.1 mm	0.611	43.1 mm	26063
EC algorithm	67.6 mm	-28.2 mm	0.210	61.5 mm	18109
Chang et al. 1987 (asc node) Chang et al. 1987 (desc node)	71.6 mm 70.7 mm	-8.4 mm 1.6 mm	0.011 0.029	71.1 mm 70.8 mm	26726 27521
SPD algorithm (asc node) SPD algorithm (desc node)	67.1 mm 63.9 mm	-12.7 mm -3.1 mm	0.052 0.121	65.9 mm 63.9 mm	29559 29451
Armstrong et al. 2001 (asc node) Armstrong et al. 2001 (desc node)	72.3 mm 73.7 mm	-44.1 mm -42.9 mm	0.044 0.029	57.3 mm 59.9 mm	21796 24791

The results indicate that the FMI approach was more accurate than that of the other approaches. The results were acquired using SSM/I based satellite data-derived SWE estimates in comparison with ground truth snow depth measurements conducted from Russian snow course measurement (INTAS-SCCONE snow course measurements).

It is evident from Table 1 that the Chang algorithm (and the two derivates investigated) had large RMS errors against the validation data, while the SPD algorithm performed slightly better than the EC algorithm suite in this respect. The relatively weak performance of the EC algorithm suite was expected, as it was developed originally for Canadian land cover and snowpack characteristics, and appears to be hampered by the lack of direct 10 GHz measurements from SSM/I that are utilized to retrieve SWE from AMSR-E measurements under deep snow conditions across the boreal forest [4]. In terms of bias, both the original Chang algorithm and the SPD algorithm perform relatively well when using data from SSM/I descending orbits. The overall bias value is misleading however, as a slight overestimation for shallow snow is compensated by a very large underestimation of areas with high SWE.

The FMI algorithm shows RMSE of 43.2 mm for Eurasia with the complete dataset (26063 samples). Restricting the analysis to SWE values below 150 mm, the FMI algorithm gives an RMSE of 33.5 mm (23889 samples). Other algorithms show RMS errors well beyond this. An illustration of the SWE estimation accuracy for different SWE intervals acquired using the FMI algorithm is shown in Figure 1.

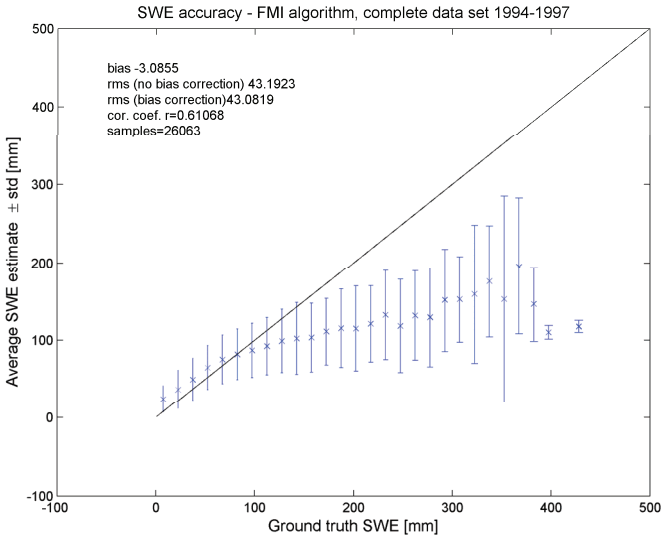

Figure 1. A visualization *of the FMI SWE estimation algorithm performance over Eurasia.*

The passive microwave SWE retrieval algorithms have a well documented tendency to systematically underestimate SWE under deep snow conditions, as also seen in Figure 1. This is due to a change in the

microwave behaviour of the snowpack (when SWE exceeds approximately 150 mm, the snowpack transitions from a scattering medium to a source of emission). The highest RMSE and bias values, and lowest correlations for all algorithms were observed for the conditions where SWE exceeds 150 mm threshold.

Similar evaluations were carried out for the Finnish and Canadian test regions. The analyses provided similar results giving a clear indication for the GlobSnow consortium to proceed with the FMI algorithm for the generation of the full long term data sets. The purpose of the team is to produce the 30 years daily SWE data set before August 2010. The long term data along with the comprehensively documented evaluation results will be made openly available for all interested parties. Additional information on the evaluations and the project can be found on the GlobSnow-website: http://globsnow.fmi.fi. Access to the data sets, the documentation and the evaluation results can be acquired by contacting the first author.

3. REFERENCES

[1] Pulliainen, J. Mapping of snow water equivalent and snow depth in boreal and sub-arctic zones by assimilating space-borne microwave radiometer data and ground-based observations. Remote Sensing of Environment. 101: 257-269.

[2] Chang, A. T. C., J. L. Foster, and Dorothy K. Hall. 1987. Nimbus-7 Derived Global Snow Cover Parameters. *Annals of Glaciology* 9: 39-44.

[3] Derksen, C. 2008. The contribution of AMSR-E 18.7 and 10.7 GHz measurements to improved boreal forest snow water equivalent retrievals. *Remote Sensing of Environment*. 112: 2700-2709.

[4] Derksen, C., A. Walker, and B. Goodison. 2003. A comparison of 18 winter seasons of in situ and passive microwave derived snow water equivalent estimates in Western Canada. *Remote Sensing of Environment* 88(3): 271-282.

[5] Aschbacher, J. 1989. Land surface studies and atmospheric effects by satellite microwave radiometry. Ph.D. dissertation, Univ. of Innsbruck.

[6] Armstrong, R.L. and Brodzik, M.J., 2001. Recent northern hemisphere snow extent: A comparison of data derived from visible and optical satellite sensors. *Geophysical Research Letter*s, vol. 28, pp. 3673-3676.

[7] Kelly, R., A. Chang, L.Tsang, and J. Foster. 2003. A prototype AMSR-E global snow area and snow depth algorithm. IEEE Transactions on Geoscience and Remote Sensing. 41(2): 230-242.

[8] Solberg, R., J. Amlien, H. Koren, B. Wangensteen, K. Luojus, J. Pulliainen, M. Takala, J. Lemmetyinen, T. Nagler, H. Rott, F. Muller, C. Derksen, S. Metsamaki, and K. Bottcher. 2009. Global Snow Monitoring for Climate Research - Design Justification File. European Space Agency Study Contract Report 21703/08/I-EC Deliverable 1.7. 246 pages.