Validation of the AFWA-NASA Blended Snow-Cover Product in Finland, 2006–2007

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ABSTRACT

Satellite and in-situ data for snow extent and snow water equivalent (SWE) are evaluated in Finland for the 2006-2007 snow season as part of a validation exercise for a recently-developed U.S. Air Force Weather Agency (AFWA) - NASA blended snow cover product. Finnish Meteorological Institute (FMI) daily weather station data and Finnish Environment Institute (SYKE) bi-monthly snow course data are used as ground truth. Early comparison results display positive agreement between the AFWA NASA Snow Algorithm (ANSA) snow extent and SWE maps and in situ data, with discrepancies in accordance with known AMSR-E and MODIS snow mapping limitations. Future ANSA product improvement plans include improved resolution and inclusion of fractional snow cover in the ANSA data product. Furthermore, the AMSR-E 19 GHz (horizontal channel) with the difference between ascending and descending satellite passes (Diurnal Amplitude Variations, DAV) will be used to detect the onset of melt, and QuikSCAT scatterometer data (14 GHz) will be used to map areas of actively melting snow.

Keywords: snow map; validation; remote sensing; Finland

INTRODUCTION

The recently developed U.S. Air Force Weather Agency (AFWA) and NASA Snow Algorithm (ANSA) blended snow cover product provides a data product with the benefit of both visible and passive microwave snow mapping capabilities (Foster et al., 2007). The Moderate-Resolution Imaging Spectroradiometer (MODIS) snow cover product (Hall & Riggs, 2007) excels in clear sky snow conditions, and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) snow water equivalent (SWE) data product (Kelly et al., 2003) permits all-weather snow mapping as it can sense snow through cloud cover. Current AMSR-E known mapping limitations occur with shallow snow cover, very cold surfaces (low brightness temperatures), as well as with increased snow crystal grain size (Foster et al., 2007). By fusing data products, complementary capabilities are combined and product limitations are reduced to provide an enhanced blended product snow map. The ANSA product provides global cloud-independent snow mapping through the entire snow season with greater accuracy than either visible or passive microwave technologies alone. Currently, the ANSA product is created in a single, global, daily, 25 km resolution map, and is available from June 2002 to the present. Additional details on the ANSA product can be found in Foster et al. (2007) and Foster et al. (in preparation).

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Further, the ANSA product provides information on snowpack ripening and snowmelt onset. QuikSCAT data will be included to provide information on actively-melting snow (Nghiem et al., 2001). Future developments to the ANSA product include delineation of wet snow areas using QuikSCAT Scatterometer data using an algorithm developed by Nghiem et al. (2001), and an algorithm to measure melt onset using a Diurnal Amplitude Variation (DAV) algorithm (Tedesco et al., 2005) which is based on the DAV technique developed by Ramage and Isacks (2002) and well-known large-amplitude snow variations in the microwave signatures of wet vs. dry snow.

Previous validation of the ANSA product has involved various locations in North America, including the Lower Great Lakes region (Hall et al., 2007) with MODIS snow product validation in the same region (Ault et al., 2006) and the Rocky Mountains (Tedesco et al., 2005). The Lower Great Lakes ANSA validation work done by Hall et al. (2007) – studying the winter of 2002 to 2003 – showed improved snow extent mapping capability with the ANSA product as compared to using either the MODIS snow extent product or the AMSR-E snow water equivalent product alone. The Cold Lands Project Experiment (CLPX) which took place in the Rocky Mountains in Colorado during the winters of 2002 and 2003, demonstrates the limitations of passive microwave snow mapping – as shallow snow at snow boundaries was missed by AMSR-E, however, detected by the MODIS snow mapping algorithm (Tedesco et al., 2005).

To extend the ANSA validation work, Finland was chosen as a validation site due to several factors, including the relatively flat topography, an extensive in-situ ground truth data network with superb spatial and temporal coverage, a long snow season, as well as a possible overlapping interest with Global Precipitation Measurement (GPM) project validation. In-situ data used for ANSA blended snow cover product validation in Finland was acquired from the Finnish Meteorological Institute (FMI) weather stations and the Finnish Environment Institute (SYKE) snow courses. Three locations in northern and central Finland were selected for daily weather station data based on available data, temporal coverage, as well as variation in land cover distribution. Snow course data were obtained for several locations throughout Finland.

STUDY AREA AND DATA

Although Finland is situated between 60° and 70° N, its climate is more moderate than many locations of similar latitude such as southern Greenland and southern Alaska due to the Atlantic Gulf Stream thermohaline ocean circulation pattern. Nevertheless, high latitude atmospheric circulation patterns affect the region (Kondratyev, 1996) and can produce drastic storms and rapid climatic changes that are distinct to areas where polar and tropical air masses intersect. Further, Finland displays both maritime and continental climate characteristics due to the many surrounding bodies of water (Baltic Sea, Barents Sea, Gulf of Bothnia, Gulf of Finland) and land features (Scandinavian Keel mountain range, southern Finland lake district) (FMI website, "Finland's Climate," 2008). In regards to terrain, Finland is characterized by having relatively little changes in relief. Only in the extreme northern reaches do elevations exceed 1,000 m.

Typical winter precipitation in Finland is moderate, with several tens of millimeters of rain and several tens of centimeters of snow per month. (FMI website, "Finland's Climate," 2008; Koistinen, 2005) The Finnish snow season typically averages 100-220 snow days per year and from 20 to 110 centimeters of snow depth (Koistinen, 2005). The 2006-2007 snow season displayed less than average snow extent; the 2006 year is on record as one of the warmest, with the mildest winter since climate records began in the early 1900's. (FMI website, "A record mild December ended an unusually warm year 2006," 2008)

Generally, the land cover in Finland consists largely of boreal forest with Norwegian Spruce and Scotch Pine, as well as agricultural and water covered land (Hallikainen et al., 2003). Forest density increases from north to south; the northern boreal forests contain more sparse forest cover with more open land – typically characterized by bogs (Hallikainen et al., 2002; Luojus, et al., 2007). Scotch Pine forests dominate Norwegian Spruce in the northern areas of Finland (Hallikainen et al., 2000).

In-situ Data: Daily Snow Cover, Snow Depth

In-situ data were provided by FMI (http://www.fmi.fi) for 9 weather stations from three areas in Finland: Sodankylä, Taivalkoski, and Kärsämäki (Figure 1), daily, from 1 October 2006 thru 31 May 2007. Finland validation test sites were selected based on available in-situ snow data as well as variation in land cover distribution. The three southern FMI weather stations near Kärsämäki, could be potentially tied in with GPM validation (restricted to the southern most stations only due to the GPM mission's 65-degree inclination orbit). In the mid-to-high latitude Finland weather stations, from the Finnish National Land Survey, percent forest, agricultural land and water changes by approximately 94%, 1%, 5%, Sodankylä; 88%, 1%, 11%, Taivalkoski; and 56%, 41%, 3%, Kärsämäki as determined by Finnish National Land Survey data per Hallikainen et al., 2003.

The daily FMI weather station data parameters include: snow depth, state of ground, precipitation and cloud cover information. The state-of-ground parameter provides detailed information on the snow cover present in the vicinity of the station (e.g. dry or wet snow, snow at station or snow in surrounding areas, and the presence of ice or water/ponds). Additionally, the weather station data are not automated; the station data include daily manual observations.

Table 1. List of 9 Finnish Meteorological Institute daily weather data stations used in this study.

Station ID (LPNN)	Station Name	Latitude	Longitude	Elevation (m)
8405	Kittilä Tepsa	67°33'	25°41'	205
7707	Savukoski Värriö	67°28'	28°00'	220
7501	Sodankylä	67°22'	26°37'	179
6707	Taivalkoski Paloasema	65°34'	28°14'	203
6704	Taivalkoski Inget	65°44'	28°33'	248
6702	Kuusamo Maanselkä Kurkijärvi	65°56'	28°58'	310
4506	Pyhäjärvi Ol Lohvanperä	63°46'	26°05'	160
4407	Kärsämäki Venetpalo	63°53'	25°47'	120
4405	Haapajärvi Välioja Nokkous	63°45'	25°28'	130

From the FMI daily data, precipitation (rainfall) was mapped at the 9 field stations over the 2006-2007 snow season (Figure 2). Rainfall maximums occurred in October, December and May, with minimums in February and April. Although the amount of rainfall varied among the 9 field stations throughout the season, the seasonal pattern at each station is generally consistent among the 9 stations.

In-situ data: SWE snow courses

A typical SYKE snow course is an approximately 2-4 km long trail, spanning various types of terrain that are characteristic of the location. At approximately 80 locations along the snow course, snow depth measurements are made and averaged based on terrain classification. From the snow depth and snow density measurements, and the number of observations made, SWE is calculated for 6 snow course environment classifications (open area, forest opening, pine dominating forest, spruce dominating forest, deciduous dominating forest and open bog). These extensive measurement sets are made once or twice per month, with data extending back to 1946. For further snow course information, please see the SYKE website at http://www.environment.fi. Several snow course measurements from the 2006-2007 season throughout Finland were obtained. However, snow course data were not available at all stations and all time periods in the winter

2006 – 2007 season. Snow course data were provided for the majority of the 2006-2007 season in the Sodankylä area.

RESULTS

ANSA snow extent comparison

MODIS collection 5 snow cover data were used to create the October 2006 – May 2007 ANSA maps used in this study. ANSA and FMI snow extent data at each of the 9 FMI stations at 15 day intervals are compared. For the purpose of ANSA and in-situ data snow extent comparisons, the ANSA categories are compared via the thematic option of the ANSA snow product – "snow" or "no snow." "Snow" contained values reporting snow with both AMSR-E and MODIS data; similarly "no snow" contained values with neither AMSR-E nor MODIS reporting snow. Results of the snow extent comparison are presented in Figure 3. In general, the ANSA and in-situ snow extent data agreed well at the 9 stations throughout the Finnish snow season. Known product benefits and weaknesses are evident – including excellent agreement in the mid to late season when both MODIS and AMSR-E data are available, and decreased agreement in periods of darkness when no MODIS input data are available (late December, January). Additionally, when there is shallow snow cover and it is cloudy, when MODIS data are not available, shallow snow cover is often missed. This is a known AMSR-E snow mapping limitation.

AMSR-E SWE comparison

The comparison of AMSR-E derived SWE data corresponding with mid-month SWE snow course measurements at the Sodankylä Observatory are displayed in the AMSR-E Scandinavian SWE maps (Figure 4a) and the AMSR-E SWE / SYKE snow course SWE histogram plot (Figure 4b). The AMSR-E SWE maps display relatively low SWE values in the beginning of the 2006-2007 winter, with a progression of higher values through mid-season, and the expected SWE decline at the end of the season. For the AMSR-E SWE/ snow course SWE histogram comparison, the terrain category "pine dominating forest" was selected as the snow course environment for the histogram comparison based on forest species description presented in Hallikainen et al. (2000).

There is general agreement between the AMSR-E and snow course SWE measurements, with greater SWE measurement differences observed in February and March than the other months (November, December, January). As this was the first set of comparisons completed, as well as the only set of data currently available at one location throughout a large portion of the snow season, further SWE comparisons are needed. Nevertheless, known AMSR-E SWE mapping issues that may explain the deviations – including possible shallow snow cover, cold surfaces, or increased snow crystal grain size typical of the end of season snow.

FUTURE DIRECTIONS

Early results show good general agreement between the ANSA and in situ data. Future ANSA product improvement plans include a 5-km improved resolution global product as well as inclusion of fractional snow cover (from MODIS). Further, the AMSR-E 19 GHz (horizontal channel) with the difference between ascending and descending satellite passes will be used to detect the onset of melt, and QuikSCAT scatterometer data (14 GHz) will be used to map areas of actively melting snow.

Future work may also include collaboration with the Go North! educational outreach team (**www.polarhusky.com**). Scandinavia was the focus of their 2008 field work. The extensive field data gathered on their expeditions could prove beneficial to snow validation studies.

FIGURES

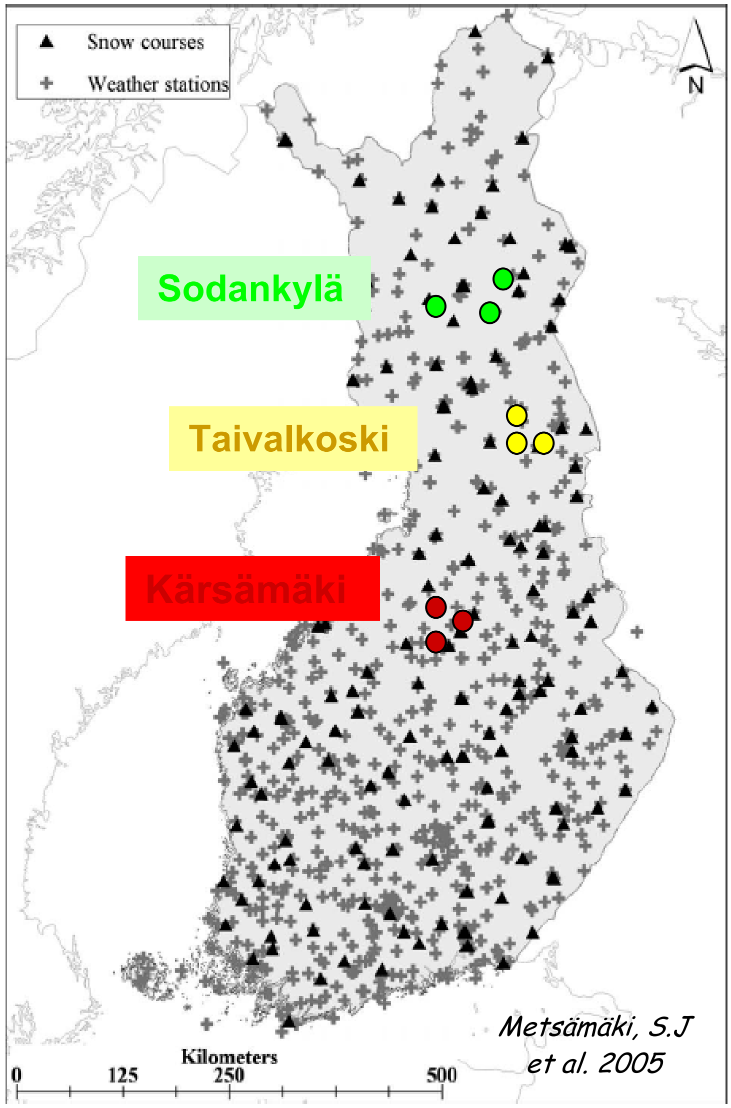


Figure 1. Base map of Finland from Metsämäki et al. (2005), with an overlay of the locations of the 3 areas and the 9 FMI snow extent weather stations used in this study.

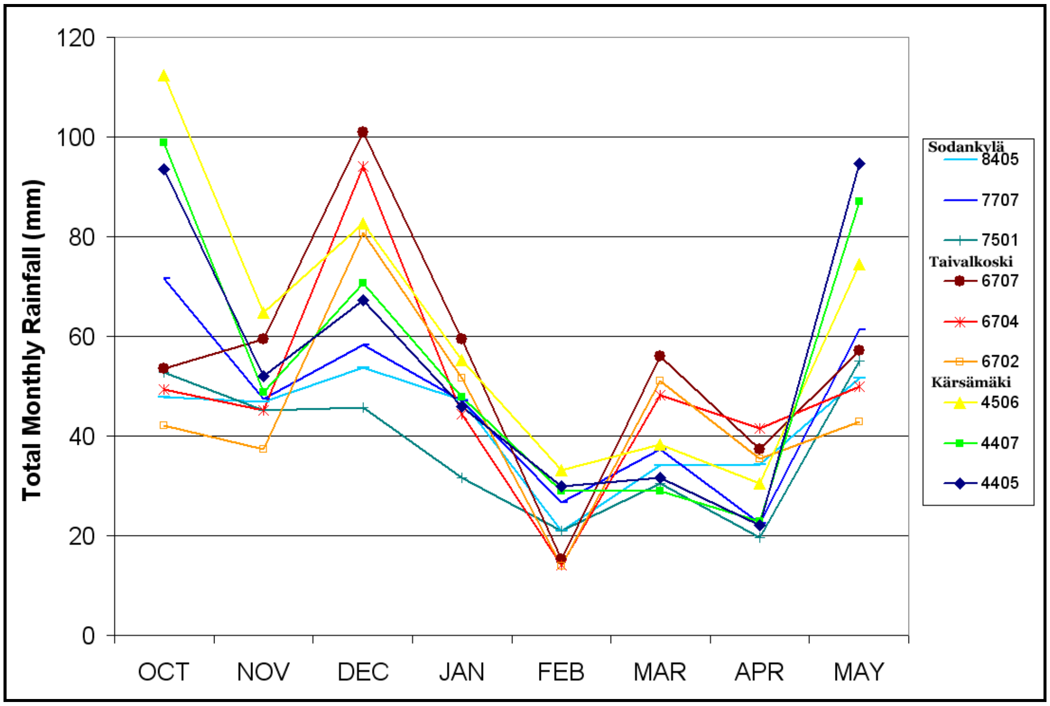


Figure 2. Total monthly rainfall precipitation shown in millimeters. Daily rainfall data were summed for the month at each of the 9 weather stations in Finland, based in the areas of Sodankylä (stations 8405, 7707, 7501), Taivalkoski (6707, 6704, 6702), and Kärsämäki (4506, 4407, 4405).

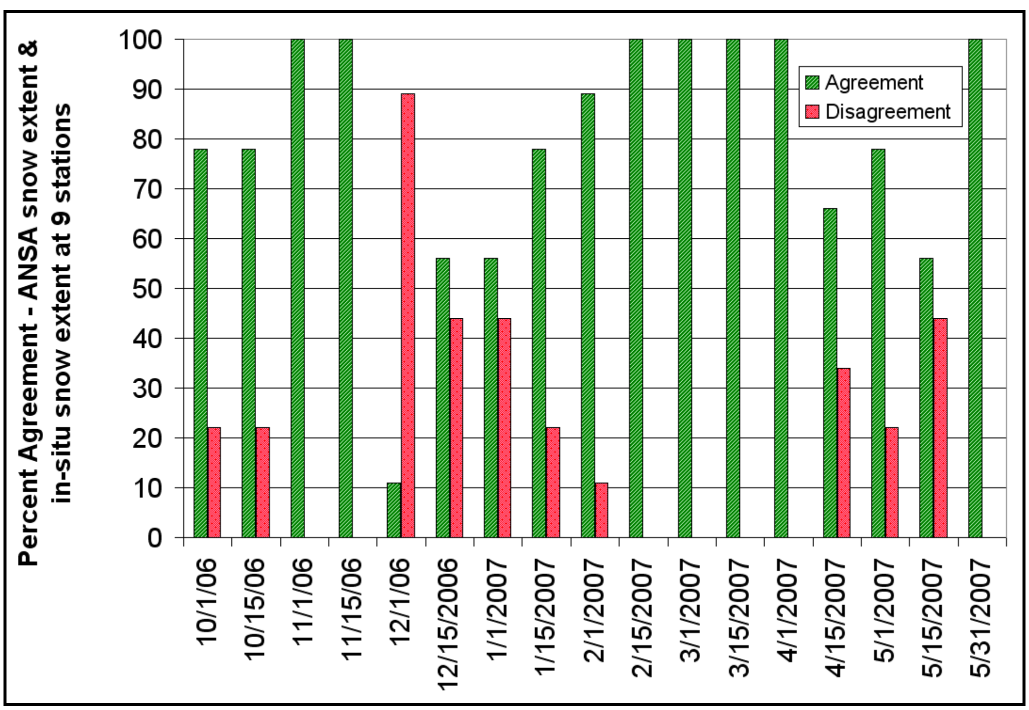


Figure 3. Comparison of ANSA snow extent and FMI snow measurements at the 9 FMI data stations.

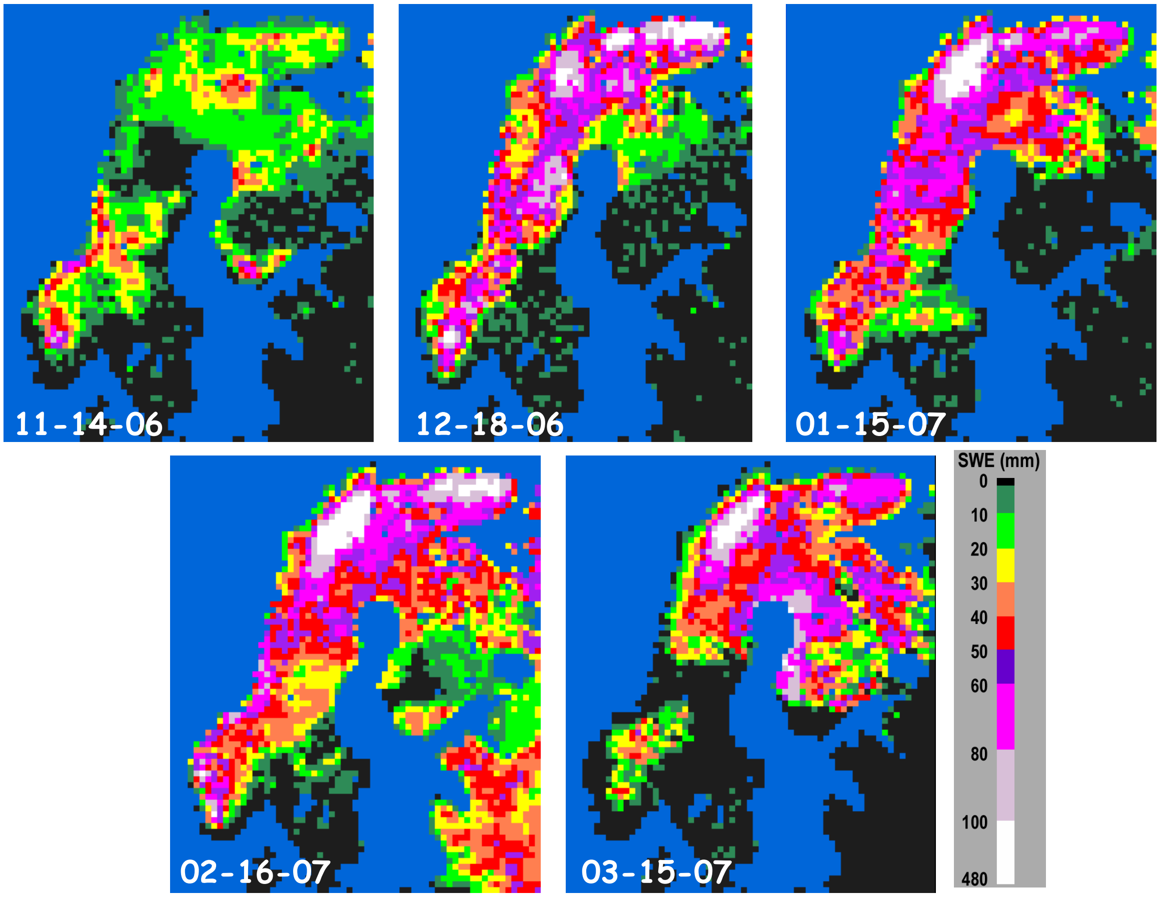
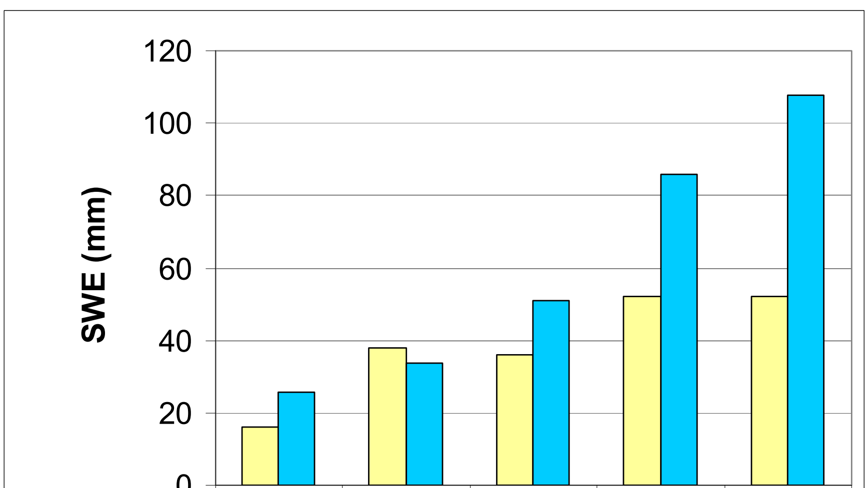


Figure 4a. AMSR-E SWE maps for all of Scandinavia for the snow course comparison dates in November 2006 though March 2007.



	11/14/2006	12/18/2006	1/15/2007	2/16/2007	3/15/2007
AMSR-E SWE	16	38	36	52	52
Snow Course SWE	25.5	33.9	50.8	86	107.6

Figure 4b. AMSR-E SWE and snow course SWE histogram comparison at the Sodankylä stations for November 2006 – March 2007.

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