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4th summary report of snow data

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LIFE+ PROJECT NAME or Acronym

Climate change indicators and vulnerability of boreal zone applying innovative observation and modelling techniques

Data Project

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Data Beneficiary

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List of abbreviations

FMI	Finnish Meteorological Institute
CSS	Continuous Snow Season
DoY	Day of Year
e-code	A code from FMI weather station network describing the snow conditions in the surroundings.
FSC	Fractional Snow Cover
MoD	Snow Melt-off Day
RMS	Root mean squared difference
SD	Snow Depth
SYKE	Finnish Environment Institute
WMO	World Meteorological Organization
RIHMI	Russian Research Institute for Hydro-meteorological Information

1 Summary

This document provides an update to the deliverable report "Third summary report of snow data" (30/09/2016) and replaces the earlier report. We give a general description of the *in situ* observations used in the calibration and validation of snow cover extent (2011-2016) and the snow melt-off day (2001-2016). The *in situ* datasets include observations on snow patchiness made at the snow courses by the Finnish Environment Institute SYKE (starting from 1950s), snow e-code observations from FMI weather stations and snow observations from Russian weather stations. Furthermore, the snow melt-off day was determined from time series of snow depth at weather stations in Finland and Russia.

2 Snow data

2.1 SYKE snow courses

Ground reference data feasible for evaluation of fractional snow cover (FSC) retrievals is often relatively difficult to obtain. This is because FSC is typically registered by human observers. Moreover, fractional snow typically varies rather widely in space and time, and therefore single point observations are not necessarily representative of the local spatial variation. This representation also depends on the landscape character and other prevailing conditions. The observations should be conducted over an area corresponding to the pixel size of the applied satellite sensor, and the timing should match the satellite overpass at least so that no major changes in snow cover occur. The snow course network governed by the Finnish Environment Institute (SYKE) has a heritage from the beginning of the 20th century. The network consists of ~160 courses which are visited on a monthly basis. A snow course is a 2-4 km long transect passing through different landscapes; the observer registers the snow information typically at 80 locations along the transect. The observations include snow depth (SD, measured with a stick), snow density (measured with a snow tube) and fraction (%) of snow-free ground (visually estimated for an area within a 25 m radius of the observer's location) (Table 1). Hence, FSC=100%−Fraction of snow-free ground. The map of the Finnish snow courses and the trail of a snow course plotted over a digital photograph are shown in Figure 1.

Note: the four squares shown in the Figure 1 (right) correspond to 1×1 km^2 snow product pixels that cover the course; at least these pixels should be used when comparing the snow product against the in situ observations along the course. Also a larger window (e.g. 3×3 product pixels) can be used. In either case, an average of the selected product pixels is taken and compared with the average FSC calculated from the observations along the snow course.

Proper *in situ* observations are particularly difficult to obtain when only trace amounts of snow are present. In a scale of a pixel, these easily remain unnoticed by human observers if only several samples are taken at ground level. The route of each snow course maintained by SYKE is individually planned so that it should represent a locality of a few square kilometres. The trail goes through different landscapes in order to catch the differences in snow conditions; the information of the prevailing landscape is assigned to each measurement location. The landscapes are: pine forest, spruce forest, mixed forest, broad-leaf forest, forest opening and open bog.

Table 1. Measurements performed at each snow course.

Parameter	Description	# meas./site	Unit
Snow depth	- at least 10 for each land cover type	50 or 80	cm
Snow patchiness	- the % terrain covered by snow - at least 10 for each land cover type	50 or 80	%
Snow water equivalent	- the water content/m^2 if the snow pack would be melted - at least 1 for each land cover type	10 or 8	[mm] w.e.
Snow density	- at least 1 for each land cover type	10 or 8	kg/m^3

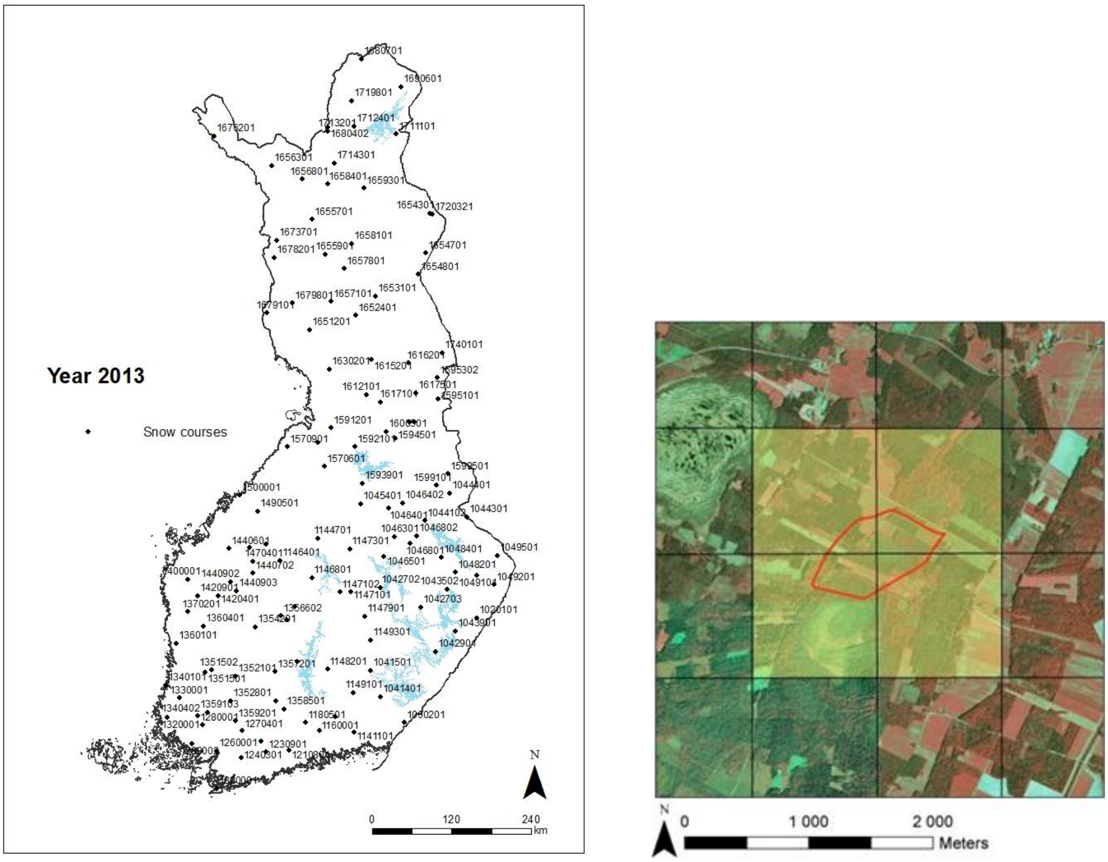

Figure 1. Left: Location of active snow courses in 2013, Right: an example of the route of a snow course.

Actions related to the snow course data:

Snow course observation are extracted from hydrological data bases in SYKE (2001-2016) and further processed to allow comparisons with satellite observations related to snow properties. The following data fields are retained in the final Excel-file: *1. Snow course ID,* 2. *coordinates (lat,long) in WGS-84 system, 3. Date of observation, 4. Snow depth, 5.*

Patchiness, 6. Landcover type. The landcover-specific average values are also calculated and provided as separate Matlab-tables, so that one table is created for each individual snow course visit.

As a new feature concerning the processing of Snow course data: Patchiness was converted to Fraction of snow-covered area; FSC=100-Patchiness (%), to be consistent with the EO-retrievals. In addition, the matlab-files including the visit-specific average for each land cover type now include also standard deviations for Snow Depth and for FSC. These would be useful when interpreting the results of in-situ validations and also when developing new approaches for validation.

While collecting snow course data, updates also for the course location were made. For instance, in 2015-2016, the track (route) of three snow courses was changed due to the changes in local land/vegetation cover. These changes were updated also in the GIS-database on the routes. In addition to the updates presented above, the 2015-2016 courses were rasterized in order to enable their use in validation of the snow products. The resulting rasters are in two different resolutions, 250 m 500 m, enabling the validations of different resolution snow maps.

For five selected snow courses around Sodankylä-Pallas area a historical time series has been processed and is available for the last 30 years period.

2.2 FMI weather station e-codes

The weather station network of the Finnish Meteorological Institute (FMI) in Finland consists of ~250 stations, where observations on snow depth (point-wise) and snow coverage (within the range of vision) are made on a daily basis. Figure 2 presents the locations of the weather stations. Snow coverage is described with a particular e-code following the definitions presented by the World Meteorological Organization (WMO), see Table 2. Observations of snow coverage were discontinued at many of the stations in 2009 due to the automation of observing protocols, but in many stations it is still recorded.

Table 2. Description of e-codes.

E-code	Description
0	Dry snow free terrain, vegetation can be covered by moisture from dew or fog.
1	Wet snow free terrain.
2	Snow free terrain with water ponds.
3	Terrain frosted or covered with surface ice.
4	Open terrain snow free, some snow in forested areas.
5	Snow covering over 0%, but less than 50% of the terrain.
6	Wet or re-frozen snow covering over 50% but less than 100% of the terrain.
7	Wet or re-frozen snow covering 100% of the terrain.
8	Dry, loose snow covering over 50%, but less than 100% of the terrain.
9	Dry, loose snow covering 100% of the terrain.

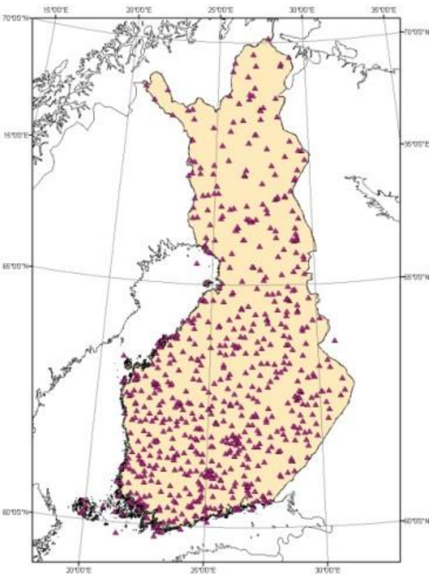

Figure 2. FMI weather stations with e-code observation.

Although expected to represent the average snow conditions in the locality, the snow observations may introduce a bias towards less snow than is actually present in the surrounding area, corresponding e.g. to a pixel of a satellite image. This is because each weather station is located in an open area, where snow typically disappears earlier than in forest areas. In order to evaluate how well the point-wise observation applies to a larger surrounding area, the correspondence between the e-code and the nearby same day's snow course FSC – providing a better spatial distribution – was analysed and found to be reasonable. This correspondence is considered to be an indication of spatial representativeness of point-wise observations in the scale of pixel-size of the Earth-observation imagery used in Monimet-project. Figure 3 presents the results of the analysis. The spatial representativeness is further supported by the good correlation between snow depth observations, again from the weather stations and snow courses within a distance of <4 km for data from years 1991-2008. The correlation coefficient is 0.94, with a root mean squared (RMS) difference of 10.1 cm, indicating that for snow depth, point-wise observations also represent the snow conditions in a larger spatial domain.

For comparing the e-code and the snow product, a product pixel centered nearest to the station location is identified. FSC from this one pixel or from a larger window (e.g. average FSC from 3×3 pixels) can be employed in the comparisons.

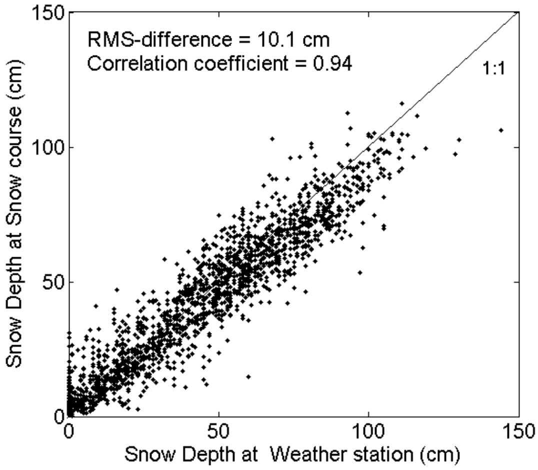

Figure 3. Correspondence of snow depth from weather stations and from snow courses.

Action related to weather station data:

E-code observations have been extracted from FMI data bases (2001-2016) and processed for the comparison with satellite observations on snow cover. The data fields retained in the final Excel-file are the following: 1. *coordinates (lat,long) in WGS-84 system, 2. Date of observation, 3. Snow depth, 4. e-code.*

2.3 Russian RIHMI weather station data

In addition to the Finnish in-situ data, the data near the area of Finland would benefit the evaluation of Monimet snow products. The standard suite of measurements from weather stations in the Russian Research Institute for Hydro-meteorological Information (RIHMI) network include observations of snow cover (Bulygina et al. 2015a). Snow depth, the fraction of snow cover around the station and information on snow characteristics around the station are daily measured and observed. The data is also flagged with quality measures based on: general snow conditions, consecutive snow depth measurements, and temperature data (Table 3).

For Monimet purposes observation sites (11 sites) covering areas west from longitude of 32ºE (eastern limit of the Monimet target area) was extracted and is ready to be used. For Monimet purposes – since not having earlier experience of this dataset, observations for snow season 2011-2012 was first fetched. Since then, the dataset has been expanded within Monimet to cover data from 01 January 2001 up to September 2016. This data has been fetched to SYKE and is available for the project. This dataset covers more than 43724 daily observations. The data fields retained in the final Excel-file are the following:

StationID; latitude; longitude; ease2north; ease2east; elevation; Time; snowDepth; FractionalSnowCover; qualityFlagGeneral; qualityFlagSD; qualityFlagTemp.

Data is basically provided as open access; SYKE has now registered as a data user, which was the requirement set by RIHMI. The instructions for using the data are also available at SYKE.

Table 3. Basic information, measurements and flags of the snow observations at RIHMI weather stations.

Basic Information	
World Meteorological Organization (WMO) index number (5-sigit code)	
Year, month and day	
Measurements	***Units/ Uncertainty***
Snow height in cm Notes: value 9999 – the observation was rejected or observation was not made	[cm]/ ±1cm
Extent of snow cover around the station is estimated from 0-10 describing fractional snow cover of (0-100%) Notes: value 99 – the observation was rejected or observation was not made	%, depends on the observer
General Snow Status Flags	
Value of snow depth is correct	
More than 50% of the area around the station	
Snow cover absent at site, however snow is recorded in the vicinity of the station	
Snow cover is less than 0.5 cm	
Observations were not made or snow depth value was rejected	
Snow depth quality flags	
Value of snow depth is correct	
Value is doubtful on conditions that Abs(D)>30 & abs(ΔH1)>10 & abs(ΔH2)>10 Notes: D=ΔH2-ΔH1, ΔH is the difference between the neighboring snow depth values	
Temperature Flags	
Value of snow depth is correct	
H^=0 & Tmean >5 & Tmin>0	

3 Snow melt-off day from weather station observations

Action B.2 provides maps on the timing of end of snow melt (Melt-off Day, MoD) in Finland covering the period from 2001 to 2016. The detection of MoD was based on the pan-European Snow Extent product from the Copernicus Service Snow and Land Ice (CryoLand, http://www.cryoland.eu/) with a spatial resolution of 0.005°× 0.005° (~500 m). MoD was also determined from Monimet FSC-time series (covering Finland).

For the evaluation of satellite-derived MoD maps with *in situ* observations from weather stations, we earlier determined the end of snow melt date from time series of snow depth and e-codes. The day of the first snow cover, the first snow-free day and the number of days with snow cover were determined from the time series of snow depth and e-codes for all available stations and observation years. We used two threshold values, zero and 1 cm, for the determination of the end of melt from observations of snow depths (SD).

In the latest approach, the melt-off day is considered as the first day of the snow-free period following at least two weeks' (14 days) continuous snow season (CSS), as this is a method widely used. CSS has been earlier defined e.g. by Choi et al. (2010) and Lindsay et al. (2015), the latter study permitting CSS to take place at any time during the snow season, while the former paper uses temporal constraints for CSS to take place. Snow-free condition is indicated by a SD observation of 0 cm. Hence, the near vicinity of a weather station is considered snow-covered if the observed snow depth is >0 cm. We allow also intervening snow-free days during the whole snow season in general, but melt-off day is defined only for in-situ stations which provide the CSS. This practice excludes the in-situ stations which report temporally very sparse snow observations. Should the in-situ station provide the CSS, a search allowing also short snow periods (after CSS) is launched. If such a new snow period is found, the MoD is identified as the first snow-free day after this shorter period. However, the time series of SD may not provide too many of short snow periods separated by intermittent snow-free days. Therefore the searching procedure identifies (maximum) three days' snow peaks occurring after the CCS and removes those from the time series with the assumption that they do not represent a new snow period. However, snow periods longer than three days are retained in time series and MoD is identified as a first snow-free day after them. Also, if the total length of SD time series is less than 50 days, or in case of data gaps, the station data is discarded. A gap refers to at least three consecutive days' period of no data. The searching procedure allows three gaps ≤3 days; more gaps result in the exclusion of the station from the analyses. The in-situ SD-based MoD is denoted as MoD_{insitu} here onwards. Figure 4 shows an example of the snow depth time series from a Finnish Weather station. In this particular case the last short snow peak is neglected and the final MoD_{insitu} is ~Day of Year (DoY) 90.

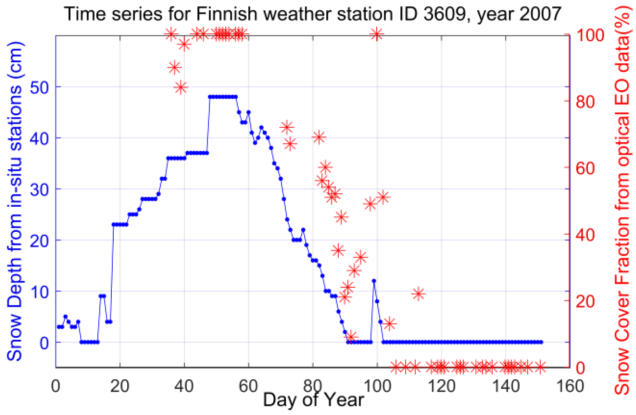

Figure 4. Snow Depth time series for a Finnish Weather station.

Since in Monimet also RIHMI stations, not providing a similar kind of e-code indicating the snow coverage, are used for the evaluation of MoD, it was decided to use SD only. This also enables to widen the application area and validation to the regions where e-codes are never available. As reported in the 3rd summary report, the in-situ –based SD does not have a considerable effect on the MoD. That is why it was decided to use threshold of 0 cm to indicate snow-free situation.

For future accuracy assessment of the MoD, associated with the accuracy of FSC-retrievals an analysis on the relationship of FSC and SD was compiled. The results are presented in Figure 5. The analysis were made from snow course data in years 2002-2016, so the average SD and average FSC were calculated, first for all available land cover types and then separately for open areas and forests. Mean and standard deviation of all observed FSC-values were calculated for SD-categories [cm]: 0-5, 5-15, 15-25, 25-35, 35-45, 45-55, 55-65, 65-75, 75-85, 85-95, 95-100. It is clear from the figure that at small SDs, the deviation of FSC is relatively high, but the deeper the snowpack, the lower is the FSC variation so that above 50 cm, FSC is 100% with standard deviation of 0. For smaller SDs, there is a slight difference in FSC mean and standard deviation in different land cover types – the most pronounced perhaps at SD category 0-5cm: in open areas shallow snowpack has somewhat lower FSC than in forests. This may be explained by the effect on wind in open areas, as snow is drifted towards the forest edge.

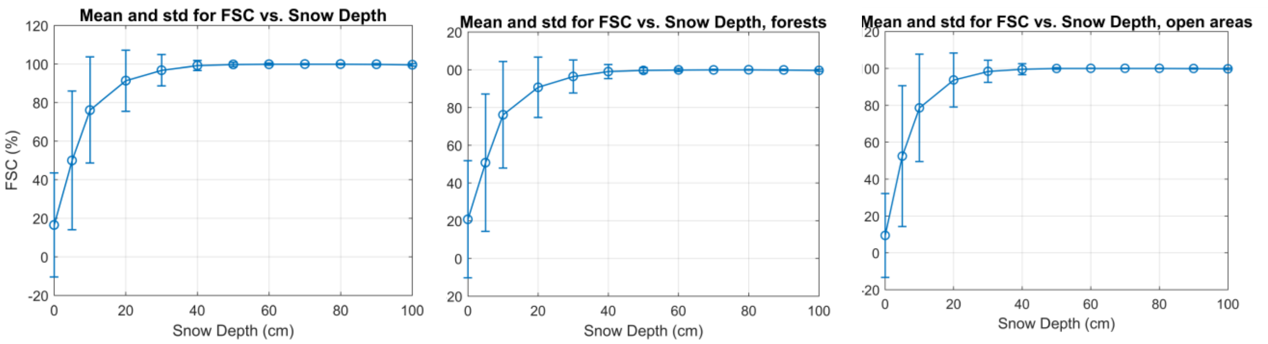

Figure 5. Snow Depth vs FSC calculated from Finnish Snow course in 2002-2017, mean and standard deviation are presented for SD-categories.

4 References

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