Recommendations for automatic measurements of snow water equivalent in NVE

Heidi Bache Stranden, Bjørg Lirhus Ree & Knut M. Møen

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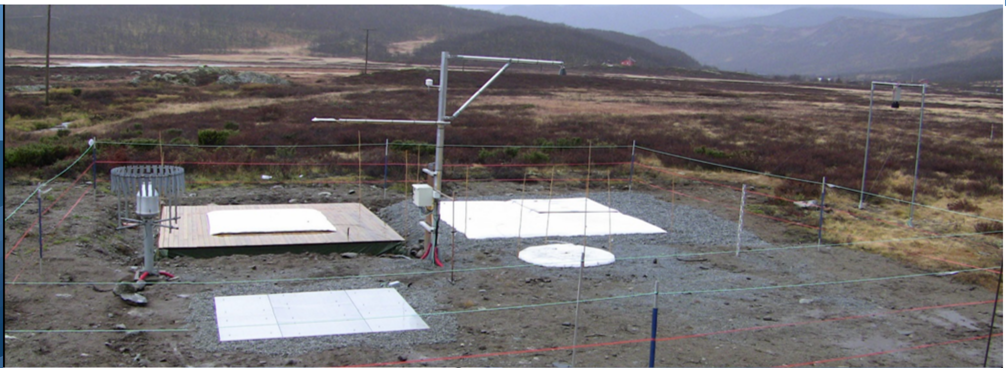

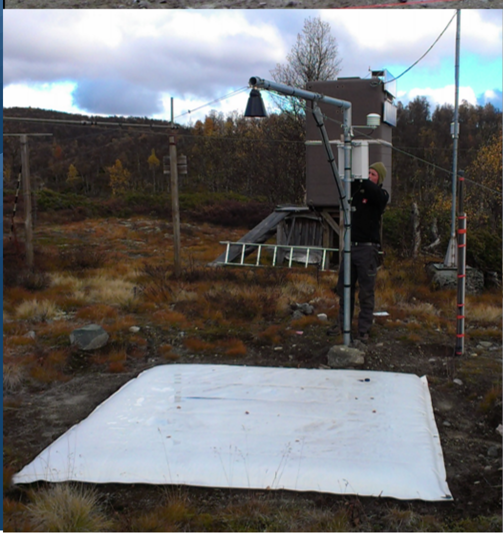

RAPPORT

Recommendations for automatic measurements of snow water equivalent in NVE

Utgitt av: Norwegian Water Resources and Energy Directorate

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Trykk: NVEs hustrykkeri
Opplag: 20
Forsidefoto: Snow measurement sensors. Photo: NVE.
ISBN 978-82-410-1148-1

Sammendrag: In this report, we summarize and conclude on which automatic snow water equivalent sensor to recommend under different conditions and at different locations. All three types of sensors that we analysed has limitations either according to a maximum level of recorded snow water equivalent, climatic challenges or instrumentational challenges. The gamma attenuation sensor is suitable for measuring snow water equivalent in maritime climate with frequent freezing and thawing cycles during winter, as well as alpine climate. However, the gamma

Emneord: Automatic measurements of snow, snow water equivalent, SWE, snow pillow, snow scale, gamma attenuation sensor, Campbell CS725

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November 2015

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Preface

This report gives guidelines and recommendations for Norwegian conditions on how to measure snow water equivalent automatically with snow pillows, snow scales and gamma attenuation sensors.

Since we started to evaluate our automatic snow measurement network in 2009, both colleagues in NVE and local observers have been involved. We are grateful for all their feedback and valuable work. Several reports which describes the different test sites and installations, has been written the last six years (e.g. Ree et.al, 2011, Stranden and Grønsten, 2011, Stranden et. al, 2014), and this report summarizes the experiences and conclusions.

We would deeply acknowledge our snow colleagues Elise Trondsen and Ronny Løland who gave us valuable feedback during the work with this report, and Per Morten Ørsleie who helped us with estimating the costs for the different snow stations.

Oslo, November 2015

for
Morten Johnsrud
Director

Morten N. Due
Head of Section

Summary

NVE have since 2009 done thorough testing and gained experience on how to measure snow water equivalent automatically. We have measured snow water equivalent (SWE) automatically by using snow pillows, snow scales and gamma attenuation sensors, and data from the sensors are evaluated against measurements of snow depth, manual measurements of snow water equivalent and by visual inspection.

The snow pillow (NVE2010) may be a well-suited installation in alpine climate, where mild weather and rain seldom occur during wintertime. The cost of a snow pillow station, including setup costs, is less than for the NVE snow scale stations or a gamma attenuation station. This combined with less comprehensive groundwork compared to the NVE snow scale, makes a snow pillow preferable at many places. Challenges and limitations regards a snow pillow is related to the risk of leakage and reload of snow due to layers of crust, ice and windblown snow. The latter limitations makes the snow pillow less suitable at locations with frequently freezing and thawing cycles during wintertime.

The gamma attenuation sensor also have some limitations, mainly due to the limited measuring range. With a snowpack exceeding 600 mm, the uncertainty in the measurements become too large. The gamma attenuation sensor is also expensive compared to a snow pillow, but easier to install than the NVE snow scale. Stations using this instrument should be connected to the power grid due to relatively large current draw. The gamma sensor need to be calibrated by the manufacturer each 7’th year.

We find the NVE designed snow scale (“Møen2525”) promising. When wooden boards are used as top cover, and with the size of 5 x 5 m, we think both the effect of different thermal properties between snow and ground and snow and the snow scale in addition to the spatial differences in snow load are minimized. The snow scale might be suitable in both continental- and maritime climate, regardless of snow amount. The cost of a NVE snow scale station is higher than for a snow pillow, and a NVE snow scale requires more construction work than a pillow or the gamma attenuation installation. This may limit the suitable locations for a NVE snow scale as the transportation of concrete fundaments and wooden beams could be a challenge, or at least expensive, in remote areas.

The development of automatic snow water equivalent sensors are continuously in progress. Hopefully new instrumentation and knowledge will improve the quality of snow measurements in the future.

1. Introduction

Snow is an important part of the Norwegian hydrology, and measurements of snow is inherently important. *Snow depth* is quite easy to measure, either manually by a graded scale or by automatic snow depth sensors. The challenge is that hydrologist need knowledge of the *snow water equivalent* (SWE) to get an estimate of the total runoff and for flood forecasting in river basin where snowfall occurs. Snow water equivalent (SWE) is the height of water obtained by melting the snowpack in a given area, and depend on both snow depth and snow density.

To monitor the accumulation and melting of snow regularly, the first automatic *snow pillow*s were installed in Norway during the mid-sixties (Tollan, 1970). Since then, the technology has been improved and redesigned and new ways of automatic monitoring of snow water equivalent have been tested and invented. As also Johnsen and Schaefer (2002) points out, the reliability of snow readings from a snow pillow could vary from one year to another, which makes it both time consuming and challenging to measure and analyse snow water equivalent data from the sensors.

In 2009, NVE started to analyse their own snow station network. Prior to 2009, our snow stations network consisted of ~25 snow pillows and some snow depth sensors, but after thorough review of all the stations 7 of them was terminated as snow pillow locations. Most of them were located on the west coast with “non-alpine” climate or at locations with large wind influence. A type of *gamma attenuation sensor* was tried without success in 2004, as the instrument was not designed for installation in the harsh winter climate (Møen, 2010). Our first snow science test site was established in 2009 at Filefjell, while a second snow science test site was established at Anestølen in 2011. They are both equipped with both snow depth sensors, snow pillows, snow scales and gamma attenuation sensors. We have analysed data from the science test site and our remaining snow stations with a view to data quality, operating conditions and reliability of data.

This report summarizes the results from our work and gives guidelines for future establishment of automatic SWE-stations. Our recommendations are based on experiences with more than 30 snow pillows of different types, two snow scales and four gamma attenuation sensors. Chapter 2 “Instruments for measuring snow water equivalent” describe different type of stations, while chapter 3 “Guidelines” summarize NVE`s guidelines in a table. Advantages, limitations and further work are discussed in Chapter 4 “Discussion”. Here our network and experiences are compared with international research. More details about the instrumentations, setup parameters and advanced parameters for scientific use are presented in appendix A-D. Costs per snow water equivalent station are estimated in appendix E.

Even if our guidelines are followed, there are no guarantees that the instruments will work properly. Unexpected technical problems and rare weather conditions may occur and disturb the measurements. Following the guidelines in this report will nevertheless make you better equipped to avoid the problems we have had during the last decades.

2. Instruments for measuring snow water equivalent

We have tested two different types of snow pillows, two types of snow scales and a gamma attenuation sensor. Both snow pillows and the snow scales have in common that they are installed at the ground prior to snowfall and that they register the accumulation and melting of the overlying snow. In contrast to this, the gamma attenuation sensor is installed above the ground, *calculating* the accumulation and melting of snow from measurements of gamma radiation. The instrument makes an indirect measurement of snow where observed attenuation of gamma rays is used to calculate the water content between the sensor and the ground.

2.1 Snow pillow NVE1997

Various snow pillow designs have been used by NVE throughout time. The pillow called “NVE1997” is a round-shaped snow pillow made of PVC filled with a mixture of water and ethanol (Figure 1). The pillow has a diameter of 2 meters and an area of 3,14 m^2. Until 2010, this type of pillow was the preferred instrument for measuring snow water equivalent automatically in Norway. From 2002, the snow pillows were made with a new softener in to the PVC. Unfortunately, this softener dissolved slowly by ethanol and made the PVC fabric brittle (Ree et. at, 2011, appendix G), and ethanol started to diffuse through the PVC. The diffusion of ethanol vapour was susceptible to influence creation of ice layers between pillow and snowpack that made the pillow even more exposed for bridging and pressure distribution to the ground. If ethanol is used as anti-freeze solution, it is important to use a type of fabric that is not open for diffusion (e.g. Neoprene). Advantages and limitations using this type of snow pillow are listed Table 1 and Table 2. Further limitations regard snow pillows as a snow water equivalent sensor are also discussed in Johnson and Schaefer (2002) and Egli et. al (2009).

By spring 2015, NVE has five of this type of pillows in use, but they are subsequently replaced with either the new type of pillow (“NVE2010”), snow scales or gamma attenuation sensors as their lifetime exceeds. This type of pillow are frequently replaced by either a NVE2010-snow pillow, snow scale or gamma attenuation sensor in NVE network as their lifetimes exceeds or the data quality tends to be insufficient.

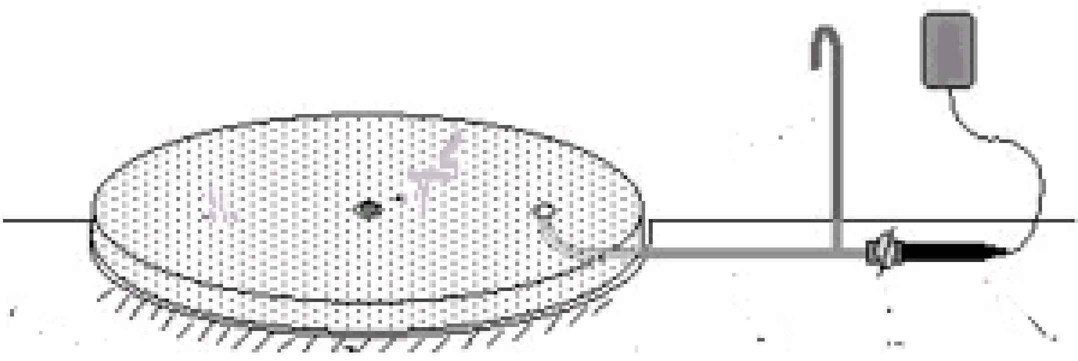

Figure 1. Snow pillow NVE1997. Illustration by NVE.

Table 1. Advantages by using snow pillow NVE1997

Advantages
Easy to install.
A direct measurement.
Do not need 24/7 power supply. A solar panel may give sufficient power supply at remote locations.
Could be installed in remote areas.
Cheaper than the known alternatives (snow scale and gamma attenuation sensor).

Table 2. Limitations by using snow pillow NVE1997

Limitations
May be too small in areas with large snowpack.
NVE had problems with ethanol diffusing through the PVC-membrane after the producer changed softener in the PVC in 2002. When ethanol is used as the anti-freeze solution, a proper membrane should be used.
The pillow may puncture. A fence around the pillow protect the pillow for e.g. animals and reduce the risk for punctuation. A secure cover during summertime also prevent the pillow from damage and keep the material in the shade from strong sunlight.
The transportation of ~300 litres of water and ethanol may be challenging in remote areas.
Not suitable in non-alpine climate. Layers of crust, ice or windblown snow could cause bridging and increase the uncertainty in the measurements.
Need preparation of the ground below the pillow prior to installation to ensure a levelled and well-drained location and to fluctuate the pillow with the ground.

2.2 Snow pillow NVE2010

The snow pillow “NVE2010” is a square shaped pillow made of PVC (same type as NVE1997) (Figure 2). The change in shape from the circular shaped NVE1997 pillow to the squared NVE2010 shaped pillow is based on a holistic evaluation regard size, possible reload effects and production requirements at the manufactures. The size of the pillow filled with anti-freeze solution is 2,5 x 2,5 meters (6,25 m^2), which makes it twice as large as the NVE1997. Propylene glycol is the preferred anti-freeze solution, with a mixture rate of 70 % water and 30% glycol (in total at least 700 litres). In contrast to ethanol, propylene glycol does not diffuse through the PVC-membrane, and is thus recommended in snow pillows made of his type of PVC. Appendix G in Ree et.al (2001) describes how different antifreeze solutions affects a snow pillow membrane. By spring 2015, NVE had 15 active stations with this type of pillow in use. See appendix B later in this report or appendix F in Ree et.al (2011) for further specifications of this type of pillow. In Table 3 and Table 4, advantages and limitations by using the NVE2010-snow pillow are listed.

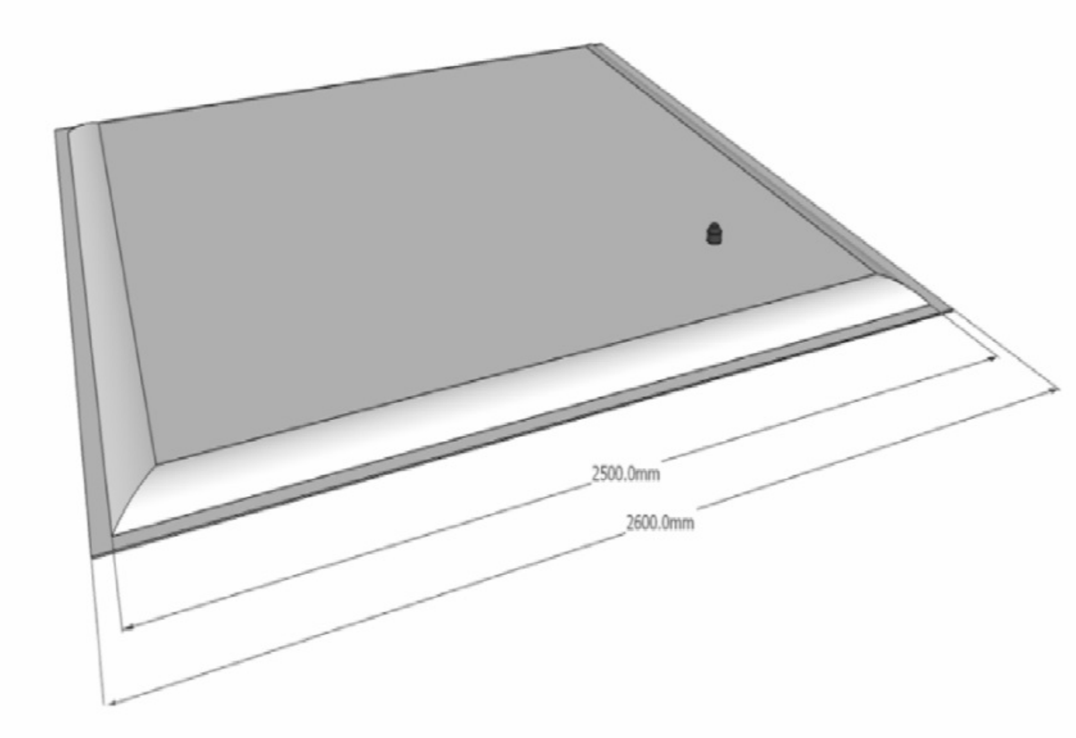

Figure 2. Snow pillow NVE2010. Illustration by NVE, Ree et.al, 2011.

Table 3. Advantages by using the snow pillow NVE2010

Advantages
Easy to install compared to the construction of the NVE snow scale.
A direct measurement.
Do not need 24/7 power supply. A solar panel may give sufficient power supply at remote locations.
Could be installed in remote areas.
Cheaper than the known alternatives (snow scale and gamma attenuation sensor). See appendix E for estimated prices.

Table 4. Limitations by using snow pillow NVE2010

Limitations
The pillow may puncture. A fence around the pillow protect the pillow for e.g. animals and unauthorized people and reduce the risk for punctuation. A secure cover during summertime also prevent the pillow from damage and keep the material in the shade from strong sunlight.
The transportation of at least 700 litres of water and glycol may be a challenge in remote areas.
Not suitable in non-alpine climate. Layers of crust, ice or windblown snow could cause bridging and increase the uncertainty in the measurements.
Need preparation of the ground below the pillow prior to installation to ensure a levelled and well-drained location and to fluctuate the pillow with the ground.

2.3 NVE Snow scale (“Møen2525”)

The NVE designed snow scale “Møen2525” is based on a standard scale principle, with four load cells recording weight of a rectangular, rigid platform (Figure 3). The dimensions is 5 x 5 m (25 m^2), and it is dimensioned to withstand 25 tons of snow (1000 mm SWE). Further increase in the dimension to adapt higher snow load is possible. The construction consist of laminated wood beams placed on four load cells with wooden boards or wooden beams with a corrugated metal plate on top. Our experiences shows that a top deck of wooden boards it preferable compared to the impermeable corrugated metal top deck. The effort of a permeable scale is also discussed by among others Johnson and Schaefer (2002). Figure 3 illustrates the snow scale with wooden boards as top deck. Appendix C describes further specifications about this type of scale. As of autumn 2015, NVE has two snow scales in operation. Table 5 is list of advantages, while Table 6 is a list of limitations using the snow scale.

Table 5. Advantages by using the NVE snow scale “Møen2525”

Advantages
A direct measurement
Do not need 24/7 power supply. A solar panel may give sufficient power supply at remote locations.
Covers a large area (25 m^2). Further increase of area and dimensions are easily done.
No need for antifreeze solutions.
Robust construction without moving or flexible parts. Animals – or people – can walk on it without damaging the construction. Manual control measurements can be done directly at the scale.

Figure 3. Snow scale Møen2525. Illustration by Knut Erik Ree

Table 6. Limitations by using the snow scale "Møen2525"

Limitations
Comprehensive ground work. At most locations it is preferable to use an excavator to prepare the scale site, in addition concrete pillars needs to be established as a base for the load cells. This may be a challenge in remote areas. As for snow pillows, the area need to be well drained to avoid influence of soil- and groundwater.
More expensive than a snow pillow. See appendix E for estimated prices.
Need to be installed properly, see specification in appendix C
Need more testing in areas with layers of crust and ice.

2.4 Passive gamma attenuation sensor

A gamma attenuation sensor measures attenuation in natural radioactive radiation emitted from the ground under the sensor. The calculation of snow water equivalent is based on the attenuation of radiation emitted by two different isotopes: Potassium (^{40}K) and Thallium (^{208}Tl). The higher attenuation the higher SWE. The gamma attenuation sensor we have used is the "CS725" manufactured by Campbell (Campbell, 2015). At this time, we have no knowledge of other companies offering this type of sensor on a commercial basis.

The gamma attenuation sensor is mounted above the ground, “looking” downwards to the ground/the snow pack. When installed ~3m above the ground, it measures snow water equivalent indirectly over an area of ca 100 m^2 (Campbell, 2015). Given sufficient bareground radiation (Campbell, 2015), 600 mm snow water equivalent is the upper limit of snow to be measured by the sensor, with ±15percentage uncertainty (Campbell, 2015). To meet the need for measurements of larges snow pack, the manufacturer may work with developing sensors for higher snow loads in the future.

By spring 2015, NVE has three gamma attenuation sensors in operation in Norway. In addition, one other sensor own by a hydropower company (Statkraft) is operational. Our experiences is that this sensor work very well in snow packs less than 600 – 800 mm snow water equivalent (Stranden et. al, 2015, Stranden & Ree, 2014a). Advantages and limitations with this type of sensor are listed in Table 7 and Table 8. Please pay attention to the limitation regards the sensors maintenance. The sensor need to be calibrated at the manufacture’s each 7th year.

Figure 4. The gamma attenuation sensor CS725. Photo: www.campbellsci.ca

Table 7. Advantages by using the gamma attenuation sensor

Advantages
Measure a large area (100 m^2) when installed 3 m above ground.
Not affected by layers of crust, ice and windblown snow.
Easy to install, even in remote areas.
Does not require groundwork prior to installation. Reduced field work/installation costs compared to snow scales (see appendix E).
Obviously no need for anti-freeze liquid.

Table 8. Limitations by using a gamma attenuation sensor

Limitations
Not designed to measure more than 600 mm snow (depending on the background radiation).
Need constant power supply of approx. 200mA @ 12V. Connection to power grid are recommended, but other sources as solar panels or windmills may work.
An indirect way of measuring snow.
Need to be calibrated prior to snowfall against both bareground radiation and ground- and soil water level. Variations in the ground- and soil water level may affect the calibration.
Need to be calibrated at the manufacturer's each 7th year.
Quite expensive (twice the price) compared to a snow pillow. See appendix E for estimated prices.
Significant increase in ground and soil water may disturb the measurement during snowmelt or snow accumulation, making it hard to tell the exact date of snow cover start and end.

2.5 Other instruments, in Norway and elsewhere

Several other institutions and companies have also tested and evaluated different SWE instrumentations.

Stähli et.al (2004) evaluated a snow cable sensor, later known as SNOWPOWER (Egli et.al, 2009), while Sommer and Fiel (2007) describes a similar sensor, the SPA -Snow Pack Analyzier. They are both based on the principle of measuring impedance along a flat band cable to determine the dielectric coefficient of the snow along the cable. From the dielectric coefficients, the volumetric water content of ice, snow and water can be estimated and hence the snow density. Used together with snow depth measurements snow water equivalent can be calculated.

As Stähli et. al (2004) points out a proper installation of the snow cable snow cable is critical with regard to stability and the formation of unwanted air gaps along the cable. On the other hand, Stähli et. al (2004) also claims that the snow cable sensor provided quite robust measurements, which corresponded well to manual observations. Egli et. al (2009) points out the significant noise in SNOWPOWER data, which makes the unfiltered data from the SNOWPOWER difficult to use. The benefits of a snow cable regard to e.g. a snow pillow is that the snow cable can be installed in hill slopes, and that layers of ice and crust in the snow pack does not affect the measurements.

Both Johnson et. al, (2015), Johnson et. al, (2007), Sommer (2015) and CEN/TR 15996 (2010) describes a new type of snow scale. Both the scale described in Johnsons papers and the scale described in Sommer (2015) are constructed in the same way. They consist of an instrumented centre-panel surrounded by eight or six panels that act as a buffer to the centre panel regard to edge stress (e.g. bridging).

At one of our test-stations, we had the possibility to test and evaluate the snow scale from Sommer Messtechnik – Sommer SSG Snow Scale (Sommer, 2015). This scale has a center panel and six buffering panels. Advantages with this type of scale is the very easy setup and the easy installation compared to e.g. the NVE snow scale. There are no need for heavy groundwork and concrete as with the NVE-scale, and no need for antifreeze liquid as for snow pillows. The scales panels are perforable in order to promote uniform melting on both the sensor and the surrounding snow. Our experience with the snow scale are limited to three seasons (2010-2011, 2011-2012 and 2012-2013). In the first and latest years, the performance of the scale where as good as pillows and the Møen2525-snow scale. During the 2011-2012 -winter, which was a mild winter, reports from field told us that the scale were totally covered by ice which corresponds very well to the incorrect and erroneous snow water equivalent measured by the scale. Both our snow pillows and the NVE snow scale did perform well that season.

Snow water equivalent measurements by GPS, GPS Receivers and GPR has been tested e.g. by Koch et.al (2014) and Schmid (2015) and is used in snow avalanche predictions and to estimate the liquid water content in snow. We have no knowledge on their performance under Norwegian conditions.

3. Guidelines

The following table (Table 9) summarizes and gives guidelines to which installation to use when measuring snow water equivalent automatically at different locations. Only the sensors described in chapter 2.1. – 2.4 are included. Please see chapter 2 and appendix A to C for further details about the instruments. The following table may be used as a guiding table. Chapter 4 “Discussion” describes and discuss advantages, limitations and other characteristics regards the different sensors that may give the reader improved basis for decision-making. Using the additional parameters described in appendix D can make it easier to interpret and correct data from the different sensors.

Table 9. Guidelines for automatic measurements of snow water equivalent

	Alpine climate	**Non-alpine climate**	**SWE > ~700 mm**	**SWE < ~700 mm**	**Windy locations**	**Forest**
Snow pillow, NVE1997[1]						
Snow pillow, NVE2010	X		(X)[2]	X		(X)
Snow scale, Møen 2525	X	Likely	(X)[3]	X		X
Gamma attenuation sensor	X	X[4]		X	X	X[5]

[1] The combination of ethanol as anti-freeze solution and the particular PVC-type is not recommended.
[2] Even though we do not recommend it, we do have examples of pillows with reliable registrations of 1000 mm snow water equivalent, prefidencial in alpine climate.
[3] Not tested on high SWE yet, but it seems promising. Further increase of area to meet the need for measurements of high snow load is easily possible.
[4] Be aware that rapidly rising soil water content during spring may disturb the measurement.
[5] You may need a collimator to prevent the sensor from picking up gamma rays emitted from surroundings trees.

4. Discussion

Since 2009, NVE have tested and gained experiences with different types of SWE-sensors.

<u>*Snow pillows*</u>

An experiment in 2010 (Ree et. al, 2011) with small pillows filled with different type of anti-freeze showed that ethanol diffused through the PVC-membrane NVE have used, damaged the membrane and directly exposed the snow around the pillow to ethanol vapour. Ree et. al (2011) concluded that combination of ethanol and PVC increased the probability for development of ice layers above the pillow. NVE`s producer of snow pillow membrane changed the softener in the PVC in 2002, and the time of change in softener is highly correlated with the beginning of the ethanol diffusion problem. Pillows established by NVE prior to 2002, are mainly not encumbered with this defect. Ethanol is also a very corrosive anti-freeze, and we have experienced that many pressure sensors were damaged and gave wrong SWE-data because of the corrosive ethanol. Special pressure sensors (e.g. Hytrell or FEP) is designed to withstand the corrosion, and hence more recommended in snow pillows.

Short lifetime of snow pillows can often be related to punctuation. This can be caused by incautiousness of personnel, elks or reindeer walking on the pillows or small rodents gnawing on the pillow or the instrumentation. A fence around the pillow may protect the sensors from humans and animals. It may also be useful to have a top plate on the top of the pillow. This can also prevent relief of pressure trough the pillow. We do have experiences with a top-plate made of poly-wood fastened to the pillow by straps. Stranden and Ree (2014) analysed data from pillows with and without top plate, but did not found any significant difference between a pillow with such a plate and a pillow without plate, although they points out that a plate *might* be advantageous at other locations. One practical benefit regard the plate is that manual measurements of snow depth and snow density (with proper equipment) on the pillow is done with reduced risk of punctuation.

Experiences with propylene glycol as antifreeze solution gave good results (Ree et. al, 2011) as propylene glycol does not diffuse through the PVC membrane as ethanol does. Propylene glycol is also the preferable antifreeze solution in other countries e.g. Swiss (Egli et. al, 2009), Canada (Corner, 2008). Square shaped pillows is the preferable pillow shape in most of the countries worldwide (CEN/TR 15996, 2010). However, changing the pillows shape, increasing the size or changing the liquid in the pillow is not likely to prevent all kinds of snow pillow troubles. Johnson and Schaefer (2002) and Johnson and Marks (2004) claims that one of the biggest sources of error using snow pillows (or other types of pressure sensors) is the different thermal characteristic in the transition zone between snow and ground and snow and snow sensor. The different thermal conditions produces a difference in the rate of snowmelt. Different snowmelt rate in this zone is insignificant to the total amount of snow water equivalent, but it is important to the microclimate around the pillow and hence the data quality. If the snowmelt rate is higher in the transition zone between snow and snow-sensor than between snow and ground, this could cause an underestimation of snow water equivalent (snow bridging). In the opposite case, if the snowmelt rate is lower just above the snow pillow than just above the ground, the sensor will overestimate the snow water equivalent. According to Johnson and Marks (2004), the magnitude of error could be from 40 -200 % and errors due to different thermal conditions are mainly present in isothermal snow packs. Johnson and Schaefer (2002) points out that this source of snow pillow errors is more likely to be present in the transition between winter and spring and in climate where mild weather often occurs during winter.

A brief look into snow temperature data from one of our Norwegian test sites, does not produce as clear results regards snow temperature differences and snow sensors errors as shown in Johnson and Schaefer (2002) and Johnson and Marks (2004). A closer study of snow temperature and snow sensors errors for Norwegian test sites needs to be done in the future.

Ree et. al (2010) analysed snow pillow errors and found a clear correlation between snow pillow errors and climatic conditions. The pillow with most errors were mainly located in “non-alpine” climate, i.e. at the western part of South Norway, where mild weather during winters often occur. This corresponds very well to Johnson and Schaefer (2002), who claims that errors in snow water equivalent measurements are more frequently present in climate where multiple thawing and freezing cycles are present during winter. In alpine climate, mild weather and snowmelt during winter occur less frequently. Errors in SWE recordings due to thermal conditions at the ground is less frequent during winter until the snowpack gets isotherm in the beginning of spring.

To minimize the risk of errors in alpine climate, a large installation is favourable (Johnson and Schaefer, 2002). The benefit of a large installation/sensor is also pointed out by CEN/TR 15996 (2010). The NVE2010 pillow is larger than the NVE1997 pillow and thus supposed to give data with fewer errors than the NVE1997 pillow, at least in alpine areas. The differences in anti- freeze liquid, shape and pressure sensor are also explaining the improved results with the NVE2010 pillow. Another reason for the overall impression of improved quality with introducing the NVE2010 pillow, is the fact that some stations with old NVE1997-pillows were terminated as the list of measurement errors of those stations seemed to be endless. The terminated stations were mainly located in non-alpine areas, and as Johnson and Schaefer (2002) points out, both the risk for errors and the magnitude of errors are higher in non-alpine regions than in regions with more stable winter climate.

Johnsons et. al (2007) point out the risk of leakage of antifreeze solutions into the environment by using a snow pillow. NVE uses propylene glycol (Commercial product name “Brineol MPG 20”) as an anti-freeze solution and this product is non-dangerous according to existing regulations (Kemetyl, 2015). Although the propylene glycol NVE is using is characterized as non-dangerous according to existing regulations, risk of punctuation and leakage has both economical and operational consequences.

Snow scales

To avoid using pillows filled with antifreeze and to improve automatically measurements of snow water equivalent in non-alpine climate, NVE developed the snow scale, Møen2525 in 2008. At that time, we did not know of other commercial snow scales.

The snow scale, Møen2525, provides, like the snow pillow, a direct measurement of SWE, and at several places, a snow scale may be preferable compared to a snow pillow. This applies for example in “non-alpine” climate. The snow scale, Møen2525, can easily be made larger than the snow pillow, thus it is less likely that the shear stress will affect the measured values. The major disadvantage of the snow scale is that it is more demanding to install than a snow pillow. It requires, among other, concrete foundation, which can be a challenge in remote areas. On the other hand, a snow pillow requires at least 700 litres of water/antifreeze solution, which also might be challenging to transport in remote areas. The scale described in Johnson et. al (2015) and Sommer (2015) does not require as heavy ground work as the NVE scale.

The snow scale Møen2525 differs from the scales described in e.g. Johnson et. al (2015) and Sommer (2015) as it consists of only one panel, compared to the nine-panel scale in Johnson et. al (2015) and the seven-panel scale in Sommer (2015). According to Johnson et. al (2015) and Sommer (2015), a one-panel scale will suffer from the effect of snow reloading (bridging). Even if the eight (Johnson et. al, 2015) or six (Sommer, 2015) additional panels in the above mentioned studies act as a buffer regard to reload and bridging, we think the dimensions of the NVE snow scale compensate for the lack of buffering panels. The dimensions of the NVE snow scale is 5 x 5 m, as opposed to 3 x 3 m including buffer panels in Johnson et. al (2015) and 2,8 x 2,4 m including buffer panels in Sommer (2015). The specific measurement area of the scale in Johnson et. al (2015) and Sommer (2015) is limited to the centre panel (~0,9 m^2), while the specific measurements area on Møen2525 is as big as the installation (25 m^2). We still believe that a larger measurement area is favourable.

Stranden and Grønsten, (2011) showed that both our NVE scale and the seven panel scale from Sommer worked very well under cold winter conditions, but as described in Fjeldheim and Barfod (2013) when a mild winter with repeated thawing and freezing cycles occurred, the seven panel scaled differed remarkable from the others. The reason for the development of a heavy layer of ice around the seven panel scale could be caused by both site-specific conditions (e.g. the draining possibilities in ground below the scale) or by the scale’s structure (e.g. if water between the panels refreezes). Before any conclusions are drawn, regards the shape, size, material and overall scale-concept (according to i.e. permeability), a more detailed analyse of the data quality that specific winter need to be done.

The scales in Johnson et. al (2015) and Sommer (2015) are made of perforated panels that allows melt water to penetrate to the ground, which again is supposed to level the differences in thermal conductivity between snow and the ground and snow and the snow scale. Our two Møen2525-scales are covered either with wooden boards or wooden beams with a corrugated metal plate on top. The wooden covered scale is more or less as permeable as the scales in Johnson et. al (2015) and Sommer (2015), while the scale with the corrugated metal plate on the top is non-permeable. According to Johnsen et. al (2015), it is essential that the scales allows melt water to percolate, to level the differences in thermal conductivity. The NVE scale with the non-permeable, corrugated metal plate has suffered from technical or structural problems half of the operative time, while only one of the four seasons provided data with good quality. For the last and fourth season, poor data quality *may* be caused by the effect of the non-permeable cover. In addition, this scale is located in a mild, maritime climate where freezing and thawing happens frequently during winter and thus the effect of different thermal conditions is more present (Johnson and Schaefer, 2002).

Passive gamma attenuation sensor

We will recommend the use of a gamma attenuation sensor in non-alpine climate, where snow pillows and snow scales are found to give data with poor quality. However, one of the limitations by using the gamma attenuation sensor is the maximum amount of snow water equivalent measured. As the gamma attenuation sensor calculates snow water equivalent based on measurements of attenuated gamma rays, the maximum level of snow water equivalent is limited by the amount of gamma rays emitted from the ground. We have experienced that when the snow water equivalent exceeds 600 -800 mm (Stranden et. al, 2014), the amount of gamma rays registered by the sensor is so small that the error in the snow water equivalent calculations become too large. Corner (2008), also points out the increasing error in the measurements with increasing snow water equivalent. At locations with less bareground radiation, we have seen that the “threshold level” for reliable data is lower than 600 mm water equivalent. However, the manufacturer are continuously working to improve their sensors, and a larger snow pack may be measured with less uncertainty in the future.

The major advantage with using the gamma attenuation sensor is that layers of crust, ice or windblown snow in the snow pack do not affect the measurements. When installed ~3 m above the ground, the sensor measures the snow water equivalent in area of ~100 m^2, which is much larger compared to any of the other sensors. This makes the gamma attenuation sensor preferable in non-alpine and/or windy climate. Nevertheless, many of the western mountains with non-alpine climate in Norway also have a lot of snow, and the limitation of 600 mm will limit the suitable locations for using a gamma attenuation sensor in Norway.

Another limitation regard the gamma attenuation sensor is the power consumption. The sensor need constant supply of power, which can be a challenge in remote areas. Corner (2008) also points out this limitation. However, in remote areas, without power grid, a solar panel in combination with a windmill may produce enough power. The gamma attenuation sensor need to be maintained at the manufacturer’s each 7th year. It may be challenging and time consuming to maintain the sensor at the manufacture’s, but compared to a snow pillow or at snow scale a 5-10 years lifetime is foreseeable.

Other measurement techniques

A work around to the problem of measuring snow water equivalent might be to measure only snow depth and calculate snow water equivalent. Among others, Sturm et. al (2010) and Jonas et. al (2009) tried to estimate snow water equivalent from snow depth measurements. The motivation for this is the fact that snow depth is quicker and easier to measure in field than snow water equivalent e.g. with ultrasonic sensors or graded sticks, and the number of snow depth stations worldwide exceeds the number of snow water equivalent stations (Sturm et. al, 2010). Jonas et. al (2009) showed that snow water equivalent could be estimated by measurements of snow depth combined with information about site altitude, site location and season. Another way to get an estimate of snow water equivalent could be the combination of automatic registrations of snow depth combined with manual observations of snow density. At places where snow pillows usually fail to work, this might be a good solution. On the other hand, at locations with more than 600 mm snow water equivalent, where a snow pillow or a gamma attenuation sensor will have trouble, manual measurements are not easily done either.

5. Conclusions

During the last six years, we have analysed data from our three different types of snow stations; snow pillow, snow scale and gamma attenuation sensor. All of the installations have both advantages and disadvantages. The climatic conditions, snow conditions and setup-conditions will give guidelines for which installation to be recommended.

The snow pillow (NVE2010) may be a well-suited installation in alpine climate, where mild weather and rain seldom occur during winter. The cost of a snow pillow station, including setup costs, is less than for a NVE snow scale stations or a gamma attenuation station. This combined with less comprehensive groundwork compared to the NVE snow scale, makes a snow pillow preferable at many places. Risk of punctuations and leakage, different thermal conditions, bridging due to ice lenses or windblown snow in the snow pack are some limitations and drawbacks related to the use of snow pillows (Johnson and Schaefer, 2002, Egli et. al, 2009, Johnson et. al, 2015 and Ree et. al, 2011).

We still find the NVE snow scale “Møen2525” promising as a new way of measuring snow water equivalent automatically in Norway. We assume that the effect of different thermal properties between snow and ground and snow and the snow scale (Johnson and Schaefer, 2002 and Johnson and Marks, 2004) and the spatial differences in snow load are minimized with the permeable and increased size. The snow scale might be promising in both continental and maritime climate, regardless of snow amount. The cost of a NVE snow scale, groundwork and installations cost included, is higher than for a snow pillow. Another drawback with the snow scale regard the other instruments, is that the snow scale requires more construction work than a pillow or a gamma attenuation sensor. This may limit the number of suitable locations for a NVE snow scale as the transportation of concrete fundaments and wooden beams could be a challenge, or at least expensive, in remote areas. The benefits and limitations regards other types of snow scales are not fully discussed in this report, and our conclusions regards snow scales are mainly based on the NVE snow scale.

We will recommend the use of a gamma attenuation sensor in non-alpine climate, where snow pillows and snow scales are found to give data with poor quality. However, the gamma attenuation sensor have some limitations, mainly due to the limited measuring range. With more snow than 600 mm, the uncertainty in the measurements are too large. The gamma attenuation sensor is also expensive compared to a snow pillow, but easier to install than the NVE snow scale. Due to relatively large current draw, stations using this instrument should be connected to power grid. This type of sensor also need to be calibrated by the manufacturer each 7th year at the manufacturer’s.

Even if our guidelines are followed, there are no guarantees that the instruments will work properly. Unexpected technical problems and rare weather conditions and ground- and soil water contents may disturb the measurements and hence the data quality. Following the guidelines in this report will nevertheless make the reader better equipped to avoid the problems we have had during the last decades. The development of automatic snow water equivalent measurements are continuously in progress, and new instrumentation and knowledge may improve the quality of snow measurement in future.

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Appendix

A Operational conditions

NVE`s snow measuring sites are all full-automatic with a data logger and they collect real time data 24/7. Figure 5 is a principle sketch of a standard station with snow depth sensor and temperature sensor in addition to instrumentation for snow water equivalent. Data transmission from the data logger goes by GSM/GPRS minimum once a day. Most of our stations gets power supply from solar panel and battery, except from the gamma stations that are connected to the power grid because of the high power consumption.

We measure the following parameters at all our snow stations:

- Air temperature (described in appendix D)
- Snow depth (described in appendix D)
- Snow water equivalent (snow pillow, snow scale, passive gamma attenuation sensor)
- Battery voltage (to ensure charging, and for giving the field hydrologist possibility to e.g. change battery before the station falls out because of lack of power).

Two of our snow stations are also full-climatic stations and measures more than 100 parameters, while other stations are located nearby ground water- or soil water measurement sites. Meteorology-observations and/or observations of ground- and soil water might be helpful for analysing and validate snow data. Recommended supporting parameters are further described in appendix D.

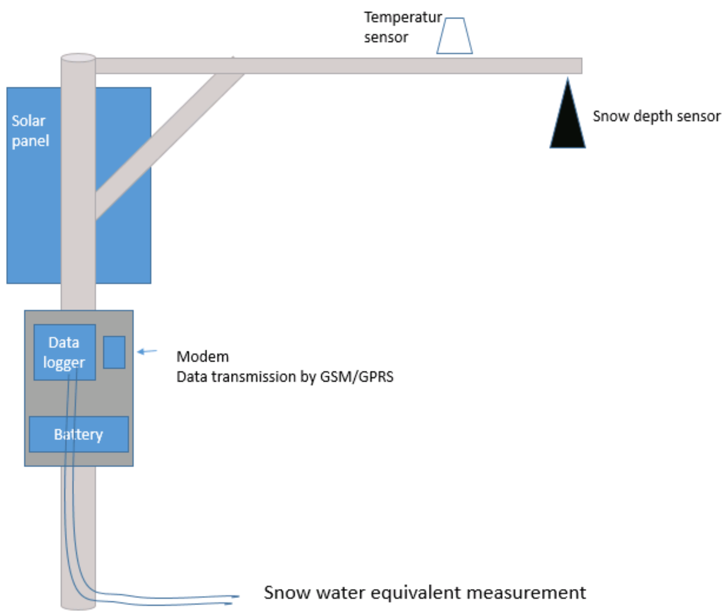

Figure 5. Principle sketch of a snow measuring station with snow depth sensor and temperature sensor in addition to a snow water equivalent sensor.

B Snow pillow NVE2010 – specifications

Nearly all of the stations in the NVE snow station network are equipped with a NVE2010 snow pillow. Figure 6 shows the instrumentation.

Prior to establishing a new snow measurement site thorough observations in field is necessary both summer and wintertime. It is important to find a representative and well-drained location to make a good installation. It is also important to survey wind direction and potential wind transportation over the location to minimize wind effects. To avoid disturbance of nearby obstacles on the snow water equivallent measurements, a minimum distance of 2 meter to the edge of the installation should be kept. For further information about how to find a well-suited location see CEN/TR 15996 (2010) and Ree et. al (2011).

When a proper location for the snow pillow is found, it is usually necessary to do some groundwork before installation. To drainage the area, we recommend that the pillow lie on a bed of 5-10 cm permeable sand with gravel beyond in an area of minimum 3 x 3 m. The area under the pillow must be levelled, and the top of the pillow should fluctuate with the surrounding terrain. Otherwise, the snow cover at the pillow will differ from the surroundings. Drainage around the pillow avoid water lying at or around the pillow, and reduce probability for the pillow to “freeze in”.

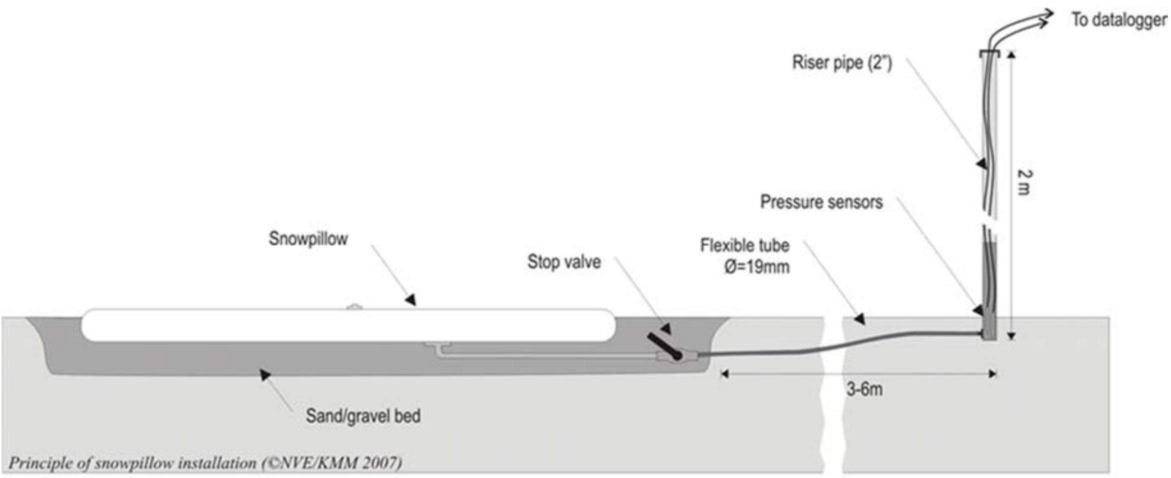

Figure 6 Principle sketch of a snow pillow.

The NVE2010 snow pillow are made of PVC and have an effective measurement area of 2,5 x 2,5 m (6,25m^2). It is filled with at least 700 liters of a mixture of water (70 %) and propylene glycol (30%) to a thickness of 10 cm. The freezing point of this liquid is then about -15^{o}C. If the pillow is located in an area with very low temperature prior to the earliest snowfall during autumn, a higher content of propylene glycol can be used to lower the freezing point of the liquid. The pillow is easily filled with anti-freeze through the vent at top of the pillow or through the riser-pipe. When filling the pillow with liquid it is important to ensure that no air bubbles captures inside the pillow. A higher concentration of propylene glycol in the riser pipe lowers the freezing point, and is highly recommended.

Different types of anti-freeze solutions has been tested and evaluated in NVE (Ree et. al, 2011), and we recommend to use propylene glycol as anti-freeze. Other anti-freeze solutions can be used, but be aware of the corrosive effect and that they are compatible with the pillow membrane material, as described in chapter 2. Commercial name of the propylene glycol used by NVE is “Brineol MPG 20” and it is non-toxic according to existing regulations (Kemetyl 2015).

In NVE, it is standard to locate the pressure sensors in a riser pipe. Bottom of the riser pipe should be levelled beneath bottom of the pillow. We use two separate sensors to provide redundancy and to be able to detect sensor errors. Advantages by placing the sensors in a riser pipe compared to place it directly in the pillow is that it is much easier to change sensors when necessary, and it is easy to inspect the level of liquid in the pillow by observing the liquid level in the riser pipe. The instrumentation are also more protected for small rodents that may gnaw over wires. Decreasing liquid level in the riser pipe indicate a leakage and if necessary refill of anti-freeze solution can be done through the riser pipe. Drawbacks by using pressure sensors in riser pipes compared to place the pressure sensors directly into the pillow, is that the riser pipes are more exposed to low temperature and freezing during early winter with less snow. This might cause errors and incorrect measurement. Hence, it is critical to calibrate the sensors to a temperature range below zero. It is also important to ensure that the pressure sensors tolerate the anti-freeze solution. We have gained experiences with pressure sensors membrane being dissolved because of the corrosive anti-freeze solution. Ethanol is a corrosive liquid and for pillows filled with this it is recommended with special sensors (e.g. FEP or Hytrell). Propylene glycol is less corrosive, so ordinary pressure sensors may be used in those pillows. However, we do recommend an antifreeze-tolerance test in advance.

To simplify the precise location of the pillow during winter, when it is all covered by snow, the location of the pillow should be marked with e.g. reference poles. It might also be necessary to protect the installation against animals and skiers/hikers by a fence. Ensure that the fence does not disturb the accumulation and melting of the snow pack, and have a minimum distance to the edge of the pillow of at least 2 meter. If possible, the pillow should be covered with a suitable cover during summertime to prevent damage. It is also possible to fasten an e.g. poly-wood plate on top of the pillow by straps to protect the pillow in both summer- and wintertime. This would also prevent relief of pressure through snow season, and reduce risk of punctuation when doing manual measurement at the site.

We do recommend annual inspections of the snow pillow prior to first snow fall. The zero point of the pressure sensor need to be confirmed annually and the snow pillow should be cleaned and visually inspected to see if there are any signs of leakages or damages of the pillow or rest of the instrumentations. We do recommend to refill a 50%-50% mixture of water –propylene glycol in riser pipe annually to maintain the freezing point of the anti-freeze solution in the riser pipe.

Further descriptions and guidelines for installations of snow pillow and snow mass registrations devices are given in CEN/TR 15996 and Ree et. al 2011 (appendix F).

C The NVE Snow Scale "Møen2525" – specifications

Guidelines for finding a good location for snow scale are the same as for snow pillow. The area should be well drained, and it is important to survey wind direction and potential wind transportation over the location to minimize wind effects. Further information about how to find a well-suited location are given by CEN/TR 15996 (2010) and Ree et. al (2011).

In absence of a commercial snow scale, NVE designed their own scale in 2008, called "Møen2525". Figure 7 is a principle drawing of the snow scale. The Møen2525 scale is based on a standard scale principle with a frame mounted on four load cells. The scale are dimensioned to measure a maximum snow water equivalent of 1000 mm, but upgrading to higher snow loads is easily done.

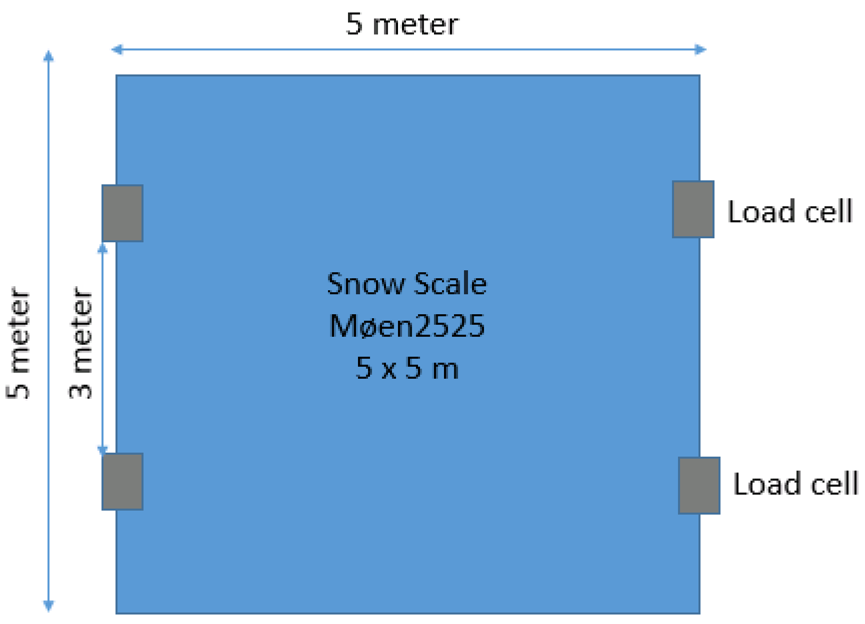

Figure 7. Principle sketch of the snow scale "Møen2525".

Prior to installation of a NVE snow scale, comprehensive groundwork need to be done. It is preferable to install the scale on frost-free masses, and the area need to be well drained to avoid influence of ground - and soil water. Top of the scale should fluctuate with the terrain around. The precompiled scale has a height of 35 cm, and at most location it is preferable to use an excavator to dig the 40-50 cm deep hole for building the scale. The scale lies on four pillars of concrete with loads cells at top, shown in Figure 8. The concrete fundament for each load cell must be dimensioned for at least 5 tons, and have a diameter of 300 mm. The top of the four fundaments should not have a relative height deviation greater than 10 mm, and each concrete fundament need to be completely plane and smooth (accuracy ±1mm/m). The soil conditions determine whether the masses around the scale need to be stabilized with e.g. a small retaining wall. We do recommend using steel-liner between the girders and the weighing cells to stiffen the constructions and avoid deformation of the girders. Top of the scale can be made of e.g. impregnated wood. Figure 9 are a more detailed sketch with dimensions of the girders and the wooden topside.

It is important that top of the scale allows melt water to percolate through (e.g. Johnson and Schaefer, 2002). This would minimize the thermal difference between the scale and the surrounding soil. The NVE snow scale are made with a top layer of wooden beams, and even though the wooden boards will moisten during the autumn, we do believe that the moisture content in the wooden boards are constant during winter and spring and hence do not influence the measurements.

Avoid installations at locations with high groundwater level/water level during spring, as rapidly raising groundwater level or melt water may cause the scale to float.

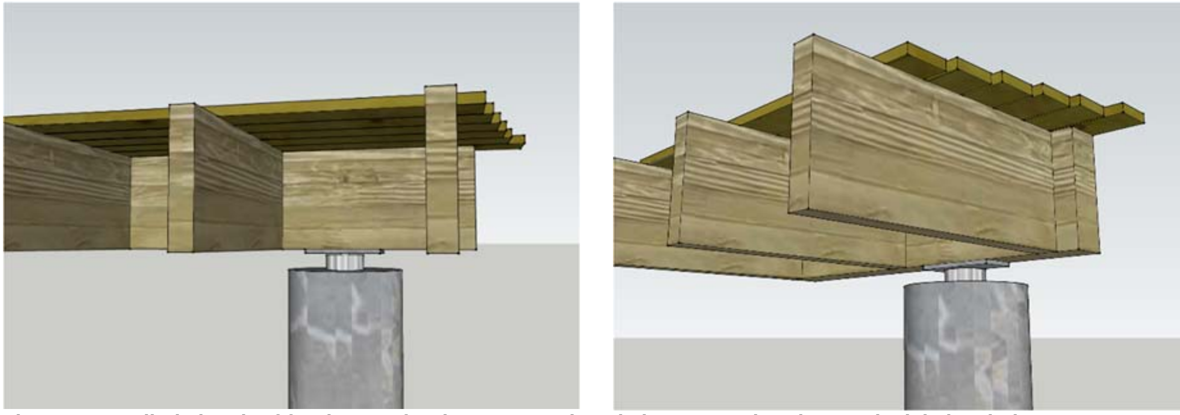

Figure 8. Detailed sketch of fundament for the snow scale. It is important that the top deck is leveled with the surrounding terrain.

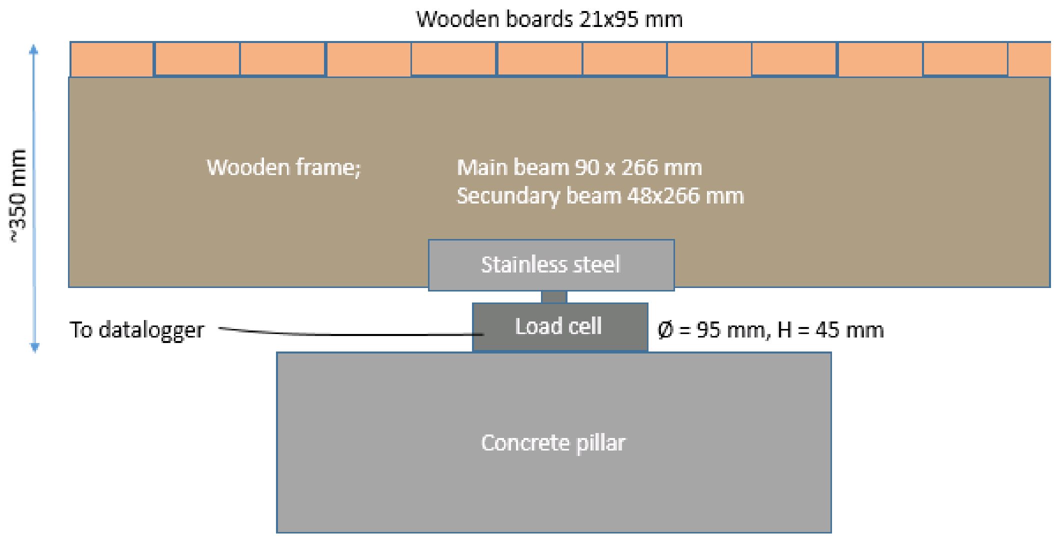

Figure 9. Dimensions of the different parts of the Møen 2525 snow scale.

D Recommended supporting parameters

To make it easier to detect and correct errors in the automatic snow water equivalent data we do recommend measurements of some additional parameters:

Air temperature

Air temperature at the stations are essential to distinguish between precipitation as rain and precipitation as snow, and hence an important parameter for evaluate and validate SWE data. The station may have a separate temperature sensor or one integrated with the snow depth sensor.

Snow depth.

Measurements of snow depth is an important supporting parameter since SWE is highly correlated with snow depth. If the snow depth start to accumulate without being followed by an increase in SWE the snow is either extremely fair or it indicates that something may be wrong. A decrease in snow depth normally happens when the snow start to settle and do not give any indication on trouble.

The most common type of snow depth sensor used at snow measurement stations are ultrasonic sensors (Figure 10), but other techniques e.g. laser and radar are also possible. The ultrasonic sensors emit ultrasonic waves (50 kHz) to the snow surface, and calculates the distance to the snow surface by measuring the time delay of the echo that is reflected back from the surface. Since the speed of sound in air varies with temperature, the temperature must be measured in order to compensate for this. NVE has experienced that the difference between temperature corrected snow depth and not-temperature corrected snow depth can be up to several tens of centimetres (Ree et. al, 2011). Older snow depth sensors (e.g., Campbell SR50 and SR50A) does not have a temperature sensor included, and the correction need to be done retrospectively. Newer snow depth sensors (e.g. Campbell SR50AT and Summer Messtechnik USH-8) has its own temperature sensor, and does temperature correction automatically.

Figure 11 shows a principle sketch of an instrumentation for snow depth measurement. The height of the snow depth sensor depends of how much snow that is expected in addition to a blanking zone. The blanking zone for the instrument varies with different producers, but are usually around 0,9 m. The measuring field for the sensor depends on the height of the sensor and the beam angle of the instrument e.g. 12^{o} for USH-8 sensor and 30^{o} for Campbell SR50AT. To avoid interruption in the measuring field it is important to have long enough distance between the pole and the measuring field (Figure 11).

Limitations regards a snow depth sensor and its data quality may be that very fair snow or windblown snow during snow storms may lead to false registration of data. The membrane inside the sensor also need to be changed on regular basis.

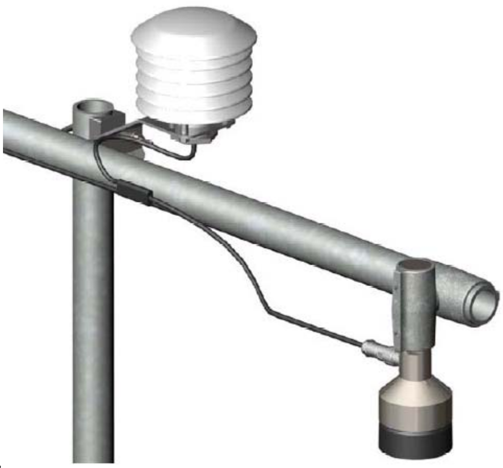

Figure 10. To different types of Snow depth sensors. A: Campbell SR50AT, Photo: www.campbellsci.ca B: Sommer USH-8, photo: http://www.sommer.at/

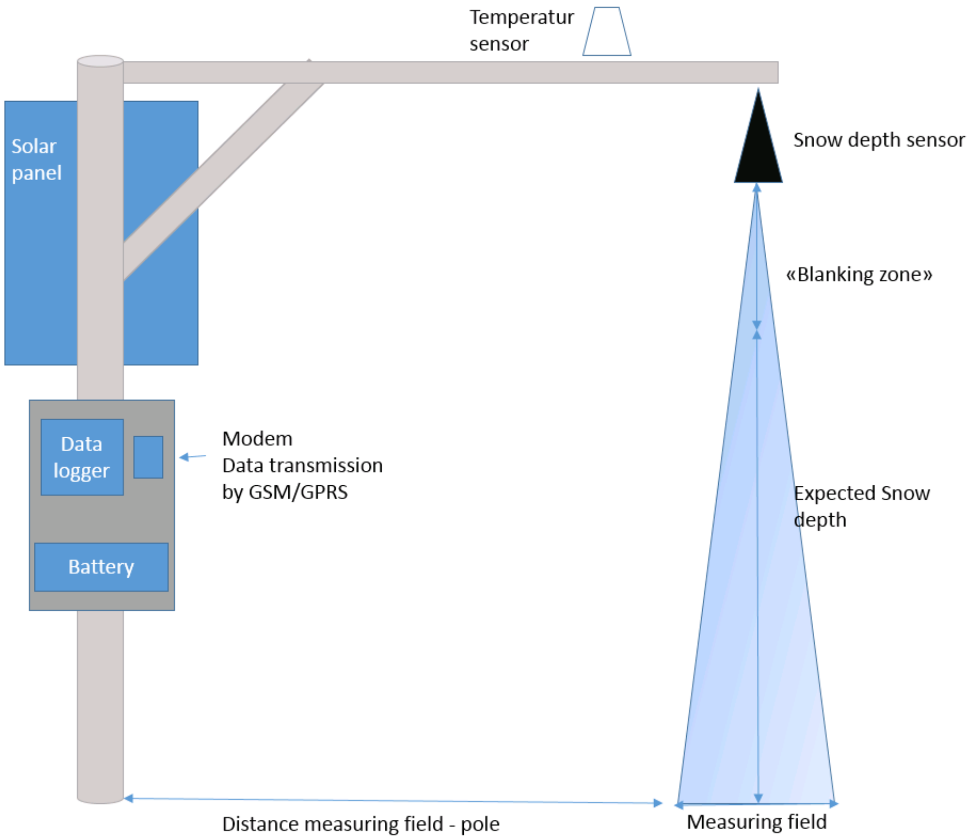

Figure 11. Principle sketch of a snow depth sensor instrumentation.

Manual control measurement

When establishing a new snow station it can be valuable to measure the snow water equivalent manually on regular basis, at least during the first season. We would although recommend to do it every season in order to detect irregularity in the automatic registrations.

When doing manual measurements it is always a risk of inaccuracy and human errors. It is thus recommended that the crew are well educated, and if possible, the same crew measures the same station each time. It is also important to use suitable equipment as different types of cutters and tubes have different sources of errors and ads bias to the measured values (as mentioned in e.g. Strurm et. al, 2010 and CEN/TR 16588, 2014). NVE recommends 10-25 measurements of snow depth (depending on the size of the station and the instrument type) and 2-3 measurements of snow density at each control campaign.

Precipitation

Combined with measurements of temperature, measurements of precipitation is a very useful supporting parameter at snow measurement stations. At three of NVE`s snow water equivalent stations we have Geonor rain gauge, otherwise precipitation data from nearby meteorological stations are used.

Soil moisture content

The gamma attenuation sensor measures attenuation in radiation from two radioactive isotopes, Potassium (^{40}K) and Thallium (^{208}Tl). As the radiation first has to penetrate the top soil, differences in soil moisture content and ground water level may influence the registrations.

We have experienced, when the ground- and soil water content increases notably due to snow melt, it may affect our gamma attenuation measurements. In particular, we have observed this at one of our stations, which is located in the bottom of a valley. Melt water from the surroundings hillsides results in significant increasing soil- and ground water, in which again results in spikes in the SWE-data from the gamma attenuation sensor. Even though this spikes are easy to detect and removed from data, measurements of soil water content would give valuable information about what is going on.

Snow temperature

At three of four of our stations with gamma attenuations sensor, we also measures temperature at the ground and temperature in the snow pack 15 cm above the ground. Reduction in snow water equivalent due to melting (not evaporation and sublimation) will cause liquid water in the snow pack, which percolates down towards the ground. With a high-resolution temperature sensor at the above mentioned positions, this process can be pinpointed in time and used as an indication if an observed reduction in SWE is plausible or might be erroneous. The importance of measurements of snow temperature near the ground is also pointed out in Johnson and Marks (2004).

E Estimated cost per snow water equivalent sensor/ station.

Estimated cost (in €) per each type of snow water equivalent sensor/station are given in Table 10. **Basis costs** includes among others snow depth sensor, temperature sensor (PT100), and instrument cabinet and power supply. The basis cost for the gamma attenuation sensor are slightly lower than for the snow pillow and snow scale mainly due to the differences in power supply. As a solar panel will give sufficient power to a snow pillow or a snow scale, the gamma attenuation need to be connected to the power grid. The installation costs by connecting the sensor to the power grid is estimated to be slightly lower than the cost of a solar panel. When the gamma attenuation sensor is installed with solar panel and a windmill, additional cost nedd to be added.

As in Table 10, there are differences in estimated cost related to field work/installation of the different snow sensors. **Fieldwork cost** includes personnel cost (construction workers, hydrologist and/or engineers), rent of machinery and ground work. Due to the more complex groundwork prior to installation of the snow scale, e.g. concrete pillars and more, and more time consuming installation, the cost for the snow scale is higher than the others. The cost related to personnel may vary from location to location and among countries and companies.

The **SWE-sensor cost** for a snow pillow includes a 2,5 x 2,5 m snow pillow with riser pipe, pipe coupling, “Brineol BPG 20”-glycol and two pressure sensors. The SWE-sensor cost for the NVE snow scale “Møen2525” includes concrete, wooden beams- and boards and four pressure cells. The SWE sensor cost related to the gamma sensor are exclusively related to the specific sensor.

A snow depth sensor need maintenance in field each 7th year, while the expected lifetime for e.g. instrument cabinet and solar panel and battery is 8-10 years. Expected lifetime for the different snow water equivalent sensors is from 5 years (snow pillow) to 10 years (snow scale). The gamma attenuation sensor needs maintenance each 7th year at the manufacturer’s. The snow scale Møen2525 has only been tested for 5 years by now, but all its components are supposed to have a lifetime of at least 10 years. E.g., a fence to prevent animals and others on the pillow may extend the lifetime of a snow pillow.

Table 10. Estimated cost (in €[6]) per each snow water equivalent station

	Basis cost[7] in €	Field work[8] cost in €	SWE-sensor costs €	Total cost in €	Estimated lifetime
Snow pillow	7400	2600	3700	13700	5-8 yrs.
NVE Snow Scale "Møen 2525"	7400	10100	5800	23300	~10 yrs. (but only 5 yrs. experience by now)
Passive Gamma attenuation sensor CS725	7100	2600	18000	27700	Need maintenance at manufacturer's each 7th yr. We have only 5 yrs. experience by now.

[6] Exchange rate EUR –NOK by September, 30 2015 (1 NOK = € 9,52)
[7] Basis cost includes snow depth sensor on a mast/pole, temperature sensor, instrument cabinet, and logger for transferring data to NVE, modem with GSM-subscription, solar panel or power grid fee and battery.
[8] Field work includes work done by NVE personnel (hydrologist and engineers), construction workers and rent of machinery including mechanical digger and digger diver if necessary. The personnel cost may vary, and the field work costs are hence guiding costs.

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