Dear referee:

Thank you very much for your careful review and valuabe suggestions, the revisions were made as follows:

The authors present a data set of liquid water content (LWC) profiles recorded with the Finnish Snow Fork over the course of two winter seasons. The recorded profiles are statistically compared to measured air temperature and snowmelt rates or basal discharge (?) during different prevailing meteorological conditions. A special focus is set on so-called rain-and-snow (ROS) events. The main outcome of the manuscript is that LWC is dependent on high air temperature, net radiation and rain-on-snow events which is quite trivial and known since the early beginning of snow science. In addition, the authors describe how to measure and calculate the energy balance. Temporal evolution of LWC are presented and discussed based on prevailing weather conditions. Statistical models based on air temperature and LWC profiles are presented.

At present state the manuscript does not fulfil the requirements and standards for being published in The Cryosphere. Methods, data, results and discussion are erroneous and do not substantially improve our understanding on the field of melting snow covers. Many assumptions are wrong and the interpretations of the results leads to the conclusion that the authors misinterpret known and general valid physics in wet snow science (see major points). The manuscript does not fulfil the requirement of good scientific practice. Analysis, data and interpretation are not clear and comprehensible. Language is not concise which results in a text which is hardly comprehensible. The manuscript lacks a detailed and correct presentation of the used methods. In fact, I am quite surprised that the manuscript passed the relatively demanding editor process of TCD.

Answer: The liquid water in snow comes from snowmelt or rainfall. In the absence of rainfall, liquid water comes from snowmelt generated by sensible heat, latent heat and net radiation. The liquid water decrease due to discharge and refreeze. So the analyze of the distribution and temporal variation of LWC was influenced by those factors in this paper. Many studies analyzed the characteristics of LWC, However, those studies usually conducted at one day or a few days. Furthermore, due to the limit of the measurement methods, the vertical resolution of measured LWC was usually very low. Thus, we measured the snow LWC at every 2 cm depth from the surface to the bottom using a Finnish Snow Fork gauge almost every day in snowmelt period. Many studies analyzed or simulated the liquid water movement in snow according to the melt water waves, or using the method of dye tracer. But those studies seldom measured or analyzed the value and variation of LWC, especially in the natural snow, which was conducted in our study. Some studies analyzed the ROS event effect on snowmelt, these studies usually focused on the change of snowmelt rates, but didn’t measure or analyze the snow LWC. So we chose three ROS event to analyze the variations of LWC under different weather conditions. Based on our observations, the snowmelt period was divided into three stages, and then we propose three typical LWC diurnal and vertical profile types in the three stages. Through using Snow Frok, we can easily and rapidly distinguish the three profile types, and the variation of LWC under different weather conditions in different period. It might be more practical and sufficient for avalanche and runoff forecasting.

(1) The paper relies heavily on measurements performed with the Finnish Snow Fork. Although all results are based on these measurements no error analysis was performed. Based on some results and Figures, it is obvious that the error is far from negligible. The authors mention in their

Introduction the work presented by (Techel and Pielmeier, 2011) where the accuracy of the Snow Fork was discussed and compared to the Denoth-capacity probe (Denoth, 1994). In that publication the authors measured dry snow using the Snow Fork and obtained values ranging from 0.3% to 1.8% by vol. for dry snow. The presented Figures suggest that the authors do not know at which resolution LWC values are obtained with the presented method. The accuracy of the method is probably in the range of 1% by vol. and Figure 4a shows just dry snow conditions. The differences in the values just reflect differences in density showing snow layers with low density on top of dense snow. The basal layers which consist of depth hoar are again less dense. So I guess that the pre-melt season is simply the period where dry snow conditions prevail. A temperature profile could verify this. Figure 4b shows in a very nice the advancing of the wetting which is known to have shock-wave like pattern (Colbeck, 1972). The explanation (p. 4148, lines 6-14) for the shape of liquid water distribution makes no sense to me. Low air temperature is not connected to this process. The authors claim to show spatial distributions of liquid water content, but in fact they just present the time evolution in 1-D. In some sections the explanation reveal that the authors did not understand the present knowledge on water movement in snow. In section 2.5 the authors try to explain some sort of tipping-bucket model for water transport or in other words the water-holding capacity. The entire section is incomprehensible as important variables of Eq. (14) are not explained. Eq. (15) does not explain the fraction of ice, but rather some sort of porosity. What do you mean with partial density of ice on p. 4145, line 10?

Answer: In the revised paper, we add the analyses about the accuracy of LWC measurement as follow: snow LWC measurement ranged from 0 to 10%, with accuracy of 0.3%; snow density measurement ranged from 0% to 0.6 g cm^{-3}, with accuracy of 0.005 g cm^{-3}. In order to check the measured accuracy of the LWC, we measured the LWC in dry snow (hand test dry and snow temperature≤-0.2℃, from Dec 12, 2009 to Jan 3, 2010). The Snow Fork recorded a range from 0% to 0.67%, mean LWC=0.05%, median LWC=0%, standard deviation=0.097%, n=772. 73.6% of the LWC were 0%, 95.3% of the LWC were less than 0.3%. Kattelmann et al (1999) and Techel et al (2011) measured the snow LWC, results showed small liquid water have been measured in snow with snow temperature below 0℃ (LWC<1%). Thus, the LWC measured using Snow Fork was reliable. In order to analyze the spiatial variation of LWC influence on the measured accuracy. The LWC datasets measured in spring 2009 (from March 11 to March 30 2009) were chosen to analyze the influences of LWC spatial distribution on the accuracy of measurement, The LWC was measured using the same method, the maximum and minimum snow depth was 67.5 cm and 16 cm, respectively. At this year, two profiles of LWC was measured each time, the distance between two profiles was bigger than 0.3 m. The range of LWC was from 0% to 5.12%, the average value was 1.61%. Figure 1a shows LWC distributed near the symmetrical line in different wetness conditions. The LWC data of two profiles were analyzed using the paired-samples T test, which indicated that there was no significant difference between the LWC of two profiles (p=0.054>0.05). Figure 1b shows the average difference of LWC was 0.25%, 71.5% of the differences were not bigger than the measurement accuracy (0.3%), 17.9% of the differences ranged from 0.3% to 0.6%, 10.6% of the differences were bigger than 0.6%. The differences which were bigger than measurement accuracy mainly distributed in the range of LWC was bigger than 1% (figure 1c). The differences which were bigger than measurement accuracy may be caused by spatial variations of LWC. The observation site was chosen in the meteorological observation field (in spring of 2009 and 2010), with the uniform underlying surface and meteorological condition, so the influence of spatial difference on LWC is very small. When the LWC was bigger than 1%, the average of differences was 0.368%, so the spatial variation of LWC was from 0.068% to 0.368%. When the LWC was less than 1%, the average of differences was 0.121%, so the spatial variation of LWC was from 0 to 0.121%.

We reanalyse the snow LWC distribution and movement in snow, and add the analyses in the section 3.2 as follow: In the transitional period (figure 5a), from the snow surface to the 10 cm under the snow surface, the snow temperature was bigger than 0℃ in the midday, which indicated the snow melt occurred in the snow surface. From the 20 cm under the snow surface to the bottom, the dry snow conditions prevailed, and the snow temperature was below 0℃. Thus, the snow period was in the transitional stage that the surface snow began to melt and the LWC gradually increased but still less than the liquid water-holding capacity. We want to emphasize that surface snow began to melt and have partly liquid water movement in the snow layer, but no liquid water was drained from the snowpck. So we used the “pre-snowmelt period” to define the stage.

In the mid-snowmelt period (figure 5b), we revise the explanation of the liquid water distribution as follow: in the depth range of 0 to 30 cm, the diurnal variation of mean LWC drastically increased from 0.36% to 2.74%. The snow temperature showed that snow liquid water refreeze in the night and melted in the daytime, for example, the minimum and maximum air temperature were -8.5℃ and 9.5℃, the lowest and maximum snow temperature in 23 cm depth were -0.77℃ and 0.1℃, respectively. Thus, the LWC’s drastic change in this depth range can be attributed to the effect of refreeze-melt cycle. The interface between fine snow and coarse snow was just located in the range from 30 cm to 40 cm depth under the snow surface (the interface located in the 34 cm depth in this day), where fine-grain snow overlies coarse-grain snow, liquid water accumulated in the boundary due to the capillary pressure difference (Wankiewicz, 1979; Hirashima et al., 2010). Retention of water by this mechanism was considered to exceed the storage potential between snow grains (Colbeck, 1977). Waldner et al’s (2004) experiments indicated that the refreezing processes may have caused the retardation at the different snow grain size layer boundary. So the liquid water from the upper layer accumulated in this depth in the daytime. Furthermore, due to the snow temperature was bigger than 0℃, the liquid water didn’t refreeze in the night. Thus, this snow layer was a liquid water source for the next layers. The drastic decrease from 30 cm to 40 cm depth may be ascribed to the snow grain size difference. From 40 cm to the snow bottom, the diurnal change in LWC was small and stable (i.e., from 0.37% to 0.43%). The variation characteristics of snow LWC determined the variation characteristics of discharge (Figure 6b). Due to the impeding effect of the capillary pressure difference, the liquid water was absorbed and retained in the snowpack, the observed snowmelt rate was different from calculated snowmelt rate, and high discharge was not formed.

In the late-snowmelt period (figure 5c), we add the explanation of the liquid water distribution as follow: With LWC increased, the snow was under saturated condition in the daytime. Tusima (1978) demonstrated the growth speed of snow grain diameter have an inverse relationship with the square of grain diameter under saturated conditions. Thus, the growth speed of fine grain diameter is bigger than coarse grain snow. As the grain diameter difference between fine grain and coarse grain gradually decreased, the properties of the whole snow became relatively uniform in the late-snowmelt period. The phenomenon that the liquid water was absorbed and retained in the snowpack due to the impeding effect of the capillary pressure differences disappeared. The rate of metamorphism is greatly accelerated under saturated conditions and grains are coarsened

(Wakahama, 1975). These larger grains are responsible for the increase in hydraulic conductivity (Glass et al., 1989). Furthermore, because of the larger grain size in the saturated condition, the intrinsic permeability of the porous medium is higher than in the unsaturated condition (Colbeck, 1974). Thus, the liquid water rapidly flowed to the next layer and discharged in this period. Figure 6c showed the observed discharge flow only one hour lagged behind the snowmelt calculated according to the energy budget, and the time of liquid water outflow was comparatively concentrated.

In the section 2.6 (snow liquid water-holding capacity), we add the explanation of the variables of Eq. (14). The ice mass fraction of snow (f_{ice}) can be calculated using the follow equation:

$$m_{ice} = m_{snow} - m_{water}$$

$$f_{ice} = \frac{m_{ice}}{m_{snow}} = \frac{m_{snow}}{m_{snow}} - \frac{m_{water}}{m_{snow}}$$

$$f_{ice} = 1 - \frac{m_{water}}{m_{snow}}$$

$$f_{ice} = 1 - \frac{\frac{m_{water}}{v}}{\frac{m_{snow}}{v}} = 1 - \frac{\frac{m_{water}}{v}}{\rho_s} = 1 - \frac{\frac{v_{water} \times \rho_{water}}{v}}{\rho_s} = 1 - \frac{W_{vol}}{\rho_s}$$

Where f_{ice} is the ice mass fraction of snow, m_{ice} is the unit snow volume of ice mass, m_{snow} is the unit volume of snow, m_{water} is the unit snow volume of liquid water mass, v is the unit snow volume, ρ_{water} is the water density, v_{water} is the liquid water volume, W_{vol} is the LWC by volume, and $\gamma_{\mathrm{i}} = \frac{m_{ice}}{m_{snow}}$ is the partial density of ice.

Colbeck, S. 1974. Water flow through snow overlying an impermeable boundary. Water. Resour. Res., 10, 119-123.

Colbeck, S. 1977. Roof loads resulting from rain-on-snow. CREEL Report 77-12. U.S.Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, pp, 16.

Glass, R., Steenhuis, T., and Parlange, J. 1989. Wetting front instability, 1. Theoretical discussion and dimensional analysis. Water. Resour. Res., 25, 1187-1194.

Hirashima, H., Yamaguchi, S., Sato, A., and Lehning, M. 2010. Numerical modeling of liquid water movement through layered snow based on new measurements of the water retention curve. Cold Reg. Sci. Tech., 64, 94-103.

Kattelmann, R., and Dozier, J. 1999. Observation of snowpack ripening in the Sierra Nevada, California, U.S.A. J. Glaciol., 45(151), 409-416.

Wakahama, G. 1975. The role of meltwater in densification processes of snow and firn. IAHS Publication 114, pp, 66-72.

Waldner, P., Schneebeli, M., Ute Schultze-Zimmemann., and Fluher H. 2004. Effect of snow structure on water flow and solute transport. Hydrol. Process., 18, 1271-1290.

Wankiewicz, A. 1979. A review of water movement in snow. In: Proceedings Modeling of Snow Cover Runoff (ed. by Colbeck, S., and Ray, M), U.S.Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, pp, 222-252.

Techel, T., and Pielmeier, C. 2011. Point observations of liquid water content in wet snow-investigating methodical, spatial and temporal aspects. Cryosphere., 5, 1-14.

Tusima, K. 1978. Grain coarsening of ice particles immersed UB pure water (in Japanese with English abstract). Seppyo 40, 155-156.

(2) Modelling and measurements of the energy balance are presented, however, why these calculations were done is nowhere explained. I guess that snowmelt rates were calculated based on energy balance in combination with snow density, but this is not mentioned within the text. In some parts of the text the authors talk about snow melt in other I assume that the authors rather want to say basal outflow or discharge. The energy balance and its component are expressed as energy with the unit MJ m^{-2} but then described as fluxes (Wm^{-2}), e.g. sensible heat flux (p. 4142, line 15). It is a bit puzzling why the recording of air temperature, which is fairly simple, is explained in detail while other components necessary to accomplish energy balance calculations (e.g. snow surface temperature) are completely neglected. Where does the information of the snow surface temperature in Eq. 5 (p. 4142, line 21) come from? Did the authors correct z_0 for varying snow heights?

Answer: we analyzed the relationship between energy balance and LWC in different snowmelt periods in the section 3.1. We also analyzed the influencing of ROS eventson the energy balance, and then analyzed the variation of the LWC in the section 3.3. Furthermore, we add the calculated snowmelt according to the energy balance in snow surface. Through comparing the observed snowmelt rate and calculated snowmelt rate, we analyzed the influencing of snow melt and liquid water movement on LWC in the section 3.2.

In the original paper, the snowmelt rate was observed through snow lysimeter. In the revised paper, snowmelt rate was obtained through two methods: snow lysimeter (observed snowmelt rate) and calculated according to the energy balance in the snow surface (calculated snowmelt rate). The observed snowmelt rate was observed through lysimeter. A galvanized iron box of 1 m×1 m×0.05 m was placed before snowfall in the winter. A tube was welded at the bottom of a corner. The snowmelt water was discharged through the tube and was collected by a plastic kettle. To avoid the loss of water result from evaporation and splash, the inlet diameter of the plastic kettle was bigger than the tube diameter no more than 1 cm. The snowmelt water was weighed every 2 h in the daytime, 1-3 times in the night. The accuracy of the electronic balance is 0.001 kg (1 g).

If the snow temperature is 0℃, the calculated snowmelt rate can be computed using the following equation (Kuchment et al, 1996):

$$S_c = \frac{Q_m}{\rho_i L_{li}} \times S \times \rho_w \tag{17}$$

where S_c is the calculated rate (kg m^{-2} h^{-1}), Q_m is the total energy (MJ m^{-2}), ρ_i is the ice density (917 kg m^{-3}), ρ_w is the water density (1000 kg m^{-3}), L_{li} is the heat of fusion (J kg^{-1}), S is the snow lysimeter area (1 m^2).

In the original paper, we didn't use unit Wm^{-2} to express the energy balance and its component.

In the revised paper, we add the explanation of snow surface temperature and snow temperature. The snow surface temperature was calculated using the following equation:

$$T_{ss} = \left(\frac{L\uparrow}{\varepsilon\,\sigma}\right)^{\frac{1}{4}} - 273.15 \tag{4}$$

where T_{ss} is the snow surface temperature (℃), $L\uparrow$ is the upward longwave radiation, the value was measured using pyrgeometers (EKO Instruments Co., Ltd. with a precision of ±2.5%), ε is the snow emissivity (0.98), σ is the Stefan-Boltzmann constant (5.670303×10^{-8} W m^{-2} K^{-4}).

Snow temperature was measured (precision=0.2 ℃) by the platinum resistor probe (RTD) of a dual-channel RC-500+ automatic recorder (supplied by JingChuang Electronics Manufacturing

Co., Ltd., Shanghai). The probes, which were buried after a snowfall, were positioned at precise depths under the snow cover. The upper seven temperature probes were positioned at 0, 2, 5, 10, 15, 20, and 30 cm from the snow surface. A probe was permanently placed at the base of the snow layer, whereas the other probes were placed according to the actual snow depth. To avoid movement caused by gravity, the probes were held by a self-made wooden stand. The wooden stand was pierced with holes at 1 cm intervals; the probes were inserted into snow through the holes and paralleled with ground surface, which allowed the compaction of the snow cover to be observed. To avoid the air pathway, the wooden stand which adjoined the snow pit was buried by the nature snow. The snow temperature data were collected at ten-minute intervals. We did not correct z_0 in different snow heights; the value of z_0 was taken to 0.006 m according to Boon's study. In the original paper, I miswritten "0.06", but the correct value was used in the calculated process.

(3)In the last section of the Results and Discussion part, the authors present regressions of snow height with liquid water content. Could you please provide any explanation on the physical validity of that assumption?

Answer: we add the explanation on the physical validity of the assumption in this section as follow: The snow depth has inverse relationships with snow LWC and the snowmelt, snow depth decrease while snow LWC increase. The snow depth influences on the advancement of the wet front. Under the influence of snowfall, the snow depth increase but LWC decrease. During and after snowfall, gravity forces are concentrated in the grain bond, which break, slide, partly melt and so on (Golubev et al, 1998), this process is usually with snow depth decreasing. The effect on the average LWC in the snowpack is dependent on the thickness of the snow cover. A thin snow cover would require much less melt to achieve a certain value for average LWC than a thick snow cover. In this section we use "Regression equation of snow average LWC" instead of "Regression equation of snow average LWC". The expression of average LWC maybe removes the confusion about the regression.

Golubev, V., and Frolov, A. 1998. Modelling the change in structure and mechanical properties in dry-snow densification to ice. Ann. Glaciol., 26, 45-50.

(4) Throughout the paper, there are many grammatical errors and misused words. I am well aware that it can be difficult for authors whose first language is not English to prepare a paper to be published in an international journal. However, the poor language makes the paper hard to follow and leaves the reader confused. In addition, structure is missing in every section. Parts of the methods are presented at the end of the Results section, the manuscript stops with a short discussion and a proper Conclusion is not provided. It is hard to understand what kind of data were used for which analyses. A thorough discussion of the results is missing.

Answer: we revised the grammatical errors and misused word as far as possible. We revised the conclusion and explained what kinds of data were used for analyses. We also added a thorough discussion in the revised paper. Based on our observations, the snowmelt period was divided into three stages, then we propose three typical LWC diurnal and vertical profile types in the three stages. Through using Snow Fork, or hand test method, we can easily and rapidly distinguish the three profile types. It might be more practical and sufficient for avalanche and runoff forecasting. In the transition period (figure 5a, type 1), the diurnal freeze-melt cycles only occurred in the snow surface. From the 20 cm under the snow surface to the bottom, the dry snow condition prevailed. Due to the lower snow temperature, snow didn't melt intensely, so melt-freeze crust was not easily formed in the snow surface. With the energy and liquid water from the rainfall increased, the snow LWC increased. Influenced by the effect of capillary barrier, the liquid water accumulated at the boundary between fine grain snow layer and coarse grain snow layer. In mid snowmelt period, the liquid water in low snow layer remains less (figure 5b, type 2). The diurnal freeze-melt cycles frequently occurred in the upper snow layer, which caused the melt freeze crust formed. Furthermore, the liquid water accumulated in the upper snow layer, and the snowfall, sleet and rainfall event frequently occurred in this period, which easily leads to the intense avalanche activity. At this stage, first water discharge at the base of the snowpack can be observed. Due to the liquid water content was absorbed and retained in the snowpack, the water outflow was less and changed with time slightly (figure 6b). However, we should pay special attention to the first snowmelt flood due to the breakup of river ice in this period. In our study area, the first snowmelt flood usually is the most destructive hydrological events in the spring. With the liquid water increase and wet snow metamorphism, the snowpack gradually become fully wet and homogenize (figure 5c, type 3). At this stage, more preferential paths established due to the coarser grain. The water infiltrated at high speed, the outflow will respond quickly to additional input of melt water (Singh et al, 1997). Thus, a flood peak formed in every day in this period (figure 6c). A large amount of energy may be supplied by a rainfall event, but the rapid percolation rates lead to very little energy exchange for melt. Contrary to the clear day, the snowmelt flood was not easily formed in the rainy day (17 Apr, figure 11). If the snowpack was under high saturated conditions for long time after rain fall, the snowpack can generate big snowmelt floods from rainwater (hold in snowpack) and snowmelt in the clear day (18 Apr, figure 11).

Singh, P., Spitzbart, G., Hubl, H., and Weinmeister, H. 1997. Hydrological response of snowpack under rain-on-snow events: a field study. Hydrol. Process., 201, 1-20.

Minor points

Units are not consistent throughout the manuscript. Densities are sometimes expressed as g cm^{-3} and in other places as kg m^{-3} .Please be consistent.

Answer: In order to make the unit of snow density consistent in the paper, we revise the expression of Eq. (2) and Eq. (16).

Equations have missing explanation

Answer: done

Recheck the References, there are many typos and inconsistencies with the text.

Answer: done

Please use the terminology given by the International Classification of SeasonalSnow and Ice on Ground (Fierz et al., 2009).Do not use "pre-snowmelt season". Rather use the terminology given in (Colbeck, 1972) and (Jordan etal.,2008).

Answer: I have substitute "pre-snowmelt period". for "transitional period"

P. 4139, lines 3-5: I want to see a reference

Answer: we add a reference (Fierz and Fohn, 1994) to explain LWC was hard to measure， which limited the application of snow LWC.
Fierz, C., and Fohn, P. 1994. Long-term observation of the water content of an Alpine snowpack. Proceedings International Snow Science Workshop 1994 Snowbird, Utah, USA, 117-131.

P. 4139, line14: Change to Techel et al., 2011
Answer: done

P. 4139, line 17: Do not use “stable” in this context. There is no mechanical or hydraulic stability within the context.
Answer: I cited a reference, of which the author used the word “stable” to describe this snow period, and to express that the variation of snow properties is slight in this period. So it’s not first use like this in my paper.

P. 4140, line 6: You do not present spatial changes, all Figures are in1-D.
Answer: In revised paper, we use the “vertical distribution” instead of “spatial change”.

P. 4140, line 18: What do you mean with “dry-cold type”?
Answer: the “dry-cold type” snow has these properties: low density, low snow temperature and low volumetric moisture content, and depth hoar develop largely.

P. 4140, lines 21-22: What kind of density? Snow? What do you mean with other factors?
Answer: the density was snow density; the other factors were thickness of different snow layer, snow temperature, the snow grain size sometimes.

P. 4140, lines 25-26: Please specify the time-zone. In Figure 6, 8 and 10 your midday radiation peak seems quite strange.
Answer: the time-zone is the Beijing time (GMT+8) in the original paper. In the study area, the local time lag behind 2 hours to the Beijing time, the time-zone is GMT+6. We revised in the paper and figures.

P. 4141, line 1: Why did you dig out a entire column, what was your measurement setup, how did you insert the Snow Fork? Any side effects?
Answer: In order to study the vertical variation of the snow LWC, a entire column has to be dug out, the measurements were conducted at every 2 cm depth from the surface to the bottom using a Finnish Snow Fork gauge, and the measurements were always undertaken on a same sidewall of snow pit and parallel to the layer stratigraphy. If the Snow Fork was operated by two people, 60 single measurements on vertical profile can be finished less than 5 min, which was important for reducing the potential problem. For example, the snow pit exposed long time may disturb the water flow.

P. 4141, line 20: How exactly did you calculate the afternoon value for LWC?
Answer: the afternoon value for LWC was measured using the Snow Fork. In the revised paper, we add the accuracy of LWC measurement.

P. 4142: I suggest rewriting lines 1-9.
Answer: done

Eq (12) and Eq (14) have the same variable, but obviously describe something different.
Answer：In the revise paper we use different symbols represent the variables.