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Interactive comment on “Snow mass decrease in the Northern Hemisphere (1979/80–2010/11)” by Z. Li et al.

Z. Li et al.

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Thank the reviewer for providing careful revision and valuable suggestions. The response and the revision of the questions are listed below one by one.

General comments: From the title, this paper claims to provide a definitive assessment of trends in the total amount of water stored in the seasonal snowpack (SWE) over land areas of the Northern Hemisphere. What the paper actually does is provide an estimate of SWE trends from essentially a single source (satellite passive microwave) evaluated against surface snow depth observations made at open locations (a biased sample), that systematically underpredicts SWE for values above 100 mm, and that ignores mountainous regions of the NH with the largest snow accumulations. SWE is a challenging variable to monitor at the hemispheric scale: in situ observations are

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variable in space and time (tend to be concentrated over mid-latitude watersheds); satellite-derived estimates of SWE from satellite passive microwave data have well documented problems (wet snow, areas with extensive depth hoar, deep snow); re-analyses and reanalysis-derived reconstructions are strongly dependent on precipitation which varies considerably across datasets. The bottom line is that any attempt to provide a definitive estimate of how hemispheric land seasonal snow water storage has changed over the past 40 years really has to look at multiple sources of information to generate some sort of consensus (and estimate of uncertainty) as no one source is likely to give a completely reliable picture. As it stands, this paper is not publishable because the results are not supported with independent results. One potential solution may be to clearly delimit the study and results to NH land areas where the PMW retrievals can be shown to reproduce observed variability and change in SWE (i.e. non-forested regions with SWE < 100 mm) and modify the title accordingly e.g. “Snow mass trends in shallow seasonal snowpack: : :” The paper also requires extensive revisions to address gaps in the methodology and improve readability.

»Response: According to your suggestions, our title is changed to “Snow mass trends in the northern hemisphere (1979/80-2010/11) estimated from satellite microwave radiometers.” We have to admit that the SWE products estimated from the satellite are more or less biased from the truth. It is limited by the accuracy and sensitivity of the satellite sensors. But the satellite has its advantage which is supplemented in the introduction part as “the SWE values retrieved from satellite passive microwave data are suitable for global scale monitoring and temporal analysis as a result of the wide swath of these data, the all-weather imaging capabilities of the passive microwave radiometry (PMR), and PMR’s multifrequency response to the presence of snow on land.” Our work tries to improve the accuracy of the existing SWE products derived from satellite. Besides, we add more comparison with ground station data to evaluate the accuracy of our results.

Detailed comments Page 1 Abstract: Line 2: Climate change is driving the snow cover

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changes not the other way round.

»Response: Accepted. The expression is changed to “Snow cover has a key effect on climate change and hydrological cycling, and vice versa. Meanwhile, it is the water supply to a sixth of the world’s population across the northern hemisphere.”

Lines 4-5: The statement that “reliable data on trends in snow cover is lacking” is misleading. This may be the case for SWE but snow cover extent trends for NH are published in the recent IPCC assessment.

»Response: Accepted. We think this sentence is better changed to “Therefore, reliable data on trends in snow cover in the northern hemisphere is needed urgently”

Line 6: The statement “Here we verify the accuracy” is too definitive given the limitation and uncertainties in the surface observations. Suggest you replace this with “Here we evaluate three existing: : .”

»Response: Accepted. “Verify” is changed to “evaluate”

Line 8: The term “new SWE product” is misleading. You have merged information from two existing products which is not the same as creating a new product.

»Response: Accepted. “new” is changed to “blended”

Lines 14-15: Suggest you replace this last sentence with something like “Temperature increases over NH land areas of 0.17 degree/decade over the 1979-2011 period are considered to be one of the main drivers of the observed SWE declines.”

»Response: Accepted. “During the same period, the temperature in the study area raised 0.17 degree/decade, which is thought to be the main reason of SWE decline” is changed to “Temperature increases over NH land areas of 0.17 degree/decade over the 1979-2011 period are considered to be one of the main drivers of the observed SWE declines.”

Introduction Line 17: Suggest you replace “The world’s snow cover: : : and plays...”

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with “Snow cover plays a crucial role in the global climate system and regional water supply...”

»Response: Accepted. The sentence is changed to “Snow cover plays a crucial role in the global climate system and regional water supply...”

Line 20: Why do you stop at 2006? The evidence from the recent IPCC assessment and BAMS State of Climate suggests the hemispheric SCE is continuing to respond to warmer temperatures.

»Response: The expression is changed to “Snow cover extent (SCE) has shrunk over the northern hemisphere since 1970s (Karl et al., 1993; Gao et al., 2012; Déry and Brown, 2007; Armstrong and Brodzik, 2001). ”

Line 22: SWE is a more comprehensive than what?

»Response: We wanted to say that SWE is a more comprehensive than SCE. The sentence is changed to “Compared to SCE, snow water equivalent (SWE) is a more comprehensive parameter. . .”

Line 24: Please use the definition for SWE from the International Classification for Seasonal Snow on the Ground “the depth of water that would result if the mass of snow melted completely (Fierz et al., 2009)” Fierz, C., Armstrong, R.L., Durand, Y., Etchevers, P., Greene, E., McClung, D.M., Nishimura, K., Satyawali, P.K. and Sokratov, S.A. 2009. The International Classification for Seasonal Snow on the Ground. IHP-VII Technical Documents in Hydrology N_83, IACS Contribution N_1, UNESCO-IHP, Paris.

»Response: Accepted. Thanks very much for providing detailed information about the definition of SWE. The expression in the manuscript is changed and the reference is added :’ Compared to SCE, snow water equivalent (SWE) is a more comprehensive parameter that takes into account snow extent, density and depth, and represents the depth of water that would result if the mass of snow melted completely (Fierz et al., 2009).’

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Lines 24-26: Liston and Heimstra (2011) provide one estimate of pan-Arctic SWE trends from a reanalysis-driven reconstruction. This is not definitive and has to be placed in the context of other estimates.

»Response: Accepted. We changed our expression. “The pan-Arctic average trend in peak seasonal SWE was -0.17 cm/decade” is changed to “The pan-Arctic average trend in peak seasonal SWE was estimated to be -0.17 cm/decade”

Page 2 Line 1: What do you mean by “the variation in SWE differed in place and time”? Are we still talking about Liston and Heimstra? I think you need to start a new paragraph here on data sources for monitoring SWE. You also need to modify your numbering scheme for the three datasets [you mention three but only have two numbers]. Why do you only consider PMW data? You do not provide any justification for using solely PMW derived SWE. There are extensive in situ SWE data available from Russia (Bulygina et al. 2011) for evaluating SWE trends over Eurasia.

»Response: Accepted. “The variation in SWE differed according to location and time” should be changed to “The variation in SWE differed greatly according to location on the earth.” It is independent of the former sentence, and it is changed to a new paragraph. The numbering scheme is divided into three parts. In this work, we mainly use the existing SWE products from satellite passive microwave. The in situ data are used to evaluate the accuracy of the satellite products, rather than estimate the SWE trends directly. To avoid misleading, we changed the title of the manuscript to “Snow mass trends in the northern hemisphere (1979/80-2010/11) estimated from microwave radiometers” We carefully read the paper ‘Changes in snow cover characteristics over Northern Eurasia since 1966’ (Bulygina et al. 2011). Although this paper measures the snow change in different time range to us, we find that it still gives important information in snow cover comparison. For example, the average snow depth distribution is very close in this paper and our results. In section 3 we also added the comparison of the changing trend between this paper and our results.

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Page 4 Line 10: Suggest you modify this to read “In situ snow depth measurements from 7388 surface stations in the GHCN-D dataset were used to evaluate the monthly SWE products”.

»Response: Accepted. The sentence is changed to “In situ SWE measurements from 7388 surface stations (Fig.1) in the Global Historical Climatology Network-Daily (GHCN-DAILY) dataset were used to evaluate the monthly SWE products”

- How did you convert the snow depth to SWE? Did you assume the same fixed 0.24 density as GlobSnow?

»Response: In this study, the snow densities of the three existing SWE products are different according to their own inversion algorithm. We use the suggested snow densities in respective SWE products.

- You do not provide any evaluation of the ability of the merged PMW data to capture interannual variability in SWE i.e. comparison of regionally-averaged SWE time series. You could use the available in situ SWE observations from Russia for this purpose. They do not cover the entire NH but allow an evaluation of SWE retrievals by snow climate region.

»Response: Accepted. The comparison between the merged SWE product and the ground data in Russia is added in section 3 as “The SWE changes from 1966 to 2010 were recorded in 958 ground meteorological stations and analyzed in Russia (Bulygina et al., 2011). Although cover different time span, the ground truth data are still useful to make comparison with our results. During 1966 to 2010, the SWE increases in Western and Central Siberia, eastern European Russia; the SWE decreases in western European Russia and Eastern Siberia. These trends are generally the same with our results.”

Page 7 - You need corroborating information from other sources to support your trend estimates (e.g. in situ estimated SWE trends from GHCN-D snow depth obs, trends

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from Liston and Heimstra (2011) reconstruction, published trends from other studies such as Bulygina et al. 2011).

»Response: Accepted. We added the comparison of Bulygina et al. 2011 and our results as introduced in the above response.

Page 9 Line 1: I do not understand what you mean by “and the 30 mm threshold is acquired.”

»Response: Accepted. Maybe our expression is not clear. We want to express that “for SWE > 30mm, the GlobSnow product is more accurate than the NSIDC products, and for SWE < 30mm, the situation is reversed.” This sentence is changed to “and the 30 mm threshold of the three SWE products is acquired.”

Section 4.1 needs rethinking by the authors as it does not relate to any specific analysis carried out in the study and there are no clear conclusions presented.

»Response: Accepted. We added why we make this discussion, because “According to the comparison in Russia and North America, the general SWE changing trends are similar with our results, but there are also some differences due to different data sources and different processing procedures.” The conclusions in this part is stated as “the blended SWE is the best choice for satellite inversed SWE. The blended product is superior in the northern hemisphere for the past 30 years, and it is more suitable for total SWE or average SWE calculation in the whole northern hemisphere, but it is not necessary the most accurate choice for a certain region or a certain time. ”

Line 13: What global monthly gridded datasets? There can be large differences in precipitation trends between datasets.

»Response: Accepted. The used precipitation and temperature data are supplemented in section 2.1. “The global monthly gridded datasets of temperature and precipitation are called “GHCN CAMS Gridded 2m Temperature (Land)” and “GPCC Global Precipitation Climatology Centre”. Both of these are produced by NOAA. Their spatial

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resolution is 0.5° latitude * 0.5° longitude (globally gridded into $360 * 720$ pixels) and date from 1948 to April 2013 and from January 1901 to 2010, respectively. Although the spatial resolution of these datasets is lower than that of the EASE-Grid, they are suitable for the analysis of significant variations in SWE at the regional scale.”

Section 4.2: This entire section is shaky. The authors should read Raisanen (2007) before trying to attribute the SWE changes to temperature and/or precipitation. Räsänen (2007) Warmer climate: less or more snow? Climate Dynamics February 2008, Volume 30, Issue 2-3, pp 307-319 <http://dx.doi.org/10.1007/s00382-007-0289-y>

»Response: We read the paper of Raisanen carefully and supplemented more analysis in this section. The paper simulates SWE changes with precipitation and temperature. We supplemented the gridded precipitation and temperature trend of the past 32 years (Figure 9) in the snow covered regions to analyze the relation between SWE and climate change. The added parts in this section is “The increasing precipitation in form of snow increases snow accumulation, but in a warmer world, the increasing temperature accelerates snowmelt, and it increases the possibility of precipitation in forms of rain, which may severely destroys snow cover. The balance between the temperature and precipitation depends whether snow will be actually reduced or increased (Cox et al., 2000, Räsänen, 2008). On regional scale, the relation among SWE, precipitation and temperature becomes more complex. The global monthly gridded datasets of temperature and precipitation trends for the past 32 years are calculated and shown in Fig. 9. In North America the temperature increases and precipitation decreases in winter except Alaska, thus it is not surprising that the SWE decreases in this region. In Eurasia, the temperature generally decreases in December and February, but increases in March. The precipitation increases in mid-latitude (50° - 60° N) and Western Siberia, but decreases in Central and Eastern Siberia. Although the SWE decreases with temperature increases globally, the situation is complicated in Eurasia.”

Conclusions: Line 13: Suggested rewording “: : are evaluated with in situ snow depth observations”

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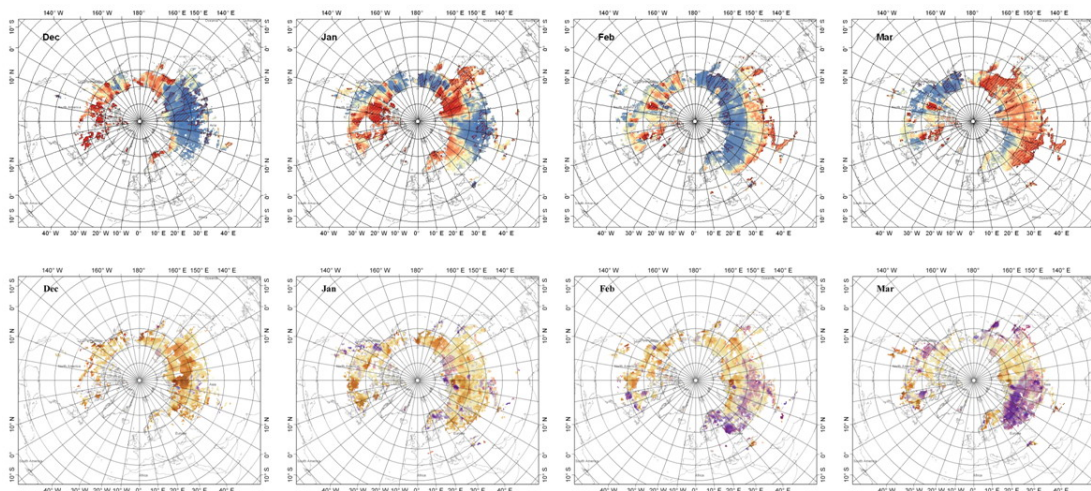
»Response: Accepted. The sentence is changed to “Three SWE products, NSIDC (SSMR&SSMI), NSIDC (AMSR-E L3) and GlobSnow are evaluated with in situ snow depth observations.”

Line 16: The sentence starting “Based on the validation results: : :” is not clear. Note that the presence of regions of SWE increase and decrease under conditions of increasing trends in temperature and precipitation is an expected result (see Brown and Mote, 2009). Brown, R.D. and P. Mote, 2009: The response of Northern Hemisphere snow cover to a changing climate. J. Climate, 22, 2124–2145.

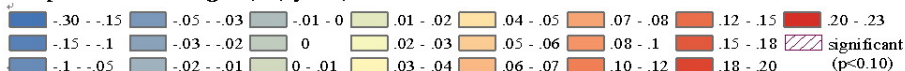
»Response: Accepted. The sentence “Based on the validation results..” is changed to “Based on the evaluated results”. In the end of the conclusion, the sentence “Both the temperature and precipitation increased in the study area, but the temperature rise is speculated to play a more important on snow cover.” is deleted. It is only a speculation, rather than a conclusion from our work.

[Interactive comment on The Cryosphere Discuss.](#), 8, 5623, 2014.

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Temperature change (°C/year)



Precipitation change (mm/year)

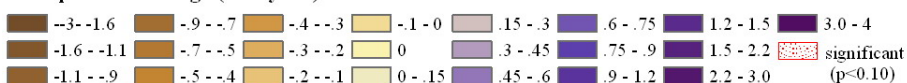


Fig. 1. Figure 9 Temperature (upper) and precipitation (lower) changes during the period 1979/80–2010/11 in the northern hemisphere. The precipitation change only use the grids which have continuous precipita

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