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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.

huanglei@radi.ac.cn

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Response to reviewer 3: Thanks for reviewing this manuscript and providing very helpful suggestions. The questions will be responded and revised one by one as follows:

General comments This study employs multiple satellite-derived snow water equivalent products to evaluate snow mass across Northern Hemisphere lands since the advent of passive microwave remote sensing over 30 years ago. The authors determined that the NOAA products (called NSIDC) were most accurate at SWE values below 30mm, while the GlobSnow product was best above 30mm. Employing these products led to the conclusion that there has been an overall loss of SWE during this portion of the satellite era. They attribute this loss to increasing surface air temperatures. The use of multiple datasets in the analysis is an interesting and commendable approach. However the ground station data validation discussed in 2.2 is not tremendously convincing for any of the satellite SWE products. In essence the estimates are not being compared to "ground truth SWE" as they state. Rather they have generated SWE based on snow depth measurements and the Sturm snow densities. I realize that there are far too few actual SWE observations available globally, so seemingly their approach may be the best available. However they should state this as such. Given the innovative nature of the approach and the "first shot" at a hemispheric trend evaluation, I believe this manuscript is ultimately publishable. However it is not yet fully ready. Some of my reasoning is based on the writing style, which at times makes it difficult to follow. However there also are some fundamental items that need further attention prior to publication. They are listed below.

»Response: Thank you very much for the suggestions. We will response to the questions one by one and present our revisions.

1. Intro: there are more recent publications than 2006 that speak to shrinking NH snow cover extents. They particularly address spring SCE losses (Brown and Robinson; Brown and Derksen)

»Response: Accepted. The reference are added and the sentence 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)."

2. Methods: in the first sentence mention that the radiometers are flown on polar orbiting satellites.

»Response: Accepted. We supplemented that the radiometers are flown on polar orbiting satellites: 'SMMR and SSM/I are passive radiometers that flow in the polar orbiting satellite and their brightness temperatures at frequencies of 18(19) GHz and 37 GHz are employed to estimate SWE.'

3. Methods: explain "the inversion algorithm"

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»Response: Accepted. First, ‘the inversion algorithm’ is changed to ‘the SWE inversion algorithm’. Second, the explanation is added about the algorithm: Their brightness temperatures at frequencies of 18(19) GHz and 37 GHz are employed to estimate SWE, since the soil-emitted microwaves will be scattered and attenuated by the snow-pack as they travel upward. This kind of attenuation is confirmed to be connected with the microwave wavelength and with snow properties such as the amount of snow, snow grain size, snow density, presence of ice lens and snow wetness. The Change algorithm is implemented in this product using SMMR and SSM/I data as follows:

SMMR: SWE=C(Tb18H-TB37H) (1)

SSM/I: SWE=C(Tb19H-Tb37H-5) (2)

where SWE is the snow water equivalent in mm, C is a coefficient (set as 4.77 here) related to snow grain size physically based on forward simulations with a radiation transfer model, and Tb18H (Tb19H) and Tb37H are the brightness temperatures at the 18(19) GHz and 37 GHz horizontal polarization, respectively. For SSM/I data, the 19 GHz frequency takes the place of 18GHz on the SMMR and an adjustment of -5 is made to the spectral difference, as necessary.

4.Methods: overall, the authors don’t set up the methodology well. More explanation and discussion is needed.

»Response: Accepted. The method about the trend analysis is added, and the introduction and processing of the gridded datasets of temperature and precipitation data are added. First, the trend analysis method is added in section 2.4 as ‘An advanced approach named the trend-free pre-whitening (TFPW-MK) test was used here to detect whether a significant trend exist in hydro-meteorological data series, as its advantages on removing influences induced by serial correlation and potential interactions between a trend slop and a lag-one autoregressive (AR(1)) process when both of them exist simultaneously in a time series (Yue et al., 2002; Zhang et al., 2000). The TFPW-MK method has been widely used for hydro-meteorological trend assessments

(Gao et al., 2012). ' Second, in the discussion section, we discussed the SWE with climate change in a global and regional scale: On a global scale, most climate data and models agree that there is a near-surface warming trend due to the rising levels of greenhouse gases in the atmosphere (Barnett et al., 2005). According to the fifth IPCC report (IPCC, 2013), the global warming rate over the past 15 years (1998-2012) has been 0.05 [-0.05 to +0.15] °C/decade and for the period since 1951 (1951-2012) the rate is calculated as 0.12 [0.08 to 0.14] °C/decade. 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 could severely destroy snow cover. The balance between the temperature and precipitation depends whether snow will be actually reduced or increased (Cox et al., 2000, Räisänen, 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.

5. Methods: I suppose that the issue passive mw snow sensing has with thin covers isn't much of a problem when looking at large-scale SWE observations. However that associated with wet snow must certainly be a problem near the periphery of the pack in all seasons and pack-wide in spring. This should be addressed.

»Response: About the thin and wet snow, it should be stated that 'Due to the saturated brightness temperature response, wet snow or temporary thin snow layers are not reliably detected and are masked by observed brightness temperature values using an empirical equation.' This sentence is added in the text.

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6. Results: the description of where snow lies in December and March is incorrect. For instance, in both months the average snowline in North America is close to the US/Canadian border, not nearly as far north as they mention in December or equivalent with the average in January and February as they state for March.

»Response: The SWE boundary in this study is different to the snow line. First, the radiometer satellite is sensitive to the snow only when their thickness reaches a certain extent. Second, during the past 30 years, the absence of snow in one or several years will cause severe bias in trend analysis, therefore, we only pick the pixels which have continuous SWE records in the past 30 years to avoid the bias. Above all, the analyzed SWE extent in this study will be smaller than the normal snow covered regions.

7.Results (line 16): are the drops statistically significant? If so, this must be state as such.

»Response: The drops are statistically significant. The significance level is supplemented. 'During this period, the changing rate was -9.08±6.90 Gt/year in December, -13.15±8.74 Gt/year in January and -10.87±10.56 Gt/year in February ($p<0.1$). It should be noted that the February results are not statistically significant. In March the rate accelerated to -13.16±6.6 Gt/year ($p<0.1$). '

8. Results: a better comparison with SCE would be welcome. Overall (not just looking regionally) is the greatest impact on reduced SWE a loss in extent or a loss in SWE where the snow resides?

»Response: The SCE change is introduced in this section. "In December, snow cover is mainly located between 55°N and 70°N in Eurasia and between 60°N and 70°N in North America. Snow cover extends to mid-latitude regions near 50°N in January in Eurasia and North America, and there is little difference between January, February and March in these areas."

9. Discussions: with precipitation increasing and SWE decreasing might there be rain

falling on the snowpack or perhaps the use of the Sturm densities can't be fully used (given density changes over time with warming)? This should be discussed further.

»Response: Accepted. Yes, the increasing temperature may increases the possibility of precipitation in forms of rain, which will reduce snow accumulation. The expression is added as '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, Räisänen, 2008). '

10. Discussions: I'm not sure how the discussion in the last two paragraphs fits within this section. Perhaps it should be in the Introduction (of course without starting off by mentioning the decrease found in this study.

»Response: In this section we want analyze the connection between SWE change and temperature/precipitation. To make more specific analysis, we added the temperature and precipitation trend (Figure 9) in the snow covered areas. The connection between SWE and climate change is discussed on global scale and on regional scale. This revision has been introduced in the question 4.

11. Conclusions: the authors are quick to attribute the SWE loss to increasing temperatures (also mentioned at the end of the abstract. They should consider that the warming might in part be due to the loss of snow cover. At best they shouldn't be so certain in their assertion without looking into this further.

»Response: Accepted. "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 in the conclusion in order not be misleading, because it is only a speculation in our work and it need more evidence in the future.

Interactive comment on The Cryosphere Discuss., 8, 5623, 2014.

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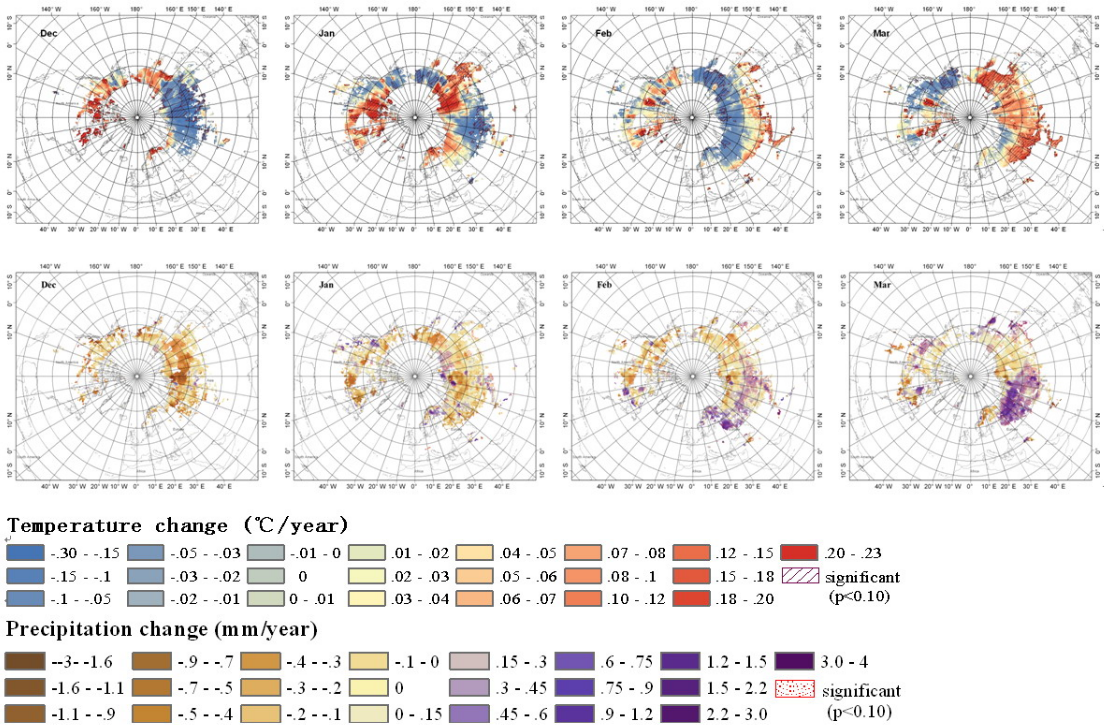

Fig. 1. Figure 9 Temperature (upper) and precipitation (lower) changes during the period 1979/80-2010/11 in the northern hemisphere. The precipitation change only use the grids which have continuous precipita

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