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Interactive comment on "Snow mass decrease in the Northern Hemisphere (1979/80–2010/11)" *by* 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.

Summary: In this paper, the authors introduce a merged data product of Northern Hemisphere snow water equivalent (SWE) derived from three remote sensing products. The original remote sensing products are compared to in situ observations of snow depth and assumptions on snow density, with the NSIDC data closer to observations when SWE < 30 mm and the Globsnow data closer to observations when SWE > 30 mm. The merged data then are used to assess trends in SWE between 1979/80 and 2010/11 using the Mann-Kendall Test. Large declines in the months of January and February are found, with more moderate trends in December and March. Coin-

cident with these trends are rises in air temperatures that may have led to the SWE declines. There are some results in this manuscript that will be of interest to the readership of the journal. However, there are considerable issues with the paper including its structure, the validation of the SWE data and the trend analyses. The language and graphics also need improvement as described in my report below:

»Response: Thanks for reviewing this manuscript and gives constructive and helpful suggestions. In the following we will respond and revise the questions and revise one by one. We hope the quality of this manuscript will be improved.

General Comments: 1) Some of the language used in the paper needs to be considerably improved. Some language issues are highlighted in the specific comments below.

»Response: Thanks for detailed revision in language. We will revise the language carefully.

2) The introduction is rather brief and should be expanded to better summarize existing SWE products and their relative accuracy. Further to this, motivation for this work and hypotheses or research questions should also be provided in this section.

»Response: The introduction section is expanded. The detailed information of the SWE products are introduced in section 2.1. Besides, we supplemented three points. First, the SWE data is lacking :"Considerable progress has been made recently in determining trends and variability in snow extent datasets, however, an adequate understanding of the snow water equivalent (SWE) remains lacking and elusive.". Second, the advantage of satellite data compared to ground station measurements, "For climate applications, 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. In addition, continuous time series of these data are available dating back to 1978. Third, we analyzed that SWE are in urgent need, “On one hand the SWE data are in urgent need for monitoring climate change and its possible influence on human life, on the other hand, the accuracy of the existing satellite derived SWE products is not clear in northern hemisphere scale. Therefore, in this paper the accuracy of the existing SWE products from PMR are evaluated with the ground meteorological stations, and an optimized SWE product is generated to analyze the SWE changes from 1978/80 to 2010/11.

3) How sensitive are the inversion algorithms for the remotely sensed SWE data to the assumed snow densities? How realistic is the assumption of a constant snow density over time?

»Response: Yes, the SWE products are sensitive to snow density. In this study, the snow densities of the three existing SWE products are different. The snow densities were suggested by the product releasers which were considered to be the most suitable for the inversion algorithm of their own products. We use the passive microwave and the suggested inversion algorithm and snow densities.

4) Rather than using meteorological stations that record snow depth and then make assumptions about snow density to infer ground-based SWE measurements, why not use direct observations of SWE? There are many snow pillow stations or snow survey sites in the United States (e.g., SNOTEL stations), Canada (e.g., BC River Forecast Centre snow pillow stations) and Russia (snow survey sites) that would be suitable for this comparison.

»Response: In our early work, we want to find the ground meteorological data to validate the SWE products from satellite. We only find that GHCN-DAILY data provide continuous station data from 1978 to 2012 in the northern hemisphere scale. The GHCN-DAILY dataset only provide the snow depth data, so it is a pity.

5) Throughout the text, consider using “data blending” rather than “data merge”.

»Response: Accepted. The data merge is changed to data blending throughout the text.

6) Aspects of the methodology are provided in section 3 (“Results”) and should therefore be moved to section 2 (“Methods”) instead. This includes information on the Mann-Kendall trend test (p. 5629) and what p-value is considered statistically-significant in the present study. Furthermore, the source of the air temperature and precipitation data needs to be provided along which the exact regions over which trend analyses are assessed

»Response: We accepted the suggestions. The trend analysis method introduction is shifted to section 2.4 as “Trend analysis”. In this section the method is introduced 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). ” The temperature and precipitation data are also supplemented (Figure 9). The sources of these data are introduced in section 2.1 as “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 resolution is 0.5° latitude ïĆť 0.5° longitude (globally gridded into 360 ïĆť 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. ”

7) As the remote sensing products are not capable of inferring deep snow (SWE > 180 mm to 200 mm), regions where this threshold is often surpassed during winter (e.g., the mountainous terrain of western North America, Alaska, and northern Quebec

and Labrador) should be masked out from the analyses (Figures 3-5). Given regions that experience commonly deep snowpacks contribute disproportionately to the overall snow mass of the Northern Hemisphere, how reliable are the trend results provided here (Figure 6)? Further to this, given the errors found in Figure 2 are as large as the observed trends shown in Figure 5, can one trust the results of the trend analyses?

»Response: Regarding to deep snow of mountain areas, GlobSnow SWE product has been used in the trend analyses, in which the mountainous areas of Northern Hemisphere have already been masked out from it. “The mountain mask applied is derived from 4 minute averaged ETOPO2 data set which includes the Global elevation and bathymetry on 2x2 minute grid from the National Geophysical Data Center (NGDC). The dataset was original published in September 2001 and was revised to include correction to Caspian Sea area in April 2006. It contains improvements that include the blending of satellite altimetry with ocean soundings and new land elevation data from the Global Land One-km Base Elevations (GLOBE) project”, which is cited from the product handbook. Therefore, regions where the value of SWE often surpassed the estimating capability of the algorithm are excluded from GlobSnow SWE product. They are shown as blank in Rocky Mountains and spots scattered in Alaska, northern Quebec and Labrador in Figures 3-5. Regarding to reliability of overall snow mass of the Northern Hemisphere in Figure 6, it is to be clarified that firstly, the total snow mass is composed of the sum of thin snow (as SWE<30mm) from NSIDC products and the sum of deeper snow (as SWE>30mm) from GlobSnow product, according to the comparison results in Fig 5; secondly, it only contains dry snow which can be detected by passive microwave radiometry and not include wet snow and thin snow less than several centimeters. Apparently, the total snow mass is less than the true data, but more closer to it than any other individual estimated SWE product. For general measurement, we assume that it is more reliable than the results induce only from one source of derived products. Regarding to the effects of the estimated errors on the trends in Fig 5, we should state that, SWE values of a pixel which has been tested all come from a unique SWE product and therefore, only systemic errors induced from this product

existed in each pixel. The SWE products underestimate the SWE true values in deep snow regions systematically, and we pick the products which are most close to the true value, therefore, we think that the trend analysis are still meaningful.

Specific Comments: 1) P. 5624, line 4: Revise to “are lacking”.

»Response: Accepted. ‘is’ is changed to ‘are’, but ‘lacking’ is changed to ‘needed urgently’, according to the first reviewer.

2) P. 5625, line 8: Change to “Imager”.

»Response: Accepted. ‘Imagers’ is changed to ‘Imager’.

3) P. 5625, line 9: List the AMSR-E Le Global SWE product as the second one in your list, and then the GlobSnow SWE product as the third.

»Response: Accepted. AMSR-E is separated as the second one, and the GlobSnow is the third one.

4) P. 5625, line 11: Delete “the” before “two”.

»Response: Because AMSR-E product is separated, here we change ‘both the two…’ into ‘both the first and the second products…’ to connect it with the first product.

5) P. 5625, lines 16-18: The language could be improved here.

»Response: Accepted. The two sentences are changed to ‘Due to their different inversion algorithms, the three SWE products have different estimated accuracies. However, there is no error analysis of the products that has been produced at the scale of the northern hemisphere during their period of operation.’

6) P. 5626, line 11: Change the “&” with “and”.

»Response: The “&” is changed with “and” throughout the text.

7) P. 5626, line 16: Delete “the” before “Boston”.

»Response: ‘the’ is deleted here.

8) P. 5626, line 24: Change the “&” with “and”.

»Response: The “&” is changed with “and” throughout the text.

9) P. 5627, line 11: Insert “the” before “Global”.

»Response: The first reviewer also point out that this sentence is improper. The whole sentence is changed to ‘In situ snow depth 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 (each of them with at least 15 days’ snow cover)’.

10) P. 5627, lines 12 and 14: Delete “in order” where it is not needed.

» Response: ‘in order’ is deleted.

11) P. 5628, line 2: Delete “the situations”.

»Response: ‘the situation’ is deleted.

12) P. 5628, line 19: Delete “in order”.

»Response: ‘in order’ is deleted.

13) P. 5628, line 22: Replace the “&” with “and”.

»Response: The “&” is changed with “and” throughout the text.

14) P. 5628, line 26: Change to “Simulated data were: : :”

»Response: ‘was’ is changed to ‘were’.

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

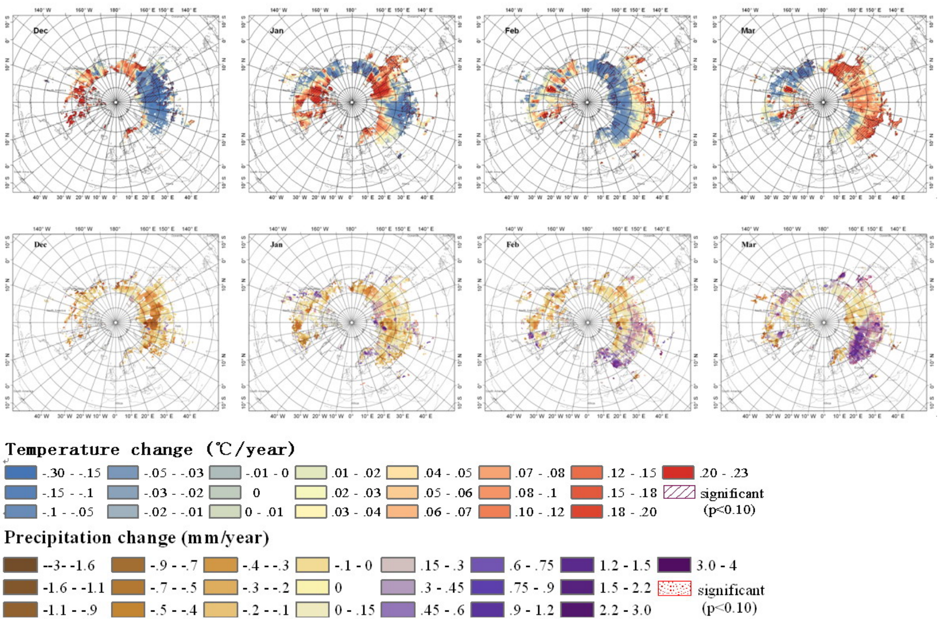

Fig. 1. Figure 9 Temperature (upper) and precipitation (lower) changes during the period 1979/80-2010/11 in the northern hemisphere. The precipitation change only use the grids which have continuous precipita