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Interactive comment on "Snow density climatology across the former USSR" *by* X. Zhong et al.

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Reply to S.Dery's Interactive comment on "Snow density climatology across the former USSR" by X.Zhong et al.

First of all, we appreciate the reviewer for his constructive and insightful comments and suggestions for this manuscript. We consider all comments and suggestions seriously. All comments are very helpful for further revision of our manuscript. We have made all necessary changes based on the reviewer's comments and suggestion as described below.

S.Dery's General Comments: 1) While the results of the snow density climatology are important and should be published, the present study provides little explanation as to

the distribution and trends of snow density observed across the former USSR. What are the meteorological and surface conditions that result in the spatio-temporal distribution of snow density? For instance, is there any relationship between snow density and snow depth or air temperature? Further analyses on other hydrometeorological variables would be helpful in interpreting the results of the snow density climatology.

Reply: We need to explain the reasons of the variations in distribution and trends of snow density observed across the former USSR and clearly analyzed the relationships between snow density and other factors (snow depth, wind speed, air temperature) that we did not discuss in the text. We added these in Results and Discussion:

Snow densities were consistent with the distributions of snow depth from September to March, especially in the western areas across the former USSR, which increased with increasing depth significantly. In the thawing period, snow density increased by higher air temperature. Snow density did not come up quickly in the eastern Russia because most sites located in forested environments, which were less affected by wind speed. And little changes in snow depth and low air temperature led to slow changes in densities in the arctic coast.

2) In relation to this, a climatology of observed air temperature, snowfall, wind speed and snow depth during winter across the former USSR would be helpful in assessing and interpreting the results of the snow density climatology.

Reply: We need to add this part of the discussion in the text in order to interpret the climatology and changes of snow density. In part 3.1, we added the climatology of snow depth to assessing the spatial distribution of monthly mean snow density:

Snow densities were consistent with the distributions of snow depth from September to March, especially in the western areas across the former USSR, which increased with increasing depth significantly. Furthermore, air temperature was an important factor for snow density. In the thawing period, snow density increased with higher temperature. Snow density did not come up quickly in the eastern Russia because most sites located in forested environments, which were less affected by wind speed. And little changes in snow depth and low air temperature led to slow changes in densities in the arctic coast.

Snow depth, wind speed and air temperature were used to interpret the reasons of variations in annual mean snow density in part 3.2:

There is a peculiar drop in density in 2000s. We analyzed the interannual trends of snow depth, wind speed and air temperature across the former USSR during 1966 to 2008. From the period of 2000 to 2008, air temperature increased obviously which lead to snow depth decreasing significantly. Furthermore, wind speed reduced clearly compared with the past. Therefore, these may be one reason for a sudden drop in snow density during the 2000s.

3) Is there any information about the vertical profiles of snow density within the snow pack or are only bulk values available for each site of interest?

Reply: In our paper, snow density for each site was only the bulk density. The bulk values were made every 100 or 200 m, and then be averaged.

4) Some of the figures and their captions require modifications

Reply: I agree with you. Thank you.

Specific Comments: 1) P. 3381, line 29: It appears there is a space missing in "to 1993".

Reply: We revised. And the reference was wrong, we revised:

Mean SWE had also been estimated from the monthly mean snow depth, snow cover extent, and an assumed monthly mean snow density over much of southern Canada for the period from 1964 to 1993 (Brown, 2000).

2) P. 3382, line 16: Could you expand on what results Ma and Qin (2012) found for snow density across China?

Reply: We expanded the results of Ma and Qin in the text. Make changes in the text:

Ma and Qin (2012) presented the spatiotemporal changes in snow density across China. The results showed that the inter-monthly variation in snow density was obvious, and the annual mean snow density was smaller over the Tibetan Plateau compared with Northwest and Northeast China.

3) P. 3384, line 4: This should read "points".

Reply: We revised it.

4) P. 3384, line 26: Insert the year of publication for Sturm et al.

Reply: We inserted it.

5) P. 3387: Snow densities are reported here to three decimal figures whereas they were previously reported only to two decimal figures. Please be consistent with the presentation of the results.

Reply: We made the presentation of snow densities consistently, which were reported to two decimal figures.

6) P. 3390, line 18: Insert "the" before "1990s".

Reply: We inserted it.

7) P. 3393, line 5: Insert the appropriate units for the standard deviation of snow density.

Reply: We inserted.

8) P. 3394, lines 1-3: Are there relationships between snow density and other environmental factors (such as latitude, vegetation types, meteorological conditions, etc.)? Elevation appears to explain only a small fraction of the observed distribution of snow densities.

Reply: In this part, we need to analyze the relationship between snow density and geographical features. In addition to elevation, we added the relationship between snow density and latitude to discuss. The results showed that among snow classes, the highest correlation was found in prairie snow, with the correlation coefficient was 0.58. In contrast, snow density was lowest associated with latitude for tundra snow, the correlation coefficient was just 0.28.

9) P. 3395, line 18: This should read "was affected".

Reply: We revised it.

10) P. 3396, line 4: Insert "the" before "1970s".

Reply: We inserted it.

11) P. 3396, line 11: Insert "a" before "normal".

Reply: We inserted it.

12) P. 3397, lines 21-22: Do you have the volume and page numbers for this reference?

Reply: We added it.

Brown, R. D.: Historical variability in Northern Hemisphere spring snow-covered area, in: Ann. Glaciol., International Glaciological Society, 25, 340-346, 1997.

13) P. 3403, Figure 2: Is it possible to have the legend "37%" below the top of the graph?

Reply: We revised it.

14) P. 3404, Figure 3 and others: There is no need to provide details about the axes in the caption as this is self-evident. The second sentence in the caption should start as "Dots represent the . . ."

Reply: We wanted to explain the meanings of X and Y in the equation, we revised.

In the equation, Y stands for snow density in g $cm{-}3$, and X for date.

15) P. 3405, Figure 4: Again, this should read "Dots represent. . ."

Reply: We revised it.

16) P. 3408, Figure 7: Why is there a sudden drop in snow density in the 2000s? What explains this regime shift in snow density and departure from the previous trend? Were different measurement techniques of snow density implemented at that time in the former USSR?

Reply: Thank you very much for your suggestion. Bulygina et al. (2011) indicate that although the procedure for making snow observations changed in the past, there have been no changes in the observation procedures since 1965. From Fig.8 of our text, the annual variation of monthly snow density, we can find that there was a significant decrease trend during the 2000s in April, which may be the main reason of snow density decreased suddenly in Fig.7. We analyzed the reason of the decrease in April, which was caused by the significant increase of new snowfall with low density. Then, we analyzed the interannual trends of snow depth, wind speed and air temperature across the former USSR during 1966 to 2008. From the period of 2000 to 2008, air temperature increased obviously which lead to snow depth decreasing significantly. Furthermore, wind speed reduced clearly compared with the past. Therefore, these may be the reasons for a sudden drop in snow density during the 2000s. We added the discussion in the text.

17) P. 3410, Figure 9: The last sentence of the caption should read: "Red circles represent decreasing trends while blue circles denote increasing trends in snow density."

Reply: We revised it.

18) PP. 3411-3413, Figures 10-12: Is the PDF of snow density based on daily or monthly values? The caption should clarify this point. The mean and standard deviation values shown on the plot should be given units. What do the arrows on the x-axis denote?

Reply: In Figs.10-12, the PDFs of snow densities were calculated by snow density which were measured every 5 to 10 days interval. We added the explanation in the methodology and the caption of Fig.10. We added the units of the mean and standard deviation values in the caption of Fig.10. The denotation of arrows on the x-axis had been explained in the caption of Fig.10, which bracket 2.5% and 97.5% of snow density.

19) Pp. 3414-3415, Figures 13-14: Please insert the units for elevation on the x-axis label.

Reply: We inserted them.

Interactive comment on The Cryosphere Discuss., 7, 3379, 2013.