The Cryosphere Discuss.,
doi:10.5194/tc-2016-182-RC2, 2016


The Cryosphere Discussions

# *Interactive comment on* "Spatiotemporal Variability of Snow Depth across the Eurasian Continent from 1966 to 2012" *by* Xinyue Zhong et al.

**Anonymous Referee #2**

Received and published: 18 October 2016

Review of Spatiotemporal 1 Variability of Snow Depth across the Eurasian Continent from 1966 to 2012, by Zhong et al.

The paper by Zhong et al (2016) investigates the spatio-temporal variability of snow depth (and snow water equivalent or SWE to a lesser extent) over the Eurasian continent over the 1966-2012 period. For this they assembled a considerable dataset of historical snow data measured at meteorological stations and snow courses during the period. The authors are to be commended for assembling this dataset and performing the climatological analysis. While the breath of the interpretations and conclusions remains somewhat limited and could be improved, this paper could serve as a valuable reference for future snow studies on the Eurasian continent. My main reserve concern



the trend detection method, and the analysis of the physiographic control of snow depth spatial variability. Suggestions to improve the analyses are given below.

Main comments

1) methods ïĆğ Methods to measure snow depth. The authors describe the snow course data, How is snow depth/snowfall measured at other stations? Is the method similar in the different countries?

ïĆğ Choice of time window for analysis. The snow year was defined from July 1st to June 30th. Why this choice of period? Figure 3 shows that snow seems to begin accumulating in September but snow remains in June in northern Russia and the Tibetan Plateau. So the chosen analysis window may not be optimal and should probably begin, and end, later so as to capture the complete seasonal cycle over the studied area.

ïĆğ Trend detection. Trend detection in environmental time-series is a delicate topic and this is a big concern for this study, as the 'significant' trends reported could be cited in future works. The authors seem to have used ordinary linear regression (OLS) with classical hypothesis tests (Fisher or 'F-test' on the variance explained, and/or Student T test on regression coefficients). These parametric tests make the assumption that the data is normally and independently distributed. The authors have not reported on checking these assumptions, and I doubt that the time series presented in the figures are free of autocorrelation. As a result I question the validity of much of the 'significant' linear trends reported in this study and suggest the author should apply a statistical test which account for the serial correlation of time-series. A suggestion is given below.

If the data are normally distributed, OLS can be used but the degree of freedom for the significance test must be adjusted for the reduction in the degree of freedom caused by the auto- ('serial) correlation. If the data is not normally distributed, transformation or a non-parametric test is necessary. The Mann-Kendall trend test is commonly used on non-normal data. Here again serial correlation must accounted for. The authors

could quickly apply a normality test and the Durbin-Watson statistic to the residuals of their regression to diagnose these problems. One possible approach to take the autocorrelation into account using OLS is outlined in Weatherhead et al. (1998):

Weatherhead, E. C., et al. (1998), Factors affecting the detection of trends: Statistical considerations and applications to environmental data, J. Geophys. Res., 103(D14), 17149–17161, doi:10.1029/98JD00995.

Another possibility is to apply pre-whitening to the time series. A pertinent paper is:

Yue, S., Pilon, P., Phinney, B. and Cavadias, G. (2002), The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrol. Process., 16: 1807–1829. doi:10.1002/hyp.1095 ïĆğ Wavelet analysis (P8, L26-30 and P9, L1-20) The description of the wavelet analysis is very confusing and seems unnecessarily complicated, due to their limited role in the paper. It does not allow the reader to understand what was done to the data and to replicate the analysis. This section really cuts the flow of reading and should be reworked altogether in order to bring out the essential, with proper supporting references. Which wavelet transform was used in the end, a continuous or discrete? Which wavelet family/filter? From my understanding of this paragraph you applied a discrete wavelet transform, excluded the high-frequency components and then used the inverse transform to reconstruct the lower frequency signal. Or is it that you applied an averaging filter on the wavelet coefficient before reconstructing the signal with the inverse wavelet transform?

2) Results and discussion

Physiographic and climatic control on spatial variability of snow depths The analysis of the factors controlling the spatial variability of snow depths is somewhat limited in breadth. The authors show a general increase in snow depth with latitude and a general decrease in snow depth with increasing altitude. Large-scale control on snow depth will be mainly dependent on the interplay between latitude and altitude but also distance to moisture sources (continentality) and position relative to orographic barriers. Together



these will determine the snowfall rate. For such a large and topographically contrasted region as the Eurasian continent, ignoring these last two effects does not allow a clear understanding of large-scale snow depth spatial variability in the region. The negative (but poor) relationship between snow depth and altitude shown by the authors is largely explained by the continentality and rain shadow effect of the high Tibetan Plateau, while at higher latitude snow depth does seem to increase with altitude in response to orographic enhancement of snowfall. The authors should try to incorporate quantitatively the effects of continentality and barrier effect into their analysis, or at least provide a more in depth discussion of their results in the light of known large-scale physiographic control on the snow cover, with proper supporting references.

The authors further investigate the spatial relationships between mean air temperature, mean snowfall and snow depth. They find that spatial variations in snowfall are positively correlated with snow depth while temperature is negatively, but poorly, correlated with snow depth. While generally interesting, these findings are somewhat expected and do not bring new insights on how the snow cover responds to climate across Eurasia.

Relationships between mean (Eurasian) climate and snow depth over time

The authors revealed interesting increases in snow depth, SWE, temperature and snowfall rates over the study period. However the analysis and interpretation of these tendencies remains somewhat superficial. This section could be enhanced by quantitative analysis, i.e. by performing correlation analysis, and/or multiple correlation/regression analysis to highlight the respective influence of temperature and snowfall changes on mean Eurasian snow depth and SWE. Even more interesting would be to see this analysis done spatially, perhaps in a future study. This would probably highlight the effect of continentality and position relative to orographic barriers on the response of the snow cover to climate.

Specific comments and editorial changes

P3, L13. Although snow cover extent reduced with climate warming, snow depth still increased in northern Eurasia (Kitaev et al., 2005; Bulygina, 2011). Over which period?

P3 L23, 'a' thin snow cover results...

P3 L24. Frauenfeld et al. (2004) indicated that in permafrost areas the maximum snow depth by the end of winter has a significant influence on the active layer depth during the following summer.

P3, L28. The numerical modeling results showed that the rate of mean annual ground surface temperature increase with the increasing maximum snow depth was about 0.1 °C cm-1 for the maximum snow depth at 15 cm. This sentence is convoluted and hard to understand, please rephrase more clearly. Maybe: The numerical modeling results showed that the mean annual ground surface temperature increases with increasing snow depth at a rate of 0.1 °C cm-1 until up to a snow depth of 15 cm...?

P4, L2, ...also increased with snow depth.

P4, L5: Furthermore, snow accumulation an important freshwater resources and has direct impacts on the hydrological cycle.

P4, L11. Adam et al. (2009) suggested that the variations in snow depth will significantly affect the hydrological regime of the Arctic in the future.

P4, L14-26: here you describe trends in snow cover and other variables. Please mention the period over which these changes were observed for respective studies

P4, L28. Snow depth is also closely related to other large-scale atmospheric circulation indices, such as the North Atlantic Oscillation /Arctic Oscillation (NAO/AO) indices. For example, Beniston (1997) found that the NAO....

P5, L8. In order to obtain a wider range of snow depth...Wider range is imprecise. In order to increase the spatial coverage? and/or spatial resolution?

P5, L18. Ground-based snow measurement remains the basis for verification of remote



sensing and instrumental data...

P6, L1. 'TP' = Tibetan Plateau I presume, but I don't think it was defined before.

P6, L15. on a daily basis.

P6, L15. Suggested change: Historical snow course data over the former USSR from 1966 to 2011 were also used in this study

P6, L17 snow surveys performed throughout the accumulation season

P6, L19. Snow surveys were conducted over 1–2 km-long transects.

P6, L20. Snow depth was measured every 10 m in the forest, and every 20 m in open terrain.

P6, L22. SWE: define once

P6. L25 ... over the former USSR. Why only over USSR? Maybe complete sentence with ... 'where SWE data are available..'

P6 L25. SWE was measured every 100 m along the 0.5-1.0 km courses and every 200 m along the 2 km course.

P6, L27. Precipitation data were divided proportionally into daily solid and liquid data, and the solid-to-liquid fraction was determined according to daily mean temperature (Brown,2000). I suggest replacing by: Daily precipitation was partitioned into a solid and liquid fraction, based on daily mean temperature (Brown,2000). You then describe the partitioning equation in the following sentence. $S_rat : whatdoesratstandsfor..?$

P7, L9. Quality control steps. (1) daily snow depth observations (equal to or greater than 0 cm, not including missing data) for <15 days in one month were omitted; This is confusing. Do you mean that months having less than 15 days with snow depth data were omitted from the analyse? If that so rephrase in that sense. (2) snow data from stations with <20 years of measurements during 1971-2000 were excluded; I suggest

replacing by: Stations with less than 20 years of data during the 1971-2000 period were excluded from the analysis. 3) data exceeding two standard deviations compared with the annual average value during 1966-2012 were omitted. Add: 'At each station,' before the sentence.

P7, L16. We defined a snow year as the period from July 1st of a current year to June 30th of the following year. Why this choice of period..? maybe add short complement to the sentence: '... so as to insure that the complete seasonal snow cycle is captured across the study region...' Also, I note in Figure 3 that snow remains in June in some areas, and seems to begin accumulating in September. So the chosen analysis window may not be optimal and should probably begin and end later.

P7, L17. Because the procedures for taking snow observations have changed over the course of the studied period, there were some inhomogeneities in the data.

P7, L25....World Meteorological Organization (WMO) climatological products. A reference would be needed here.

P7, L25. A threshold of 15 days was selected because the snow cover duration in some areas of China was less than one month, and the data for 15 days' snow depth in a month were relatively stable. Do you refer to the previously defined quality control step 1? If this is the case this sentence should go in the quality control paragraph. You can here recall it in short sentence.

P8. L2. In order to capture the primary...

P8, (4) Linear trend coefficient of snow depth: the linear trend coefficient of snow depth for each station was obtained by linear regression analysis with respect to time, and thus represents the rate of change in snow depth for a period of time. Replace 'for a period of time' by 'over time'? Or by: 'for a >20 year time period'. Statistical test on linear trend: see main comments...

P8. L23. ...each station and averaged the anomalies for all stations to the anomalies



for the whole Eurasian continent. : 'averaged the anomalies for all stations to obtain mean anomalies for the whole Eurasian continent'.

P8, L26 -. Description of wavelet analysis. See main comment on this. You need to include at least once key reference.

P9, L12. We used an averaging filter for wavelets analysis. Using this method, values that are too small or too large may be excluded; This description is really unclear. Please simplify and add proper references so that the interested reader can fin further explanations on the technique used, if wanted.

P9, L15. obtained from filtering. Remove extra space.

P9, L26. increased with the latitude... A maximum annual mean snow depth... in the west of the Yenisey River

P9, L28. ...were observed in some areas of China. 'some areas' is rather vague, can you be more descriptive? ....due to wind speed, topography, underlying ground surface, and climatic conditions (refs). This is a rather very general statement which does not bring any insights. Of course snow depth will vary everywhere due to these factors... if you do analyse in a later section how these factord affect the spatial variability, mention it. 'The relation between these factors and spatial snow depth variability is further investigated in section xxx'...

P10, L5. The regions with the smallest annual mean snow depth (<5 cm) were located in most areas of the Caucasus Mountains. This is a bit surprising given the high elevations. Is there an elevation bias here? (snow stations are at low elevations?)

P10, L13. varied with the latitude

P10, L15. . ( 201.8 cm) :here as elsewhere in the text you can should round the snow depth to the nearest centimeter, as this is the probably accuracy of the measurements.

P11, L4.... in northern Siberia. Remove extra space between in and northern

P11, L21. ...the increasing rate of snow depth. increasing rates of snow depth

P11. L19-22: linear trends and results plotted on Figure 4: were trends computed on annual anomalies or on the wavelet filtered series? You must provide a trend test that accounts for the autocorrelation of time-series (see main comment).

P12, L1. There was a sharp increase of 3.5 cm in the maximum snow depth during the 1970s, then fluctuated from the late 1970s to the early 1990s. : then fluctuations from... Perhaps be more precise: what type of fluctuation?

P12, L20. the rate of increase being about 0.6 cm decade

P14, L2. in monthly mean snow depth decreased,

P14, L3. Changes in monthly mean snow depth were consistent with the trends in winter over the former USSR but more stations with the decreasing trends in the southern Siberia. Do you mean: 'but more stations with decreasing trends were found in southern Siberia'?

P14, L5. There were few stations with statistically significant trends of snow depth across China; for these, monthly snow depths tended to decrease at most stations.

P14, L11. To explore the spatial variability of snow depth,

P14, L15. snow depth to the north of 40°N

P14, L23. because a snow depth. remove extra space between 'a' and 'snow'

P14. This result indicates that elevation is an important factor affecting snow depth in these regions. I find this statement and the preceding analysis a bit over simplistic. At large scales the snow cover can be tought to depend on latitude, altitude and distance to moisture source (continentality). I feel you are missing the third factor in our analysis. The poor, and generally negative relationship between elevation and snow depth is interesting because it is contrary to what would be expected from orographic effects on precipitation amounts and phase. What you show is that the high elevation of the TP



does not cause larger snow depth compared to surrounding lower lands. Continentality seems to be the main driving factor here: the TP is in the rain shadow of the Himalaya and as such is moisture-deprived. This should be better discussed, and analysed in the paper. This effect could be investigated, perhaps using a simple continentality index (e.g. http://glossary.ametsoc.org/wiki/Continentality). These indices rely on temperature annual ranges. You could use the closest distance to coast as another simple index.

P15: section 3.4.

You begin the section by stating that ' Variations in snow depth are closely related to climate change'. But what is investigated is the influence of spatially variable climate factors (mean temperature and mean snowfall) on snow depth, and NOT the effect of time-varying climate on snow depth. To do so you would have to test the influence of changing temperatures and snowfall/precipitation on snow depth over time. Rephrase the introduction of the section to clearly explain that you investigate spatial relationships between mean temperature and snowfall on mean snow depths.

The spatial relationship between air temperature and snow depth will be undoubtedly complex when considered an area as big and topographically diverse as the Eurasian continent. Your analysis is till interesting as it shows that snowfall is the main factor driving spatial variability in snow depth, at this spatial scale. However snowfall rates and air temperature must also be somewhat correlated, as snowfall depends on precipitation and temperature (precipitation phase). I suggest that you also calculate and report the partial correlation coefficients, i.e. to show the influence one variable while removing effect of the other, on snow depth.

You do examine the effect of changing climate on snow depth and mass in Figure 10 for the composite eurasian and russian records. This analysis is qualitative and while interesting and valuable, it could be enriched by calculating and presenting the correlation coefficients between series. Especially for the SWE series, how much of the

variance can be respectively explained by air temperature and snowfall? Even more instructive would be to perform this analysis on a station basis and map the results. We would then learn about the spatially variable climate control on snow.

P15, L7. Snow depth significantly decreases with increasing air temperature ($P \leq 0.05$),

P15, L17. increases

P15, L21. The significant increasing snowfall can explain the sudden drop in snow density observed from the mid-1990s through the early 2000s (Zhong et al., 2014): fresh snow with low snow density. Explain the last statement better in a separate statement. Why does increasing snowfall decreases snow density? Is it the mean density of the snowpack? Increasing snowfall in response to warmer temperature should increase the density, both of fresh snow, and perhaps of the whole snowpack due to faster metamorphism and increased compaction...

P15, L26. increasing trend of changes in snow depth. trend in snow depth? or trend in the rate of change?

P15, L27. In fact, the climatology of snow depth not only influenced by air temperature and precipitation, but also with other climatic factors and atmospheric circulation. Poor formulation, rephrase.

P16. L7. These discrepancies may result from differences in the time frame

P16. L26. during the different study periods.

P16. L.26-28. The sensitivity of snow cover to air temperature and precipitation for each station showed regional differences (Fallot et al., 1997; Park et al., 2013). The amount of snowfall can be affected by climate change, and leading to differences in snow depth at different times (Ye et al., 1998; Kitaev et al., 2005). This is why simple spatial relationship between air temperature and snow depth do not exist...

P17, L5. and is the main reason. Extra space between 'and' and 'is'



P17, L10. Therefore, we will select a typical climate zone to research the climatology and variations of snow cover. This rather vague... your study looks at large scale control on snow cover and this is what this dataset allows. Studying small scale (topography, vegetation) effects on the snow cover requires other kind of data, sampled at a higher spatial resolution. I would remove this sentence.

You should better discuss your results in the light of what is known about large-scale control on snow cover: latitude, altitude and continentality are the main geographical factor which drive snowfall rates and hence snow depths. I find your analysis and the discussion on page 17 somewhat incomplete in this respect.

---

Interactive comment on The Cryosphere Discuss., doi:10.5194/tc-2016-182, 2016.