Dear Dr. Kääb and Dr. Gruber,

Thank you very much for providing us the opportunity to improver our paper based on the referees' valuable comments. We have revised the manuscript according to the reviewers' comments and suggestions. Enclosed please find the revised manuscript, responses to the referees, as well as a list of changes. The responses are marked blue. We hope these revisions have improved our manuscript to make it suitable for publication in "The Cryosphere." If you have any questions or concerns about this paper, please don't hesitate to let me know. We look forward to hearing from you soon.

Sincerely yours,

Tingjun Zhang

The summary of the changes and responses to Referees' comments are listed below. The page, line, and figure numbers refer to our revised manuscript. The changes have been indicated in the paper using bold font.

We thank the Anonymous Referee's for their comments on our manuscript. We also appreciate the careful consideration and detailed evaluation. Our replies are included in blue font.

1. You don't mention your paper "Response of changes in seasonal soil freeze/thaw state to climate change from 1950 to 2010 across China" in JGR, 121(11), pp.1984-2000, 2016. You should make very clear the differences to this paper and compare in detail the results and conclusions, i.e. build this paper on the previous one.

Response: Thank you very much for giving us the opportunity to clarify the differences between this manuscript submitted to The Cryosphere, and our study already published in JGR. The unique aspects of this submitted manuscript are that, rather than using stations records alone and focusing on the point-scale or using coarsely gridded data at the large scale, we develop regional-scale gridded fields based on the combination of station data and gridded data. We then employ the Stefan solution to investigate soil freeze depth at the point and regional scale. The JGR manuscript did not do this. Furthermore, we also analyze the potential driving factors (including climate and environmental factors), which, again, JGR publication did not do. Please see the difference in Table 1. In the study, we also introduced the difference, please see L69-72.

Table 1. Comparison of two manuscripts

	The Cryosphere Manuscript	*JGR-Earth Surface* Manuscript
Study Target	Soil freeze depth (SFD).	surface soil freeze/thaw status
Objectives	1) To investigate the spatiotemporal variability of seasonal soil freeze depth from the point- to the regional-scale 2) To analyze the potential forcing variables of soil freeze depth across China.	1) To assess the spatiotemporal variation of seasonal soil freeze/thaw status across China, incorporating a land cover classification
	1) Using daily air temperature	1) Establish the relationship

Methodology	to estimate freezing index, and daily soil temperature to compute the soil freeze depth, we obtain the edaphic factor (E-factor) through the simplified Stefan Solution 2) Combining freezing index, derived from gridded air temperature, and the E-factor, we estimate the spatiotemporal variability of soil freeze depth at the regional scale using the simplified Stefan Solution	between monthly air temperature and monthly freeze days (based on soil temperature at 5 cm) in different land cover types, use monthly air temperature ranges in each land cover type to classify the surface soil freeze/thaw states into three types: completely frozen (CF), partially frozen (PF), or unfrozen (UF) 2) Use gridded monthly air temperature to quantify the spatial variability of soil freeze/thaw states, and evaluate the area extent of surface soil freeze/thaw states at the monthly and annual scale
Main Conclusions	1) The spatial distribution of SFD variability is influenced by latitude and elevation across China; 2) Using 839 sites we found that the SFD decreased significantly, at -0.18 cm/year from 1967 to 2012, equal to a net change of 8.05 cm; 3) On the regional scale, the 1950–2009 spatial variation of SFD ranges 0.0–4.5 m across China, with most areas exhibiting significant decreases between less than 0.0 and -0.4 cm/year; 4) A negative between SFD and mean annual air temperature (MAAT), mean annual ground surface temperature (MAGST), TI_a (air thawing index), and TI_s (surface thawing index). Surprisingly, we found that there is no correlation between SFD and SND. The environmental factor vegetation (NDVI) is negatively correlated with SFD, indicating that 64% of	1) Changes in area extent of seasonal soil freeze/thaw state are somewhat different and complicated compared to temperature trends. The mean annual area extent of soil CF state decreased statistically significantly at a rate of -0.043×10^6 km^2/decade from 1950 to 2010. For the soil UF state, the mean annual area extent increased significantly by about 0.037×10^6 km^2/decade. However, the mean annual area extent of soil PF state increased statistically significantly by 0.032×10^6 km^2/decade from 1950 to 1993, and exhibited no change from 1993 to 2010. 2) The monthly area extent of CF state decreased significantly for all months, but decreased for the UF state. The PF state showed a complex pattern, increasing during November–March and decreasing in the other months. 3) During 1950–2010, the freeze status value decreased

	the changes in SFD can be accounted for by vegetation.	statistically significantly from winter to summer, and increased from spring to summer. Spatially, the maximum status value was mainly located in the south of China. The minimum value was in the north of China and on the Tibetan Plateau.

2. Line 35: how can permafrost area (23%) and seasonally frozen ground (>80%) be more than 100%?
Response: Thank you for catching this. We have revised it in L42-44 "…. or approximately 23% of its land area, mainly on the Tibetan Plateau; regions with SFG occupy about 50% of the land area in China (Zhou et al., 2000)."

3. Section 2.1.3. Mention/discuss why no reanalysis data sets were used instead of MMGAT? Reanalysis data could allow for some additional/alternative tests of meteorological parameters and their trends.
Response: In this study, we chose the gridded observational dataset from the University of Delaware's 1900–2014 terrestrial air temperature gridded monthly time series. The reason is that this dataset combined the completely observation station data, considered the complex terrain, which have been used for frozen ground study across China (Peng et al., 2016). Considering the complex terrain of frozen ground distribution, we used a simple and popular method to improve the accuracy of gridded air temperature, and the detailed description of the method is in L150-159.

The MMGAT dataset has been evaluated against meteorological station data, and the result (please see L157-159) indicates good agreement.

4. Section 2.16. What about other potentially important environmental data (geology, wetness, other meteorological data, albedo, cloud cover …)? See also previous comment. It is not obvious why NDVI should be the most important other influence to SFD.
Response: Thank you for your suggestion. As you say, there are many other environmental factors affecting SFD. However, it is difficult or impossible to obtain these in-situ data, and some factors we cannot quantify. Thus, we chose some of the more obtainable variables such as NDVI. We did not think that NDVI would be the most important factor influencing SFD, but figured it might be important. Compared with other environment factors, NDVI is a relatively reliable product.

The reasons why we choose NDVI rather than other environmental variables, e.g. geology, wetness, albedo, cloud cover are:

(1) At the regional scale, NDVI is considered as more reliable by comparing with observational data (Bao et al., 2015). Taking wetness for an example, a reanalysis or remote sensing product would not have very good accuracy compared to observational data, especially in the cold seasons. Further, remote sensing can only get soil moisture in a shallow, to soil layer. (Yang et al., 2007; Chen et al., 2013). Therefore, we consider NDVI as the only environmental factor here.

(2) NDVI is selected here to partly represent the influences of soil conditions (e.g. wetness and soil type), topography (slope aspect), geology and albedo since NDVI can react these potential variables.

5. Line 128: wouldn't the usage of a reference level other than sea level, i.e a level closer

to the real elevations (for instance, mean elevation of regions) be less sensitive to uncertainties in the estimated lapse rates? In particular for the Tibet Plateau, where most of the SFDs > 0 are found? Uncertainties would not be extrapolated but only interpolated.

Response: Thanks! We agree. For the sea level or a reference level question, we revised it as reference level in L154-155 "…. a reference level (elevation of 0 m)…".

For the uncertainties question, the reason why we used this method to process MMGAT is because of the complex terrain across China, especially in the mountain area in western of China. Through the 1-km DEM dataset and the lapse rates, we can improve the accuracy of MMGAT (Qin et al., 2015 & 2016; Zou et al., 2015).

6. Line 227: You list a number of reasons for the spatial SFD variability, but given no indication that they in fact could lead to the observed variations. Some influences, such as albedo, could actually be tested.

Response: Thank you for your suggestion. In the previous manuscript L227, it just list several possible reasons for SFD variability in northwest of China. Taking a panoramic view of the study, this part seems confused. Further, we have detail discussion about the potential driving factors of soil freeze depth. Please see the more comprehensive explanations about it in section 4.1. For your suggestion about albedo, at the regional scale, albedo product includes remote sensing dataset (e.g. MODIS, GLASS), and reanalysis datasets (e.g. ERA-Interim). These datasets are not good agreement with observational data, especially in the cold season, and with snow cover (Fig. 1). However, observational albedo data are really difficult to obtain. Your suggestions are really good, and we will further obtain the dataset in the field in a special study area, and hopefully can get new results for this study.

Hopefully, you can agree with us. Thanks!

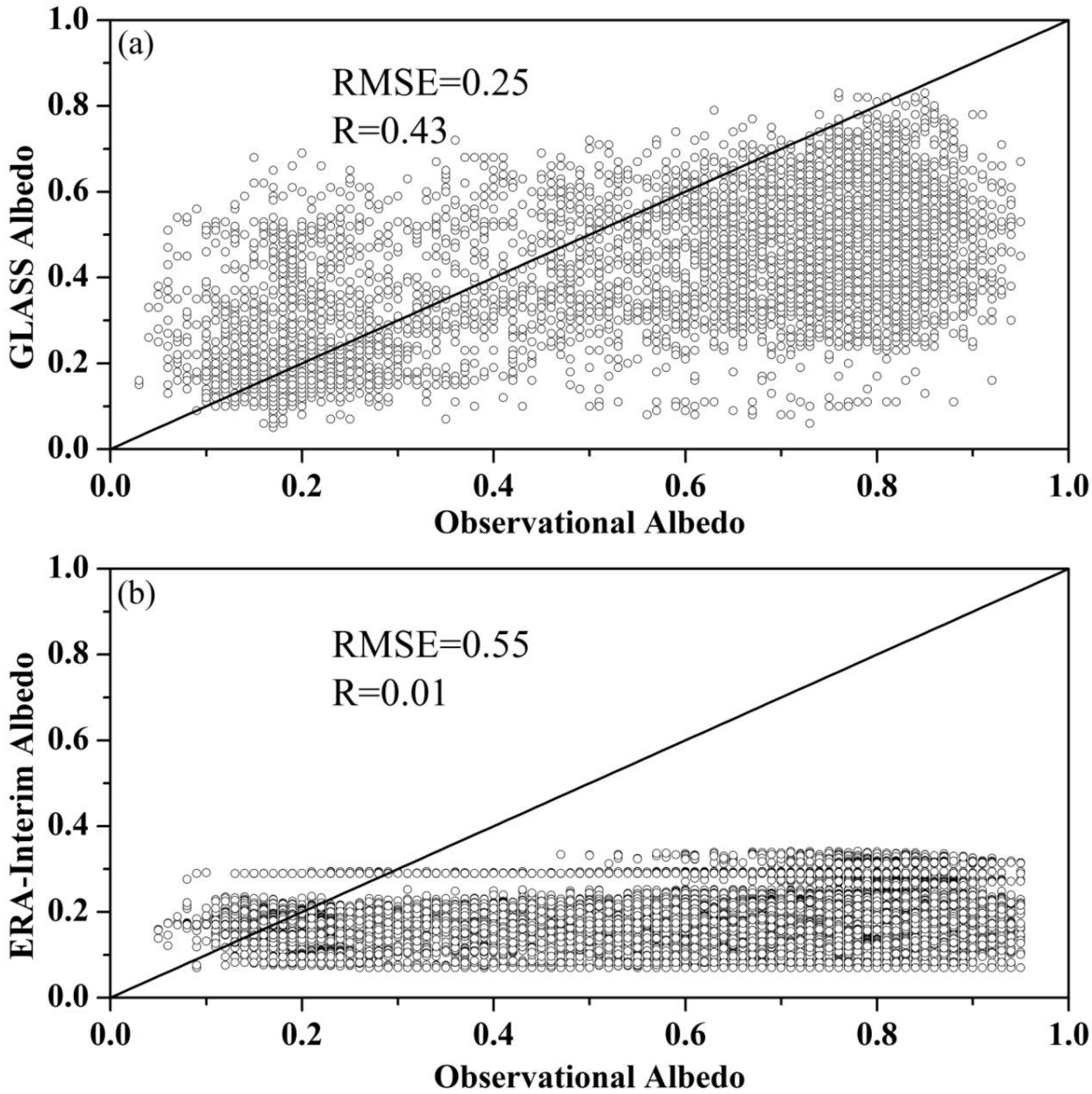

Fig.1 Comparison of albedo between observational and others derived remote sensing dataset (GLASS), reanalysis dataset (ERA-Interim). Combined with in-situ albedo of less than 90 sites (only 20 sites across China), here evaluate the GLASS albedo with 8-day temporal resolution, and daily ERA-Interim albedo during1996-2012. The RMSE of albedo is 0.25 and 0.55, respectively. Results show that GLASS and ERA-Interim albedo are not good agreement with in-situ, which are not suitable for using in this study.

7. Mention and discuss the relation of soil freezing and permafrost from your data, as you mention permafrost at several places.

Response: Ok! Soil freeze depth in seasonally frozen ground represents the *maximum* soil freeze depth, while in permafrost regions it means *potential* soil freezing depth. However, we mostly focus on the maximum thaw depth (actually active layer thickness) in permafrost regions. In fact, the potential soil freezing depth in permafrost regions can also reflect climate change in permafrost regions (Zhou et al., 2000).

8. Fig. 1, 4a, 7: what is the inset to the lower right? It does not contribute. Remove.

Response: Thanks! We remove it.

9. Fig 4: your panel sequence is a, c, b, d? Why not a, b, c, d?
Response: Ok, we have revised it.

10. Fig 6: very hard to see differences. Better show anomalies with respect to the mean SFD?
Response: We agree, however, Fig. 7 (original figure 6) is intended to show the spatial distribution of SFD for several decades. Fig. 8 (original figure 7) can show the temporal variability of SFD. Thus, fig. 8 shows the differences. Below we show the SFD anomaly in decades with respect to the 1950 –2009 mean. If you and the editors think this figure is useful to include in our manuscript, we can gladly do so.

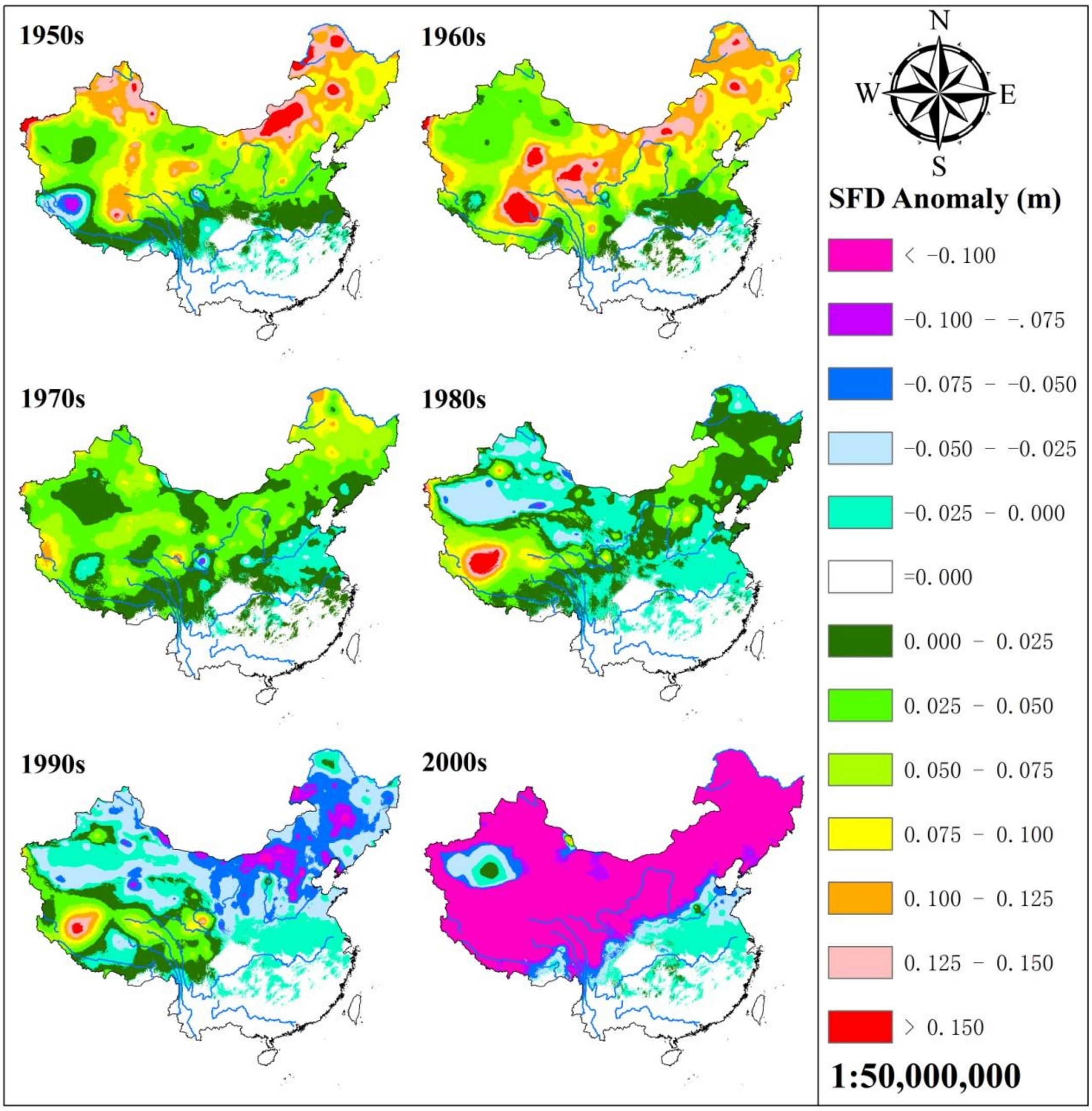

Figure 2. Spatial variability of SFD anomaly for the decades of the 1950s, 1960s, 1970s, 1980s, 1990s, and 2000s, with respect to the 1950–2009 mean across China.

11. Fig 10: I think the relation between SFD and NDVI needs more discussion. Why is it correlated on a year to year basis? You mainly discuss influences of vegetation on SFD, but couldn't both SFD and NDVI variations simply reflect the same drivers? Temperature -> Growing season? Temperature/precipitation -> Water availability? I think it doesn't hold to just say….the detailed physical mechanism will require further future work. You need to discuss at least the fundamental mechanisms, otherwise showing the NDVI doesn't make much sense.
Response: Thank you for pointing this out. We have added more discussion about the

relationship between SFD and NDVI in the discussion part. The reason why we analyzed the relationship between annual NDVI and SFD is that the SFD represents the maximum soil freeze depth in one year (i.e. it is an annual value).

For the relationship between SFD and NDVI, we have explained it in two ways, please see L350-378 "A negative correlation between SFD and vegetation, as quantified by NDVI, is found. Vegetation change has a significant influence on the climate system mostly through changes to the surface radiative energy budget, which can be affected the SFD. Based on previous research, vegetation varies in different land cover types and responds to climate change via different physical mechanisms (Snyder et al., 2004), e.g., changes in the surface albedo (e.g., bare ground versus vegetation cover), vegetation transpiration, and shading effects (Kelley et al., 2004; Snyder et al., 2004; Swann et al., 2010; Chang et al., 2012; Zhang et al., 2012). In the cold season, less/decreased vegetation will be more easily snow covered, thus increasing the albedo considerably. Increasing albedo results in less net radiation at the land surface, as more incoming solar radiation is reflected from the surface. Then, the surface air temperature will decrease considerably due to less energy absorbed at the surface. For the colder land surface, the sensible heat flux is reduced. Further, the vegetation decrease results in reducing evapotranspiration, which decreases the latent heat flux (Snyder et al., 2004). Compared to increased vegetation cover, less vegetation causes a large annual-average increase in the surface albedo with the largest changes in the winter and spring seasons, which reduces the amount of net radiation at the surface, making the surface colder and resulting in SFD increases. Conversely, vegetation increases could lead to decreasing SFD. The vegetation's effect on transpiration is primarily important in summer, while SFD primary occurs in winter and spring (Snyder et al., 2004).

The significant negative correlation between NDVI and SFD demonstrates their inverse relationship. Results from many previous studies indicated that there has been a vegetation increase, or a greening trend, in different regions during the past several decades (Peng et al., 2011; Piao et al., 2011; Zhang et al., 2013; Zhu et al., 2016). Because climate change controls the spatial distribution of vegetation, most studies examine vegetation variability as impacted by climate change, including temperature and precipitation (Bao et al., 2015; Huang et al., 2016). Results showed that increasing temperature and precipitation result in vegetation increases. Similarly, figure 8 shows that rising temperature results in a SFD decrease. The negative relationship between SFD and NDVI indicates the effect of vegetation on SFD, and also their inverse relationship."

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