Study on Snow Line in the Tianshan Mountains Based on MODIS Image

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Abstract Using MOD10A1, temperature and precipitation of 21 meteorological observatories and HJ-1/CCD data from July to September during 2002 – 2013, this paper takes the Tianshan Mountains as the study area to analyze the space distribution characteristics of snow line and its influencing factors. The results show that the snowline distribution of southern and northern slopes of the Tianshan Mountains is that it is high in the south and east but low in north and west; the snowline of southern slope is sparse and there is a small spatial gradient change; the snow line is dense in the middle of northern slope, and the spatial gradient change is not large. Through the analysis of the whole study area, it is found that the correlation coefficient between snow line altitude and temperature is 0.159, and the partial correlation coefficient between them is –0.212; the correlation coefficient between snow line altitude and precipitation is –0.668, and the partial correlation coefficient between them is –0.676. Precipitation is the dominant factor that affects the distribution of snow line of southern and northern slopes of the Tianshan Mountains.

Key words Southern and northern slopes of the Tianshan Mountains, Snow line, Correlation coefficient

1 Introduction

Snow line is a product of the climate[1], and an important indicator of modern glaciers[2-3]. The varying snow line can indicate climatic changes[4-5], and also reflect snow melting. Therefore, the accurate monitoring of snow line change is of great significance to the analysis of water resources utilization, atmospheric circulation, climate evolution and disaster[6-7]. Deng Yuwu *et al.*[8] use the glacier catalogue data to establish the snow line field of glacier system in southern Tibet and analyze its spatial distribution characteristics. Wang Yilin *et al.*[9] use the same method to establish the snow line field in Qinghai-Tibet Plateau and analyze the influencing factors of its distribution. Zhang Jie *et al.*[10] use remote sensing data and meteorological data to analyze the snow line changes in the Qilian Mountains. Xiao Qinghua[4] studies the glacial snow line changes since Pleistocene in the Qilian Mountains by changes in temperature and precipitation. However, these studies are focused on the Qinghai-Tibet Plateau[11-14]. Currently, there are few studies on Xinjiang and only some experts use the survey data to analyze the characteristics of the snow line[15-16]. Few scholars study the factors influencing the snow line distribution in Xinjiang based on meteorological data. With the southern and northern slopes of the Tianshan Mountains as the study areas, this paper uses MOD10A1, temperature and precipitation data of 21 meteorological stations and HJ-1/CCD data to study the distribution of snow line in the southern and northern slopes of the Tianshan Mountains and the main influencing factors.

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2 Data and methods

2.1 Study area This paper selects the southern and northern slopes of the Tianshan Mountains as the study areas. The northern slope of the Tianshan Mountains features a transitional climate from humid to semi-arid climate[17], with the annual average temperature of 0.9 ℃. The extreme minimum temperature is – 37 ℃, and the extreme maximum temperature is 33 ℃. The average annual precipitation is 450 – 800 mm[18]. In recent years, as the temperature rises, the height of permanent snow line has increased by nearly 60 m, and the regulation and storage capacity of reservoir in the mountain is weakening[19]. The southern slope of the Tianshan Mountains features a typical temperate continental climate. The precipitation is rare in the winter, and the precipitation from October to March in the next year accounts for 13% of the annual precipitation. The precipitation from April to September accounts for 89% of annual precipitation, and this period is the "rainy period" for the southern slope of the Tianshan Mountains[20]. The rate of increase in precipitation in the southern slope is higher than in the northern slope, and especially the western part of southern slope is the area with the largest increase in precipitation in recent decade[21].

2.2 Research data MOD10A1 covering Xinjiang from July to September during 2002 – 2013 are acquired from the data center of NASA Earth Observing System Data Gateway; temperature and precipitation data of 21 meteorological stations during 2002 – 2013 acquired from Xinjiang Meteorological Information Center; 30m HJ – 1/CCD data in 2013 downloaded from China Resources Satellite Application Center Network (http://www.cresda.com/n16/n1115/n1432/index.html).

3 Determining of time and extraction of snow line

The changes in snow area in a year can be generally divided into three stages[10, 22]: snow accumulation period (September to April in the next year); transition period (May); ice and snow melting period (June to August). Using MOD10A1 data during 2002 – 2013, we calculate the daily snow-cover area from June to August annually in the study area, and get the date with the minimum snow-cover area every year. It is calculated that the 197th day is the earliest date with the smallest snow area, and the 236th day is the latest date. Due to large anomaly, the 197th day is removed, and the 205th day is regarded as the earliest date with the smallest snow area. So the date in this study is identified as the 205th day to the 236th day. We extract the snow line elevation with probability of snow at 3%, 6%, 9% and 100%, respectively, and take HJ-1/CCD as "true value" for error analysis. The ratio when the error is smallest is regarded as the threshold value of snow line extraction, and the method of using this threshold value to extract snow line is the snow duration ratio method. Through the statistical analysis, it is found that when threshold value is 75%, the deviation from "true value" is smallest, so 75% is identified as the threshold value of snow line extraction using the snow duration ratio method.

4 Establishment and distribution of the snow line field

4.1 Establishment of the snow line field With 75% as the threshold value, we overlap the MOD10A1 data in the 205th-236th day in 2013, and map out the snow line by human-computer interaction, and extract the height, longitude and latitude. In ArcGIS, we call the ETgoWizard module of Sharelt Company to generate 10′×10′ grid, and use Overlay/Intersect command in ArcToolbox to extract the latitude and longitude of sampling points in the grid and calculate the height of snow line and other attribute data. Using Excel, we get .dbf attribute file, take ET-Index as the primary field for extended sorting, and take ET-Index as the classification field to calculate the arithmetic mean of latitude, longitude and height of snow line. Each grid obtained only has one kind of virtual glacier data, as shown in Fig. 1a. Through the frequent grouping and averaging of adjacent glaciers in the study area, it can eliminate the influence of local terrain on snow line as much as possible, and truly reflect the distribution of the snow line[23]. By ordinary Kriging method, we conduct interpolation on the snow line points in the southern and northern slopes, of the Tianshan Mountains, and based on interpolation, use "surface analysis/contour" to generate the contour. In order to generate a more regular and clean-cut contour of snow line height of the southern and northern slopes in the Tianshan Mountains, there is a need to perform the curve smoothing on contour, as shown in Fig. 1b.

4.2 Distribution of the snow line field The establishment of snow line field can clearly reflect the space distribution characteristics of snow line. As can be seen from Fig. 2, the snow line in the study area is high in north but low in north, and high in east but low in west; the snow line is sparse in the southern slope, and the space gradient change is small; the snow line is dense in the middle of northern slope, and the space gradient change is large. The lowest value of snow line appears in the western part of northern slope in the Tianshan Mountains, with the height of 3800 m; the snow line value gradually increases in the east and southwest, and peaks in the southwest direction (4800 m). The height of snow line gradually decreases from south to north, with the latitude zonal distribution characteristics, following the general rule of global snow line distribution. The height of snow line gradually decreases from east to west, showing the longitude zonal distribution characteristics.

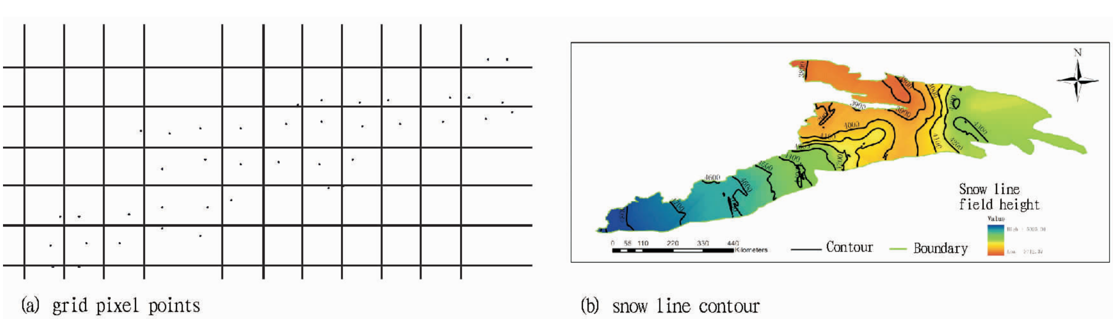

Fig. 1 Grid pixel points and snow line contour of the southern and northern slopes in the Tianshan Mountains

5 Analysis of the factors influencing snow line distribution

5.1 Temperature and precipitation interpolation In this paper, using the spline interpolation method of ArcGIS, we perform the interpolation on temperature and precipitation data of the meteorological stations in the study area, to obtain the temperature and precipitation interpolation maps (Fig. 2). As can be seen from Fig. 2a, the temperature distribution is complex in the study area. Overall, it is low in north but high in south, first decreases and then increases from west to east. Due to the barrier role of the Tianshan Mountains, there is a huge difference in the temperature between South Xinjiang and North Xinjiang. South Xinjiang features a warm temperate climate with more sunshine hours and higher seasonal temperatures; North Xinjiang has a temperate continental arid and semi-arid climate with more clouds and lower temperature. As can be seen from Fig. 2b, the precipitation in the northern slope is more than in the southern slope; the precipitation gradually decreases and then increases from west to east in the northern slope; the precipitation gradually increases and then decreases from west to east in the southern slope.

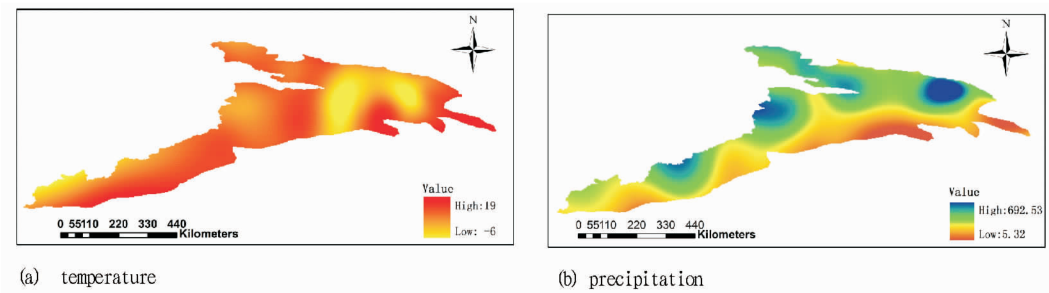

Fig.2 Temperature and precipitation interpolation maps of the southern and northern slopes in the Tianshan Mountains

5.2 Correlation analysis of meteorological factors and snow line

5.2.1 Temperature-snow line correlation. We perform the correlation analysis of temperature data and snow line height data extracted from 600 points (Table 1). As can be seen from Table 1, there is a weak positive correlation between the height of snow line and temperature, and the correlation coefficient is 0.159. From Table 2[24], it can be found that it is a low degree of correlation. The terrain is extremely complex in the southern and northern slopes of the Tianshan Mountains, the precipitation varies in different regions, and the temperature may be affected by the precipitation in the same latitude and longitude, so there may not be a close positive correlation between snow line and temperature in the study area. We perform the partial correlation analysis on temperature and snow line height data of 600 points, and calculate the partial correlation coefficient at −0.212 after excluding the influence of precipitation (Table 1). The correlation is negative, contrary to the correlation results, indicating that precipitation has a great impact on the correlation between temperature and the height of snow line. At the same time, it can be concluded that after removing precipitation factor, the correlation between temperature and the height of snow line is weak. Thus, it can prove our previous inference that in the southern and northern slopes of the Tianshan Mountains, temperature is not a major climatic factor that affects the height of snow line, and it may be combined with slope degree and slope direction to have an impact on the height of snow line.

Table 1 Correlation and partial correlation between temperature or precipitation and snow line

	Temperature	Precipitation
Correlation with snow line	0.159	−0.668
Partial correlation with snow line	−0.212	−0.676

Table 2 Correlation coefficient and correlation degree

Correlation coefficient(r)	Correlation degree
$0.8 < \lvert r \rvert < 1$	High degree of correlation
$0.5 < \lvert r \rvert \leqslant 0.8$	Moderate correlation
$0.3 < \lvert r \rvert \leqslant 0.5$	Low degree of correlation
$0 \leqslant \lvert r \rvert \leqslant 0.3$	Very low degree of correlation

5.2.2 Precipitation- snow line correlation. We perform the correlation analysis of precipitation data and snow line height data extracted from 600 points (Table 1). As can be seen from Table 1, there is a clear corresponding relationship between the height of snow line and precipitation in the same position. If snow line lowers, precipitation will increase; if snow line rises, precipitation will decrease. The height of snow line and precipitation are negatively correlated, and the correlation coefficient is −0.668, which is consistent with results of previous studies. Thus we infer that in the southern and northern slopes of the Tianshan Mountains, precipitation is a major factor influencing the height of snow line. To verify this conclusion, we exclude the impact of temperature and do partial correlation analysis, to calculate the partial correlation coefficient at −0.676, indicating that precipitation is moderately and negatively correlated with the height of snow line. Thus it proves the previous inference that in the southern and northern slopes of the Tianshan Mountains, precipitation is a major factor influencing the height of snow line.

6 Conclusions

The snow line in the southern and northern slopes of the Tianshan Mountains is high in north but low in north, and high in east but low in west; the snow line is sparse in the southern slope, and the space gradient change is small; the snow line is dense in the middle of northern slope, and the space gradient change is large. Through an overall analysis, it is found that the correlation coefficient between the height of snow line and temperature is 0.159 and the partial correlation coefficient between them is −0.212; the correlation coefficient between the height of snow line and precipitation is −0.668 and the partial correlation coefficient between them is −0.676. Precipitation is a major factor influencing the height of snow line.

References

[1] JIANG FC, WU XH, WANG SB, *et al*. Characteristics of space distribution of the climatic snowing in China[J]. Journal of Geomechanics, 2002, 8(4): 289–296. (in Chinese).

[2] JU YJ, LIU GN, WEI X. Equilibrium line altitude of mountain glacier as a proxy of climate changes[J]. Journal of Glaciology and Geocryology, 2007, 29(4): 613–616. (in Chinese).

[3] ZHANG RJ, ZHAO FY, FANG HB, *et al*. Remote sensing survey of existing snowlines in the past 30 years in Qinghai – Tibet Plateau[J]. Remote Sensing for Land & Resources,2010,23(2):59 –63. (in Chinese).
[4] XIAO QH, ZHANG WS, ZHANG W, *et al*. Study on snowline and climate changes during different ice ages in the Qilian Mountains since pleistocene [J]. Arid Zone Research,2008,25(3):426 –432. (in Chinese).
[5] HAN F, ZHANG BP, TAN J, *et al*. The effect of mountain basal elevation on the distribution of snowline with different mountain basal elevations in Tibetan Plateau and its surrounding areas[J]. Geographical Research,2014,33(1):23 –30. (in Chinese).
[6] ZHANG Y, HUANG XD, WANG W, *et al*. Validation and algorithm redevelopment of MODIS daily fractional snow cover products[J]. Arid Zone Research,2013,30(5):808 –814. (in Chinese).
[7] CHENG Y, XU DX, SONG XL. Evaluation of the effects of summer climate change on glacier development in the West Qilian Mountain over the last 50 years[J]. Arid Zone Research,2009,26(2):294 –298. (in Chinese).
[8] DENG YW, XIA ZC, QIN JX. Creating fields of equilibrium Line altitude and analyzing their space distribution characteristics in the Southern Tibet Glacier System[D]. Changsha: Hunan Normal University, 2005. (in Chinese).
[9] WANG YL, WANG TB. Analyses of modern snowline and its influential factors in the Tibet[D]. Lanzhou: Lanzhou University, 2010. (in Chinese).
[10] ZHANG J, HAN T, WANG J. Changes of snow – cover area and snowline altitude in the Qilian Mountains, 1997 –2004[J]. Journal of Glaciology and Geocryology,2005,27(5):649 –654. (in Chinese).
[11] WANG JG, WANG ST, ZHUANG XC, *et al*. Snow – ice disaster indexes and risk assessment in the pastoral area in North Xinjiang[J]. Arid Zone Research,2014,31(4):682 –689. (in Chinese).
[12] WANG LP, XIE ZC, DING LF, *et al*. Establishing the field of equilibrium line altitude of the glacier system in the Chiangtang Plateau based on geographic information system and its distribution characteristics [J]. Arid Land Geography,2010,33(5):692 –702. (in Chinese).
[13] XIAO F, DU G, LING F, *et al*. Digital extraction of snowline based on flow path analysis[J]. Journal of Remote Sensing, 2010,14(1):62 –67. (in Chinese).
[14] NIE N, ZHANG ZJ, ZHANG WC, *et al*. Analysis of the characteristics of the glacier system and typical glacier change based on remote sensing in the Yarlung Zangbo River Basin during the past 30 years[J]. Journal of Glaciology and Geocryology,2013,35(3):541 –552. (in Chinese).
[15] JIANG ZX. Analysis on the trend surface of western modern science line of China[J]. Scientia Geographica Sinica,1987,7(1):1 –8. (in Chinese).
[16] WANG X, XIE ZC, FENG QH. The calculated ELA and uts distribution characteristics of the glacier system in the Tarim River Basin[J]. Journal of Glaciology and Geocryology,2003,25(4):380 –388. (in Chinese).
[17] SHANG HM, WANG WK, DUAN L, *et al*. Simulation on groundwater regulation based on ecological water table in the northern foot of Tianshan Mountain[J]. Research of Soil and Water Conservation,2014,21(6):1 –4. (in Chinese).
[18] LI ZY, LUO GP, ZHOU DC, *et al*. Eco – geographical characteristics of alpine timberlines on northern slope of Tianshan Mountains[J]. Journal of Desert Research,2010,32(1):122 – 131. (in Chinese).
[19] SU LT, SONG YD, ZHANG ZY. Response of the climate and ecological environment in northern slope of the Tianshan Mountains to global warming since recent 40 years[J]. Arid Land Geography,2005,28(3):342 –346. (in Chinese).
[20] ZHOU X, CHEN DJ. The characteristics of climate vertical variation of the southern slopes of Tianshan Mountains[J]. Journal of Mountain Research, 1998,16(1):47 –52. (in Chinese).
[21] LI C, WANG RH, HUANG J. Variation characteristics of temperature and-precipitation in the north of Tianshan Mountains in recent 50 years[J]. Research of Soil and Water Conservation,2013,20(6):117 – 124. (in Chinese).
[22] LI GH, WANG C, XI XH, *et al*. Extraction of glacier snowline based on airborne LiDAR and hyperspectral data fusion[J]. Remote Sensing for Land & Resources,2013,29(3):79 –84. (in Chinese).
[23] DENG YW, XIE ZC, LI LL. Creating the distribution field of equilibrium line altitude based on GIS in the southern of Tibet and analyzing its distribution characteristics [J]. Yunnan Geographic Environment Research, 2006,18(3):10 – 14. (in Chinese).
[24]SHI LW. SPSS statistic analysis[M]. Beijing: Tsinghua University Press, 2012: 145 –147. (in Chinese).

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Shitouzhai Scenic Area; Langgong Scenic Area; Dishuitan Scenic Area; Balinghe Scenic Area), and the last four are the untapped resorts. In the development of plan for these four resorts, it is necessary to be based on protection and rational use of landscape resources and consider the rural residential construction and development in the scenic area, to reflect the harmony between man and nature. Meanwhile, in the building plan of rural residential areas in the scenic area, it is necessary to make clear target on the population size and land use in the rural settlements in accordance with the requirements of resource protection and ecological capacity in the scenic area, which can not only reserve space for rural construction and development, but also avoid scenic area loss caused by land expansion.

References

[1] DUAN RJ, HAO JM, ZHANG JX. Land utilization and changes on eco – service value in different locations in Beijing[J]. Transactions of the Chinese Society of Agricultural Engineering, 2006, 22(9): 21 –28. (in Chinese).
[2] WANG L, YANG J, HU YM, *et al*. Quantitatively study on landuse ecosystem service value in Guangzhou City[J]. Bulletin of Soil and Water Conservation, 2009(4): 229 –234. (in Chinese).
[3] TAN YZ, WU CF. The laws of the information entropy values of land use composition[J]. Journal of Natural Resources,2001,18(1): 112 –117. (in Chinese).
[4] TIAN GJ, ZHANG ZX. Dynamic change of land use structure in Haikou by remote sensing and GIS[J]. Journal of Natural Resources, 2001, 16(6): 543 –546. (in Chinese).
[5] LIANG ZP, ZHOU X. Land on dynamic change analysis and prediction on Guigang City, Guangxi[J]. Resource Development & Market, 2007, 23(9): 795 –798. (in Chinese).
[6] QIU DC. Land resource science[M]. Chongqing: Southwest China Normal University Press, 2005. (in Chinese).
[7] CAI HS, ZHU HD, ZHANG XL, *et al*. Dynamics analysis of the ecological capacity in Po – yang Lake Nature Reserve based on RS and GIS[J]. Acta Ecologica Sinica, 2007, 27(11): 4751 –4757. (in Chinese).
[8] Wackernagel M, Onisto L, Bello P, *et al*. National natural capital accounting with ecological footprints concept[J]. Ecological Economics,1999(29): 375 –390.