



Editorial

# An Overview of Ecosystem Changes in Tibetan and Other Alpine Regions from Earth Observation

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## 1. Introduction

Alpine ecosystems have shown sensitive responses to climate change during the past few decades. Investigations of the changes in the structure, functions, and services of alpine ecosystems benefit ecosystem management and improve our ability to predict future changes in alpine ecosystems in response to the projected level of climate warming. The Qinghai–Tibet plateau (QTP, the largest and highest alpine ecoregion in the world) is located in southwestern China (26–39.8°N, 73.3–104°E) and covers over 2.5 million km<sup>2</sup>, with an average elevation above 4000 m. Climate warming in the QTP has been observed to be about two times that of the global average since the 1980s. Therefore, the QTP’s ecosystems are expected to undergo substantial changes. In recent years, to better understand the ecological changes in the QTP and their impacts on ecosystem services, the Chinese government conducted two large scientific projects regarding the QTP, namely, the second scientific expedition to the Qinghai–Tibet Plateau and the scientific research into the construction of the Sichuan–Tibet Railway. Considering this context, we organized a Special Issue entitled “Ecosystem Changes in Tibetan and Other Alpine Regions from Earth Observation” for the journal *Remote Sensing*. This issue focuses on the QTP as well as other alpine regions and aims to collect the most recent research on the monitoring of land surface processes (e.g., vegetation productivity and vegetation phenology) based on remotely sensed observations and analyzing their relations with climate factors and anthropogenic activities (e.g., grazing, engineering, and urbanization).

We have received a total of 17 submissions and finally published 8 research papers, all of which focused on the remote sensing of vegetation changes in the QTP. The objective of this Editorial is to offer an overview of the latest findings and contributions from the studies published in this Special Issue. We also provided a short outlook on the research topic of the remote sensing of ecosystem changes in the QTP.

## 2. Overview of Contribution and Future Perspectives

The eight papers in this issue cover a wide range of topics regarding the QTP, including spatiotemporal changes in vegetation phenology, greenness, and productivity; the influence of climate drivers and anthropogenic activities; and the development of basic remote-sensing data. We summarized this research progress via four dimensions.

First, the increasing influence of precipitation on vegetation growth in the QTP was found by several studies in this Special Issue. We generated a word cloud by using the words in the abstracts of the published eight papers and observed that the word “precipitation” occurs very frequently (Figure 1). Cheng et al. [1] investigated the effects of the pre-season temperature and precipitation as well as their interactions on spring phenology across the QTP from 2000–2017. Based on redundancy analyses, they found a



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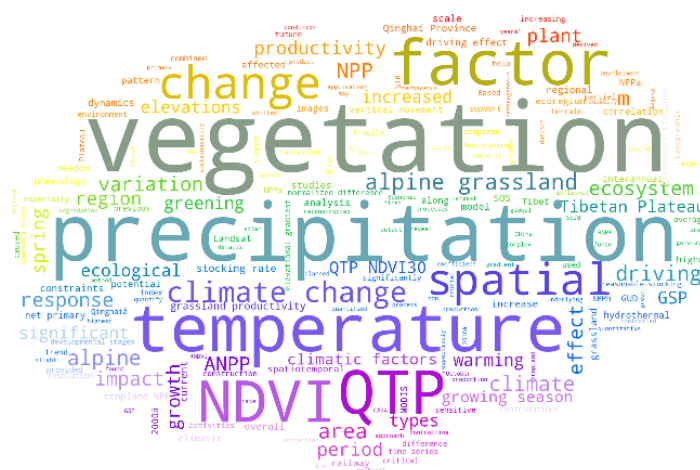
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strong relative contribution of pre-season precipitation to interannual variations in the start of the growing season (SOS), particularly in the western, drier ecoregion of the QTP. More importantly, the impact of the pre-season temperature on SOS was strongly regulated by precipitation, with an observation that a 10 mm increase in pre-season precipitation results in a 2% increase in the contribution of pre-season temperature in a QTP meadow. These results highlight that, in addition to the direct effect, the indirect effect of pre-season precipitation on SOS should be considered in ecosystem models for superior SOS predictions under the scenario of future climate change. The increasing impact of precipitation on grassland productivity in the QTP was suggested by both Zha et al. [2] and Zhai et al. [3]. During the past two decades, the partial correlation coefficient between growing-season precipitation and the net primary production (NPP) increased from 0.01 for the period from 2000–2009 to 0.78 for 2010–2019 [2]. The precipitation during July–August was a more prominent factor than air temperature with respect to the regulation of grassland productivity [3]. All these studies call for more attention to the investigations of the vegetation growth status in response to precipitation changes in the QTP.



**Figure 1.** Word cloud showing the word occurrence frequency in the abstracts of the published papers in this Special Issue. Larger words indicate a higher occurrence frequency.

Second, two papers address studies examining the elevational gradient-related changes in vegetation greenness and productivity and the different influences of climate factors corresponding to different altitudes [4,5]. Pan et al. [4] investigated the velocity of the vertical movement of vegetation greenness isolines using monthly composited Landsat NDVI values from 1992–2020 and analyzed the associated influence factors on the vertical movement. They found that for the vertical movement of the greenness isoline, precipitation and temperature are the dominant drivers in the elevations below and above 3000 m, respectively. In terms of terrain, slope has a more significant influence on the movement of greenness isoline than aspect. This study provides further evidence that vegetation in higher elevations is more sensitive in response to the current climate warming. Focusing on the cropland ecosystem in the QTP, Tao et al. [5] analyzed the influence of climate factors on the crop NPP along the altitudes. Solar radiation was found to have consistent positive relations with crop NPP in all elevation bins, whereas temperature shows negative relations with crop NPP in lower elevation bins and positive relations in the elevations above 2100 m. Understanding the different controlling factors improves agricultural management in the QTP.

Third, the influence of anthropogenic activities on the alpine ecosystem was assessed by this Special Issue's included studies. Zhao et al. [6] proposed a method to quantify the potential of the stocking rate in the alpine grassland and evaluated the status of the stocking rate during the last decade. The potential of the stocking rate was defined as the difference between the NPP generated by anthropogenic activities and the NPP consumed

by current livestock. Their work revealed the presence of overgrazing in more than 60% of alpine grasslands in the Qinghai Province, where the carrying capacity should be reduced; additionally, other alpine regions also cannot increase their stocking rate in the future in order to comply with the objective of regional sustainable development. Xu et al. [7] evaluated vegetation activities along the key construction project in the region (i.e., the Sichuan–Tibet railway). The Hurst exponent values estimated from the NDVI time-series data showed a risk of grassland degradation in the future, highlighting the importance of focusing on the influence of railway construction on alpine ecological environments in the next decade.

Fourth, Cao et al. [8] reconstructed a high spatiotemporal NDVI time-series dataset for the entire QTP, which was generated through the fusion of the MODerate resolution Imaging Spectroradiometer (MODIS) NDVI and the Landsat NDVI data using the gap-filling and Savitzky–Golay methods. The 8-day and 30-m resolution NDVI data provide an opportunity to monitor various land surface processes at fine spatiotemporal scales, such as vegetation activities along the altitudes. This dataset is freely available from the National Tibetan Plateau Data Center (<http://data.tpdc.ac.cn/en/data/80ee374d-b956-4c51-9572-ee4f6017e0d7/?q=%E6%9B%B9%E5%85%A5%E5%B0%B9>, accessed on 2 September 2022).

Inspired by the incredible recent progress in remote-sensing technology, we expect further progress in the following research directions. First, spatiotemporal changes in vegetation phenology of the QTP are affected by multiple climate factors. The existing process-based phenology models still lack the ability to simulate interannual variations in vegetation phenology [9], which greatly limits the prediction of projected phenology under future climate change. With the development of machine learning techniques, particularly deep learning, the potential of data-driven models for the simulation of vegetation phenology and vegetation growth processes requires exploration. Second, high spatiotemporal remote-sensing data are highly necessary for ecosystem monitoring in alpine regions with a complex terrain. Spatiotemporal fusion is the most useful technology to generate such data for a historical period. However, the performance of spatiotemporal fusion may be unsatisfactory in some scenarios, such as the those involving temporally continuous cloud contamination in satellite images [10]. Currently, the commercial PlanetScope constellation can provide multispectral images at a daily time scale with a 3 m spatial resolution, which may be increasingly applied in some local regions of the QTP with complex terrain. Third, comprehensive evaluations are required to ascertain the influence of the increasing degree of anthropogenic activities (urbanization and the Sichuan–Tibet Railway construction) on alpine ecosystem services in the next decade.

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## References

1. Cheng, M.; Wang, Y.; Zhu, J.; Pan, Y. Precipitation Dominates the Relative Contributions of Climate Factors to Grasslands Spring Phenology on the Tibetan Plateau. *Remote Sens.* **2022**, *14*, 517. [[CrossRef](#)]
2. Zha, X.; Niu, B.; Li, M.; Duan, C. Increasing Impact of Precipitation on Alpine-Grassland Productivity over Last Two Decades on the Tibetan Plateau. *Remote Sens.* **2022**, *14*, 3430. [[CrossRef](#)]
3. Zhai, D.; Gao, X.; Li, B.; Yuan, Y.; Jiang, Y.; Liu, Y.; Li, Y.; Li, R.; Liu, W.; Xu, J. Driving Climatic Factors at Critical Plant Developmental Stages for Qinghai–Tibet Plateau Alpine Grassland Productivity. *Remote Sens.* **2022**, *14*, 1564. [[CrossRef](#)]

4. Pan, Y.; Wang, Y.; Zheng, S.; Huete, A.R.; Shen, M.; Zhang, X.; Huang, J.; He, G.; Yu, L.; Xu, X.; et al. Characteristics of Greening along Altitudinal Gradients on the Qinghai–Tibet Plateau Based on Time-Series Landsat Images. *Remote Sens.* **2022**, *14*, 2408. [[CrossRef](#)]
5. Tao, J.; Xie, Y.; Wang, W.; Zhu, J.; Zhang, Y.; Zhang, X. Elevational Gradient of Climate-Driving Effects on Cropland Ecosystem Net Primary Productivity in Alpine Region of the Southwest China. *Remote Sens.* **2022**, *14*, 3069. [[CrossRef](#)]
6. Zhao, L.; Liu, Z.; Hu, Y.; Zhou, W.; Peng, Y.; Ma, T.; Liu, L.; Li, S.; Wang, L.; Mao, X. Evaluation of Reasonable Stocking Rate Based on the Relative Contribution of Climate Change and Grazing Activities to the Productivity of Alpine Grasslands in Qinghai Province. *Remote Sens.* **2022**, *14*, 1455. [[CrossRef](#)]
7. Xu, B.; Li, J.; Luo, Z.; Wu, J.; Liu, Y.; Yang, H.; Pei, X. Analyzing the Spatiotemporal Vegetation Dynamics and Their Responses to Climate Change along the Ya’an–Linzhi Section of the Sichuan–Tibet Railway. *Remote Sens.* **2022**, *14*, 3584. [[CrossRef](#)]
8. Cao, R.; Xu, Z.; Chen, Y.; Chen, J.; Shen, M. Reconstructing High-Spatiotemporal-Resolution (30 m and 8-Days) NDVI Time-Series Data for the Qinghai–Tibetan Plateau from 2000–2020. *Remote Sens.* **2022**, *14*, 3648. [[CrossRef](#)]
9. Shen, M.; Wang, S.; Jiang, N.; Sun, J.; Cao, R.; Ling, X.; Fang, B.; Zhang, L.; Zhang, L.; Xu, X.; et al. Plant phenology changes and drivers on the Qinghai–Tibetan Plateau. *Nat. Rev. Earth Environ.* **2022**, 1–19. [[CrossRef](#)]
10. Chen, Y.; Cao, R.; Chen, J.; Zhu, X.; Zhou, J.; Wang, G.; Shen, M.; Chen, X.; Yang, W. A new cross-fusion method to automatically determine the optimal input image pairs for NDVI spatiotemporal data fusion. *IEEE Trans. Geosci. Remote Sens.* **2020**, *58*, 5179–5194. [[CrossRef](#)]