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Editorial

Land-Atmosphere Interactions and Effects on the Climate of the Tibetan Plateau and Surrounding Regions

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1. Introduction

The global climate has undergone unequivocal warming. According to the sixth assessment report of the Intergovernmental Panel on Climate Change, the global surface temperature in the first two decades of the 21st century (2001–2020) was 0.99 °C (0.84 to 1.10 °C) higher than that from 1850–1900. Moreover, the global surface temperature from 2011–2020 was 1.09 °C (0.95 to 1.20 °C) higher than that from 1850–1900 [1]. Meanwhile, accelerating climate change exerts more influence on polar regions, high-altitude zones, and ecologically fragile areas. Often referred to as 'the Third Pole' and 'the Roof of the World', the Tibetan Plateau (TP) conserves vast areas of mountain glaciers, permafrost, and seasonally frozen soil and is the largest high-elevation portion of the cryosphere sensitive to global climate change [2]. In this context, quantitative assessment of the land–atmosphere interaction processes, as well as their effects on the TP and its surrounding regions, is not only essential for understanding the energy and water cycles in the cryosphere and hydrosphere but also crucial for understanding the Asian monsoon system and predicting the climate of Asia and the Northern Hemisphere [3].

To this end, this Special Issue aimed to present recent scientific advances on (1) the estimation of key land surface properties, (2) processes in the atmospheric boundary layer, (3) monitoring of glaciers and glacial lakes, (4) hydrometeorological processes, (5) vegetation dynamics and their response to weather and climate, etc.

Twenty-three articles are published in this Special Issue, covering progress on the following: land surface energy budget, glacier elevation change and snow phenology, the spatiotemporal distribution of precipitation, properties of land surface characteristic parameters, and evaluations of current models and products. The effects of climate change on high-altitude lakes were also included in this Special Issue.

2. Highlights of Research Articles

The land surface energy budget over the TP was analyzed via both remote sensing datasets and in situ observations. Based on empirical orthogonal function analysis of the summer surface sensible heating, a decadal decreasing trend was reported as the first dominant mode over the TP with an explained variance of 20.1% [4]. An enhanced water vapor supply and convergence over the TP were revealed, which led to an increase in the total cloud cover and a decrease in surface downwelling shortwave radiation. The reduction in downwelling shortwave radiation was found to dominate the shrinkage of surface sensible heating. Meanwhile, a zonally asymmetric pattern with positive (negative) sensible heating anomalies in the western (eastern) TP represented the second dominant mode (with an explained variance of 14.2%) [4]. At the station level, the sensible (latent) heat flux was the dominant energy balance component at the Ngari and Qomolangma (Linzhi, Muztagh, Nagqu, and Nam Co) stations. The radiation/energy balance components and surface characteristic parameters exhibited distinct diurnal cycles (e.g., a 'U' shaped curve of the surface broadband albedo was reported) [5]. Based on measurements at eight plateau stations in TIPEX III (the third Tibetan Plateau experiment for atmospheric sciences), the daily mean surface heating field varied from 70.2 to 101.2 W/m^2, with sensible (latent) heat flux from 18.8 to 60.1 W/m^2 (10.1 to 74.7 W/m^2) [6]. A negative correlation between surface heating field density and the intensity of the South Asian summer monsoon was also verified at Baingoin, Nagqu, Nam Co, and Lhari stations [6].

Glaciers and snow phenology are sensitive indicators of climate change, both being involved in and affecting energy/water transfer processes. Global warming has led to significant changes in high-altitude glaciers. Shen et al. [7] developed an 'elevation-aspect bin analysis method' to estimate the intra- and interannual elevation changes of glaciers in the High Mountain Asia (HMA) region. An accelerating decreasing trend of glacier elevation was reported in most regions of the HMA, with mean change rates of -0.21 ± 0.12 m/year during 2003–2008 and -0.26 ± 0.11 m/year during 2003–2020. The variation in glacier elevation showed distinct spatial differences. The decreasing rate gradually decreased from the marginal region to the inner area of HMA, which indicates that the marginal areas of the TP may be zones facing significant risk [7]. Meanwhile, the spatiotemporal variation characteristics of snow disasters over the TP were also evaluated [8]. The frequency, duration, average snow depth, and grade of snow disasters over the TP all depicted a declining trend in the long run. Using the farmer and pastoralist well-being (FPWB) index, which has a negative relation with snow disaster risk, the whole TP area was divided into five distinct regions: Kashgar (I), Shigatse (II), Nagqu (III), Qamdo (IV), and Yushu (V), with gradually decreasing risks of snow disasters [8]. According to Wu et al. [9], factors such as precipitation, solar radiation, and air temperature significantly affect snow phenology. Precipitation was positively correlated with snow accumulation and maintenance, while solar radiation and air temperature functioned negatively. Comparatively, the quantity of snow was more sensitive to solar radiation, while its persistence was more sensitive to air temperature. The mean change rates of snow depth and snow cover maintenance days were estimated to be -0.06 cm/year and -0.37 day/year, respectively [9].

The spatiotemporal variability of precipitation was also focused on in this Special Issue. Meng et al. [10] reported that precipitation in most areas of the three rivers' source regions decreased in spring, autumn, and winter, while summer contributed the most increases. In contrast with the 2000s, the afternoon precipitation slightly decreased in the 2010s, while the nighttime precipitation increased significantly. Cao et al. [11] derived similar results, i.e., the diurnal maximum precipitation was found to be concentrated in the early evening, showing a distinct diurnal cycle. In addition, the raindrop size exhibited significant seasonal variability in the premonsoon, monsoon, and postmonsoon periods. The highest (lowest) concentration of small raindrops was observed in monsoon (winter) precipitation, while large raindrops dominated the premonsoon precipitation [12]. Shen et al. [13] found that the precipitation particles above high mountains have distinct characteristics, such as lower droplet number concentrations and larger diameters, compared with those over plains. In addition, both Wang et al. [14] and Yang et al. [15] concluded that soil moisture plays a more dominant role in precipitation-use efficiency and evapotranspiration-precipitation coupling. Moreover, Shikhovtsev et al. [16] utilized the fifth generation ECMWF (European Centre for Medium-range Weather Forecasts) atmospheric reanalysis (ERA5) precipitable water vapor (PWV) data within 2010–2020 to establish a functional relation between the PWV and the elevation, exhibiting that the decrease of PWV with the elevation was exponential with a height scale of 1000 m. The ERA5 product was also reported to overestimate the PWV values by 1–2 mm in the Big Telescope Alt-azimuthal region (40°N–50°N, 35°E–55°E) [16].

Surface characteristic parameters are significant factors affecting the accuracy of surface process assessments. Li et al. [17] developed an algorithm to generate high-spatial-resolution soil moisture during the thawing season in the permafrost environment using Sentinel-1 and Sentinel-2 data. The comparison with ERA5-Land, Global Land Data Assimilation System (GLDAS), and European Space Agency Climate Change Initiative (ESA CCI) products indicated that this proposed method is able to provide more spatial details and achieve better performance in permafrost areas over the TP. The typical land cover types, alpine desert, alpine steppe, alpine meadow, and alpine swamp meadow, displayed distinct differences in soil moisture, with mean values of 0.16, 0.20, 0.23, and 0.26 m^3/m^3, respectively [17]. The soil's apparent thermal diffusivity (k) is also vital for investigating soil surface heat transfer. Tong et al. [18] determined the magnitude of k at hourly, daily, and monthly scales via a conduction–convection method. The monthly k varied from 0.4×10^{-6} to 1.1×10^{-6} m^2/s at the wet site, with values from 1.7×10^{-7} to 3.3×10^{-7} m^2/s at two dry sites, displaying magnitude differences under different soil moisture conditions. In addition, Ren et al. [19] reported that the Bowen ratio decreased significantly with an increase in soil moisture or effective precipitation. The Bowen ratio in the semiarid region was 1.5 times higher than that in the semihumid region during the growing season. Moreover, Zhang et al. [20] analyzed the profiles of the atmospheric refractive index structure constant (C_n^2), reporting unique optical turbulence characteristics compared with plain areas.

Several articles have evaluated the current models or products of near-surface hydrometeorological variables. Huang et al. [21] conducted a systematic assessment of three widely used air temperature products, namely, ERA5L, GLDAS, and China Meteorological Administration Land Data Assimilation System (CLDAS). Among these three products, CLDAS is more consistent with observations and can better describe temperature distribution and variation details than ERA5L and GLDAS for the Asian region. CLDAS is 0.53 K higher than the in situ observation, while ERA5L and GLDAS are lower than in situ measurements by −3.45 K and −1.40 K, respectively [21]. Liu et al. [22] reported that WRF applying the default glacial albedo scheme overestimates the albedo with a mean error of 0.18, while WRF applying a modified glacial albedo scheme slightly underestimates the albedo with a mean error of only −0.08. The default glacial albedo scheme gives a relatively high albedo value of 0.68, causing an underestimation of the net shortwave and net radiation. In contrast, the modified glacial albedo scheme provides a mean albedo value of 0.35, which is close to in situ measurements. In addition, Liu et al. [23] compared the leaf area index (LAI) estimations from 35 Earth system models that participated in the sixth Coupled Model Intercomparison Project (CMIP6) and found that these models overestimated the LAI trend over alpine vegetation, grassland, and forest but underestimated it over meadow and shrub. More than 70% of the models overestimated the LAI during the 1981–2014 growing seasons, indicating that the greening of grassland in the TP was greatly overestimated. Moreover, five complementary relationship-based models, requiring only routine meteorological variables to estimate actual terrestrial evapotranspiration, were evaluated by Shang et al. [24], with biases ranging from −94.2 to 28.3 mm/year. These models provide a simple and convenient approach for evapotranspiration estimates.

Finally, the responses of TP lakes to climate change were also quantitively investigated. The lake surface water temperature of the largest freshwater lake in the TP, Ngoring Lake, was estimated to have a warming rate of 0.6 K/decade. However, comparison with its nearby small saline lake, the Hajiang Salt Pond, depicted distinct differences due to the salinity effect. The high salinity of the small saline lake made the annual mean lake surface water temperature 2.6 K higher and resulted in a 0.02 K/decade more significant warming trend than freshwater lakes at the same depth [25]. Moreover, the lakes in the Qaidam Basin were estimated to have undergone accelerated expansion. In the two study periods of 2003–2011 and 2011-present, the air temperature, precipitation, and runoff increased steadily, while the expansion rate of Tuosu Lake in the Qaidam Basin increased from 1.22 km^2/year to 3.38 km^2/year. This significant increase in the lake expansion rate reflects groundwater's substantial contribution to lake expansion [26].

3. Conclusions

This Special Issue compiles the up-to-date progress on the following: land surface energy budget, glacier/snow phenology, the spatiotemporal distribution of precipitation, properties of land surface characteristic parameters, evaluations of current models and products, and high-altitude lake processes over the TP and its surrounding regions. These selected papers are novel and timely in informing the land–atmosphere interactions driven by climate change. The collation of these papers will provide quantitative references for better assessment and prediction of the land–atmosphere interactions and their effects on "the Third Pole" and its surrounding regions.

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