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Upscaling analysis of aerodynamic roughness length based on in situ data at different spatial scales and remote sensing in north Tibetan Plateau

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ABSTRACT

The aerodynamic roughness length (z_{0m}) is a crucial parameter in quantifying momentum, sensible and latent heat fluxes between land surface and atmosphere, and it depends greatly on spatial scales. This paper presents a tentative study on the upscaling analysis of z_{0m} in the north Tibetan Plateau based on in situ data from eddy covariance (EC) and large aperture scintillometer (LAS) and leaf area index (LAI) of MODerate-resolution Imaging Spectroradiometer (MODIS) with 250 m and 2 km spatial resolutions. The comparison of z_{0m} calculated from EC (z_{0m_EC}) and LAS (z_{0m_LAS}) data indicates that z_{0m} at both scales has apparent seasonal variations and is in good agreement with the LAI result. However, z_{0m_LAS} is higher than z_{0m_EC}, which is attributed to the differences in roughness elements in their footprints. An upscaling relationship for z_{0m} is developed with z_{0m_EC}, z_{0m_LAS} and LAI with 250 m spatial resolution of MODIS. In addition, an altitude correction factor is introduced into the vegetation height estimation equation because the cold environment in the north Tibetan Plateau, which is due to its high altitude, has a strong influence on vegetation height. The z_{0m} retrieval with 250 m spatial resolution in the rain season is validated with z_{0m_EC} at sites Nagqu/Amdo, Nagqu/MS3478 and Nagqu/NewD66, and the agreement is acceptable. The spatial distribution of z_{0m} retrievals at small spatial scale in the north Tibetan Plateau from June to September 2012 shows that the z_{0m} values are less than 0.015 m in most areas, with the exception of the area in the southeast part, where z_{0m} reaches 0.025 m owing to low altitudes. The z_{0m} retrievals at large spatial scale in the north Tibetan Plateau from June to September 2012 range from 0.015 to 0.065 m, and high values appear in the area with low altitudes. The spatial distribution and frequency statistics of z_{0m} retrievals at both spatial scales reveal the influence of altitude and LAI on the z_{0m} in the north Tibetan Plateau, suggesting the uniqueness of the Tibetan Plateau.

1. Introduction

With its high altitude and huge terrain, the Tibetan Plateau has a profound influence on Asian and global climate (Duan and Wu, 2005; Wu et al., 2007; Wu and Zhang, 1998; Yang et al., 2014a). Part of the influence of the Tibetan Plateau on the climate is through the land–atmosphere interactions. The aerodynamic roughness length is a key parameter in quantifying sensible and latent heat fluxes between land surface and the atmosphere. Thus, obtaining accurate values of aerodynamic roughness length in the Tibetan Plateau is of great significance for further understanding its influence on the climate.

The z_{0m} estimates from in situ observation in the Tibetan Plateau are estimated by applying the Monin–Obukhov similarity theory either to the multilayer data of wind speeds and temperatures (Brown and Hugenholtz, 2012; Li et al., 2000, 2001) or to EC data (Li et al., 2015; Wang and Ma, 2011; Yang et al., 2014b). Both methods can provide reliable z_{0m} estimates when the underlying surface in their footprints is flat and uniform. However, the ratio of the effective fetch to measurement height is 100, making the z_{0m} estimates calculated from the two methods represent a limited area. Moreover, the z_{0m} estimates from the two methods may introduce deviations when applied to a large region where the underlying surface is uneven or heterogeneous.

Remote sensing products provide vegetation information with wide spatial coverage and good temporal sampling frequency, making it possible to estimate z_{0m} at a regional scale. Raupatch developed a model to estimate aerodynamic roughness length with LAI (Raupach, 1994; Raupach, 1992), and Jasinski then provided the estimates for parameters of four vegetated land surfaces for this model (Jasinski et al., 2005). With parameters suggested by Jasinski, the model developed by Raupatch has been widely used to retrieve z_{0m} values of an underlying surface with high vegetation (Borak et al., 2005; Chen et al., 2015;

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Colin and Faivre, 2010; Hu et al., 2014; Tian et al., 2011). With a different method for addressing u*/U and d/h, Massman developed another model for estimating aerodynamic roughness length with LAI (Massman, 1997; Massman and Weil, 1999), and this model was used in the Surface Energy Balance System (Su, 2002), which was used to retrieve surface fluxes in the Tibetan Plateau and produced reliable fluxes (Chen et al., 2013a; Han et al., 2016; Ma et al., 2014a, 2011; Oku et al., 2007).

Nevertheless, the z_{0m} retrievals from remote sensing must be validated with in situ results, which are usually estimated from EC data or the profile data of wind speed and temperature. As noted above, the z_{0m} estimates from the two methods can represent a limited area, revealing the problem of inconsistency in spatial scales. Scintillometer technology provides a possible solution to this problem. With the light paths varying from hundreds to thousands of meters, the LAS is able to measure the turbulence fluxes over a very large area. Therefore, LAS could provide surface fluxes and land surface parameters, the spatial scales of which may agree better with remote sensing (Tang et al., 2011).

The EC and LAS data of Nagqu Station of Plateau Climate and Environment and NDVI product of MODIS were collected in this study. The objective of this study is to attempt an upscaling analysis of aerodynamic roughness length on the basis of z_{0m} estimates at two spatial scales and remote sensing products. The climate and underlying surface conditions of north Tibetan Plateau are introduced in Section 2. The data processing is included in Section 3. The results and discussions are presented in Section 4 and the conclusions are given in Section 5.

2. Study area

The north Tibetan Plateau (31.0°–36.0°N, 91.0–94.0°E) is esteemed as a region sensitive to climate change and has been chosen as a key area for a series of scientific programs, such as the GEWEX Asia

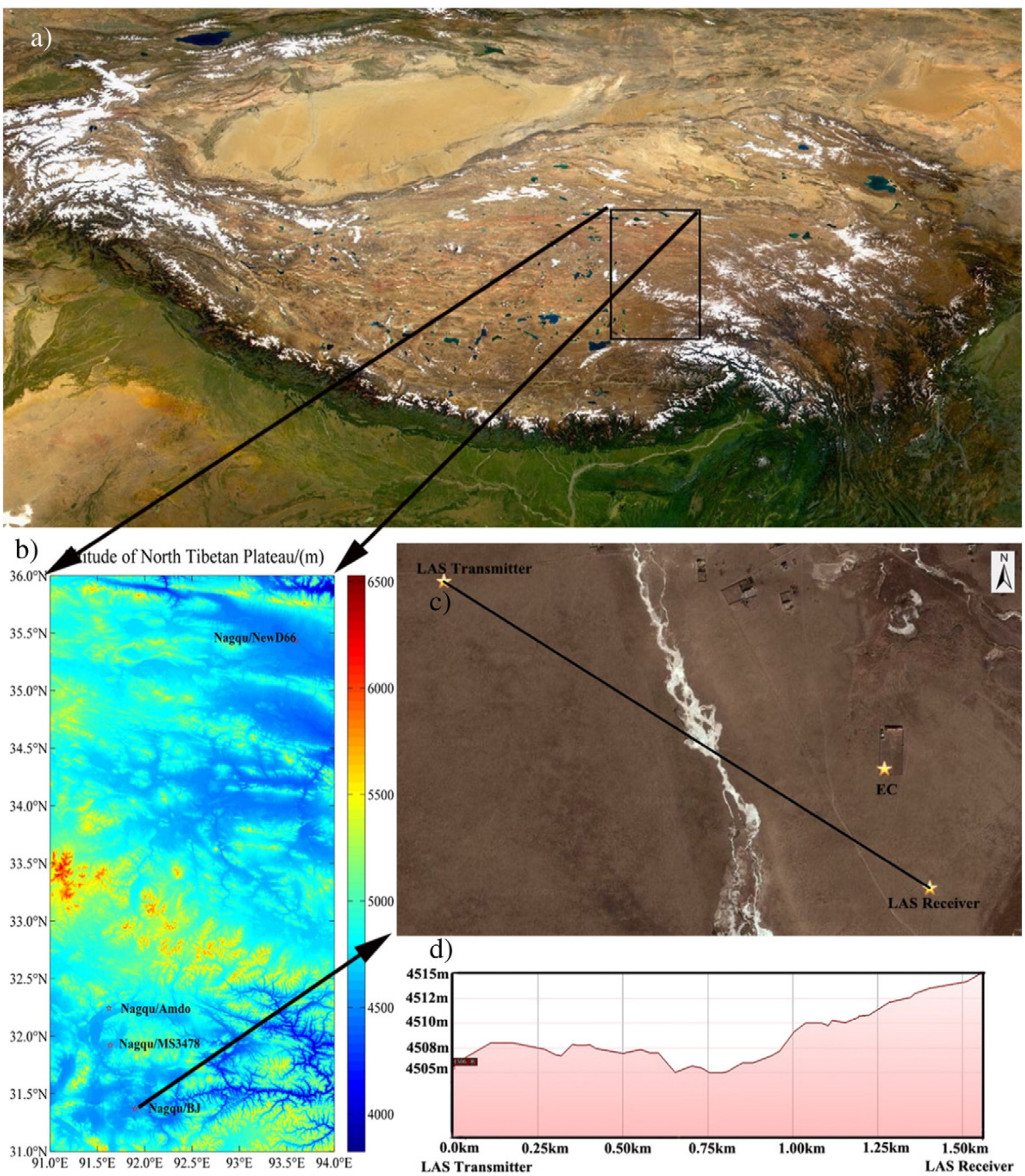

Fig. 1. The location of a) the study area in the Tibetan Plateau, b) four sites of Nagqu Station. c) The locations of EC and LAS and d) the topography along with LAS light path at Nagqu/BJ.