International Journal of Applied Earth Observation and Geoinformation 47 (2016) 50–59

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

A method for sensible heat flux model parameterization based on radiometric surface temperature and environmental factors without involving the parameter KB^{-1}

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ARTICLE INFO

Article history:
Received 29 March 2015
Received in revised form
12 November 2015
Accepted 18 November 2015
Available online 17 December 2015

Keywords:
Sensible heat flux
Radiometric surface temperature
Environmental factors
Heihe river basin

ABSTRACT

Sensible heat flux is a key component of land–atmosphere interaction. In most parameterizations it is calculated with surface-air temperature differences and total aerodynamic resistance to heat transfer (R_{ae}) that is related to the KB^{-1} parameter. Suitable values are hard to obtain since KB^{-1} is related both to canopy characteristics and environmental conditions. In this paper, a parameterize method for sensible heat flux over vegetated surfaces (maize field and grass land in the Heihe river basin of northwest China) was proposed based on the radiometric surface temperature, surface resistance (R_s) and vapor pressures (saturated and actual) at the surface and the atmosphere above the canopy. A biophysics-based surface resistance model was revised to compute surface resistance with several environmental factors. The total aerodynamic resistance to heat transfer is directly calculated by combining the biophysics-based surface resistance and vapor pressures. One merit of this method is that the calculation of KB^{-1} can be avoided. The method provides a new way to estimate sensible heat flux over vegetated surfaces and its performance compares well to the LAS measured sensible heat and other empirical or semi-empirical KB^{-1} based estimations.

1. Introduction

Sensible heat flux is an important energy source for lower atmosphere and a significant component of land–atmosphere interaction. Accurate estimation of sensible heat flux is meaningful for the research on monsoon circulation, climate change and precipitation (Yang et al., 2009; Wang and Li, 2011). Many remote sensing studies have used the single source bulk formulation to estimate sensible heat flux, H, as follows:

$$H = \frac{\rho C_p (T_{aero} - T_a)}{R_{ah}} \quad (1)$$

where ρ (kg m^{-3}) is the mean air density at constant pressure, C_p (1013 J kg^{-1} °C^{-1}) is the specific heat capacity of air, T_{aero} is the aerodynamic temperature from a mixed-surface (soil, air and vegetation) temperature source, it can be significantly different from the directional radiometric surface temperature T_s. T_a is the air temperature at the reference height and R_{ah} is the aerodynamic resistance to heat transfer calculated between the source/sink level for heat and the reference level, given by:

$$R_{ah} = R_a + r_{ex} = \frac{1}{ku_*}[\ln(\frac{z_{ref} - d}{z_{om}}) - \psi(h)] + \frac{1}{ku_*}\ln(\frac{z_{om}}{z_{oh}}) \quad (2)$$

where R_a is the aerodynamic resistance to momentum transfer between height $d + z_{om}$ (d is zero plane displacement height, and z_{om} (m) is roughness length for momentum transport), z_{ref} (m) is the reference height, z_{oh} is the roughness length for heat and related to the aerodynamic parameter KB^{-1} and z_{om} ($KB^{-1} = \ln(z_{om}/z_{oh})$). KB^{-1} expresses the difference between the effective eddy diffusivities for momentum and heat exchange since the diffusion process for heat transfer adds to the convective exchange of air. The other terms in Eq. (2) are excess resistance (r_{ex}), von Karman's constant (k = 0.41), the friction velocity (u_*) and stability correction functions for heat ($\psi(h)$). In practical applications, there is often no equipment for measuring the aerodynamic temperature, so the radiometric surface temperature (T_s) derived from the thermal sensors of various satellites has been explored as a potential replacement for T_{aero}. Replacing T_{aero} with T_s in Eq. (1) makes the aerodynamic parameter KB^{-1} has a radiometric component to relate H to radiometric surface temperature and translates to merely fitting a largely empirical parameter no longer connected

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http://dx.doi.org/10.1016/j.jag.2015.11.015
0303-2434/

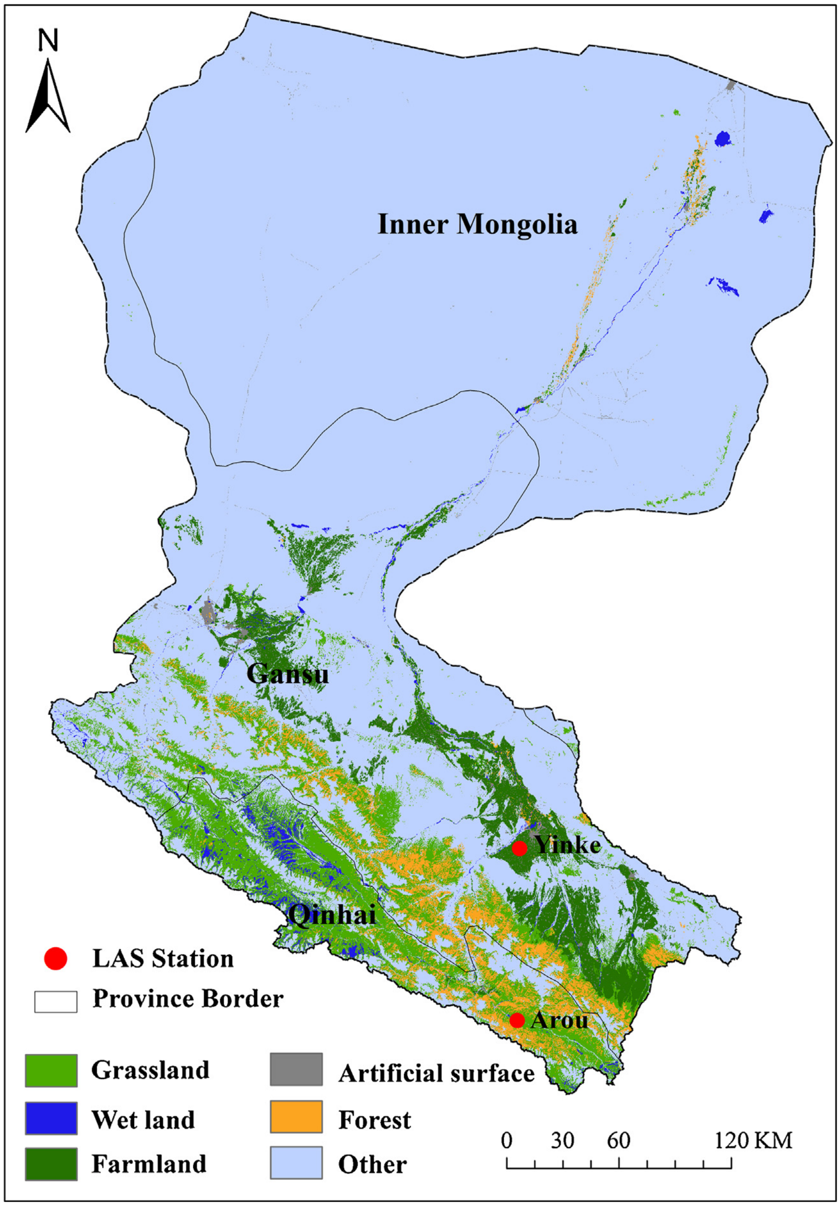

Fig. 1. Land cover of Heihe river basin and locations of the two LAS sites (Yinke and Arou).

to its theoretical background (Garratt and Hicks, 1973; Lhomme et al., 2000; Norman and Becker, 1995; Stewart et al., 1994). Thus the turbulent fluxes H formulation changes to:

$$H = \frac{\rho C_p(T_s - T_a)}{R_{ae}} \tag{3}$$

R_{ae} is the total aerodynamic resistance to heat transfer.

The radiometric KB^{-1} parameter is highly complex and many formulations have been suggested over the past few decades (Lhomme et al., 1997, 2000; Massman, 1999; Matsushima, 2005; Su, 2002; Verhoef et al., 1997). The common characteristic is that the uncertainty of KB^{-1} estimations is obvious and unavoidable. Gokmen et al. (2012) proposed an updated SEBS (Surface Energy Balance System, Su, 2002) model that integrated soil moisture into KB^{-1} and improved the precision of sensible heat flux estimation under water stress, but its fitting method was complex and limited. A study by Paul et al. (2014) showed that KB^{-1} was a sensitive parameter in the estimation of ET in SEBAL (Surface Energy Balance Algorithms for Land, Bastiaanssen et al., 1998) and using a constant value was unreasonable. Both analytical and experimental studies agree that the radiometric KB^{-1} value depends on many parameters and variables, including structural parameters (e.g., vegetation roughness parameters) and environmental conditions (e.g., wind speed and surface temperature) (Troufleau et al., 1997). Therefore, it is of great interests and importance to develop a simple alternative procedure to Eq. (3) for estimating H without involving the parameter KB^{-1}. Norman et al. (1995) eliminated the need for considering KB^{-1} by using a two-layer (canopy and soil) model, however, the temperature of canopy and soil components are hard to obtain from the satellite radiometric temperature measured at a single view angle. Castellvi et al. (2014) estimated the sensible heat flux without KB^{-1} by combing the bulk transfer formulation and surface renewal analysis based on air temperature measured at high frequency.

Considering the limits of the KB^{-1}, the objective of this research is to propose a parameterization for sensible heat flux based on radiometric surface temperature and environmental factors without the KB^{-1} parameter. We focus on the single source bulk transfer equation and the total aerodynamic resistance to heat transfer