The improved ET calculation for semiarid region based on an innovative aerodynamic roughness inversion method using multi-source remote sensing data

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Abstract. The aerodynamic roughness is one of the major parameters in describing the turbulent exchange process between terrestrial and atmosphere. Remote Sensing is recognized as an effective way to inverse this parameter at the regional scale. However, in the long time the inversion method is either dependent on the lookup table for different land covers or the Normalized Difference Vegetation Index (NDVI) factor only, which plays a very limited role in describing the spatial heterogeneity of this parameter and the evapotranspiration (ET) for different land covers. In fact, the aerodynamic roughness is influenced by different factors at the same time, including the roughness unit for hard surfaces, the vegetation dynamic growth and the undulating terrain. Therefore, this paper aims at developing an innovative aerodynamic roughness inversion method based on multi-source remote sensing data in a semiarid region, within the upper and middle reaches of Heihe River Basin. The radar backscattering coefficient was used to inverse the micro-relief of the hard surface. The NDVI was utilized to reflect the dynamic change of vegetated surface. Finally, the slope extracted from SRTM DEM (Shuttle Radar Topography Mission Digital Elevation Model) was used to correct terrain influence. The inversed aerodynamic roughness was imported into ETWatch system to validate the availability. The inversed and tested results show it plays a significant role in improving the spatial heterogeneity of the aerodynamic roughness and related ET for the experimental site.

1. Introduction
The aerodynamic roughness is an essential parameter for calculating evapotranspiration (ET), which reflects the exchange of water and energy between earth surface and atmosphere. It refers to the height where the wind speed equals zero above the ground [1,2,3]. Traditionally the visible data, such as MODIS, TM has been utilized to compute the aerodynamic roughness with the empirical relationship of NDVI in the current ET remote sensing field [4]. However, NDVI can only reflect the dynamic change of vegetation-covered surface. The aerodynamic roughness will unavoidably have large
inaccuracy for the vegetation-free areas. In fact, the aerodynamic roughness is a complex interaction result of different roughness units on the earth surface. It was influenced by the micro-geometric roughness of non-vegetation area, NDVI of vegetation-covered area and severe topography.

Recent work over the past several years have reported that microwave backscattering coefficient from SAR or scatterometer is related to the aerodynamic geometric roughness [5,6,7]. Severe topography will influence the aerodynamic roughness over mountainous area as it affects wind direction and velocity very much [8]. In this paper, an improved inversion model of aerodynamic roughness for the upper and middle reaches of Heihe River Basin based on microwave, visible, infrared and DEM data has been proposed to improve the heterogeneity characteristics of ET.

2. Study area, datasets and methodology

2.1 Study area
Heihe River Basin is a typical inland river basin in the northwest of China with arid and semi-arid climate conditions. It is located from 97° 24′ - 102° 10′ in longitude to 37° 41′ - 42° 42′ in latitude with an area of about 130 000 km² [9]. There is enough liquid and solid precipitation in the upper reach of the basin and very limited precipitation in the middle and lower reaches, which is called the arid and semi-arid climate environment [10,11]. Fig.1 shows the location of Heihe River Basin and the specific research area, mainly covering the upper and middle reaches of the basin. For the topography and land cover characteristics, the upper reach is mainly the mountainous region with grass land while the middle reach is the plain area with oasis land.

![Figure 1. Heihe River Basin location, the area within the red line is the research site](image_url)

2.2 Datasets
The ENVISAT ASAR WSM data acquired in Jan. 2008, which is the winter season, was calibrated, ortho-rectified, filtered, mosaicked and re-projected into microwave backscattering coefficient in db unit with Albers Projection, as Fig.2(a) shows.

The SRTM DEM (Shuttle Radar Topography Mission Digital Elevation Model) was downloaded from NASA’s website (www2.jpl.nasa.gov/srtm). It was mosaicked, re-projected and subset as Fig.2(b) shows. The corresponding slope information of the research area was also extracted as Fig.2(c) displays.

The MODIS L1B data was downloaded from the MODIS website belonging to NASA (ladsweb.nascom.nasa.gov). The NDVI information on Jan. 6th 2008 was calculated based on MODIS red and infrared band data as Fig.2(d) presents. It is in time series as long as Terra or Aqua satellite flew over the research area and the weather is cloudless.
Figure 2. The processed multi-source remote sensing data for the research area (a) ASAR image after radiometric and geometric rectification (b) SRTM DEM (c) slope information extracted from SRTM DEM (d) MODIS NDVI on Jan.6th, 2008

2.3 Methodology

The aerodynamic roughness based on near and infrared data was calculated following formula (1):

$$z_{0a}^e = a + b \cdot \left( \frac{|NDVI|}{NDVI_{max}} \right)^c$$

(1)

Where a, b, c are the calibrated coefficients.

The topographic roughness based on DEM was acquired following formula (2)[7]

$$z_{0t}^e = z_{0a}^e \cdot \left[ 1 + \left( \frac{slope - d}{f} \right) \right] > 0$$

(2)

Where d, f is the empirical coefficients.

The radar-based aerodynamic roughness was inversed according to formula (3)[5]:

$$z_{0sr}^{sar} = \exp \left( \frac{\alpha_0 - 2.05}{2.73} \right)$$

(3)

The final aerodynamic roughness was computed using formula (4):

$$z_{0a} = z_{0a}^T + z_{0a}^{sar}$$

(4)

3. Result and analysis

The original and improved aerodynamic roughness on Jan.6th 2008 for the upper and middle reaches of Heihe River Basin was show in Fig.3 (a) and (b).
It is seen that the original aerodynamic roughness shows apparent problem for the spatial distribution and the value. The newly improved aerodynamic roughness has displayed apparently higher value in the upper reaches with steep topography, which is more close to the documentation and the fact [12]. This kind of improvement will have an apparent decrease interaction to the ET evaluation for this area.

The computed ET for the whole year of 2008 before and after introducing the inversed aerodynamic roughness was displayed in Fig.4 (a) and (b), respectively. In order to present the difference between the two results, the minus calculation has been shown in Fig.4 (c).

The original ET always presents much higher value in the mountainous region according to the field eddy correlation (EC) measurements in upstream Arou and midstream Yingke station. The recent result shows the spatial distribution of ET in mountainous region has been effectively decreased due to the improved aerodynamic roughness shown in Fig.3(b).
4. Conclusion and discussion

4.1 Conclusion
The proposed aerodynamic roughness inversion method based on multi-source remote sensing data was proved to be an effective way to characterize the spatial heterogeneity of this parameter, which promotes the ET calculation in the upper and middle reaches of Heihe River Basin to a more appropriate extent, especially for the spatial distribution.

4.2 Discussion
On one hand, present validation is mainly dependent on the improvement of spatial distribution for aerodynamic and ET results. In the next step, the field-measured data from gradient tower within the river basin will be used to validate the inversed aerodynamic roughness further.

On the other hand, although multi-source remote sensing data has been used to compute the aerodynamic roughness, the information from different bands unavoidably have mutual coupling problem, the ordinary weighting cannot be recognized as a very convincing way to deal with it. The more rational method, for instances, Principle Component Analysis (PCA) can be used to decouple the information from different bands.

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