# Comparative analysis of the application of aerodynamics impedance algorithm in high and low terrain

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**Abstract**

Aerodynamic impedance is one of the most important factors influencing surface momentum, energy and water exchange. Currently, there are many algorithms about aerodynamic impedance estimation, but most of the researches are based on a certain region or specific underlying surface, while there are few researches about the uneven terrain momentum of different levels of terrain. In this paper, aerodynamic impedance is estimated and analyzed from the perspective of different classic underlying surfaces. Based on the field observation experimental materials of a certain region's uneven terrain of different levels, and the impedance difference under the condition of different levels of terrain is compared and analyzed so as to propose the aerodynamic impedance method suitable for different kinds of underlying surfaces in this region, and improve the estimation precision of aerodynamic impedance.

*Keywords*: aerodynamics, impedance algorithm, underlying surface

## 1 Introduction

Energy balance on the land surface has always been the focus of the research of land surface process, and due to surface momentum, energy, water exchange and other important factors [1, 2], aerodynamic impedance is also very important in the research of energy balance on the surface of land. Since the 1970s, many researchers tried to research the aerodynamic impedance from measurement, parameter and other aspects, and many years of researches constantly promote the deep development of aerodynamic impedance estimation methods [3, 4].

At present, there are many algorithms about the estimation of aerodynamic impedance, but most of them are proposed based on a certain region or specific underlying surface, and when the algorithm is applied to practice, relevant parameters need to be modified and tested properly. In this paper, the aerodynamic impedance of different kinds of classic underlying surfaces in estimated and analyzed based on the field observation experimental materials of a certain region's uneven terrain of different levels [5, 6]. Meanwhile, the estimation precision of different underlying surfaces is compared and analyzed through different algorithms, and current algorithm is modified so as to propose the aerodynamic impedance method suitable for different kinds of underlying surfaces in this region, and improve the estimation precision of aerodynamic impedance.

## 2 General situation of researched area

This region is located in Northwestern China, and the test is divided into three parts: basic observation, strengthened observation and instrument parallel comparative observation [7, 8].

1) Basic observation time is from May 29, 2014 to July 6, and three conventional observation stations in the field and the east and west desert are set so as to observe wind, temperature, moisture, soil temperature, radiation balance components, whirl and corresponding vegetation, etc. mainly.

2) Strengthened observation time is from June 22, 2014 to July 6, and based on basic conventional observation, evaporation observation and captive balloon sounding observation are added to strengthened observation, and radar observation is added to the farmland station. Besides, four LW and evaporation mobile observation stations are added between three conventional observation stations. Basic observation and strengthened observation are both conducted in oasis and desert of the region.

3) Instrument parallel comparative observation is set in desert and wasteland of this region, which is very classic desert underlying surface with relatively flat and even terrain. In the observation, instruments of the first two phases are placed parallel, and the observation time is from July 15, 2014 to July 24.

## 3 Materials and methods

### 3.1 MATERIAL PROCESSING

In order to ensure the test data be more efficient, turbulent fluctuation data of relevant turbulence instrument are processed preliminarily first with relevant EdiRE software after data are obtained so as to exclude information that does not meet the physical criteria. While for data difference caused by different observation instruments, all the observations are modified by using parallel comparative data in order to reduce and eliminate the above data bias [10, 11].

Information used are the observation information obtained from 10:00 am to 17:30 pm (Beijing Time, the followings are the same) during the GHUSLE test period from May, 2014 to July, and the specific information is the temperature, radiation, wind speed, hot pass volume, and other data of west desert and field station during basic observation and strengthened observation, as well as the observed temperature, radiation, wind speed and hot pass volume of desert underlying surface during parallel comparative observation [5, 7, 12]. In order to make the data become more reliable, data quality is controlled.

Upon completing the above data, according to vortex relevant instrument measuring method proposed by Nichols, aerodynamic impedance ra value is calculated and the specific expression of this formula is as follows:

$$r_a = \rho c_p (T_s - T_a) / H_s . \tag{1}$$

Herein, Hs refers to the hot pass volume (W·m$^{-2}$) measured by vortex relevant instrument, $\rho$ is air density (kg·m$^{-3}$), $T_s$ is surface temperature (°C), $T_a$ is temperature (°C), and cp is heat capacity (J·kg$^{-1}$·K-1).

## 3.2 METHOD TO ESTIMATE AERODYNAMIC IMPEDANCE

1) Liu Algorithm.

Liu Shaoming, etc. measured the aerodynamic impedance results according to 2 methods, directly used wind speed for fitting and obtained the relation between measured results of vortex relevant measurement method and evaporation measurement method and wind as:

$$r_a = 94.909 u^{-0.9036} . \tag{2}$$

2) Verma Algorithm.

Verma, etc. considering two factors influencing the dynamics and thermal dynamics of aerodynamic impedance, supposed that the momentum equaled to roughness of heat, based on which, gave the formula of aerodynamic impedance $r_a$:

$$r_a = \frac{\ell_m}{\ell_h} r_{an}$$
$$r_{an} = \frac{[\ln(\dfrac{z-d_0}{z_{0m}})]^2}{k^2 u} \tag{3}$$
$$\frac{\ell_m}{\ell_h} = 1/(1-16R_i)^{0.25}$$
$$R_i = \frac{g}{\theta}\sqrt{z_2 z_1}(\frac{z_2}{z_1})\frac{(\theta_2-\theta_1)}{(u_2-u_1)^2}$$

Herein, ran is the aerodynamic impedance(s·m$^{-1}$) under neutral condition; $\theta$ is potential temperature (K); $z$ is height (m); and 1, 2 are the observation height of layer 2 respectively.

3) Thom-1 Algorithm.

Method to estimate $r_a$ and proposed by Thom, etc. in 1977 is as follows:

$$r_a = 4.72 \frac{[\ln((z-d_0)/z_{om})]^2}{(1+0.54u)} . \tag{4}$$

Herein, momentum roughness $z_{0m}$ of underlying surface covered with vegetation and zero-plane displacement $d_0$ are calculated respectively as follows:

$$z_{0m} = 0.04 h^{1.417} \quad , \quad d_0 = \frac{2}{3} h. \tag{5}$$

While on the bare land, momentum roughness is selected as 0.01 directly and zero-plane displacement is 0.0.

4) Improved Thom-2 Algorithm.

Because there are difference between $z_{0h}$ and $z_{0m}$, and thermal effect in arid region cannot be neglected, so after attempts, author of this paper improves the algorithm proposed by Thom, and separate $z_{0h}$ and $z_{0m}$, improvement of Equation (7) is as follows:

$$r_a = 4.72 \frac{[\ln((z-d_0)/z_{0m}) \times \ln((z-d_0)/z_{0h})]}{(1+0.54u)} . \tag{6}$$

Herein, thermal roughness $z_{0h}$ is calculated as follows:

Vegetarian underlying surface:

$$z_{0h} = 0.17 u (T_s - T_a). \tag{7}$$

Bare soil underlying surface:

$$\ln(\frac{z_{0m}}{z_{0h}}) = 2 \tag{8}$$

## 4 Analysis of results

In Figure 1, comparison between the measured values and the estimated aerodynamic impedance results of desert underlying surface by four algorithms is given first.

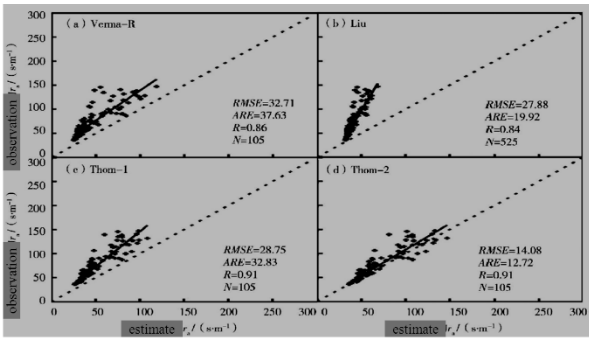


FIGURE 1 Comparison between the measured values and the estimated aerodynamic impedance results of desert underlying surface by four algorithms

In the figure, refers to average square error, refers to average relative error, N refers to the amount of samples involved in analysis, and R refers to relevant coefficients (the followings are the same). It can be seen from the figure that there is a good correlation between estimated values of various algorithms and the actually measured value, but there are still some errors. Herein, the aerodynamic impedance estimated by Thom-2 algorithm is the closest to the actually measured value with the least average square error. The largest correlation coefficient is 0.91 and the minimum comparative error is 12.72%. The error between estimated results of Verma and Thom-1 algorithms and the actually measured value is also small, and the estimation precision is only next to Thom-2 algorithm. There is a good correlation between estimated aerodynamic impedance and the actually measured value with and correlation coefficients at 0.86 and 0.91 respectively, and average square errors are all around 30.00 $s \cdot m^{-1}$. While the precision of estimated results of Liu algorithm is relatively low, with the correlation coefficient as 0.80, and average square error is large and it is 44.53 $s \cdot m^{-1}$. This is because the empirical formula causes difference in environment and weather condition, etc.

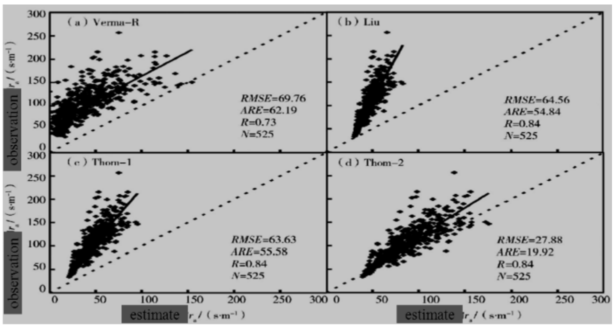


FIGURE 2 Comparison between desert aerodynamic impedance estimated by four algorithms and the actually measured value

Figure 2 is the comparison between the measured value and the aerodynamic impedance of desert underlying surface estimated by four aerodynamic impedance algorithms. There is a good correlation between the aerodynamic impedance of desert underlying surface estimated by various algorithms, and except for Verma algorithm, whose correlation coefficient is 0.73, the correlation coefficients of all the other algorithms have reached 0.84 with low universality of data however. Herein, the estimated value of Thom-2 algorithm is the closest to the actually measured value with the average square error at 27.88 $s \cdot m^{-1}$ and the average comparative error is no more than 20.0%. Estimation precision of Verma-R, Thon-1 and Liu algorithms is low, and the average square error of them is over 60.0 $s \cdot m^{-1}$, and the average comparative error is over 50.0%. The main reason is that Liu algorithm is obtained by fitting and on the basis of actually measured information, so there will inevitably be difference to use it directly to estimate the aerodynamic impedance in Gulang area. Compared with Thom-2 algorithm, the estimation precision of Thon-1 algorithm and Verma-R algorithm is relatively lower, mainly because in these two algorithms, momentum roughness is supposed to equal to thermal roughness.

While in Thom-2 algorithm, momentum roughness and thermal roughness is separated from each other so as to improve the estimation precision of aerodynamic impedance to a great extent, which suggests that it is very necessary to consider thermal roughness in calculating aerodynamic impedance in arid and semi-arid areas.

Comparison between the estimated field aerodynamic impedance by the above four algorithms and the actually measured value is shown in Figure 3.

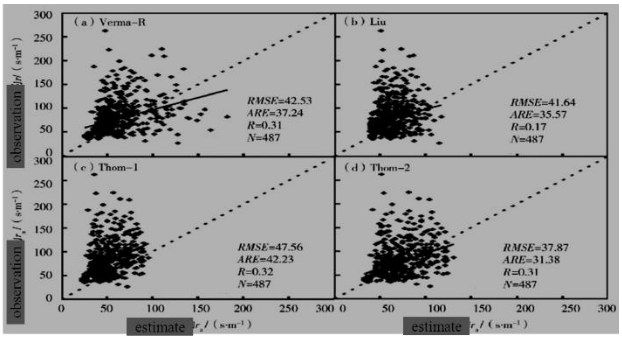


FIGURE 3 Comparison between the estimated field aerodynamic impedance by the above four algorithms and the actually measured value

It can be seen that as a whole, the estimation precision of several algorithms is lower than that of wasteland and desert underlying surface, and the estimated results and the distribution of actually measured value are dispersing with poor correlation. Herein, correlation coefficient between the estimated results of Liu algorithm and the actually measured value is only 0.17, and the correlation coefficients of other algorithms is around 0.30. This is mainly because compared with desert underlying surface, estimation factors of farmland underlying surface are complicated, and in addition to the relation with wind speed, aerodynamic impedance is also related with vegetation, etc. As shown in Figure 5, on the relatively flat and homogenous wasteland and desert underlying surface, the logarithmic relation between aerodynamic impedance and wind speed is distinct, while on the farmland underlying surface, due to different sparseness and height of vegetation and different thermal effects, the logarithmic relation between aerodynamic impedance and wind speed is not obvious.

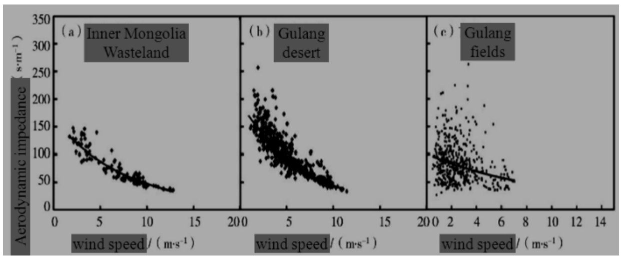


FIGURE 4 Relation between aerodynamic impedance of different underlying surfaces and wind speed

Besides, it can also be seen that when the wind speed is fast ($u > 5.0 m \cdot s^{-1}$), the logarithmic relation between aerodynamic impedance and wind speed is more obvious. While the existence of vegetation weakens the influence of wind speed, and increases the difficulty to estimate aerodynamic impedance, so precise estimation of aerodynamic impedance of complex underlying surface covered with vegetation remains for further study. However, it can be found from the comparison between aerodynamic impedance estimated by 4 algorithms and the actually measured value that the estimation precision of Thom-2 algorithm is superior to other algorithms, and the error between the estimated value and the actually measured value is relatively small with the average comparative error as 31.38%. And the average square error is minimum at 37.87$s \cdot m^{-1}$.

## 5 Conclusions and discussions

On the wasteland and desert underlying surfaces, because the underlying surface is relatively flat and homogenous, the precision of estimating the wasteland and desert aerodynamic impedance by the four algorithms is higher than that of farmland. Herein, the result of improved Thom algorithm is the optimal.

On farmland underlying surface, due to reasons like uneven vegetation density and different heights, the underlying surfaces are relatively complicated. By the comparison between the farmland aerodynamic impedance estimated by the 4 algorithms in this paper and the actually measured value, the result is poorer than wasteland and desert, herein, the estimation precision of improved Thom algorithm is still the highest.

Dynamic and thermodynamic factors are the main factors influencing aerodynamic impedance, and on desert and wasteland underlying surface, the impact of dynamic factors is greater than that of thermodynamic factors, and the logarithmic relation between aerodynamic impedance and wind speed is obvious. In farmland underlying surface, because the existence of vegetation weakens the influence of wind speed, the logarithmic relation between aerodynamic impedance and wind speed is not obvious, while the uneven coverage of vegetation causes some difficulties to the estimation precision of aerodynamic impedance of farmland underlying surfaces.

The improved algorithm's precision to estimate the aerodynamic impedance of 3 kinds of classic underlying surfaces has been greatly improved. But it is not difficult to be found that the improved algorithm's precision to estimate the aerodynamic impedance of wasteland and desert that are flat and homogenous with sparse vegetation or without vegetation is relatively high, and the degree of improvement is also large. But for farmland underlying surface covered with more vegetation of different heights, the estimation precision of improved algorithm is not ideal. This is mainly related to main factors influencing aerodynamic impedance estimation precision and the application conditions of Thom algorithm itself. Thom algorithm is developed from flat surface, and suitable for flat and homogenous underlying surface with few vegetation, and the improved Thom algorithm still has this limitation.

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