Reply to Referee #1

It seems Gong and his/her colleagues have substantially improved the manuscript in the resubmitted version. Generally, the manuscript is written clearly and understandable, but some grammars are still need to be checked and confirmed, probably by a native speaker. I like the discussion about the human impact on evaporation, i.e. vegetation degradation and sand dunes bulldozing. The impact of vegetation degradation did not only change the vegetation cover but also modify the soil conditions. I agree with the authors that the processes are complex, and still needs to be further investigated. Summarily, these relative long-term and intensive land surface water and energy observations are important for us to understand the interaction between land surface and atmosphere and even groundwater, especially in this semiarid region where the ecosystems are vulnerable. But there is still space to improve the quality of this manuscript before publication.

Answer: Thank you for your positive comments. The manuscript has been checked and revised by the English-speaking editors of AJE (the supplement is the certificate).

Other comments:

L24: I think it might be okay to generalize the results a little bit to "improve our understanding . . . in the fragile ecosystems of semiarid regions."

Answer: We changed the significance of this study in the abstract with the following sentences, please see lines 18-20 in the revised manuscript.

"This study could improve our understanding of the effects of land use/cover change on ET in the fragile ecosystem of semiarid regions and provide a scientific reference for the sustainable management of regional land and water resources"

L34: Not clear info. Please rephrase.

Answer: We rephrased this sentence with the following sentences.

"In terms of physical processes, ET is affected by net radiation (Valipour et al., 2015), water vapor pressure deficit (Zhang et al., 2014), wind speed (Falamarzi et al., 2014), and soil water stress (Allen et al., 1998). Moreover, vegetation condition is also a crucial factor influencing ET (Tian et al., 2015; Wang et al., 2011; Piao et al., 2006; Mackay et al., 2007)", please see lines 29-33 in the revised manuscript.

L 65: limiting factor for. . .

Answer: We replaced the expression of "limiting factor on vegetation" with "limiting factor for vegetation", please see line 115 in the revised manuscript.

L66: what do you mean by "common droughts"?

Answer: In this sentence, the "common droughts" referred to droughts. In order to avoid misunderstanding, we deleted "common" in this sentence, please see line 116.

L 62-73: Some detailed information might better go to study site section.

Answer: We used the information in this paragraph to describe the typical characteristics of Mu Us Sandy Land, including the sand dunes, biological soil crusts

(BSCs) and dry sand layer, which result in complex ET process. Therefore, we thought it might be better to leave some information about these typical land surface properties in this paragraph. And following your suggestion, we moved the following sentences describing the vegetation and water condition of Mu Us Sandy Land to the section 2.1 (Site description), please see lines 115-117 in the revised manuscript.
“Shortage of water is the critical limiting factor for vegetation in this regions, and drought-enduring vegetation are prevailed as a result of droughts (Wang et al., 2002; Wu, 2006). There are at least 117 shrub and semi-shrub species within the Mu Us Sandland (Dong and Zhang, 2001).”

L 81: in situ field. . . ?
Answer: Yes, we corrected it.

L88: "doubtful" is a strong word. You’d better change it.
Answer: Following your suggestion, we revised it by replacing “doubtful” with “may induce uncertainty”, please see line 65 in the revised manuscript.

L97: “. . .is little learned. . .” reads awkward. Please rephrase. Again, “field observations”
Answer: We revised the sentence from “To our knowledge, there is little learned of ET under native sparse shrubland and continuous field observations under land degradation and vegetation rehabilitation conditions.” to “Continuous field observations under both land degradation and vegetation rehabilitation processes have rarely been documented, especially in the semiarid shrubland”, please see lines 74-76 in the revised manuscript.

Yes, we corrected the word “field”.

L102 probably change measurements to measurement
Answer: We revised the word “measurements” to “measurement”, please see line 93 in the revised manuscript.

L123: is it better to say “water demand”?
Answer: Yes, we revised it.

L141: “as time went on. . .”. Please keep the same tense in one sentence.
Answer: We revised it.

L187-189: It might be better to briefly describe how you calculated latent heat flux.
Answer: We added a brief description of latent heat flux calculations by eddypro in the section 2.3 (flux data processing) with the following sentences, please see lines 179-185 in the revised manuscript.
“10 Hz 3-dimensional wind speed and water vapor concentrations that collected by EC technique were processed to half-hourly latent heat flux (λE_T) using Eddypro processing software (v5.2.0, LI-COR, Lincoln, NE USA). The main principle is that λE_T can be expressed as $\rho_a \overline{w' q'}$ (where w' is the fluctuation of vertical wind

speed, q' is the fluctuation of specific humidity and ρ_a is the air density). The software also applies the quality control of data, including spike removal, tilt correction, time lag compensation, turbulent fluctuation blocking and spectral corrections."

L198: what do you mean by "immediately"?
Answer: We used "immediately" to emphasize that we used the values before and after the data gap. In order to avoid the confusion, we deleted the word "immediately" here, please see line 201 in the revised manuscript.

L266: How did you determine the factors in this equation?
Answer: In our study, θ_r was calculated by θ at different depths ($\theta_i, i = 5, 10, 20, 40, 60, 80, 120, 160$ cm). A schematic diagram is showed in the following.

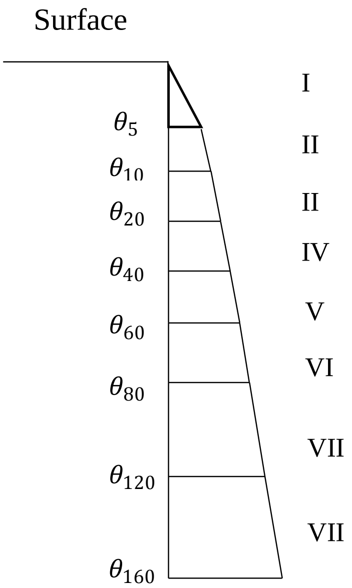

Figure 1. The schematic diagram of root-zone soil water content calculation

In the layer I (0-5 cm), the soil water profile was assumed triangular, while in the layers II, III, IV, V, VI, VII and VIII, the soil water profiles were assumed trapezoidal. Therefore, θ_r was calculated by the following equation,

$$\theta_r = \frac{0.5\begin{bmatrix} 5\theta_5 + (\theta_5 + \theta_{10}) * (10 - 5) + (\theta_{10} + \theta_{20}) * (20 - 10) \\ +(\theta_{20} + \theta_{40}) * (40 - 20) + (\theta_{40} + \theta_{60}) * (60 - 40) \\ +(\theta_{60} + \theta_{80}) * (80 - 60) + (\theta_{80} + \theta_{120}) * (120 - 80) \\ +(\theta_{120} + \theta_{160}) * (160 - 120) \end{bmatrix}}{160}$$

We added the above information in the text (please see lines 308-312 in the revised manuscript). Besides, we revised the Eq.13 in the text as well.

L291-294: Is this the commonly used method to calculate NDVI? If so, you do not need to mention these details. And I have no idea why you describe the NDVI_Terra and NDVI_Aqua. Can you clarify?

Answer: Yes, this method is commonly used to calculate NDVI. As we found that there were slight differences ($\left|NDVI_{Terra} - NDVI_{Aqua}\right| = 0.01 \pm 0.0075$) between the calculated daily $NDVI_{Terra}$ and $NDVI_{Aqua}$, we calculated NDVI by averaging $NDVI_{Terra}$ and $NDVI_{Aqua}$ in our study in order to eliminate the impacts caused by such differences.

We added the above information in the section 3.2.2 (vegetation parameter), please see lines 272-277 in the revised manuscript. In addition, we followed your suggestion to simplify the descriptions of the method to calculate NDVI by firstly deleting the superfluous sentences to describe $NDVI_{Terra}$ and $NDVI_{Aqua}$ (e.g., L449-451, L453-461, L472-473 and L474-475 in the marked-up manuscript). Then we rephrased the sentences to state the method to calculate NDVI by averaging $NDVI_{Terra}$ and $NDVI_{Aqua}$ (please see lines 267-278 in the revised manuscript).

L398-399: Since NDVI is a normalized factor and you derived the NDVI_w based NDVI, I do not think it is meaningful to quantify the impact of NDVI on evaporation. This relationship might be changed in different cases and even with different time series datasets. You can describe this relation, but it is probably not suitable as a highlight and mention it in Abstract.
Answer: We agree with you that the relationship between NDVI and ET differs in different cases or with different time series. We also discussed this point in the manuscript (section 5.1). The main purpose for describing the relationship is to compare our result with other studies in different cases to show how strong NDVI affects ET. By our survey, the relationship between NDVI and ET were reported mostly in forests and grassland. Thus, it is meaningful to fill the gap to quantify the effect of NDVI on ET in shrubland.

In summary, we described this relationship in the main body for comparison, and following your suggestion, we deleted this description in the abstract.

L412: do you mean "compared Period I with. . ."?
Answer: Yes, we revised the sentence from "compared to period I with natural land use/cover condition, …" to "compared with Period I, …", please see line 426 in the revised manuscript.

L431-434: The first-order control of evaporation is a long time debate. I agree with the conclusion, but this research might be not directly related to this conclusion. I suggest the authors weaken the tone, to use "probably" or "very likely" etc.
Answer: We followed your suggestion and revised the word by replacing "mainly" in this sentence with "likely", please see line 445 in the revised manuscript.

L545: "tolerant to" is probably followed by some "vices", not survive. Please rephrase.
Answer: We revised the sentence from "…because shrubs are more tolerant to survive in water-starved ecosystems" to "… because shrubs are easier to survive in water-limited ecosystems", please see lines 545-546 in the revised manuscript.

L 550: more water than “what”?

Answer: The missing “what” in this sentence was the word “grass”. However, we deleted this sentence “As potato consumes much more water than grass”. Because we have emphasized the fact that potato consumes more water than grass in this paragraph, please see line 842-843 in the marked-up manuscript.

Reply to Referee #2

This study assessed the relationships between evapotranspiration (ET) and change of land by analyzing the eddy-covariance measurements of actual ET together with data of a number of its potentially influencing factors including normalized vegetation index, soil water content as well as climate variables to estimate potential ET. Data are collected from a case study with different periods reflecting changes of land-use conditions, which provides further evidence to support the statistical analyses. The manuscript is well written and the knowledge promoted is a clear contribution to the understanding of how ET processes can potentially change with land-use in semiarid regions. I think this study is suitable for publication after moderate revision, with improved clarity and better flow especially for the Introduction and Methodology - please see my major comments below.

Answer: Thank you for your positive comments. We revised our manuscript by carefully following your comments and suggestions.

Major comments:

1. The Introduction launched quite well with highlighting the importance of the assessing relationship between ET to vegetation conditions in arid/semiarid regions (L28-37), followed by a comprehensive literature review explaining relevant physical mechanisms (L38-61). However, the third paragraph (L62-79) seems to be a bit disjointed as the flow of ET/vegetation stops and shifts to the case study, whereas paragraph 4 (L80-98) returns to the ET/vegetation flow and paragraph 5 again introduces the study site. I think the easiest way to improve the flow is by swapping paragraph 3 and 4 (I found this can in fact fit better with your current connecting sentences between paragraphs i.e. L60-61, L96-98). So you would have: Paragraph 1: importance of the assessing relationship between ET to vegetation conditions in arid/semiarid regions Paragraph 2: physical mechanisms on how vegetation can influence ET (finish with L60-61 which then leads to the method of assessing these impacts) Paragraph 3: method to assess the vegetation impact on ET (finish with L96-98 which then leads to the case study in a sparse shrubland) Paragraph 4: introducing the case study and how it can contribute to the above-mentioned knowledge gap. I'd also recommend combining this use some discussion from the current paragraph 5 (L99-101) to help justifying the choice of the case study. Paragraph 5: I'd recommend to leave this paragraph purely as a summary of the study (as current L102-104), and maybe elaborate a little bit with highlighting the significance of the study. I think the above structure can allow the storyline about ET/vegetation relationship to complete before introducing the study site, which provides a smoother transition and also better justification on the use of Mu US sandland as the case study.

Answer: Thank you for your constructive suggestions. According to your comments, we swapped paragraph 3 and 4 to make these paragraphs jointed, please see lines 58-92 in the revised manuscript.

In addition, we also combined the following sentences to paragraph 4 to help justify the choice of the study site.

"Coincidentally, two processes of land use/cover changes (land degradation and vegetation rehabilitation) have occurred at the edge of the Mu Us Sandy Land, providing us a unique opportunity to study the effects of land use/cover change on ET."

Furthermore, in paragraph 5, we highlighted the significance of our study by adding the sentence "Our results were expected to provide a scientific reference for the sustainable management of regional land and water resources in the context of intensive agricultural reclamation", please see lines 95-97 in the revised manuscript.

2. I appreciate the comprehensiveness of Section 2 which covers the details of data collections methods and models used to analyze different data variables. However, I found that Section 2.3.2 become a bit confusing with introducing models related to a number of variables. As this section describes the methods employed for the core analyses of the study, I think the clarity can be further improved by using further subsections for individual variables. In addition, I think the methods used for data analyses should be introduced as well. Currently the statistical methods used for data analyses are mainly described in the Results section (e.g. L325-327, L380-384, L386-L389). I think it can be clearer to summarize them in the Section 2.3.2 instead (probably as an overview in the start of this section). In this way you can better justify why these analyses are conducted and how they help to answer the research questions, while purely focusing on the results and interpretation in the Results section. And then the readers can get an overall understanding on the data analyses to be conducted and knowing what to expect in the Results section. So I'd suggest the following structure for Section 2.3.2: Sub-section 1: overview – introducing the variables which are needed for analyzing the impact of ET and vegetation conditions (these will be detailed in the following sub-sections), and what analyses will be conducted with these variables (e.g. as those introduced in L325-327, L380-384 and L386-L389 etc.) Sub-section 2: estimating potential ET Sub-section 3: estimating soil water content Sub-section 4: estimating NDVI ...

Answer: Together based on your comment 2 and 3, we separated the pervious section 2 into two sections (section 2 and section 3). In the new section 2, we mainly introduced the case study information (including site information, the measurements in our study site) and data (we thought the data here included raw data and processed data). Thus, we thought it might be better to move the previous section 2.3.1 (flux data processing) into this new section 2 as subsection 2.3. We re-arranged and revised section 2 based on the following structure:

2 Case study and data
…2.1 Site description
….2.2 Field measurements
……2.2.1 Eddy covariance system
……2.2.2 Other measurements
…2.3 Flux data processing (lines 178-212)

While in section 3, we mainly introduced the methods to calculate the footprint and the variables that have controls on ET. Following your suggestion, we added a subsection 3.3 (statistical analysis), including the statistical methods that described in the Results section previously (as you referred in this comment 2, e.g., L380-384, L386-L389 in previous manuscript). In addition, we also added the information about the reason why we chose linear function to simulate the correlations between ET and its three controlling factors (please see our reply to the minor comment 12).

For the sentence you mentioned in this comment 2 (e.g., L325-327 in the previous manuscript), which described the purpose to calculate energy balance closure, we prefer to leave them in the Result Section (lines 343-346). Because energy balance closure is a common concept and there is no need to describe it in the method part. In addition, if we move the sentence to the method part, the continuity of section 4.1 will be broken.

Therefore, we re-arranged and revised the section 3 according to the following structure:

3 Methodology
…3.1 Footprint model
…3.2 Method of analyzing controlling factors of ET
……3.2.1 Potential evapotranspiration
……3.2.2 Vegetation parameters
……3.2.3 Soil water stress
…3.3 Statistical analysis (new subsection, lines 320-329).

3. I think the Section 2 (Material and Methods) is a bit too long trying to cover different aspects including case study, measurements of raw data, data processing and analyzing. In my opinion a better way to organize these is to break Section 2 into two sections, for example as: Section 2. Case study and data (note:I'd use 'data' to refer to the raw measurements here rather than in the next section, where you introduce data-processing and analyzing.) 2.1 site description 2.2 measurements ... Section 3. Methodology 3.1 flux data processing 3.2 footprint model 3.3 method of analyzing controlling factors of ET (and if you agree with my last comment, the sub-sections can go below:) 3.3.1 ... 3.3.2 ... ...

Answer: Please see our reply to the comment 2.

Minor comments:

1. L30: 'ET' - please define acronym when it first appears in the text, and please also check if all other acronyms are properly defined.

Answer: We added the definition of ET in the text, please see line 26 in the revised manuscript.

2. L101: '4' - please spell out numbers less than 10 i.e. as 'four-year'.

Answer: We revised it.

3. L111: please delete the repeated 'temperate'. Also, is there a better way to introduce the climate zone, as currently it seems like a 'noun train' ('temperate semiarid continental monsoon climate'). You can find some examples on improving 'noun train' from http://www.webwritingthatworks.com/DGuideCOG5b.htm.

Answer: We have studied the guidelines from the link you provided. Together based on the guidelines and other scholars' studies (Yang et al., 2015; Wu and Ci, 2002). We thought the sentence might be better by changing it from "the study site is in a temperate semiarid continental temperate monsoon climate" to "This site is a semiarid area with temperate continental monsoon climate", please see line 104 in the revised manuscript.

References:

Yang, Y., Bu, C., Mu, X., Zhang, K.: Effects of differing coverage of moss - dominated soil crusts on hydrological processes and implications for disturbance in the Mu Us Sandland, China. Hydrological Processes, 29(14), 3112-3123, 2015.

Wu, B., Ci, L. J..: Landscape change and desertification development in the Mu Us Sandland, Northern China. Journal of Arid Environments, 50(3), 429-444, 2002.

4. L194-195: Would there be any impact on the results from this data removal, and would this be a limitation of the study? This should be briefly discussed (Maybe in the Discussion or Conclusion section?).

Answer: We thought there might be little impact of this data removal on our results due to the following reasons.

Firstly, in our study, the missing and rejected λE_{T} values almost occurred during nighttime (89.1% in Period I, 91.3% in Period II, 92.6% in Period III and 88.7% in Period IV), which were mainly caused by insufficient electric power supply in low air temperature environment and the low turbulence during the nighttime.

Secondly, in the nighttime, the change in λE_{T} is small, and ET values are close to zero. Therefore, after removal of the nighttime data, the errors of the gap-filled nighttime values based on the neighboring good data are small. Besides, λE_{T} values of nighttime accounted a very small proportion to the daily ET.

Thirdly, the ratios of the missing and rejected data points are not so high. For example, Falge et al. (2001) have reported that during quality control procedure of 28 flux sites, there was an average of 31% missing or rejected values of λE_{T} values. Wever et al. (2002) reported that there was 15% missing or rejected values of λE_{T} values during the quality control procedure. Mauder et al. (2006) have reported that there was an average of 20% missing or rejected values of λE_{T} values by 20 flux sites. Therefore, the ratio of rejected and missing half-hourly data in each period was reasonable and the dataset of λE_{T} after quality control procedure is reliable.

We added the above reasons in the text, please see lines 188-197 in the revised manuscript.

References:

Falge, E., Baldocchi, D., Olson, R., Anthoni, P., Aubinet, M., Bernhofer, C., Burba, G., Ceulemans, R., Clement, R., Dolman, H., Granier, A., Gross, P., Grunwald, T., Hollinger, D., Jensen, N. O., Katul, G., Keronen, P., Kowalski, A., Lai, C. T., Law, B. E., Meyers, T., Moncrieff, H., Moors, E., Munger, J. W., Pilegaard, K., Rannik, U., Rebmann, C., Suyker, A., Tenhunen, J., Tu, K., Verma, S., Vesala, T., Wilson, K. and Wofsy, S.: Gap filling strategies for long term energy flux data sets. Agricultural and Forest Meteorology, 107, 71-77, 2001.

Mauder, M., Liebethal, C., Göckede, M., Leps, J. P., Beyrich, F., Foken, T.. Processing and quality

control of flux data during LITFASS-2003.Boundary-Layer Meteorology, 121(1), 67-88, 2006.

Wever, L. A., Flanagan, L. B., & Carlson, P. J. (2002). Seasonal and interannual variation in evapotranspiration, energy balance and surface conductance in a northern temperate grassland. Agricultural and Forest Meteorology, 112(1), 31-49.

5. L208-211: It would be clearer if these lines can be presented as individual formulae (i.e. in the format of L219). Also, according to L205, the ’n’ in ’Rn’ should be subscripted - please also check that the use of other symbols is consistent throughout the text.

Answer: After considering your comment, we thought it might be better to change these lines from several formulae to the following form: “ $\mathrm{f} = a * (\mathrm{R_n} - \mathrm{G})^2 + b * (\mathrm{R_n} - \mathrm{G}) + c$ (Period I: a = 0.0014, b = 0.075, c = 10.69, R = 0.77; Period II: a = 0.0012, b = 0.056, c = 17.69, R = 0.67; Period III: a = 0.0014, b = 0.16, c = 13.24, R = 0.75; Period IV: a = 0.0015, b = -0.083, c = 25.87, R = 0.69)” , please see lines 206-209 in the revised manuscript.

In addition, we revised the $\mathrm{R_n}$ and checked the use of other symbols throughout the text.

6. L246: ’psychrometric constant’ - what is the value of the constant?

Answer: We added the equation of psychrometric constant (Eq.6 in the revised manuscript), please see lines 252-255 for detailed information.

7. L248: ’U2’ - where is it in Equation (5)?

Answer: $\mathrm{U_2}$ is used to calculate the aerodynamic resistance ($\mathrm{r_a}$, Eq.7 in the manuscript). We moved the equation of calculating $\mathrm{U_2}$ from Eq.6 to Eq.8 for better understand, please see lines 259-262 for detailed information.

8. L337: ’Ds’ - not defined as in Minor comment #1. Also, how are the data of Ds obtained? I couldn’t seem to find it in Section 2.2.2 (other measurements).

Answer: Thank you for your kind remind. We added the information of measurement that obtained $\mathrm{D_s}$ in the section of “other measurements” with the following sentence. “Sunshine duration (D_S) is measured by a sunshine recorder (CSD3; KIPP&ZONEN, Delft, the Netherlands).”

9. L337: ’normal’ - I think ’average monthly’ would be a better description here.

Answer: We revised it.

10. L347: Figure 4 has not been introduced in the text yet, should it be mentioned somewhere between L336-337?

Answer: Yes, we added the sentences of “Four-year and long-term (1954-2014) average monthly values of D_S, T_a, R_H, and P are shown in Fig.4.” in the section 4.2, please see lines 356-358 in the revised manuscript.

11. L380: ’relationships’ - ’correlations’ would be a more accurate description.
Answer: Thank you for your suggestion. We revised it, please see line 403 in the revised manuscript.

12. L389-390: the r2 only investigates linear relationships - are you expecting any non-linear relationships which are not covered here and would this be a limitation? This can be briefly discussed.
Answer: We already used several common functions (e.g., exponential function, linear function, logarithmic function and quadratic function) to fit the correlations between ET and its controlling factors (E_{TP}, NDVI and f_s). The values of determination coefficient (R^2) are listed in the following Tab. 1.

According to the results that showed in the following Tab.1, R^2 of the linear function is generally the highest. Therefore, we chose the linear function to fit the correlations between ET and its three influencing factors in our study.

We added the above information in the section 3.3 (Statistical analysis), please see lines 321-326 in the revised manuscript.

Table 1. The determination coefficient (R^2) of the correlations between ET and the three controlling factors.

	ET and E_{TP}	ET and NDVI	ET and f_s
Exponential function	0.46	0.52	0.27
Linear function	0.46	0.52	0.28
Logarithmic function	0.43	0.51	0.19
Quadratic function	0.45	0.51	0.28

13. L464: The term ’BSC’ has already been defined in L68.
Answer: We deleted the definition here.

14. L565: It should be worth highlighting some significance and contributions of this study towards the end of conclusion.
Answer: We highlighted the significance of our study at the end of conclusion with the following sentences:
“Furthermore, our results suggest that when we simulate the impact of land use/cover change on hydrological processes, vegetation factor might not be the unique factor to parameterize, instead, the integrated effects of land surface and vegetation conditions should be considered. Our study also provides a scientific reference to the regional sustainable management of water resources in the context of intensive agricultural reclamation.”, please see lines 566-571 in the revised manuscript.

15. Fig. 6: I don’t think the use of different shapes is necessary given that you are using multiple panels?
Answer: We revised Fig.6.

16. L884 (title of Fig. 6): ‘r: Pearson’s correlation significance’ should r be ‘Pearson’s correlation coefficient’ instead?

Answer: Yes, we revised it in the title of Fig.6, please see line 944 in the revised manuscript.

~~Manuscript Title~~

Monitoring the variations of evapotranspiration due to ~~the~~ land use/cover change~~s~~ in a semiarid shrubland

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Abstract

Evapotranspiration (E_T) is an important process in the hydrological cycle, and vegetation change is a primary factor that affects E_T. In this study, ~~an attempt is made to~~we analyzed the annual and inter-annual characteristics of E_T using continuous observation data from eddy~~-~~ covariance (EC) measurement~~s~~ over four ~~periods~~ years (~~1st~~ 1 July 2011 to ~~30th~~ 30 June 2015) ~~at~~ in a ~~study site located in a~~ semiarid shrubland ~~(~~of ~~the~~ Mu Us Sandy ~~land~~Land,~~)~~ ~~of~~ China. The ~~Normalized~~ normalized difference vegetation index (NDVI) was demonstrated ~~as~~ as the predominant factor that influences the seasonal variations in E_T. ~~Normalization method was adopted to exclude the effects of potential evapotranspiration (E_{TP}) and soil water stress (f_s) on E_T. Vegetation phenological process was validated to have a remarkable positive effect on n~~N~~ormalized E_T in a rate of 1.86 (the slope of normalized E_T per NDVI)~~ increased ~~remarkably along with vegetation greening.~~ Additionally,~~At the annual scale, along with~~~~Both on~~ during the ~~the~~ land degradation ~~process~~ and vegetation rehabilitation

processes, ~~both~~ E_T and normalized E_T both increased ~~as a result of~~due to ~~an~~the integrated effects of the changes in vegetation type~~s~~, topography, and soil surface characteristics. ~~We discussed several possibilities that might lead to the increase. Our study suggested that when we simulated the impact of land use/cover change on hydrological processes, the integrated effects of land surface and vegetation conditions should be considered.~~ This study could improve our understanding of the effects of land use/cover changes on E_T in the fragile ecosystems of semiarid regions and provide a scientific reference for the sustainable management of regional land and water resources~~Our work may promote our knowledgeimprove our understanding about the characteristics of ET of the mix land use/cover condition (sparse shrubland and grassland) in the fragile ecosystems of Mu Us Sandlandsemiarid regions~~.

Key words: evapotranspiration; normalized difference vegetation index~~vegetation phenology~~; land use/cover change; eddy covariance; ~~Mu Us Sandland~~semiarid ~~climate~~region

1 Introduction

Arid and semiarid biomes cover approximately~~about~~ 40% of the Earth's terrestrial surface (Fernández, 2002). Previous studies have shown that more than 50% of precipitation (P) is consumed by evapotranspiration (E_T) (Yang et al., 2007; Liu et al., 2002~~), ~~). Moreover, a slight change in E_T could have significant influences on water cycle a~~a~~nd ~~that~~ the ratio of E_T/P could increase to even 90% or more ~~in semiarid and arid areas~~in these regions (Mo et al., 2004; Glenn et al., 2007). ~~Therefore, a slight change in E_T would have significant influences on water cycle in arid and semiarid regions.~~ In terms of physical processes, E_T is affected by ~~not only~~ net~~climatological factors (e.g., direct solar radiation, air temperature, vapor pressure deficit and wind speed) but also vegetation conditions. For example, direct solar~~ radiation ~~and the ambient air temperature provide the energy to make E_T happen~~ (Valipour et al., 2015),~~.~~ w~~W~~ater vapor pressure deficit~~ is the driving force to remove water vapor from the evaporating surface to the surrounding atmosphere~~ (Zhang et al., 2014), ~~. Besides, the replacement of the saturated air with drier air depends greatly on~~ wind speed (Falamarzi et al., 2014), and soil moisture stress (Allen et al., 1998). ~~Besides~~Moreover, ~~For another side, v~~vegetation condition ~~parameter~~ is also a crucial factor influencing E_T~~. E_T dynamics differ under different vegetation conditions~~ (Tian et al., 2015; Wang et al., 2011; Piao et al., 2006; Mackay et al., 2007). ~~E_T is not only affected by climatic factors (e.g., radiation, temperature, and relative humidity), but also affected by vegetation conditions (Tian et al., 2015; Wang et al., 2011; Piao et al., 2006; Mackay et al., 2007). As such, there has been an important push to understand how E_T responds to vegetation~~

~~conditions in these regions.~~

Vegetation change mainly ~~integrates~~ include ~~the~~ phenological change (temporal) and land use/cover change (spatial). ~~The p~~Phenological change reflects~~s~~ the response of plants to climate change (vegetation greening and browning processes) (Ge et al., 2015), which actively controls E_T ~~process~~ through internal physiologies~~y~~ such as stomatal conductance (Pearcy et al., 1989)~~ and~~, as well as ~~stomatal~~ the number~~s~~ and sizes of stomata (Turrell, 1947). In general, transpiration is ~~in~~ directly proportional to stomatal conductance at the ~~the~~ leaf~~ level~~ scale (Leuning et al., 1995). ~~Meanwhile, a~~At the canopy scale, E_T is positively proportional to surface conductance, ~~that~~ which is an integration of stomatal conductance and leaf area (Ding et al., 2014). Thus, as a good indicator of vegetation phenological change, many studies have found that E_T ~~was~~ is positively related to vegetation indexes such as Normalized difference vegetation index (NDVI) (Gu et al., 2007). Land use/cover change influence~~s~~ E_T by ~~means of~~ modifying vegetation species~~ with~~ with different transpiration rates, radiation transfers within canopy (Martens et al., 2000; Panferov et al., 2001), topography (Lv et al., 2006), albedos (Zeng et al., 2009), soil texture (Maayar and Chen, 2006), litter coverage (Wang, 1992), and biological soil crusts (BSCs) (Yang et al., 2015, Fu et al., 2010; Liu, 2012; Eldridge and Greene, 1994). These complex processes result in no consensus about the effects of land use/cover changes on E_T. For example, during the land degradation process, some researchers found that warming air temperature ~~increase~~ was the ~~dominant~~ main cause to make E_T increase (Zeng and Yang, 2008; Li et al., 2000; Deffema and Freire, 2001). ~~In contrary~~By contrast, a decline in E_T was~~–~~ found ~~to~~

~~decrease~~ along with deforestation process because of ~~less~~ less transpiration (Snyman, 2001; Souza and Oyama, 2011) or higher albedo~~s~~ (Zeng et al., 2002). Moreover, no changes in~~differences of~~ E_T during land degradation ~~was~~ were also reported (Hoshino et al., 2009). ~~Therefore, the impacts of land use/cover changes on E_T still deserve further investigations.~~ ~~As such~~Thus, there has been an important push to better understand how E_T responds to vegetation ~~condition~~change, especially to the land use/cover change~~s in these regions~~.

Three methods were usually employed to assess the impacts of ~~land use/cover~~vegetation change on E_T: numerical models, paired comparative approaches and ~~the~~ in situ ~~filed~~field observations. In these methods, numerical models are widely used (Twine et al., 2003; Feddema et al., 2005; Kim et al., 2005; Li et al., 2009; Cornelissen et al., 2013; Mo et al., 2004)~~.~~. ~~H~~However, model parameterization of vegetation condition is a big challenge, as the aforementioned complex underlying mechanisms ~~mentioned above~~ may ~~can~~not be completely considered in the models. Therefore, the simulated ~~impact~~effects of ~~land use/cover~~vegetation change on E_T ~~is~~are highly dependent on ~~the~~ model parameterizations, which may ~~lead to aand there might be large~~induce~~r~~ uncertainty~~ with the resulting conclusions may be doubtful~~ (Cornelissen et al., 2013; Li et al., 2009). Paired comparative approach is –often considered ~~as~~ the best method, nonetheless,~~but~~ it is difficult to find two ~~similar medium and large-sized~~ sites with similar meteorological conditions but different ~~land use/cover~~vegetation conditions (Li et al., 2009; Lorup et al., 1998). Moreover, the method of ~~In~~in situ field observations is ~~also a~~ widely used ~~method for~~to investigate long-term land-atmosphere exchange~~ measurements~~s. However, the land use/cover conditions at ~~the ~~sites are ~~usually~~generally stable, and only the response~~s~~ of E_T to vegetation phenolog~~y~~ical changes can be ~~studied~~observed~~. For example,~~, such as the ~~characteristics of ~~E_T variations ~~under~~in grassland (Zhang et al., 2005), mixed plantation (cork oak, black locust and arborvitae) (Tong et al., 2014), vineyard (Li et al., 2015) and grazed steppe (Chen et al., 2009; Vetter et al., 2012). C~~However,~~ ~~To our knowledge, there is little learned of E_T dynamics under nativesemiarid sparse shrubland are less well understood and c~~ontinuous ~~filed~~field observations under both land degradation and vegetation rehabilitation ~~condition~~processes have rarely been documented, especially in the semiarid shrubland~~, are littlenot documented~~.

The Mu Us Sandy~~ land~~ Land is a semiarid shrubland ecosystem ~~at~~ on the northern margin of the Loess Plateau in China~~,~~. The area ~~covering~~ covers an area of only 40,000 km^2 (Dong and Zhang, 2001)~~. The region~~ and is ecologically fragile (Yang et al., 2007). ~~Shortage of water is the critical limiting factor on vegetation, and drought-enduring vegetation are prevailed as a result of common droughts (Wang et al., 2002; Wu, 2006). There are at least 117 shrub and semi-shrub species have been found within the Mu Us Sandland (Dong and Zhang, 2001).~~ In such~~ arid and semiarid~~ an ecosystem, sand dunes and ~~biological soil crusts (~~BSCs~~)~~ are commonly observed (Gao et al., 2014; Yang et al., 2015; Li and Li, 2000; Liu, 2012). Due to the ~~exists~~ existence of BSCs ~~(Yang et al., 2015; Fu et al., 2010; Liu, 2012)~~ and dry sand layers (Wang et al., 2006; Feng, 1994; Liu et al., 2006; Yuan et al., 2007), soil evaporation ~~have~~ has been effectively retained, therefore, the Mu Us Sandy Land ~~Sandland holds~~contains abundant groundwater (Li and Li, 2000). During the past decades, rapid land use/cover changes ~~has ~~have ~~taken~~ ~~place~~occurred in this region due to agricultural reclamation (~~Wu et al., 1997; ~~Wu and Ci, 2002; Wang et al., 2009; Ostwald and Chen, 2006; Zhang et al., 2007), leading to ~~a~~ dramatic changes in vegetation conditions~~s~~. With respect to the specific question of whether land use/cover changes will lead to increases in E_T or not, a continuous measurement of E_T under different land use/cover conditions is ~~needed ~~required in this region. ~~Our study site is at the edge of the Mu US Sandland. ~~Coincidentally, two processes of land use/cover changes (land degradation and vegetation rehabilitation) ha~~s~~ve occurred ~~at our study site located ~~at ~~this site~~the edge of the Mu Us Sandy Land~~,~~ ~~with long-term observations~~, ~~which ~~provid~~es~~ing us a unique opportunity to study the effects of land use/cover change on E_T~~.~~.

~~Three methods were usually employed to assess the impacts of land use/cover change on E_T: numerical models, paired comparative approaches and the in situ filed observations. In these methods, numerical models are widely used (Twine et al., 2003; Feddema et al., 2005; Kim et al., 2005; Li et al., 2009; Cornelissen et al., 2013; Mo et al., 2004). However, model parameterization of vegetation condition is a big challenge as the complex underlying mechanisms mentioned above cannot be completely considered in the models. Therefore, the simulated impacts of land use/cover change on E_T is highly dependent on the model parameterizations, and the resulting conclusions may be doubtful (Cornelissen et al., 2013; Li et al., 2009). Paired comparative approach is often considered as the best method, but it is difficult to find two similar medium and large-sized sites with different land use/cover conditions (Li et al., 2009; Lorup et al.,~~

~~1998). In situ observation is also a widely used method for long-term land-atmosphere exchange measurements. However, the land use/cover conditions at the sites are usually stable, and only the responses of E_T to vegetation phenology change can be studied. For example, the characteristics of E_T under grassland (Zhang et al., 2005), mixed plantation (cork oak, black locust and arborvitae) (Tong et al., 2014), vineyard (Li et al., 2015) and grazed steppe (Chen et al., 2009; Vetter et al., 2012). To our knowledge, there is little learned of E_T under native sparse shrubland and continuous filed observations under land degradation and vegetation rehabilitation conditions are not documented.~~

Hence, ~~Our study site is at the edge of the Mu US Sandland. Coincidentally, land degradation and vegetation rehabilitation has occurred at this site, which provides us a unique opportunity to study the effects of land use/cover change on E_T. Based~~ ~~Our study site is at the edge of the Mu US Sandland. Coincidentally, land degradation and vegetation rehabilitation has occurred at this site, which provides us a unique opportunity to study the effects of land use/cover change on E_T.~~ based on the four ~~4~~-year measurement~~s~~ of E_T by eddy covariance techniques, this study analyzed the seasonal and inter-annual variations ~~of~~ in E_T, and discussed the possible reasons for the responses of E_T to land use/cover changes. Our ~~analysis~~ results were expected to provide a scientific reference ~~to~~for ~~a~~the– sustainable management of regional land and water resources ~~management~~ in the context of intensive agricultural reclamation.

~~On the basis of understanding the impacts of land use/cover change by human activity on E_T, more effective approaches should be implemented to maintain the water~~

~~balance and sustainable regional development.~~

2 ~~Materials and methods~~Case study and data

2.1 Site description

The study was ~~carried out~~conducted at the Yulin flux site (N 38°26′, E 109°47′, 1233 m), which was established in June 2011. ~~and~~ This site is located in a landform transition zone that changes from the Mu Us Sandy Land~~Sandy land~~ to the north Shaanxi Loess Plateau (Fig. –1). The study site is in a temperate continental semiarid ~~continental temperate~~ monsoon climate. According to ~~the~~ long-term climate data (1951-2012) from a meteorological station in Yulin (Fig. –1), the annual precipitation ~~varies~~ varied from 235 mm to 685 mm, with a mean of 402 mm, and more than 50% of annual precipitation ~~is falling~~falled in the monsoon season (July-September). The mean annual air temperature ~~is~~ was 8.4 ℃ ~~during~~ over the past 61 years. The dominant soil type is sand (98% sand) (saturated soil water content: 0.43 m^{3}m^{-3}, field capacity: 0.16 m^{3}m^{-3}, residual moisture content: 0.045 m^{3}m^{-3}). There are widely distributed fixed sand dunes and semi-fixed sand dunes around the site, and the depth of the dry sand layer is 10 cm (Wang et al., 2006). The mean groundwater depth ~~of~~ at our study site from ~~1st~~ 1 July 2011 to ~~30th~~ 30 June 2015 was 3.5 m.

[Figure 1 is to be inserted here]

Shortage of water is the critical limiting factor for vegetation in ~~arid and semiarid~~this ~~regions~~sites, and drought-enduring vegetation (e.g., shrubs) ~~are~~is prevailed as a result of droughts (Wang et al., 2002; Wu, 2006). ~~There are at least 117 shrub and semi-shrub species have been found within the Mu Us Sandland (Dong and Zhang,~~

~~2001). The experimental~~The study site is mainly covered with mixed vegetation~~, one kind of vegetation is~~: the native drought-enduring shrubs with low water ~~demands~~ demand~~ such as~~ (e.g., *Artemisia ordosica* and *Salix psammophila*) (Fig. 2a)~~; the other kind is~~ and the sparse grass~~land~~ (~~ that~~ mainly distributed at the bottom of sand dunes because of the better soil moisture condition) (Lv et al., 2006). The maximum root depth of the shrubs was approximately 160 cm~~They constitute the dominant vegetation in Mu Us Sandland (An et al., 2011) and are adapted well to semiarid and arid sites. According to our observations around the flux tower on 14th June 2011, the maximum root depth of the shrubs was approximately 160 cm~~. Xiao et al. (2005) reported that the growing season of *Artemisia ordosica* and *Salix psammophila* spanned from late April to late September. Therefore, we defined the period from ~~1st~~ 1 May to ~~30th~~ 30 September as the vegetation growing season for data analysis in this study. On ~~15th~~ 15 August 2011 and ~~7th~~ 7 September 2011, we did surveys ~~about~~ of the vegetation coverage ~~with~~ by randomly ~~selected~~ selecting ~~7~~ seven samples around the flux tower (5 × 500 cm × 500 cm and 2 × 1000 cm × 1000 cm~~),~~). ~~and~~ We found that the vegetation coverage was 28.2% in August and 27.9%~~, respectively.~~ in September.

[Figure 2 is to be inserted here]

At the end of June 2012, the land use/cover condition around the eastern ~~area~~ portion of the flux tower began to be changed by farmers (~~the natural vegetation including the~~ leaves and branches ~~was~~ were cut~~ off~~, and the sand dunes were bulldozed) (Fig. ~~–~~2c), converting part of the natural vegetated land to bare ~~soil~~land, with the planning of planting potatoes in the future. As time ~~goes~~ went on, natural grass gradually grew out ~~gradually~~ in the area of bare land before ~~planting~~ potatoes were planted. Thus~~Thus~~, our study period (1 July 2011 to 30 June 2015) ~~can be~~was divided into four periods according to the land use/cover conditions: (a) Period I (~~1st~~ 1 July 2011 to ~~30th~~ 30 June 2012), the period with ~~was~~ the natural land use/cover condition (i.e., mixed sparsely distributed shrubs and grass) (Fig. 2a and Fig. 2b); (b) Period II (~~1st~~ 1 July 2012 to ~~30th~~ 30 June 2013), the~~was~~ ~~the~~ transitional period when ~~with~~ the land use/cover condition ~~starting~~ started to change ~~with (partial~~ some natural vegetation ~~being cut off~~removed and sand dunes ~~being~~ bulldozed); (c) Period III (1st July 2013 to 30th June 2014), ~~was~~ the period when the land use/cover condition constituted two parts~~,~~ ~~one was~~ : the natural vegetation zone and ~~the other was~~ the bare soil zone (Fig. 2c)~~;~~ and (d) Period IV (1st July 2014 to 30th June 2015), ~~was~~ the period when the bare soil zone ~~was~~ gradually covered by re-grow~~ing~~ing grass (Fig. 2d).

2.2 Field ~~Measurements~~measurements

2.2.1 Eddy covariance system measurements

Net exchange of water vapor between atmosphere and canopy at this site is measured by the eddy~~-~~ covariance (EC) flux measurements, which assess the fluxes of land-atmosphere (such as water and energy) (Baldocchi et al., 2001). The data are essential for the estimation of the water and energy balance (Franssen et al., 2010). At our site, the EC system is installed at a height of 7.53 m above the ground surface, using CSAT3 three-dimensional sonic anemometers (Campbell Scientific Inc., Logan, UT, USA) for wind and temperature fluctuations measurements and a LI-7500A open-path infrared gas analyzer (LI-COR, Inc., Lincoln, NE, USA) for water vapor content measurement.

2.2.2 Other measurements

Net radiation (R_n) is measured by a net radiometer (CNR-4; KIPP&ZONEN, Delft, the Netherlands), including four radiometers measuring the incoming and reflected short-wave radiation (R_S), and incoming and outgoing long-wave radiation (R_L). Sunshine d~~D~~uration (D_S) is measured by a sunshine recorder (CSD3; KIPP&ZONEN, Delft, the Netherlands). Wind speed and direction (05103, Young Co. Traverse City, MI, USA) are measured at 10 m above the ground surface. Precipitation (P, mm) is recorded with a tipping bucket rain gauge (TE525MM; Campbell Scientific Inc., Logan, UT, USA) installed at a height of 0.7 m above the ground surface. Air temperature (T_a~~Ta~~) and relative humidity (R_H~~RH~~) are measured by a temperature and relative humidity probe (HMP45C; Campbell Scientific Inc., Logan, UT, USA) at a height of 2.6 m above the ground surface. Soil water content (θ) is measured by Time Domain Reflectometry (TDR) sensors (CS616; Campbell Scientific Inc., Logan, UT, USA), soil temperature (T_S) is measured by thermocouples (109; Campbell Scientific Inc., Logan, UT, USA), and soil heat flux (G) is measured by heat flux plates (HFP01SC; Campbell Scientific Inc., Logan, UT, USA) at a depth of 0.03 m below the ground surface. These ground variables (G, θ, T_S~~T_s~~) are measured beneath the surface at two profiles~~ (1)~~: a plant canopy ~~patch ~~profile and ~~(2) ~~a bare soil ~~patch~~profile. θ and T_S~~T_s~~ are measured at depths of 5, 10, 20, 40, 60, 80, 120 and 160 cm below the ground surface. Groundwater table is measured by an automatic sensor (CS450-L; Campbell Scientific Inc., Logan, UT, USA), which is installed in a groundwater well close to the tower.

2.3 ~~2.3~~ Flux data processing

10 Hz 3-dimensional wind speed and water vapor concentrations that collected by EC technique were processed to half-hourly ~~average~~ latent heat flux (λE_{T}) using Eddypro processing software (v5.2.0, LI-COR, Lincoln, NE USA). The main principle is that λE_{T} ~~the flux~~ can be expressed as ~~[….]~~ $\rho_a \overline{w' q'}$ (where w' is the fluctuation of vertical wind speed, q' is the fluctuation of specific humidity and ρ_a is the air density).~~,~~ The software also~~which~~ applied the ~~the most recent methods for flux corrections, conversions and~~ quality control of data, including~~.~~ ~~d~~spike removal, tilt correction, time lag compensation, turbulent fluctuation blocking and spectral corrections~~ were contained in this software~~. ~~The quality control was performed on the half-hourly output files, and calculated λE_{T} was flagged as 0 (excellent quality), 1 (good quality) and 2 (bad quality, removed and need to be gap-filled), respectively.~~ ~~The basic principle of the technique is that flux is calculated ?????. The software provides almost all the essential correction procedures including (1) detection and elimination of spikes; (2) tilt correction; (3) sensor separation correction; (4) density fluctuation correction (Webb et al., 1980). The calculated half-hourly flux datasets were further filtered for the remaining spikes, instrument malfunctions, and poor quality, according to the following criteria (Papale et al., 2006): (1) incomplete half-hourly measurement, mainly caused by power failure or instrument malfunction; (2) rainy events; and (3) outliers caused by occasional spikes for unknown reasons.~~ The ~~ratios~~percentages of half-hourly λE_{T} values ~~rejected~~removed (including missing and rejected) through the quality control procedure ~~are~~were 17.3% in Period I, 20.2% in Period II, 16.5% in

Period III, and 18.6% in Period IV.~~, and ~~A~~a~~lmost all~~ missing and~~ the ~~rejected~~removed λE_{T} values occurred during the nighttime (89.1% in Period I, 91.3% in Period II, 92.6% in Period III, and 88.7% in Period IV). During the nighttime, the change in λE_{T} was small, andE_{T} values were close to zero.~~, and besides, λ~~ Therefore, after removal of the nighttimeλE_{T} values, the errors of the gap-filled nighttime values based on the neighboring good data were small. Besides, nighttime λE_{T} values accounted for only a small proportion of the daily E_{T}. Furthermore, ~~T~~the ~~ratio~~percentages of rejected and missing data in our study are close to other scholars' results. The reported percentage was summarized in a range of 15%~31% (~~For example, ~~Falge et al.~~ (~~, 2001; Wever et al., 2002; Mauder et al., 2006)~~ have reported that during quality control procedure, there was an average of 31% missing or rejected values of λE_{T} values by 28 flux sites. Wever et al. (2002) reported that there was 15% missing or rejected values of λE_{T} values during the quality control procedure. Mauder et al. (2006) have reported that there was an average of 20% missing or rejected values of λE_{T} values by 20 flux sites. In addition, λE_{T} values during nighttime changed steady and close to zero, coupling with the fact that they accounted a very small proportion throughout whole day.~~ Therefore, the dataset of λE_{T} after quality control procedure was ~~is~~considered reliable~~ to use~~.

After quality control, missing and rejected data were gap-filled in order to create continuous datasets. Three methods were applied in the gap-filling procedure: (1) ~~Daily averaged flux data were calculated by firstly gap-filled half-hourly data. L~~linear interpolation was used to fill gaps of less than 1-h by calculating an average of the values before and after the data gap~~.~~ ; (2) for ~~Larger gaps (~~gaps that ~~more~~larger than 1-h but ~~less~~smaller than 7 ~~-~~days~~) in flux data~~, the ~~were replaced by average values using~~ mean diurnal variation (MDV) method~~s~~ (Falge et al. 2001) was used~~. This method is adopted by FLUXNET for standardized gap-filling~~; (3) ~~. We found that the daily λE_T had the best correlation with daily available energy (R_n − G) rather than other environmental variables such as vapor pressure deficit (VPD) and NDVI. Therefore,~~ for ~~some large~~ gaps that larger~~more~~ than 7 ~~-~~days ~~and~~but ~~less~~smaller than 15 days in daily λE_T, we fitted the relationship between daily λE_T and the daily available energy flux (R_n − G) in each period. We chose the function f with the highest coefficient of correlation (R) in each period (Yan et al., 2013)~~.~~, and the function was expressed as $f = a * (R_n - G)^2 + b * (R_n - G) + c$ (Period I: a = 0.0014, b = 0.075, c = 10.69, R = 0.77; Period II: a = 0.0012, b = 0.056, c = 17.69, R = 0.67; Period III: a = 0.0014, b = 0.16, c = 13.24, R = 0.75; and Period IV: a = 0.0015, b = -0.083, c = 25.87, R = 0.69). Then, we used the fitted function f in each period to estimate the daily λE_T values of large gaps. In addition, ~~We chose the function f with the highest coefficient of correlation (R) in each period (Yan et al., 2013).~~ ~~The function f of each period was showed in Tab.1. Large~~ gaps of more than 7-days but less than 15 days ~~did~~ mostly ~~occur~~appeared in the winter, which accounted for a small proportion of annual λE_T.~~.~~

~~[Table 1 is to be inserted here]~~

~~2.3 Data and methodology~~3 Methodology

~~2.3.1 Flux data processing~~

~~The half-hourly latent heat flux (λET) data were calculated by EddyPro software~~

~~(www.licor.com/eddypro) based on the raw data collected from the EC technique, and it is widely used because it is comprehensive, freely available and use-friendly (Fratini et al., 2014). The calculated half-hourly flux datasets were filtered for spikes, instrument malfunctions, and poor quality, according to the following criteria (Papale et al., 2006): (1) incomplete half-hourly measurement, mainly caused by power failure or instrument malfunction; (2) rainy events; and (3) outliers caused by occasional spikes for unknown reasons. The ratios of data removed through this procedure are 17.3% in Period I, 20.2% in Period II, 16.5% in Period III and 18.6% in Period IV.~~

~~Daily averaged flux data were calculated by firstly gap-filled half-hourly data. Linear interpolation was used to fill gaps less than 1-h by calculating an average of the values immediately before and after the data gap. Larger gaps (gaps more than 1-h but less than 7-days) in flux data were replaced by average values using mean diurnal variation (MDV) methods (Falge et al. 2001). This method is adopted by FLUXNET for standardized gap-filling. We found that the daily~~ ~~λE_T~~ ~~had the best correlation with daily available energy (Rn－G) rather than other environmental variables such as vapor pressure deficit (VPD) and NDVI. Therefore, for some large gaps more than 7-days and less than 15 days in daily~~ ~~λE_T~~~~, we fitted the relationship between daily~~ ~~λE_T~~ ~~and daily available energy flux (~~~~$R_n－G$~~~~) in each period. Then we used the fitted function~~ ~~f~~ ~~to estimate the daily~~ ~~λE_T~~ ~~of gaps. We chose the function~~ ~~f~~ ~~with the highest coefficient of correlation (~~~~R~~~~) in each period (Yan et al., 2013). The function~~ ~~f~~ ~~of each period was~~

~~Large gaps of more than 7-days did occur in the winter.~~

~~$\lambda = 0.0014\ (Rn－G)^2 + 0.0746\ (Rn－G) + 10.69$~~ ~~(Period I,~~ ~~$R = 0.77$~~~~),~~ ~~$\lambda E_T =$~~

~~$0.0012(Rn-G)^2 + 0.0559(Rn-G) + 17.69$ (Period II, R = 0.67) $\lambda E_T = 0.0014(Rn-G)^2 + 0.16(Rn-G) + 13.244$ (Period III, R = 0.75) $\lambda E_T = 0.0015(Rn-G)^2 - 0.0834(Rn-G) + 25.868$ (Period IV, R = 0.69), respectively.~~

~~Large gaps of more than 7-days did occur in the winter.~~

~~Period~~	~~Formula~~	~~R~~
~~I~~	~~$\lambda E_T = 0.0014\,(Rn-G)^2 + 0.0746\,(Rn-G) + 10.69$~~	~~0.77~~
~~II~~	~~$\lambda E_T = 0.0012(Rn-G)^2 + 0.0559(Rn-G) + 17.69$~~	~~0.67~~
~~III~~	~~$\lambda E_T = 0.0014(Rn-G)^2 + 0.16(Rn-G) + 13.244$~~	~~0.75~~
~~IIII~~	~~$\lambda E_T = 0.0015(Rn-G)^2 - 0.0834(Rn-G) + 25.868$~~	~~0.69~~

~~2.3.2 Footprint model~~3.1 Footprint model

In order to determine the contributing source area of flux at our site, scalar flux footprint model proposed by H~~ei~~sieh et al. (2000) was used. The analytic model accurately ~~described~~ describes the relationship between the footprint, observation height, surface roughness, and atmospheric stability. The ~~footprint~~ fetch F_f~~F_f~~ ~~is~~ was calculated ~~by~~as follows:~~,~~

$$F_f/Z_m = D/(0.105 \times k^2)\, Z_m^{-1}|L|^{1-Q} Z_u^Q \qquad (1)$$

where k is the von Karman constant (=0.40), D and Q are ~~the~~ similarity constants (for stable conditions: D = 0.28, Q = 0.59; for near neutral and neutral conditions: D = 0.97, Q = 1; for unstable conditions: D = 2.44, Q = 1.33), L is the Obukhov Length, Z_m is the height of wind instrument (=~~7.53~~10.0 m), Z_u is defined as (~~Heish~~ Hsieh et al., 2000~~),~~):

$$Z_u = Z_m(\ln(Z_m/Z_0) - 1 + Z_m/Z_0) \qquad (2)$$

where Z_0 is the height of momentum roughness (0.05 m).

~~2.3.3 Methods of analyzing controlling factors on E_T~~3.2 Method of analyzing controlling factors on E_T ~~ET~~

It is generally recognized that potential evapotranspiration (E_{TP}), vegetation condition and soil water content are the three main factors ~~controlling~~ that control E_T (Lettenmaier and Famiglietti, 2006; Chen et al., 2014). In order to decouple the effect of vegetation change from the integrated effects of these three factors on E_T, we used a simple equation which ~~is~~ was similar ~~with~~ to the FAO single crop coefficient method (Irrigation and Drainage Paper No. 56 (FAO-56)). ~~and~~ This equation ~~is~~ can be expressed as follows~~,~~:

$$E_T = E_{TP} \times f_v(\text{vegetation}) \times f_s(\text{soil water}) \qquad (3)$$

where $f_v(\text{vegetation})$ represents the effect of vegetation change on E_T~~,~~ and $f_s(\text{soil water})$ represents the effect of soil water content on E_T.

Moreover, ~~By transforming the Eq.3,~~ $f_v(\text{vegetation})$ can be regarded as the normalized E_T, which eliminates the effects of atmospheric and soil water content on E_T and can be expressed ~~as~~by rearranging Eq. 3,

$$f_v(\text{vegetation}) = E_T/[E_{TP} \times f_s(\text{soil water})] \qquad (4)$$

~~where $f_v(\text{vegetation})$ can also be regarded as the normalized E_T which eliminates the effects of atmospheric and soil water content.~~

3.2.1 Potential evapotranspiration

E_{TP} (mm day^{-1}) was estimated by the following equation (Maidment, 1992) which is a modification of the Penman equation,

$$E_{TP} = \frac{\Delta}{\Delta+\gamma}(R_n - G) + \frac{\rho_a c_p / r_a}{\Delta+\gamma}\frac{VPD}{\lambda} \qquad (5)$$

where the units of R_n and G are mm d^{-1}; ρ_a is the air density ($= 3.486\frac{P_a}{275+T_a\cancel{T}}$, kg m^{-3}, where P_a~~P~~ is the atmospheric pressure in kPa and T_a~~T~~ is ~~air temperature~~ in degrees Celsius); c_p is the specific heat of moist air (=1.013 kJ kg^{-1} ℃$^{-1}$); Δ is the slope of the saturation vapor-pressure-temperature curve (kPa ℃$^{-1}$); ~~γ is the psychrometric constant (kPa ℃$^{-1}$);~~ VPD is the difference ~~of~~ between the mean saturation vapor pressure (e_s, kPa) and actual vapor pressure (e_a, kPa); and λ is the latent heat of vaporization of water (=2.51 MJ kg^{-1})~~;~~. γ is the psychrometric constant (kPa ℃$^{-1}$), which is calculated by the following equation,~~;~~

$$\gamma = \frac{c_p P_a}{\varepsilon\lambda} \qquad (6)$$

where ε is the ratio of the molecular weight of water vapor to that ~~for~~of dry air (=0.622).

~~U_2 is the daily wind speed at a height of 2.0 m (m s^{-1}), which was simulated by the wind speed at the height of 10.0 m (m s^{-1}),~~

~~$U_2 = U_{10}\frac{4.87}{\ln(67.8*10-5.42)}$ (6)~~

r_a is the aerodynamic resistance, which ~~was~~ can be calculated as follows (Penman, 1948~~; 1963~~)~~,~~:

$$r_a = \frac{4.72[ln(\frac{Z_h}{Z_{a0}})][ln(\frac{Z_h}{Z_{\cancel{0}ao}})]}{1+0.536U_2} \qquad -$$

(7)

where Z_h is the height at which meteorological variables are measured (2 m), and

$Z_{a\cancel{0}o}$ is the aerodynamic roughness of surface (0.00137 m) (Penman, ~~1948;~~ 1963); U_2 is the daily wind speed at a height of 2.0 m (m s^{-1}), ~~which~~and it was ~~simulated~~calculated by the wind speed at the height of 10.0 m (U_{10}, m s^{-1}),

$$U_2 = U_{10}\frac{4.87}{\ln(67.8*10-5.42)} \qquad (8)$$

~~The effects of soil water content on E_T can be described in three stages (Idso et al., 1974), stage 1: the soil water is enough to satisfy the potential evaporation rate (f_s=1); stage 2: the soil is drying and water availability limits E_T (0<f_s<1); and stage 3: the soil is dry and evaporation can be considered negligible (f_s=0). We used daily soil water content of the root depth (θ_r) to estimate f_s by the following expression (Hu et al., 2006),~~

~~$f_s = \begin{cases} = 1 & \theta_r > \theta_k \\ = 0 & \theta_r < \theta_w \\ = \frac{\theta_r - \theta_w}{\theta_k - \theta_w} & \theta_w \le \theta_r \le \theta_k \end{cases} \qquad ()$~~

~~where θ_w is the wilting value, θ_k is the stable field capacity which is considered to be equivalent to 60% of the field capacity (Lei et al., 1988; Wang et al., 2008). θ_r (m^3 m^{-3}) is the mean soil water content from surface to the depth of 160 cm (root zone) and was calculated by measured soil water contents at different depths,~~

~~$\theta_r = \frac{0.5\left[10\,\theta_5 + 15\,\theta_{10} + 30\,\theta_{20} + 40(\theta_{40} + \theta_{60}) + 60\,\theta_{80} + 80\,\theta_{120} + 40\,\theta_{160}\right]}{160}$~~

~~()~~

~~Site-averaged soil water content of each depth (θ_i; i =5, 10, 20, 40, 60, 80, 120, and 160 cm) was calculated by taking a weighted average of the measured values in the canopy and bare surface patches,~~

~~$\theta_i = \mathrm{M} \times \theta_{i,c} + (1 - \mathrm{M}) \times \theta_{i,b} \qquad ()$~~

~~where $\theta_{i,c}$ and $\theta_{i,b}$ refer to the measured soil water content of canopy patch and bare soil patch at the depth of i cm, respectively; M is the monthly vegetation coverage of undisturbed zone, and it was calculated by monthly Normalized Difference Vegetation Index (NDVI) values (Gutman and Ignatov, 1998),~~

~~$\mathrm{M} = (\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}})/(\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}}) \qquad ()$~~

~~where $\mathrm{NDVI}_{\mathrm{max}}$ is the maximum value (0.8 in this study); $\mathrm{NDVI}_{\mathrm{min}}$ is the minimum value (0.05 in this study) (Gutman and Ignatov, 1998). The calculated monthly M (27.6% and 24.2%) was consistent with the measured vegetation coverage in August 2011 (28.2%) and September 2011 (27.9%) at our study site.~~

3.2.2 Vegetation parameters

In this study, vegetation phenology ~~is~~ was represented by Moderate Resolution Imaging Spectroradiometer (MODIS)-NDVI data when the land use/cover conditions

~~is~~ were fixed. NDVI is sufficiently stable to reflect the seasonal changes of any vegetation (Huete et.al, 2002). Higher NDVI ~~usually~~ generally ~~represent~~ reflect the greater photosynthetic capacity (greenness) of vegetation canopy (Gu et al., 2007; Tucker, 1979). The daily NDVI was calculated by daily surface reflectance ~~(at 250 m)~~ data ~~from MODIS/Terra (MOD09GQ, http://reverb.echo.nasa.gov) and MODIS/Aqua (MYD09GQ, http://reverb.echo.nasa.gov) Surface Reflectance (at 250m) data within the footprint and the equation was~~,~~source area were chosen to calculate NDVI.~~ ,

$$\mathrm{NDVI} = \frac{\mathrm{NIR}-\mathrm{VIS}}{\mathrm{NIR}+\mathrm{VIS}} \qquad (9)$$

~~The Surface Reflectance data of MODIS/Terra (MOD09GQ) and MODIS/Aqua (MYD09GQ) were downloaded from reverb (http://reverb.echo.nasa.gov). MODIS Reprojection Tool (MRT) (Kalvelage and Willems, 2005) was used to reject the daily Surface Reflectance data to the Universal Transverse Mercator (UTM). The calculation of NDVI is based on its definition,~~

~~$\mathrm{NDVI}_{\text{Terra or Aqua}} = \frac{\mathrm{NIR}-\mathrm{VIS}}{\mathrm{NIR}+\mathrm{VIS}}$~~

~~(12)~~

where ~~$\mathrm{NDVI}_{\mathrm{Terra}}$ and $\mathrm{NDVI}_{\mathrm{Aqua}}$ are the NDVI values calculated from MODIS/Terra and MODIS/Aqua reflectance data, respectively;~~ NIR is the spectral response in the near-infrared band (857 nm~~);~~) and VIS is the visible red radiation band (645 nm). ~~MODIS Reprojection Tool (MRT) (Kalvelage and Willems, 2005) was used to rejectconvert the daily Surface Reflectance data to the Universal Transverse Mercator (UTM).~~ In this study, NDVI was calculated by using MODIS/Terra data (MOD09GQ) ($NDVI_{Terra}$) and MODIS/Aqua data (MYD09GQ) ($NDVI_{Aqua}$)

(http://reverb.echo.nasa.gov), respectively. As we found that there were slight differences ($\left|NDVI_{Terra} - NDVI_{Aqua}\right| = 0.01 \pm 0.0075$) between $NDVI_{Terra}$ and $NDVI_{Aqua}$, we calculated NDVI by averaging $NDVI_{Terra}$ and $NDVI_{Aqua}$ in order to eliminate the impacts of such differences. ~~In order to eliminate the poor quality data values~~T~~, t~~he calculated NDVI ~~data series stack~~values ~~needs to be~~ were then ~~firstly~~ filtered to remove anomalous ~~hikes~~ hikes and drops (Lunetta et al., 2006)~~. Hikes and drops were eliminated by removing the values that suddenly decreased or increased~~, and the ~~then~~ smoothing spline method was used to produce a smoother profile. ~~In this study, daily NDVI value was averaged from~~ ~~$NDVI_{Terra}$ and $NDVI_{Aqua}$.~~

Theoretically, land use/cover changes can be evaluated by comparing the land use/cover maps in two different periods. However, ~~the~~ transient land use/cover maps ~~are~~ were unavailable at our site. Therefore, we separated the study area within the ~~the~~ footprint ~~area~~ into two zones: ~~we assigned~~ the undisturbed zone without any land use/cover changes was deemed –as zone A~~,~~ and ~~assigned~~ the disturbed zone with land use/cover changes was deemed as zone B. In zone A, vegetation ~~condition~~ changes included only vegetation phenological changes; however, in zone B, there were not only vegetation phenological changes but also land use/cover changes. ~~By assuming~~Based on the assumption that the phenological changes caused by climate in the two zones ~~are~~ were the same, we defined an indicator (D_{lu}) ~~to be the~~as a measure of land use/cover changes:

$$D_{lu} = M_{\mathrm{A}} - M_{\mathrm{B}} \qquad (10)$$

where~~,~~ M_{A} and M_{B} are the monthly vegetation coverages of zone A and zone B, respectively. The monthly vegetation coverage was calculated by monthly NDVI values (Gutman and Ignatov, 1998):

$$M = (\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}})/(\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}}) \qquad (11)$$

where $\mathrm{NDVI}_{\mathrm{max}}$ is the maximum value (0.8 in this study) and $\mathrm{NDVI}_{\mathrm{min}}$ is the minimum value (0.05 in this study) (Gutman and Ignatov, 1998). The calculated monthly M values (27.6% and 24.2%) were consistent with the measured vegetation coverages in August 2011 (28.2%) and September 2011 (27.9%) at our study site. ~~The calculation of vegetation coverage will be described in section 3.2.3.~~

3.2.3 Soil water stress

The effects of the soil water content on E_{T} can be described in three stages (Idso et al., 1974), stage 1: the soil water is enough to satisfy the potential evaporation rate (f_s=1); stage 2: the soil is drying and water availability limits E_{T} ($0<f_s<1$); and stage 3: the soil is dry and evaporation can be considered negligible (f_s=0). We used daily soil water content in~~of~~ the root depth (θ_{r}) to estimate f_s by the following expression (Hu et al., 2006)~~,~~:

$$f_s = \begin{cases} = 1 & \theta_{\mathrm{r}} > \theta_k \\ = 0 & \theta_{\mathrm{r}} < \theta_w \\ = \frac{\theta_{\mathrm{r}} - \theta_{\mathrm{w}}}{\theta_{\mathrm{k}} - \theta_{\mathrm{w}}} & \theta_w \le \theta_{\mathrm{r}} \le \theta_k \end{cases}$$

(1~~1~~2)

where θ_{w} is the wilting value~~,~~ and θ_{k} is the stable field capacity which is considered to be equivalent to 60% of the field capacity (Lei et al., 1988; Wang et al., 2008). θ_{r} ~~(m^3 m^{-3}) is the mean soil water content from surface to the depth of 160 cm (root zone) and~~ was calculated by measured soil water contents at different depths (θ_{i}; i =5, 10, 20, 40, 60, 80, 120~~,~~ and 160 cm). From land surface to the depth of 5 cm, the soil water profile was ~~regarded~~assumed ~~as a triangle~~triangular, while ~~in~~at other depths, the soil water profiles were ~~treated~~assumed ~~as trapezoids~~trapezoidal. Therefore, the ~~root-zone~~ soil moisture of root zone was calculated ~~equation was~~ as~~,~~:

$$\theta_{\mathrm{r}} = \frac{0.5\begin{bmatrix} 5\theta_5+(\theta_5+\theta_{10})*(10-5)+(\theta_{10}+\theta_{20})*(20-10) \\ +(\theta_{20}+\theta_{40})*(40-20)+(\theta_{40}+\theta_{60})*(60-40) \\ +(\theta_{60}+\theta_{80})*(80-60)+(\theta_{80}+\theta_{120})*(120-80) \\ +(\theta_{120}+\theta_{160})*(160-120) \end{bmatrix}}{160} \qquad (1\cancel{2}3)$$

where~~, the sSite-averaged soil water content of each depth (~~θ_{i}~~;~~ (i =5, 10, 20, 40, 60, 80, 120 ~~,~~and 160 cm) was calculated by taking a weighted average of the measured values in the canopy and bare surface patches,

$$\theta_{\mathrm{i}} = \mathrm{M} \times \theta_{\mathrm{i,c}} + (1 - \mathrm{M}) \times \theta_{\mathrm{i,b}}$$

(1~~3~~4)

where $\theta_{\mathrm{i,c}}$ and $\theta_{\mathrm{i,b}}$ refer to the measured soil water contents of canopy patch and bare soil patch at the depth of i cm, respectively~~; *M* M is the monthly vegetation coverage of undisturbed zone, and it was calculated by monthly Normalized Difference Vegetation Index (NDVI) values (Gutman and Ignatov, 1998),~~

~~$\mathrm{M} = (\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}})/(\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}})$ (14)~~

~~where $\mathrm{NDVI}_{\mathrm{max}}$ is the maximum value (0.8 in this study); $\mathrm{NDVI}_{\mathrm{min}}$ is the minimum value (0.05 in this study) (Gutman and Ignatov, 1998). The calculated monthly *M* (27.6% and 24.2%) was consistent with the measured vegetation coverage in August 2011 (28.2%) and September 2011 (27.9%) at our study site.~~

3.3 Statistical analysis

In this study, we chose ~~Because of the fact that in Period I, the land use/cover condition within footprint was undisturbed in Period I,~~ ~~In order to validate EC measurements and examine the quality of flux data, we used d~~d~~aily data in period I~~ ~~was used~~ ~~to conduct the linear regression between available energy (R_nRn − G) and the sum of surface fluxes ($\lambda E_T + H$), whichthus is used to validateing EC measurements and examinexamineing the quality of flux data. In addition,~~. ~~d~~daily data in Period I ~~was also used~~ to analyze the correlations between E_T and the three controlling factors (E_{TP}, NDVI~~, NDVI$_W$ (NDVI$_W$ = NDVI$_A \times \beta$ + NDVI$_B \times (1 - \beta)$),~~and f_s). We used several common functions (e.g., an exponential function, a linear function, a logarithmic function and a quadratic function) to fit these correlations. We found that the determination coefficient (R^2) of the linear function was generally the highest. Therefore, in this study, we chose the linear function to ~~simulate~~fit the correlations between E_T and the three controlling factors. Additionally, ~~S~~significant ~~T~~t-test was performed~~calculated~~ to evaluate the degrees of these correlations~~ between E_T and its three controlling factors~~. Moreover, ~~Furthermore, d~~~~D~~data ~~in~~on rainy days was removed~~,~~ because~~ in rainy days,~~ E_T values w~~as~~ere gap-filled ~~instead of actual~~rather than measured ~~in rainy days~~. ~~In order to figure out the major seasonal factor that control E_T at our study site, significant T-test was calculated to evaluate the degree of correlation. The linear correlations between E_T and the three factors both passed the 95% t-test confidence level.~~

~~3~~ 4 Results

~~3~~4.1 Footprint and energy balance closure

Based on the footprint model, we got the half-hourly scatter data~~ of footprint fetch~~ (Eq. ~~(~~2~~)~~), and according to the wind rose diagram (Fig. ~~–~~3a), the prevailing wind directions ~~in~~ at this site were northwest and southeast~~,~~. Therefore, ~~so~~ we chose an ellipse to enclose the scatters and simulate~~d~~ the footprint (Fig. ~~–~~3b). ~~The long axis of the simulated ellipse is 1682 m, and the short axis is 1263 m.~~ There ~~were~~ was 93% half-hourly flux data within the ellipse under unstable conditions.

Additionally, ~~We~~ we measured the boundary of zone B in October 2013 when the land use/cover condition in zone B had stopped ~~to~~ chang~~e~~ing (Fig. 3b). There were 11 pixels (250 m × 250 m) in zone A~~, while there are~~ and 19 pixels (250 m × 250 m) in zone B, and thus, in the following part of calculating the weight-averaged NDVI ($\mathrm{NDVI_w}$) within the footprint fetch, we chose the weighted coefficient as $\beta = 11/(11+19)$.

[Figure 3 is to be inserted here]

EC system performance was assessed by the energy balance closure which was calculated by conducting the linear regression between available energy ($R_n - G$) and the sum of surface fluxes ($\lambda E_T + H$), which is also used to examine the quality of flux data (Wilson et al., 2002). ~~In order to validate EC measurements and examine the quality of flux data, we used daily data in period I to conduct the linear regression between available energy ($R_n - G$) and the sum of surface fluxes ($\lambda E_T + H$).~~ The linear regression yielded a slope of 0.87, an intercept of -1.42 W m^{-2}, and an R^2 of 0.82. These indicators ~~indicated~~ suggested that the measurements at our experimental site provided reliable flux data~~,~~ and that the EC measurements underestimated the sum of the surface fluxes to the extent of 13%. ~~A lot of~~Many researchers have investigated ~~the~~ energy imbalance (Barr et al., 2006; Wilson et al., 2002; Franssen et al., 2010), and there is a consensus that it is difficult to examine the exact reasons ~~leading to the~~for the imbalance.

~~3~~4.2 Characteristics of environmental variables

A brief summary of ~~the~~ key environmental variables ~~will be~~isis presented in this section. Four-year ~~averaged monthly sunshine duration (D_s), T_a, R_H, P~~ and long-term (1954-2014) average~~d~~ monthly values of D_s, T_a, R_H, and P ~~were~~are showed in Fig. 4. Monthly D_s~~D_s~~ was much higher than the long-term ~~normal~~ average monthly values, ~~of 1954-2014~~ except in July and September. The highest value of ~~monthly~~ D_s~~D_s~~ was observed in May (299.5 h) and the lowest was observed in February (206.6 h). The ~~Seasonal~~ seasonal characteristics of T_a~~Ta~~ showed a highly similar trend with that of ~~the~~ long-term average monthly values~~ of 1954-2014normal~~, and the differences were less than 1 ℃, ~~℃~~ except in July, January and March. The highest value of ~~monthly~~ T_a~~Ta~~ was observed in July (22.1 ℃~~℃~~) and the lowest was observed in December (-8.1℃~~℃~~). The values of R_H~~RH~~ ~~showed~~ were almost lower than the long-term average monthly values~~ of 1954-2014normal~~, especially in March and April. The highest R_H~~R_H~~ was observed in September (65.4%) and the lowest was observed in March (35.1%). The seasonal distributions of P were consistent with the long-term average monthly values~~ of 1954-2014normal~~, and 89.7% of P ~~happened~~ occurred in the growing season. ~~The value of~~ P was highest in July ~~was the highest~~ (120.5 mm) and~~ in January was the~~

lowest in January (0.3 mm).

[Figure 4 is to be inserted here]

The inter-annual characteristics of daily T_a, D_s, R_H, ~~Ta, RH, Ds,~~ θ_r, groundwater level (GWL), and total P in the growing season of each period ~~were~~ are listed in Tab. 1.

[Table 1 is to be inserted here]

The values of T_a ~~Ta~~, R_H ~~RH~~, P, and θ_r in the growing season of Period IV were the lowest compared ~~with~~ to those in other three periods. Periods I-~~∼~~III ~~are~~ were all wet years, while Period IV was ~~the~~ a dry year. The values of θ_r in Periods I-~~∼~~III were ~~basically the same~~similar, however, θ_r decreased by 0.0113 m^3 m^{-3} in Period IV. The mean GWL in Period III was the shallowest.

~~3~~4.3 Seasonal variations in E_T due to climate variability

The ~~Seasonal~~ seasonal curve of E_T in each year had a single peak value (Fig. 5a), with ~~the~~ higher E_T appearing mostly in the growing season while ~~the~~ lower appeared in the non-growing season. The daily E_T ~~was in a~~ ranged from 0.0 mm day^{-1} to 6.8 mm day^{-1} during the four periods, the highest E_T ~~appeared~~ was observed on 22th June 2013 ~~after when. The highest E_T appeared at~~ , which was the day after a continuous~~al~~ rainfall event that started from 19th June 2013 to 21th June 2013 (90.3 mm)~~, E_T rates normally increase rapidly after rainfall events~~. The lowest E_T appeared~~was~~ on 28~~th~~ November 2012, which was in the frozen period (late November to early March ~~in~~ at our study site). ~~In~~ On rainy days, E_{TP} (Fig. 5b) was ~~much~~ low~~er~~ due to low~~er~~ net radiation and air temperature. E_{TP} ~~was in the~~ ranged ~~of~~ from 0.2 mm day^{-1} ~~that appeared~~ in December

2011 to 17.9 mm day^{-1} ~~that appeared~~ in September 2013.

[Figure 5 is to be inserted here]

The ~~Seasonal~~ seasonal NDVI curve ~~with~~ for natural land use/cover condition (in zone A during Periods I~~∼~~-IV and in zone B during Period I) represented the process of natural vegetation phenology and it had ~~one~~ a single peak value in each year (Fig. ~~–~~5c). In early May, the seasonal NDVI curve began to increase ~~accompanied by that~~as~~and~~ the native vegetation ~~began to~~ entered the growing season, and ~~reached to the~~a maximum value (0.27±0.01) was reached in July or August. In the winter, the daily NDVI ~~basically stayed at a~~ remained relatively constant ~~value~~ (0.13±0.01). f_s (Fig. ~~–~~5d) increased rapidly in response to rainfall events of more than 5 mm a day~~,~~ and ~~also~~ decreased rapidly one or two days ~~later~~ after rainfall events. ~~During~~ From late November to early March, there was a frozen period at~~in~~ this site, and soil water content was below the wilting point. The groundwater level ~~fluctuated~~ changed obviously in the monsoon season (July to September) and mildly in the winter (December to February).

~~The relationships between E_T and the three factors (E_{TP}, NDVI$_W$ (NDVI$_W$ = NDVI$_A$ × β + NDVI$_B$ × $(1-\beta)$), fs) were analyzed and were shown in Fig. 6 (a, b, c) by daily data in Period I. Because in Period I, the land use/cover condition within footprint was undisturbed. Data in rainy days was removed, because in rainy days, E_T was gap-filled instead of actual measured.~~

[Figure 6 is to be inserted here]

~~In order to figure out the major seasonal factor that control ET at our study site,~~

~~significant T-test was calculated to evaluate the degree of correlation. The linear correlations between ET and the three factors both passed the 95% t-test confidence level.~~ The linear correlations between E_T and the three controlling factors~~ both~~ all passed the ~~95%~~ t-test at a 95% confidence level. The– ~~The determination coefficient (~~R^2~~=0.52)~~ value of the correlation between E_T and $\mathrm{NDVI_w}$ (~~$\mathrm{NDVI_w}$ (~~$\mathrm{NDVI_w} = \mathrm{NDVI_A} \times \beta + \mathrm{NDVI_B} \times (1 - \beta)$) was the largest, indicating that NDVI was ~~a dominant factor that controlling~~highly correlated with the daily variations ~~of~~ in E_T. To better quantify the effects of the phenological process on E_T, the correlation between daily ~~normalized E_T (~~f_v~~)~~ and $\mathrm{NDVI_w}$ in Period I ~~were~~ was analyzed (Fig. 7a).

[Figure 7 is to be inserted here]

A ~~Positive~~ positive linear regression was found between f_v ~~$(f_v = E_T/(E_{TP} \times f_s))$~~ and $\mathrm{NDVI_w}$ (Fig. 7a). The slope of the linear regression was used to evaluate the controlling degree between f_v~~normalized E_T~~ and vegetation phenological process, which~~. The positive regression stated the direct positive relationship between $\mathrm{NDVI_w}$ and normalized E_T,~~ indicated~~ing~~ that when $\mathrm{NDVI_w}$ ~~increases~~ increased one unit, it ~~will~~ would contribute f_v~~normalized E_T~~ to increase about 1.86 units.

~~3~~4.4 Inter-annual variations in E_T due to land use/cover changes

During the four periods, in zone A, the NDVI values of each period were ~~basically the same~~similar because the land use/cover condition was not changed. While in zone B, the peak values of NDVI first~~ly~~ declined from 0.28 to 0.15 (Period I to Period III) due to the ~~change of the~~ land use/cover~~ condition changed~~ condition changed from mixed vegetation to bare soil~~,~~. ~~and then it~~The peak NDVI value then increased to 0.22 (Period IV) due to ~~the~~ grass recovery (Fig~~ure 5(c)~~. 5c). An interesting phenomenon was found accompanied by the changing process of land use/cover conditions: E_T in the growing season ~~of each period was~~ gradually~~ observed to be~~ increased~~ing~~ from Period I to III (Tab.2), while it ~~. E_T in Period IV~~ increased ~~strongly~~ greatly in Period IV even with less precipitation, because a mass of soil water and ground water was consumed to satisfy the E_T demand (Fig. 5e).

[Table 2 is inserted to be here]

Compared~~ to~~ with Period I~~ with natural land use/cover condition~~, D_{lu}~~D_{lu}~~ values of Period II and Period III gradually increased, ~~and~~ while D_{lu}~~D_{lu}~~ of Period IV decreased. Taking August in each period as an example, in ~~August of~~ Period I, D_{lu} was 0.2%, while in ~~August of~~ Periods II~~, Period III and Period~~ -IV, D_{lu} were 2.9%, 12.6%, and 8.6%, respectively. In order to eliminate the influence of vegetation phenological change on E_T, we chose the growing season of each period to analyze the correlation~~s~~ between f_v~~normalized E_T~~ and D_{lu}.

Quantitative results of the correlation~~relationship~~ between D_{lu}~~D_{lu}~~ and ~~normalized E_T (~~f_v~~)~~ ~~are~~ are shown in Fig. 7b. ~~According to the dynamic path showed in Fig.7b,~~ ~~w~~From Period I to Period III, ~~When~~ with the changed land surface characteristics (the natural vegetation in ~~Zone~~ zone B was ~~cut-off~~cleared~~ (Period I~III),~~; the fixed and semi-fixed sand dunes were bulldozed~~,~~; the BSCs and dry sand layers~~ were~~ were disappeared) ~~(Period I~III)~~, ~~normalized E_T (i.e.,~~ f_v~~)~~ increased and the increment was more evident in Period III (from 78.5 to 88.1). When the land use/cover condition ~~of~~ in zone B gradually changed from bare soil to sparse grassland due to the self-restoring capacity of nature, ~~normalization E_T (~~f_v ~~)~~ increased ~~more~~ significantly (from 88.1 to 111.3).

~~4~~ 5 Discussion

~~4~~5.1 Implications of the ~~impacts~~ effects of phenological change on E_T

The correlations between E_T and its controlling factors inferred that at our experimental site, NDVI was the predominant factor that influences the seasonal variations ~~on~~ in E_T. The ~~strong~~ positive linear relationship between f_v~~normalized E_T~~ and NDVI ~~suggests~~ suggested that transpiration ~~is~~ was probably ~~mainly~~ controlled by the stomatal conductance and the numbers of stomata, which ~~is~~ are proportional to leaf area (Pearcy et al., 1989; Turrell, 1947), rather than the atmospheric water demand represented by E_{TP}.

Various studies have ~~tested~~ assessed the ~~relationships~~ correlation between vegetation phenological changes and E_T, and these results generally showed consistent and positive linear relationships (Nouri et al., 2014; Rossato et al., 2005; Duchemin et al., 2006; Glenn et al., 2008). However, ~~with~~ for different vegetation species, phenological changes have effects on E_T ~~in~~ to different degrees. Relative strong regressions between NDVI and E_T have been reported at forested sites (Loukas et al.~~(~~, 2005; Nouri et al., 2014; Chong et al., 2007) and grass-covered sites (Kondoh and Higuchi, 2001; Nouri et al., 2014), with ~~have analyzed the relationships between NDVI and E_T in Greece, and relative strong regressions were found in forested sites (R^2=0.78). Kondoh and Higuchi (2001) investigated the correlation between NDVI and E_T in a grass-covered site at the university of Tsukuba, and a very high~~ determination coefficients ~~(R^2=0.92)~~ higher than 0.7, ~~was showed to~~ revealing the strong control of phenological changes on E_T. ~~Nouri et al. (2014) have analyzed the relationships between NDVI and E_T in forests and grasses, and they found that determination coefficient of forests (R^2=0.94) was higher than the grassland (R^2=0.88). Chong et al. (2007) have found a strong relationship between NDVI and E_T in forests and moist savanna of Africa.~~ Thus, we speculate that, for high ~~dense~~ vegetated ecosystems, phenological changes ~~might~~ may have a strong and significant control on E_T. However, in low ~~vegetation~~ vegetated ~~cover condition~~ecosystems such as sparse shrubland in this study, the relationship between E_T and seasonal vegetation phenological change~~change~~ ~~is~~ is thus positive but relatively weak.

~~4~~5.2 Possible reasons for the effects of land use/cover changes

During Periods I~~～~~-IV, the land use/cover conditions ~~of~~ at our experimental site ~~has~~ under~~gone~~went two processes~~,~~: ~~one was the~~ land degradation process (Periods II~~～~~-III)~~,~~ ~~while the other was the~~ and vegetation rehabilitation process (Period IV). Interesting ~~phenomenon~~ phenomena ~~was~~ were found ~~that~~ during these two processes: (1) E_T and normalized E_T values ~~were~~ both increased~~, –~~ and (2) ~~and~~ normalized E_T increased much faster ~~from Period III to IV~~during the vegetation rehabilitation process than that ~~from Period I to III~~during the land degradation process.

The impact of phenological changes on E_T demonstrated that E_T ~~will~~would decrease along with the leaf browning. Thus, we expected that E_T ~~will~~ would also decrease if ~~only~~ leaves were cleared by human activities. However, during Periods II~~～~~-III, not only leaves were cleared, but also other land surface properties (all branches were cut~~-off~~, sand dunes (fixed and semi-fixed) were bulldozed, and the dry sand layers and ~~-the biological soil crusts (~~BSCs~~)~~ were destroyed) were changed, ~~making~~ resulting in ~~the~~ complex land use/cover condition~~-complex~~s. All these changed land surface properties might contribute to the increase of E_{T}. The exists of dry sand layers and BSCs were demonstrated to effectively restrained the soil evaporation rates (Wang et al., 2006; Lv et al., 2006; Liu et al., 2006; Chen and Dong, 2001; Yang et al., 2015; Fu et al., 2010; Liu, 2012). However, the bulldozing of sand dunes at our experimental site made the elevation of the flat soil surface be lower than the average elevation of the undisturbed soil surface (~~about~~approximately~~-~~ 1.5 m lower, Fig~~ure 2(d).~~ 2d), ~~which resulted that~~making the groundwater depth was much shallower than ~~before~~the pre-disturbance depth. Thus, it ~~is~~ was hard for the formation of dry sand layers with shallower groundwater ~~depth~~level. In this situation with the destroyed BSCs and the disappeared dry sand layers, the sufficient groundwater supply (Li and Li, 2000) accelerated the loss of water that stored in shallow soil through evaporation. The enhancement effect of soil evaporation ~~offset~~offset the ~~inhibition~~ inhibiting effect of transpiration ~~by~~ due to leaves clearing, which made E_{T} increase.

A secondary reason for the ~~enhancement~~ increase of soil evaporation was that ~~more solar radiation was absorbed by soil layer~~the soil layer absorbed more solar radiation during the land degradation process. In Period I, ~~with natural vegetation,~~ the radiation absorbed by the shadowed soil was the solar radiation transmitted into the canopy of shrubs and grass. However, ~~with~~ when the natural vegetation ~~being~~ was ~~cut-off~~cleared, the leaves and the branches were also removed, which made the shadowed soil exposed and enhanced the radiation absorbed by the soil, ~~thus contribute to the~~thereby ~~increase~~ increasing ~~of~~ soil evaporation (Martens et al., 2000; Panferov et al., 2001). ~~Besides~~Moreover, the removal of leaves and branches and the disappearance of sand dunes both altered the land surface albedos, which ~~. Various scholars have demonstrated that changes of land surface albedos~~ could directly alter the solar radiation absorbed by the land surface (Dirmeyer and Shukla, 1994; Greene et al., 1999), subsequently leading to the change in E_T.

~~We found s~~S~~S~~ome inconsistent results regarding the ~~response of~~ E_T dynamics ~~to~~during ~~and the possible reason contributed to the change of E_T were found from the previous analyses that aim at studying the characteristics of E_T with during~~ land degradation process were reported~~in previous studies~~~~were reported~~. ~~Although a~~A portion of~~For instance,~~ studies reported that~~–~~ E_T decreased during the land degradation process with~~but due to~~ different reasons~~the causes of this decrease were demonstrated different~~. For example, ~~Li et al. (2013) have analyzed the features of E_T during land degradation process in Qinghai-Tibet Plateau, and they found that warming air temperature was the main cause to enhance E_T.~~ Souza and Oyama (2011) and ~~However, some other scholars have opposite conclusions. For example,~~ Snyman (2001) ~~have compared E_T of natural grassland and degraded grassland resulted from overgrazing in a semi-arid are of South Africa, and he found~~demonstrated that E_T ~~was smaller of the degraded grassland~~decreased during the land degradation process due to ~~less~~ decreased transpiration in semiarid regions. ~~. Souza and Oyama (2011) have demonstrated that~~

~~desertification in a semi-arid area of Northeast Brazil contributed to the decrease of E_T due to the loss of transpiration from natural vegetation.~~ Lu et al. (2011) considered that ~~have found that E_T was lower in disturbed grazed grassland compared to the undisturbed grassland, and~~ the low~~er~~ soil water content was th~~thought to b~~e main reason ~~to the explanation to result in~~for the decrease of E_T in the land degradation process. Mao and Cherkauer (2009) also ~~have demonstrated~~reported a decrease of ~~that~~ E_T ~~decreased~~ when land use/cover condition was ~~changed~~ converted from forest~~s~~ to grass or cropland in the Great Lakes region. ~~However~~However, ~~some contrary~~~~different~~contrasting ~~phenomenon~~~~response~~results ~~were~~w~~as~~ere also reported regarding the effects of land degradation on E_T ~~by other scholars~~.~~Furthermore,~~ Hoshino et al. (2009) ~~have demonstrated~~ found that there was no difference in E_T during the land degradation ~~by~~ process associated with overgrazing in a semi~~-~~arid Mongolian grassland, and they ~~thought~~ hypothesized that the reason for this lack of change might be the short ~~time of~~ grazing time (2 years). ~~Furthermore,~~ Li et al. (2013) demonstrated that the warming air temperature was the main cause of the enhanced E_T during the land degradation process in Qinghai-Tibet Plateau. Throughout the above researches of E_T ~~under~~ during land degradation process, we found it ~~was hard~~difficult to accurately describe the features of E_T~~,~~ even when the land degradation was only manifest~~performed~~ by less vegetation coverage. Therefore, ~~in~~ at our study site with complex land surface properties (sand dunes, dry sand layers and BSCs), the ~~impact~~ effect of land degradation on E_T was much more complicated.

During the vegetation rehabilitation process (Period IV), f_V ~~normalized E_T~~

increased significantly due to the rehabilitation of grass in zone B, even though ~~with~~ less precipitation was observed compared with other ~~three~~ periods (Period I, II and III). The rehabilitation of grass, rather than shrubs, was due to the sufficient groundwater supply resulted from bulldozing the sand dunes. Previous researchers reported that sparse shrubs more commonly grew at the top of sand dunes and grass grew at the bottom of sand dunes~~,~~ because the difference~~s~~ between groundwater ~~depth~~ level and the top of sand dunes ~~was~~ was larger than that ~~the that~~ between groundwater ~~depth~~ level and the bottom of the sand dunes (Lv et al., 2006; Chen and Dong, 2001). Because transpiration increases with ~~the greening of~~ vegetation greening ~~—~~(~~this was~~as demonstrated in section ~~3~~4.3), the regrowing grass ~~will~~ would enhance plant transpiration supplied by the sufficient groundwater. More importantly, the transpiration rate of grass is higher than that of shrubs because shrubs are ~~more tolerant to drought~~easier to survive in water-limited conditions (Yang et al., 2014; Wang et al., 2002; Wu, 2006). Therefore, in the vegetation rehabilitation process, the ~~increasing rate~~enhancement of transpiration rate in Period IV was much higher than that in Periods I~~∼~~-III. Consistent conclusions of E_T increase due to the enhancement of transpiration during vegetation rehabilitation process were reported~~. For example, Qiu et al. (2011) Yang et al. (2014) and Sun et al (2006) have demonstrated that in the vegetation rehabilitation process,~~ ~~E_T increased and more water was consumed and less rainfall would infiltrate deeper soil layer~~ (Qiu et al., 2011; Yang et al., 2014; Sun et al., 2006; Li et al., 2009). ~~Yang et al. (2014) and Sun et al (2006) also considered suggest E_T would increase with vegetation rehabilitation due to the increase of transpiration.~~

~~Furthermore, Li et al. (2009) have reported that E_T increased when land use/cover condition converted from shrubland to grassland.~~ Meanwhile, the regrowing grass ~~can~~ could reduce the radiation absorbed by the soil and hence reduce ~~the~~ soil evaporation. However, the interception of radiation by the grass canopy was expected to be smaller than that by the mixed shrub and grass canopy in Periods I~~∼~~-III because the leaf area index of grass ~~is~~was smaller than the sum of leaf area and stem area indexes of the mix of shrubs and grass. Therefore, the reduction of soil evaporation in Period IV ~~may~~ might be small compared with the increment of soil evaporation in Periods I~~∼~~-III.

We noticed that the ~~groundwater level~~ GWL decreased continuously ~~from~~ after Period III due to the enhancement of E_T by the re~~-~~growth of grass and relative lower precipitation, and the regrowing grass has a higher transpiration rate ~~compared with~~than that of the native mixed shrub and grass ~~ecosystem~~. Therefore, we hypothesize~~d~~ that if the land use/cover condition of zone B ~~continues~~ continues to be grassland ~~in~~ over the next several years, the groundwater ~~level~~ level will decrease due to the larger consumption, making the soil water condition gradually become poorer for the ~~growing~~ growth of grass. Then, in this situation, the grassland is expected to degrade to shrubland in zone B because shrubs are ~~more tolerant~~ easier to survive in water-~~starved~~ limited ecosystems. Furthermore, i~~On the other hand, potato~~ n the next few years, potato will be planted in zone B. However, the water requirement of potato ~~is studied to consume~~ ~~was~~is more than 320 mm in the growing season (Qin et al., 2013; Liu et al., 2010) and the water consumption is more than that of natural grass (Qin et al., 2013, 2014; Hou et al., 2010). ~~Besides~~Thus, irrigation is necessary for planting potato ~~needs~~

~~to irrigate several times~~ during the growing season in water~~-limited environment~~limited ecosystems (Fulton et al., 1970; Liu et al., 2010; Fabeiro et al., 2001). ~~As potato consumes much more water than grass, o~~Our results ~~implied~~ imply that the groundwater ~~level~~ level ~~may~~ might continue to decrease faster with the growth of potato in the future, which may lead to a more fragile ecosystem.

~~5~~ 6 Conclusion

In this study, seasonal and inter-annual features of E_T were analyzed. ~~The d~~Daily E_T was in a range from 0.0 mm day^{-1} to 6.8 mm day^{-1} during the four periods. NDVI was the predominant factor that influences the seasonal variations in E_T, and ~~.~~ v~~V~~egetation greening had a positive effect on E_T. During the land degradation process (Periods II~~∼~~-~~Period~~ III), when natural vegetation (including leaves and branches), sand dunes, dry sand layers and BSCs were all bulldozed~~ by human activities~~, E_T ~~was observed to~~ increased ~~with~~ at a mild rate. ~~In~~ During the vegetation rehabilitation process (Period IV) with ~~sufficient groundwater~~less precipitation, E_T also increased ~~with~~ at a faster rate than that in the degradation process. Our study demonstrated that~~,~~ when land use/cover condition changed by human activities, the underlying mechanisms that lead~~s~~ to the ~~changes~~ increase of E_T were complex, and vegetation types, topography and soil surface characteristics may all~~could~~ contribute to the changes in E_T~~.ies~~. Furthermore, o~~O~~ur results suggest that when we simulate the impact of land use/cover change on hydrological processes, vegetation factor might not be the unique factor to parameterize, instead, the integrated effects of land surface and vegetation conditions should be considered. Our study also provides a scientific reference to the regional sustainable management of water resources in the context of intensive agricultural reclamation

~~On the basis of understanding the impacts of destroying virginal ecology by human activity on water cycle, calling for paying more attention to water cycle and conserve the water environment.~~

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Figure and table captions

Fig. 1. Location of the Loess Plateau and ~~the~~ map of study site (LP: the Loess Plateau; black triangle: flux tower; white triangle: Yulin meteorological station; ①: Tu River; ②: Yuxi River; ③: Yellow River)~~.~~

Fig. 2. Land use/cover conditions ~~of~~ at the study site ~~over the Loess Plateau~~: (a) the natural land use/cover condition of shrubland (photo was taken ~~at~~ on 6th August 2011); (b) the natural land use/cover condition of grassland (photo was taken ~~at~~ on 7th September 2011); (c) the undisturbed zone (natural vegetation) and the disturbed zone (bare soil) in the land degradation process (photo was taken ~~at~~ on 26th April 2013); (d) the undisturbed zone (natural vegetation) and the disturbed zone (grassland) ~~in~~ during the vegetation rehabilitation process (photo was taken ~~at~~ on 16th August 2014)~~.~~

Fig. 3. Diagrams of wind rose and footprint: (a) wind rose of the study site by using half-hourly wind speed and wind direction data~~;~~ and (b) simulated footprint by ellipse (the long axis is 1682 m, and the short axis is 1263 m; zone A ~~is~~ is the source area ~~that~~ in which ~~have not encountered any~~ land use/cover ~~change~~condition did not change, while zone B ~~is~~ is the source area ~~that~~ in which ~~have experienced~~ land use/cover condition did change ~~by~~ due to human activities; the white triangle is the flux tower)~~.~~

Fig. 4. Seasonal characteristics of four-year and long-term (1954-2014, from Yulin meteorological station) average monthly values of: (a) sunshine duration (D_S~~DS~~); (b) air temperature (T_a); (c) relative humidity (R_H~~R_H~~)~~;~~ and (d) total precipitation (P) ~~of four~~

~~periods at the study site and climatological normal~~monthly average ~~(~~ of ~~1954-2014~~ from ~~climate~~ ~~ological normal in Yulin meteorological station).~~

Fig. 5. Seasonal and inter-annual characteristics of daily (a) evapotranspiration (E_{T}, mm); (b) potential evapotranspiration (E_{TP}, mm); (c) NDVI in zone A and zone B within the ~~the~~ footprint; ~~(d) precipitation (P, mm);~~ (~~e~~d) the soil water stress of the root zone (f_s) and (e) the groundwater level (GWL, m) ~~during~~from ~~1st~~ 1 July 2011 to ~~30th~~ 30 June 2015~~.~~

Fig. 6. The correlations between daily evapotranspiration (E_{T}, mm) and its controlling factors: (a) daily potential evapotranspiration (E_{TP}, mm); (b) daily weight-averaged NDVI (NDVI_w) within the footprint ~~(NDVI_w)~~; (c) daily soil water stress of the root zone (f_s) in Period I by excluding the data ~~in~~ on rainy days (r: Pearson's correlation ~~significance~~coefficient; T: ~~T~~t-test significance)~~.~~

Fig. 7. Quantitative analysis ~~between~~ of ~~(a)~~ the correlations between (a) vegetation phenological change (NDVI_w) and daily normalized E_{T} ($f_{\mathrm{v}} = E_{\mathrm{T}}/(E_{\mathrm{TP}} \times f_{\mathrm{s}})$) in Period I (exclude~~d~~ the data ~~in~~ on rainy days and frozen days~~);~~) and (b) the indicator of land use/cover change (D_{lu}) and total normalized E_{T} ($f_{\mathrm{v}} = E_{\mathrm{T}}/(E_{\mathrm{TP}} \times f_{\mathrm{s}})$) ~~of~~ in the growing season ~~in~~ of each period.

Table ~~12~~1. Daily air temperature (T_a~~*Ta*~~, ℃~~℃~~), relatively humidity (R_H~~*R*H~~, %), total sunshine duration (~~D_s~~D_S~~D_S~~, h), soil water content of the root zone (θ_r, m^3 m^{-3}), the groundwater level (GWL, m), and total precipitation (*P*, mm) in 1954-2014 and in the growing season of each period (~~Because~~ because there were some missing data in Period IV (from 12~~th~~ September 2014 to 23~~th~~ November 2014 and from 13~~th~~ March 2015 to 22~~th~~ April 2015), we ~~got rid of~~ excluded data in these two time ranges of Periods I~~∼~~-III and 1954-2014)

~~Items~~Variable	1954-2014	I	II	III	IV
T_a~~*Ta*~~ (℃)	19.8	19.6	20.4	19.9	19.3
R_H~~*R*H~~ (%)	57.7	57.3	54.9	53.4	52
D_S~~*Ds*~~ ~~D_S~~ (h)	213.3	220.7	215.8	218.2	220.7
P (mm)	329.8	357.1	384.1	330.2	199.8
θ_r (m^3 m^{-3})	_	0.077	0.077	0.076	0.064
GWL (m)	_	-3.8	-3.6	-3.0	-3.5

Table ~~23~~2. Typical values of total evapotranspiration (E_T, mm), total potential evapotranspiration (E_TP, mm), the indicator of land use/cover change (D_lu), the soil water stress of the root zone (f_s), and normalized E_T (~~i.e.,~~ f_v $(= E_\mathrm{T}/(E_\mathrm{TP} \times f_\mathrm{s}))$) in the growing season of each period~~.~~ (~~Because~~ because there were some missing data in Period IV (from 12~~th~~ September 2014 to 23~~th~~ November 2014 and from 13~~th~~ March 2015 to 22~~th~~ April 2015), we removed the values of E_T, E_TP and f_s ~~of~~ in these two time ranges ~~in~~ of Periods I~~∼~~-III).

	~~Items~~ Period~~s~~	E_T (mm)	E_{TP} (mm)	D_{lu}~~D_{lu}~~ (%)	f_s (dimensionless)	f_v (dimensionless)
Growing season	I	238.4	876.1	-0.2	0.62	78.1
	II	236.5	870.7	4.6	0.63	79.9
	III	292.1	956	10.4	0.59	86.3
	IV	332.2	937	6	0.37	111.9

Fig. 1

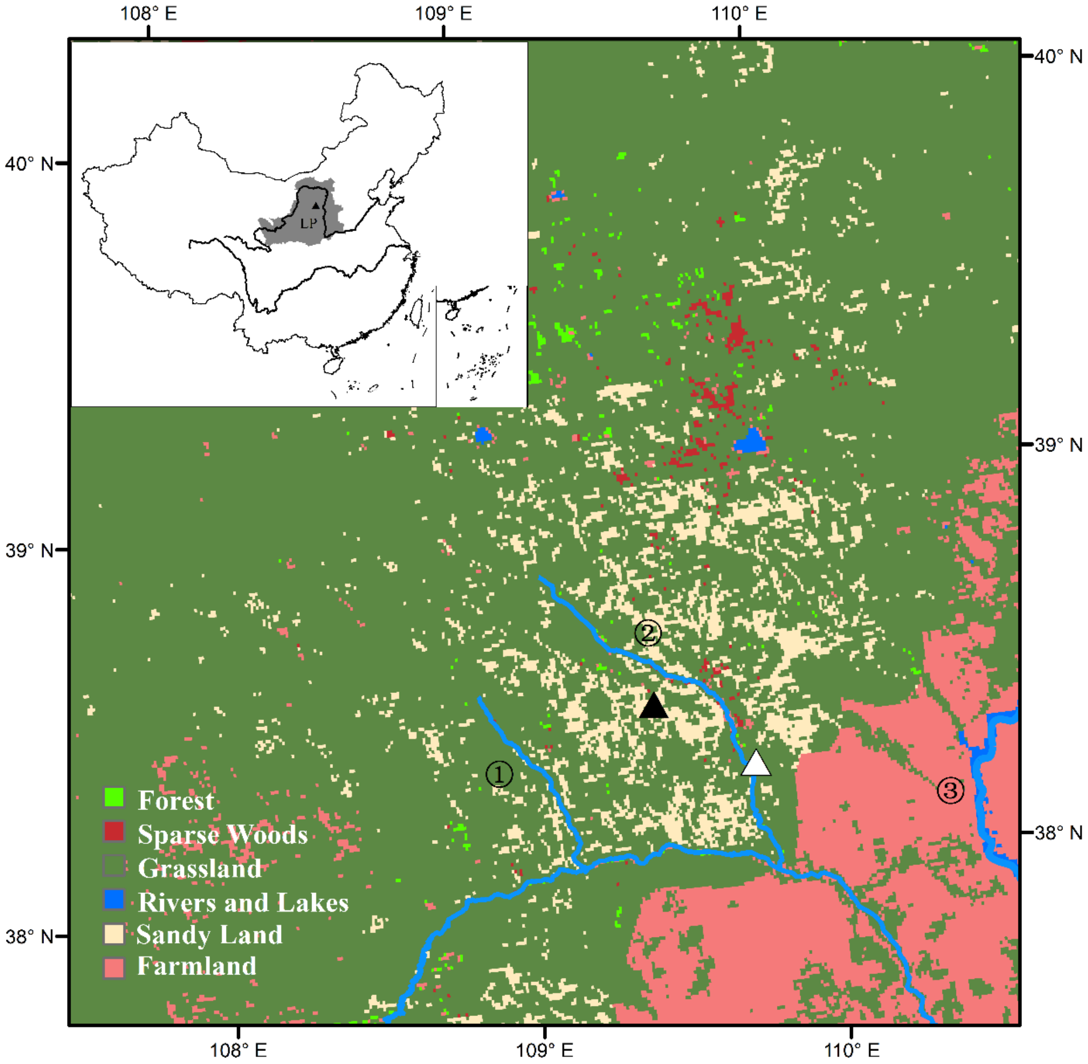


Fig. 2

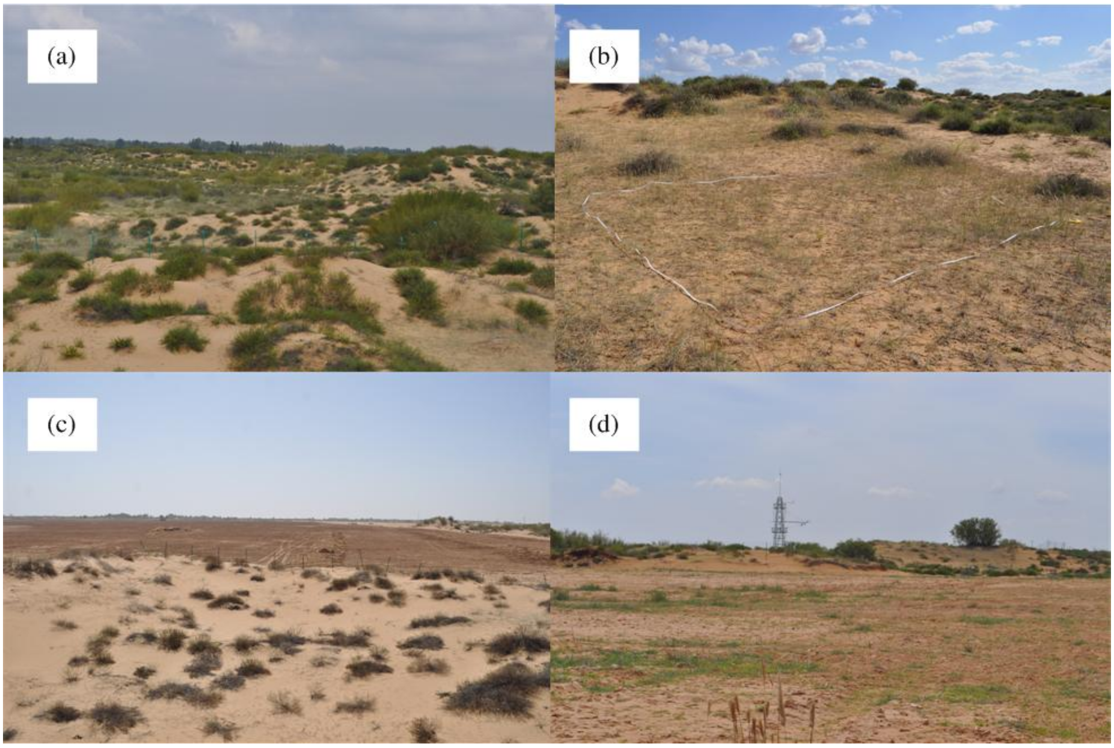

(a)
(b)
(c)
(d)

Fig. 3

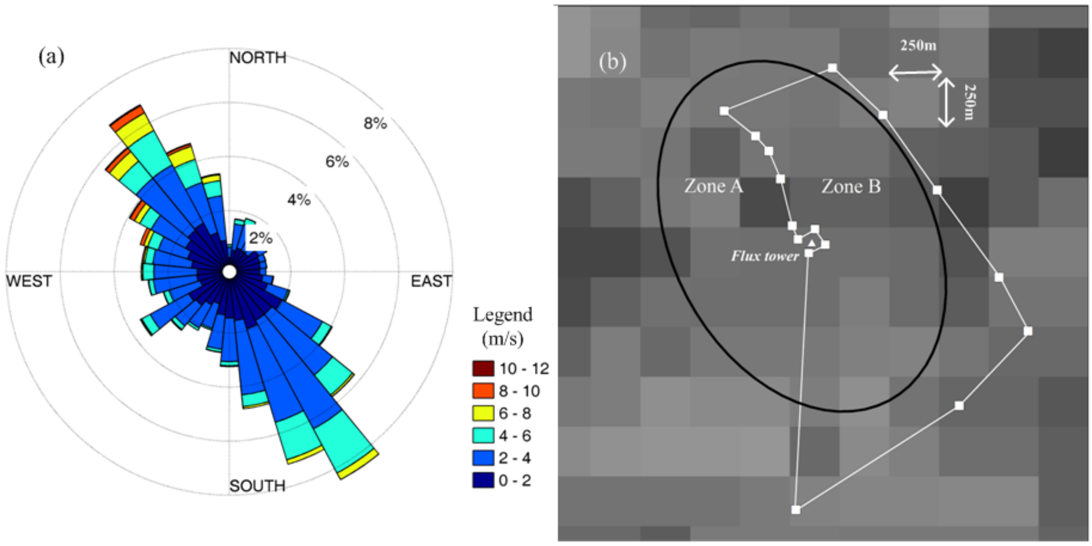

(a)
NORTH
8%
6%
4%
2%
WEST
EAST
SOUTH
Legend
(m/s)
10 - 12
8 - 10
6 - 8
4 - 6
2 - 4
0 - 2
(b)
250m
250m
Zone A
Zone B
Flux tower

Fig. 4

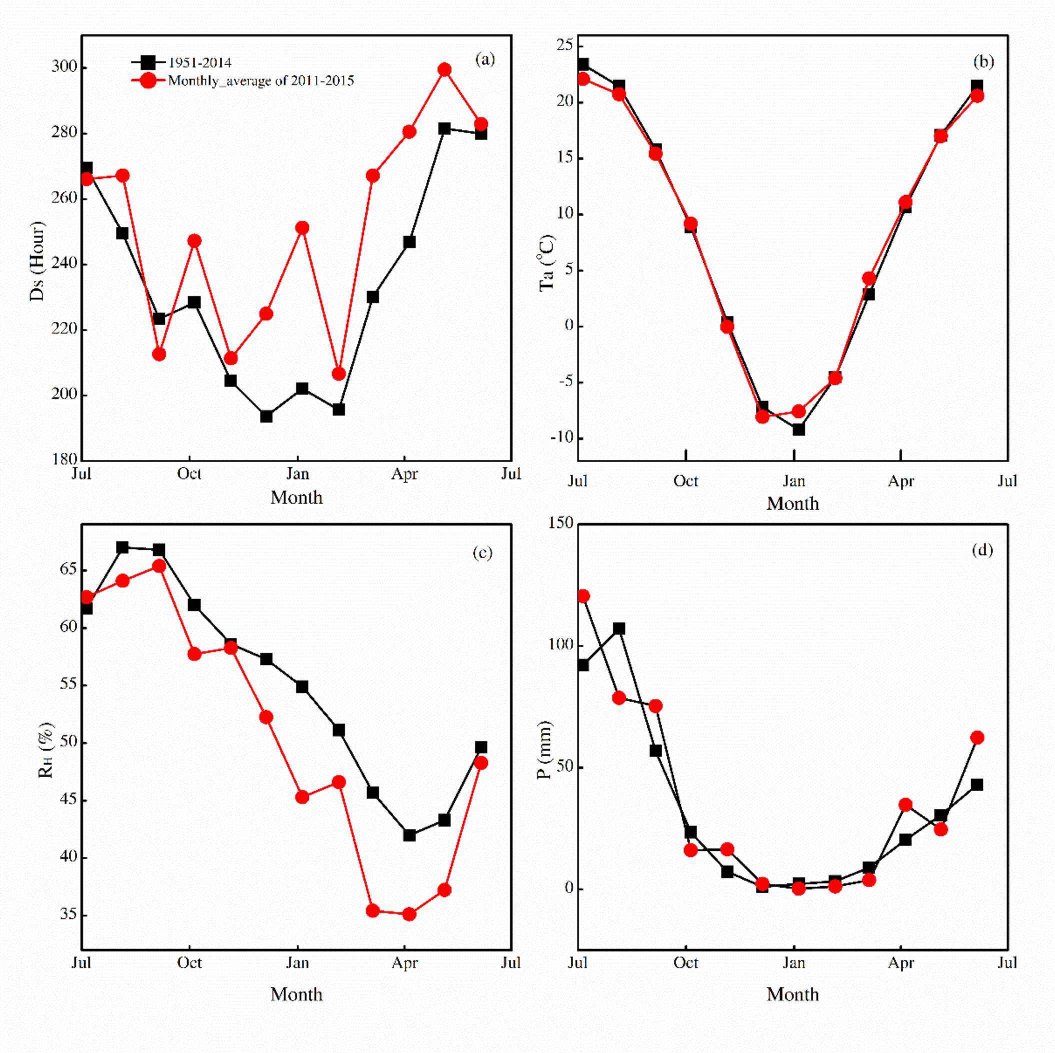

(a)
1951-2014
Monthly_average of 2011-2015
Ds (Hour)
180
200
220
240
260
280
300
Jul
Oct
Jan
Apr
Jul
Month
(b)
Ta (°C)
-10
-5
0
5
10
15
20
25
Jul
Oct
Jan
Apr
Jul
Month
(c)
RH (%)
35
40
45
50
55
60
65
Jul
Oct
Jan
Apr
Jul
Month
(d)
P (mm)
0
50
100
150
Jul
Oct
Jan
Apr
Jul
Month

Fig. 5

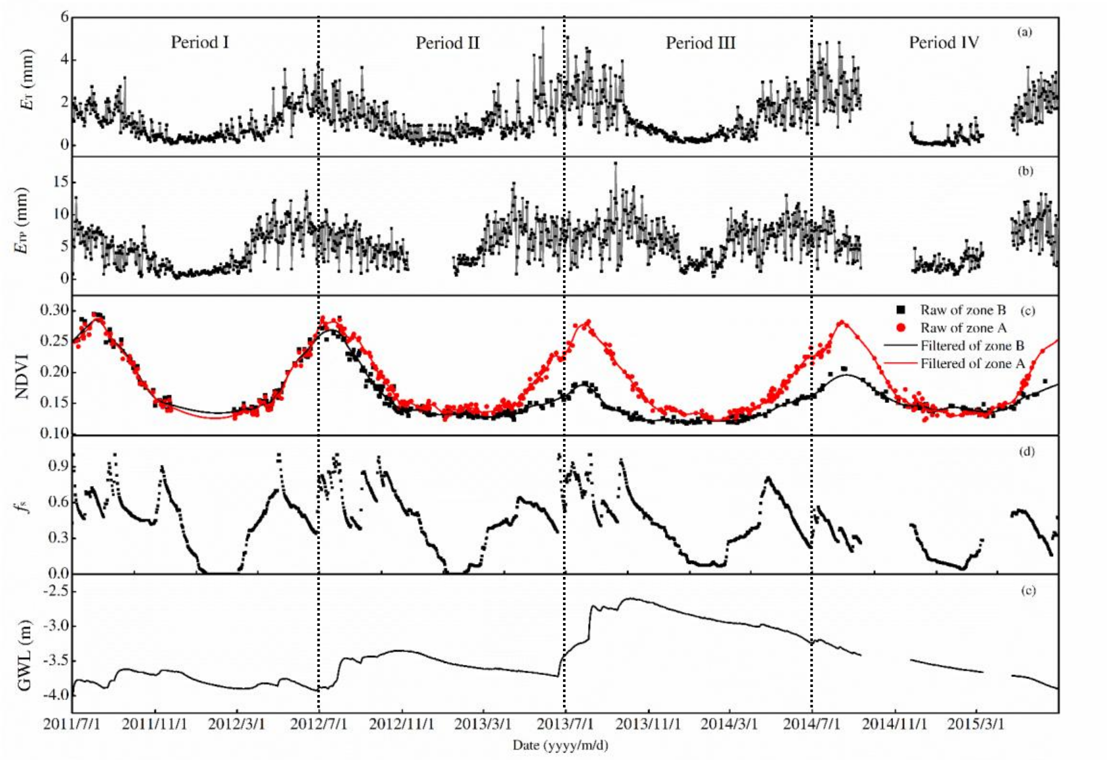

Period I
Period II
Period III
Period IV
(a)
E_T (mm)
0
2
4
6
(b)
E_{TP} (mm)
0
5
10
15
(c)
NDVI
0.10
0.15
0.20
0.25
0.30
■ Raw of zone B
● Raw of zone A
Filtered of zone B
Filtered of zone A
(d)
f_s
0.0
0.3
0.6
0.9
(e)
GWL (m)
-4.0
-3.5
-3.0
-2.5
2011/7/1
2011/11/1
2012/3/1
2012/7/1
2012/11/1
2013/3/1
2013/7/1
2013/11/1
2014/3/1
2014/7/1
2014/11/1
2015/3/1
Date (yyyy/m/d)

Fig. 6

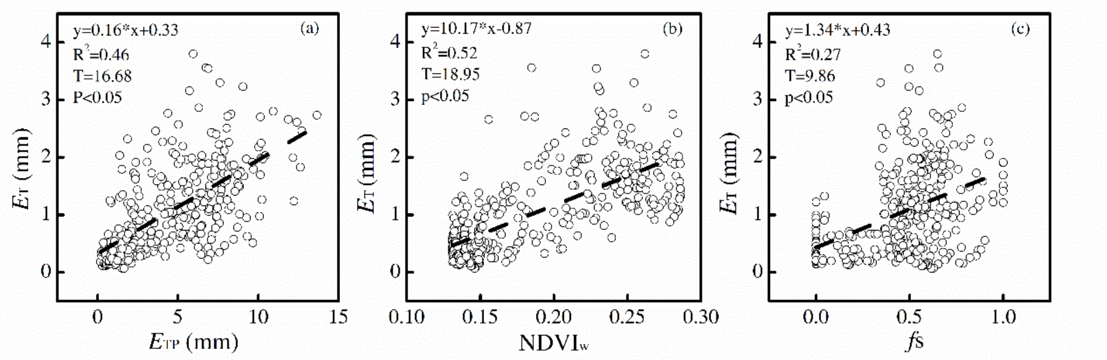
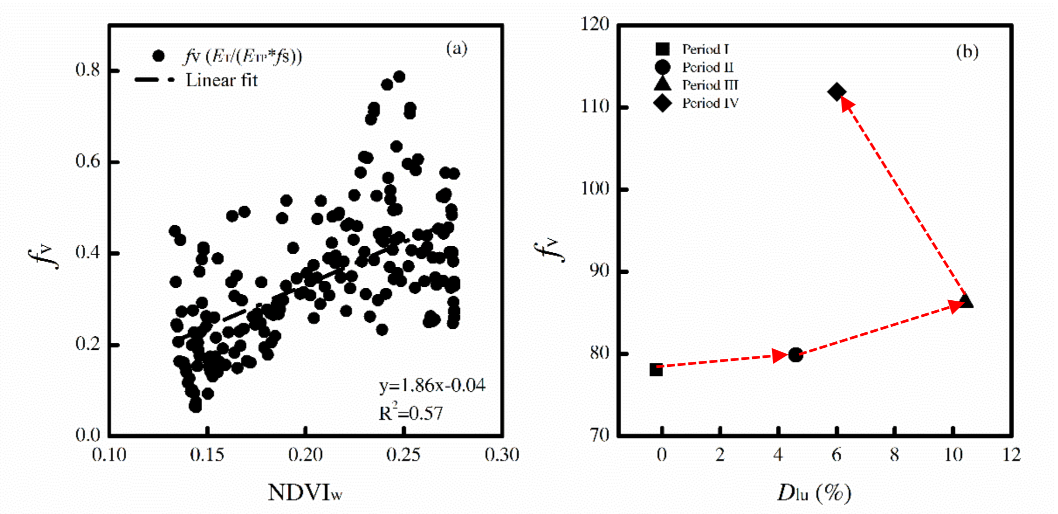

y=0.16*x+0.33
R²=0.46
T=16.68
P<0.05
(a)
ET (mm)
ETP (mm)
0
5
10
15
y=10.17*x-0.87
R²=0.52
T=18.95
p<0.05
(b)
ET (mm)
NDVIw
0.10
0.15
0.20
0.25
0.30
y=1.34*x+0.43
R²=0.27
T=9.86
p<0.05
(c)
ET (mm)
fs
0.0
0.5
1.0

Fig. 7


fv (ET/(ETP*fs))
Linear fit
(a)
fv
NDVIw
y=1.86x-0.04
R²=0.57
0.0
0.2
0.4
0.6
0.8
0.10
0.15
0.20
0.25
0.30
Period I
Period II
Period III
Period IV
(b)
fv
Dlu (%)
70
80
90
100
110
120
0
2
4
6
8
10
12

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