COVER LETTER

Dear Dr. Bishop,

Thanks for your comments and suggestions on our manuscript.

We have made substantial revisions based on two reviewers' major recommendations. In particular, we have addressed yours and the reviewers concerns about model validation using data from the datasets that have been used previously during the model development phase. We have addressed the issues by splitting the datasets and left an independent dataset (30 sites) for model validation. It appears the models developed performs well. Other issues raised by the viewers have been fixed.

I hope the revision has improved and it meet the publication requirements. We look forward to your further guidance to publish this work in HESS.

Ge Sun

On behalf of all authors

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Response to comments by Reviewer #1 on “Environmental controls on seasonal ecosystem evapotranspiration/potential evapotranspiration ratio as determined by the global eddy flux measurements” *by* Chunwei Liu et al.

We greatly appreciate the review comments and thank the reviewers for their effort. We have addressed all of the comments and present our response below. The review comments are in regular typeface, while all responses are in italics and boldface.

The manuscript ”Environmental controls on seasonal ecosystem evapotranspiration/ potential evapotranspiration ratio as determined by the global eddy flux measurements” by Liu et al. explores the possibility to extend the use of ‘crop coefficients’ from crops (as proposed by FAO) to natural vegetation. The manuscript also attempts to estimate such coefficients based on eddy covariance data from several locations in the world.

The idea is interesting, as potentially one could estimate the actual evapotranspiration from easy-to-obtain basic meteorological data, geographical location and vegetation type. Nevertheless, I think the manuscript does not deliver what it promises. The bulk of results focuses on the correlation between crop coefficient and climatological data or basic ecosystem properties (e.g., LAI), presenting mostly expected relations. The impact of this work would be greatly enhanced should the authors really tested their approach, by, e.g., calculating the crop coefficients on the basis of their multivariate linear model and basic ecosystem and climatic data and comparing the results with the estimates from eddy covariance data.

AUTHOR RESPONSE: Good suggestion. In the revision, we added new model validation results that examine the multivariate linear model using 30 other sites. The results show that the multiple models can be used for calculating monthly Kc, and monthly AET sufficiently at a large spatial scale and homogeneous ecosystems (Fig.8). (Line 130-133, 216-221, 285-290)

Aside from the specific results, the manuscript and methodology suffer from several, mostly addressable, issues: - Time scales are important, as some processes may be relevant at specific scales. Yet, it remains unclear throughout the manuscript at what time scales the method is applied and to which scales the data refer. Specifically: is the method applied at the annual time scale or at the monthly time scale? Are the data shown monthly (or annual) averages for a specific year or across several years?

AUTHOR RESPONSE: The time scale for Kc calculation is really important for model applications. Our method was applied at the monthly time scale. In the establishment of the multiple Kc models, we use monthly average Kc for several years in different sites. We only chose 78 sites to construct the model. Most validation sites have only 1-2 years eddy flux data, which do not represent the whole Kc variations among years.

To what time scales do the following statements refer? L 59 (subdaily to seasonal?), L 69 (decades to centuries?), L 88 (within a certain developmental stage?), L 138 (daily, monthly, annual or multi-annual means?)

AUTHOR RESPONSE: The time scale of AET/PET in L60 was annual. We have added this info in the manuscript. Sun et al (2015) focus on the monthly AET/PET (L68), and we made improvement in this study. The work of Kc mentioned in L88 was for growing seasons and the time scale was mostly daily. The calculation of ET_0 were calculated at the daily time scale, and we use a monthly total AET and PET to calculate Kc (L146) in this study.

Most of the eddy covariance sites are mid-to-high latitude sites, where most likely temperature and solar radiation are the limiting factors for evapotranspiration during part of the year, potentially even leading to leaf shedding in deciduous ecosystems or absence of crops in some cropping systems. Hence, rather than working at the annual scale (as suggested by L 173), it would be probably more meaningful to restrict the analyses to months in which vegetation indeed drives actual evapotranspiration, e.g., on the basis of LAI dynamics or an indicator based on temperature/day length. This would also mean considering dry/wet seasons in the few tropical ecosystems. More in general, this work would benefit from more attention to the main mechanisms defining actual and potential evapotranspiration. Accounting for seasonality is an example in this sense. Another example is the role of temperature, which appears not relevant in the introduction and method description, yet impacts both potential and actual evapotranspiration in a nonlinear way, directly and indirectly (e.g., via vegetation).

AUTHOR RESPONSE: The manuscript validates against AET using "crop coefficient method" with the eddy flux data in different land covers. However, the ratio of AET/PET is known as Kc in ET simulation for crops, and was influenced by ratio of soil evaporation to ET, canopy resistance, albedo of the canopy surface, and height of the crops in field scale (Allen et al, 1998, FAO 56). Thus, we try to calculate the AET/PET through the analyses on environmental factors including latitude, precipitation, leaf area index in a larger spatial scale. The factors such as temperature and solar radiation were used for PET calculation, and were not independent to AET/PET, as a result, we only chose independent factors to simulate the AET/PET. (Line 179-183)

The monthly AET/PET indeed can be affected by the dry/wet seasons, so we choose precipitation as an independent factor. The latitude is constant in the same site during all months, so we choose average annual AET/PET to analyze the response of AET/PET to latitude, which is a comprehensive factor for different plant communities for the same IGBP land cover type.

Finally, it would be helpful to have some more information on the crops – if annual summer crops, their winter Kc (L 164) represents other, non-vegetation related, mechanisms.

Yes，the winter seasons AET for CRO and OS is mainly depended on soil evaporation as the vegetation deforested or harvested. Thus, the different growing seasons for different crops may cause errors in modeling AET.

Finally, the dataset available to the authors is heavily dominated by temperate and boreal ecosystems, with very few tropical sites. I am well aware that only limited eddy covariance data are available from low-latitude sites. Nevertheless, I think that the authors should either limit their attention to temperate and boreal sites (underlining this limitation in their results) or obtain at least few more datasets from the currently under-represented ecosystems/regions. This second approach may require moving beyond FLUXNET data, but may greatly enhance the impact of the work.

Yes，there are still two IGBP land cover types we don't include, which are savannas(SAV) and closed shrubland (CS). The initial dataset contains different number of year, thus, we only chose the monitoring data more than 2 years to establish the multiple AET/PET model. Most of FLUXNET sites are in North America, Europe and Asia, which were mainly in temperate and boreal ecosystems, thus, the more datasets from other experiment sites will be helpful to expand the multiple model. That's a good suggestion for further research.

Minor issues: - Please use the same symbols and terminology throughout the manuscript (e.g., potential evapotranspiration is later referred to as reference evapotranspiration).

Yes，we have modified it throughout the manuscript. (Line 138)

L 63: maximum stomatal conductance may be considered an ecosystem property, but actual stomatal conductance depends not only on vegetation types, but also on soil moisture, VPD, wind speed.

Yes，we have modified it. (Line 64)

L 149: LAI is not a biomass measure; it is linked to leaf biomass via the specific leaf area, but this parameter varies across ecosystems.

Yes，we have modified it. (Line 155)

L 159: months are very not meaningful when combining data from northern and southern hemispheres; rather, refer to summer and winter.

Yes，we have noted it before the submission, however, we forget change Fig.1 since we chose 3 EBF sites in North Hemisphere to modeling Kc. We have modified it in Fig.1 and Line 130.

L 194: as pointed out on P. 10, LAI and precipitation (and latitude) are not necessarily independent. A justification of the approach is thus necessary.

Yes，we have improved it. (Line 285-286)

Whiskers in Figures 2-3 mix different sources of variability – across locations and, for each location, across years. I wonder if it would be more meaningful to distinguish these two aspects.

Yes，Fig.2 and 3 are from the same data set, and especially Fig.3 is the seasonal Kc for the multiple modeling.

Response to comments by Reviewer #2 on "Environmental controls on seasonal ecosystem evapotranspiration/potential evapotranspiration ratio as determined by the global eddy flux measurements" by Chunwei Liu et al.

We appreciate the reviewer' insightful comments. We have addressed all of the comments and present our response below. The review comments are in regular typeface, while all responses are in italics and boldface.

General comments

The authors use flux data to calibrate a simple empirical model of the actual to potential evapotranspiration ratio that can be used to calculate AET for other parts of the world, which is a subject appropriate for HESS. I have, however, some doubts about some parts of the methodology and the authors don't really show the potential of the model by applying it. Therefore, I think a major revision is needed.

AUTHOR RESPONSE: We have validated the multivariate linear model using 30 additional study sites. The results showed that the multiple models can be used for monthly Kc calculation, and can be used for monthly AET calculation for large spatial scale and homogeneous ecosystems (Fig.8). (Line 130-133, 216-221, 285-290)

I get the impression that crop methods (e.g. L 71) are applied to other ecosystems without proper consideration of how the different structure and other properties of those systems should affect the methods. Eq 2 is constructed for crop and I think it is fine to apply it to other ecosystems for a reference, but it is not correct to use the wind speed at 2 m height measured within closed forest canopies for that calculation. You need to in some way transform the wind data for those sites to open field wind speed or use another parameterization and wind speed at a higher level. As it is done now ET0 is underestimated and Kc is overestimated for the forest sites. For the within land-cover type evaluation it might not make a big difference but in the comparison of Kc levels between ecosystem (e.g. L 166-167) it will matter.

AUTHOR RESPONSE: The PET (ET0) is calculated using the measured wind speed without calibration to 2m height. The reason is that every site has different vegetation types and the height of the wind speed sensors is also different. Thus, we use the measured wind speed to calculate the PET. This treatment indeed is different from reference ET method, especially for forest land cover types. As the reviewer indicated, PET calculated in this study is larger than the reference ET for forests, so the Kc may be underestimated.

However, since future applications will be based on the AET/PET response to environment factors, the multi-variant models still could be used for calculating monthly AET in forest ecosystems as long as the PET is measured at the top of the canopy or using wind speed measured at the 2 m height at a standard weather station. In addition, in many application cases, PET is estimated without windspeed in lieu of FAO Reference ET, for example using temperature based method, so it is not an issue in regional applications. We provided more discussion on this issue in Line 142.

Specific comments

To call latitude an environmental factor (L 102) is questionable though it has a direct connection to the variation of the day length and incoming radiation over the year. Other environmental variables like temperature have some relationship to latitude and it would be better to use those or at least acknowledge that latitude is a proxy for those. This is somewhat done in the discussion (L 231-232), but is should be more clear and stated earlier.

AUTHOR RESPONSE: Revised in Line 179-183.

You have some southern hemisphere sites but it seems that you have treated them such as they were expected to have the same monthly variation as the other sites, is that correct?

AUTHOR RESPONSE: Thanks for the suggestion. We have corrected it in Fig.1 and Line 130.

How were seasonal and yearly Kc calculated, (Sum of ET over months)/(Sum of ET0 over months) or average of monthly Kc values? In my opinion the first method is correct.

AUTHOR RESPONSE: The monthly Kc should be ratio of total monthly ET to total monthly ET0. We revised it in Line 146-150.

In the discussion it would be good to discuss lag effects. There is e.g. a lag between precipitation and soil moisture that can be up to some months. And low soil moisture can lead to a loss of LAI and the low LAI can sustain for a longer period. Precipitation and LAI is included in the environmental variables but not soil moisture but Kc is partly expected to be explained by soil moisture.

AUTHOR RESPONSE: Good points and suggestions. The lack of soil moisture do decrease AET, and there will be a time lag after the precipitation occurring. However, we found little improvement in the model using a lagged Preci. Since soil moisture is not measured in many applications we opt not using it. We included some discussion on this (Line 265-268).

It would really have helped the conclusions if the model of KC developed here was applied and verified for AET. The whole conclusion is based around AET estimates but it has not been done. Some year or sites could e.g. been excluded from the calibration and used for validation.

AUTHOR RESPONSE: We have validated the multivariate linear model using 30 other sites. The results showed that the multiple models can be used for monthly Kc calculation, and thus can be used for monthly AET calculation for large spatial scale and homogeneous ecosystems (Fig.8). (Line 130-133, 216-221, 285-290)

Technical corrections

Be careful to use the same format (italic, subscript) for all the letters in your abbreviations in text, equations, tables and figures. E.g. Kc in L 100, Eq 2 and Fig 2-7.

AUTHOR RESPONSE: We have modified it. (Line 102,117 Eq 2 and Fig 2-7,)

L 108. Should be "land-cover specific" not "land cover-specific".

AUTHOR RESPONSE: Corrected (Line 110)

L 112. Why do you have an F in all forest abbreviations but not for DB?

AUTHOR RESPONSE: we have corrected it to DBF.

L 140. "is slope vapour pressure curve" please write proper English.

AUTHOR RESPONSE: we have corrected it (Line 145)

L 175. Zeros instead of circular degree symbols are used.

AUTHOR RESPONSE: we have corrected it (Line 190)

L 187-188. I suggest revising to something like "In addition to growing season, site latitude and monthly precipitation leaf area index affected the monthly Kc" if I understand what you want to say.

AUTHOR RESPONSE: we have corrected it (see Line 199)

L 190-191. I suggest “The LAI range was up to 6 in most land covers, while it only reached 3-4 in OS and CRO”.

AUTHOR RESPONSE: we have corrected it (Line 228)

L 193. “was” not “were”.

AUTHOR RESPONSE: we have corrected it (Line 231)

L 201-202. I would put the numbers within parenthesis in this sentence.

AUTHOR RESPONSE: we have corrected it (Line 240)

L 206. Delete the first “are”.

AUTHOR RESPONSE: we have corrected it (Line 244)

L 232. “increased” should be replaced by “will in most cases increase” (see specific comment above).

AUTHOR RESPONSE: we have corrected it (Line 274)

L 267 “for a” not “fora”

AUTHOR RESPONSE: we have corrected it (Line 314)

Fig 1. Maybe increase symbol size, especially ENF is hard to see.

AUTHOR RESPONSE: we have corrected it (Fig. 1)

Fig 2-4. Tell that you are showing mean and standard deviation.

AUTHOR RESPONSE: we have corrected it (Fig. 2-4)

Fig 3. You have not specified what months are included in the different seasons.

AUTHOR RESPONSE: we have corrected it (Fig.3)

Fig 5. Use proper degree sign.

Fig 5 legend. “Variation of annual Kc at : : :” might be better.

AUTHOR RESPONSE: we have corrected it (Fig.5)

Environmental controls on seasonal ecosystem evapotranspiration/potential evapotranspiration ratio as determined by the global eddy flux measurements

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Abstract: The evapotranspiration/potential evapotranspiration **(**AET/PET) ratio is traditionally termed as crop coefficient (*Kc*) and has been gradually used as ecosystem evaporative stress index. In the current hydrology literature, *Kc* has been widely used to as a parameter to estimate crop water demand by water managers, but has not been well examined for other type of ecosystems such as forests and other perennial vegetation. Understanding the seasonal dynamics of this variable for all ecosystems is important to project the ecohydrologcial responses to climate change and accurately quantify water use (AET) at watershed to global scales. This study aimed at deriving monthly *Kc* for multiple vegetation cover types and understanding its environmental controls by analyzing the accumulated global eddy flux (FLUXNET) data. We examined monthly AET/PET data for 7 vegetation covers including Open shrubland (OS), Cropland (CRO), Grassland (GRA), Deciduous broad leaf forest (~~DB~~DBF), Evergreen needle leaf forest (ENF) and Evergreen broad leaf forest (EBF), and Mixed forest (MF) across 81 sites. We found that, except for evergreen forests (EBF and ENF), *Kc* values had large seasonal variation across all land covers. The spatial variability of *Kc* was best explained by latitude suggesting site factors has a major control on *Kc*. Seasonally, *Kc* increased significantly with precipitation in the summer months. Moreover, Leaf Area Index (LAI) significantly influenced monthly *Kc* in all land covers except EBF. During the peak growing season, forests had the highest *Kc* values while Croplands (CRO) had the lowest. We developed a series of multi-~~variatelinear~~variate linear monthly regression models for a large spatial scale *Kc* by land cover type and season using LAI, site latitude and monthly precipitation as independent variables. The *Kc* models are useful for understanding water stress in different ecosystems

under climate change and variability and for estimating seasonal ET for large areas with mixed land covers.

Key words: crop coefficient, evapotranspiration, eddy covariance, modeling, water stress

1. Introduction

Evapotranspiration (ET) is one of the major hydrological processes that link energy, water, and carbon cycles in terrestrial ecosystems ~~(Fang et al., 2015;Sun et al., 2011a;Sun et al., 2011b;Sun et al., 2010)~~(Fang et al., 2015;Sun et al., 2010; Sun et al., 2011a; Sun et al., 2011b). In contrast to potential ET (PET) that depends only on atmospheric water demand ~~(Lu et al., 2005)~~(Lu et al., 2005), actual evapotranspiration (AET) is arguably the most uncertain ecohydrologic variable for quantifying watershed water budgets (Baldocchi and Ryu, 2011;~~Fang et al., 2015; Hao et al., 2015a)~~Fang et al., 2015;Hao et al., 2015a) and for understanding the ecological impacts of climate and land use change ~~(Hao et al., 2015b)~~(Hao et al., 2015b), and climate variability ~~(Hao et al., 2014)~~(Hao et al., 2014). In recent years, one of the most important research questions of ecohydrology focused on how ecosystem dynamics, precipitation, AET, and PET interact in different ecosystems at seasonal and long term scales under a changing environment (Vose et al., 2011).

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The ratio of AET to PET is traditionally termed as crop coefficient (*Kc*), and has been widely used to as a parameter to estimate crop water demand by water managers (Allen and Pereira, 2009;~~Irmak et al., 2013a~~Irmak et al., 2013a).However, this parameter has not been well examined for other ecosystems~~(Zhang et al., 2012;Zhou et al., 2010)~~(Zhou et al., 2010;Zhang et al., 2012)~~. The ratio of AET to PET has also been used as an indicator of regional terrestrial water availability, wetness or drought index, and plant water stress~~

~~(Anderson et al., 2012;Mu et al., 2012).When the AET/PET ratio is close to 1.0, the soil water meets ecosystem water use demand. The ratio of AET/PET or water stress level can be drastically different among different ecosystems in different environmental conditions, because AET is mainly controlled by climate (precipitation and PET) (Zhang et al., 2001) and ecosystem species composition and structure (i.e., leaf area index, rooting depth, stomata conductance) .~~ . The ratio of AET to PET has also been used as an indicator of regional terrestrial water availability, wetness or drought index, and plant water stress (Anderson et al., 2012;Mu et al., 2012).When the annual AET/PET ratio is close to 1.0, the soil water meets ecosystem water use demand. The ratio of AET/PET or water stress level can be drastically different among different ecosystems in different environmental conditions, because AET is mainly controlled by climate (precipitation and PET) (Zhang et al., 2001) and ecosystem species composition and structure (i.e., leaf area index, rooting depth) (Sun et al., 2011a)~~. The seasonal PET values for a particular region are generally stable (Lu et al., 2005; Rao et al., 2011), and deviation of AET/PET from the norm indicates variability in AET, which responds to precipitation and water availability when PET is stable (Rao et al., 2011). However, under a changing climate, the AET/PET patterns can be rather complex since both AET and PET are affected by air temperature and precipitation (Sun et al., 2015a;Sun et al., 2015b) and corresponding changes in ecosystem characteristics (e.g., plant species shift) (Sun et al., 2014;Vose et al., 2011).~~

~~In the agricultural water management community, the crop coefficient method remains a popular one for approximating crop water use, despite recent advances in direct ET measurement methods .~~ . The seasonal PET values for a particular region are generally stable (Rao et al., 2011;Lu et al., 2005), and deviation of AET/PET from the norm indicates variability in AET, which responds to precipitation and water availability when PET is stable (Rao et al., 2011). However, under a changing climate, the monthly AET/PET patterns can be rather complex since both AET and PET are affected by air temperature and precipitation (Sun et al., 2015b;Sun et al., 2015a) and corresponding changes in ecosystem characteristics (e.g., plant species shift) (Sun et al., 2014;Vose et al., 2011).

In the agricultural water management community, the crop coefficient method remains a popular one for approximating crop water use, despite recent advances in direct ET measurement methods (~~Allen and Pereira, 2009~~Baldocchi et al., 2001;Fang et al., 2015;Allen et al., 1998;~~Baldocchi et al., 2001;Fang et al., 2015~~Allen and Pereira, 2009). The *Kc* is termed as single crop coefficient (Allen et al., 1998;Allen et al., 2006;Tabari et al., 2013) which is affected by growing periods, crop species, canopy conductance, and soil evaporation in the field scale (~~Allen et al., 1998~~Ding et al., 2015;~~Ding et al., 2015~~Allen et al., 1998;Shukla et al., 2014b). Moreover, *Kc* can be influenced by soil characteristics, vegetative soil cover, height, plant species distribution, and leaf area index in a larger spatial scale ~~(Anda et al., 2014;Consoli and Vanella, 2014;Descheemaeker et al., 2011)~~(Descheemaeker et al., 2011;Consoli and Vanella, 2014;Anda et al., 2014). Although the Food and Agriculture Organization of the United Nations provides various guidelines for several crops (Allen et al., 1998), local measurements are still required to estimate *Kc* to account for local crop varieties and for year-to-year variation in weather conditions ~~(Pereira et al., 2015)~~(Pereira et al., 2015).

Although the *Kc* method has been widely used for estimating AET for crops, it has not been widely used for natural ecosystems for the purpose of estimating AET due to limited continuous measurements in these systems. However, as discussed earlier, ecologists and hydrologist have started to use *Kc* to quantify ecosystem stress levels, and consider *Kc* as a variable rather than a constant. Past studies found that *Kc* was influenced by the growing stages and leaf area index for maize ~~(Ding et al., 2015;Kang et al., 2003)~~(Kang et al., 2003;Ding et al., 2015)~~, winter wheat(Allen et al., 1998;Kang et al., 2003), watermelon (Shukla et al., 2014b), and fruit trees~~ , winter wheat(Kang et al., 2003;Allen et al., 1998), watermelon (Shukla et al., 2014b), and fruit trees ~~(Marsal et al., 2014b~~(Marsal et al., 2014b;Taylor et al., 2015). Variations of mid-season crop coefficients for a mixed riparian vegetation dominated by common reed (*Phragmites australis*) could be predicted by growing degree days in central Nebraska, USA~~(Irmak et al., 2013a)~~(Irmak et al., 2013a). *Kc* ranged from 0.50 to 0.85 for small, open grown shrubs, and from 0.85 to 0.95 for well-developed shrubland. The *Kc* values had a close logarithmic relationship with the canopy cover fraction in the highlands of northern Ethiopia ~~(Descheemaeker et al., 2011)~~(Descheemaeker et al., 2011). Overall, the non-agricultural ecosystems such as forests, grasslands and shrublands are heterogeneous in nature and have high soil water availability. Thus, *Kc* values for natural ecosystems have high variability (~~Allen and Pereira, 2009~~Allen et al., 2011;Allen ~~et al., 2011~~and Pereira, 2009).

Therefore, the goal of this study was to explore how *Kc* varies among multiple ecosystems with various vegetation types over multiple seasons. Another goal was to determine the key biophysical and environmental factors such as latitude, precipitation, and leaf area index that could be used to estimate *Kc*, and if *Kc* can be modeled with a reasonable accuracy in a larger spatial scale. We examined the *Kc* variations for seven land cover types by analyzing the FLUXNET eddy flux data ~~(Baldocchi et al., 2001;Fang et al., 2015)~~(Baldocchi et al., 2001;Fang et al., 2015). Specifically, our objectives were to 1)

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understand the variation of monthly *Kc* for seven distinct land covers by analyzing the influences of environmental factors (e.g., precipitation, site latitude) on *Kc*; and 2) to develop simple land~~-~~-cover~~-~~-specific regression models for estimating *Kc* with key environmental factors as independent variables. Specifically, we developed quantitative relationships between environmental factors and *Kc* by land cover type using data from FLUXNET sites for 8 croplands(CRO), 13 deciduous broad leaf forests(~~DB), 5~~DBF), 2 evergreen broad leaf forests(EBF), 34 evergreen needle leaf forests (ENF), 9 grasslands (GRA), 10 mixed forests (MF), and 2 open shrublands (OS). In-depth understanding of the biophysical controls on *Kc* for different ecosystems is important for accurately estimating AET and anticipating the impacts of climate change on ecosystem water stress and water balances.

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2. Methods

This synthesis study used the LaThuile eddy flux dataset that was developed by FLUXNET (http://fluxnet.ornl.gov/; Fig. 1), a global network that measures the exchanges of carbon dioxide, water vapor, and energy between the biosphere and atmosphere ~~(Baldocchi et al., 2001). The FLUXNET data (Baldocchi et al., 2001;Baldocchi and Ryu, 2011) have been widely used to understand the evapotranspiration processes and trend (Fang et al., 2015;Jung et al., 2010), develop AET and ecosystem models (Sun et al., 2011b;Zhang et al., 2016) and map continental-scale ecosystem productivity (Xiao et al., 2014;Zhang et al., 2016)~~(Baldocchi et al., 2001). The FLUXNET data (Baldocchi et al., 2001;Baldocchi and Ryu, 2011) have been widely used to understand the evapotranspiration processes and trend (Fang et al., 2015;Jung et al., 2010), develop AET and ecosystem models (Sun et al., 2011b;Zhang et al., 2016) and map continental-scale ecosystem productivity (Xiao et al., 2014;Zhang et al., 2016).

We used an existing database that was developed from the eddy flux measurements from ~~81~~108 sites ~~(Fang et al., 2015).~~(Fang et al., 2015). A total of 78 sites were selected to calculate monthly *Kc* for multiple years and develop *Kc* models for different ecosystems, and 30 sites were used for validating the models. According to the International Geosphere-Biosphere Program (IGBP) land cover classification system, these eddy flux sites represent nine land cover types: open shrubland (OS), cropland (CRO), grassland (GRA), deciduous broad leaf forest (~~DB~~DBF), evergreen needle leaf forest (ENF) and evergreen broad leaf forest (EBF), and mixed forest (MF). For each eddy flux tower site (Figure 1), we acquired AET and associated micro-meteorological data, such as vapor pressure deficit ~~(VPD);~~, precipitation (P), winds speed ~~(WS);~~, net radiation ~~(R_n). Reference~~. Potential daily evapotranspiration~~(ET_0~~ (PET) was calculated by the FAO Penman–Monteith equation as follows (Allen et al., 1998):

$$\cancel{ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}} \quad \mathrm{PET} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{1}$$

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where R_n is net radiation at the cover surface (MJ m^{-2} d^{-1}), G is soil heat flux (MJ m^{-2} d^{-1}), T is mean air temperature ~~at 2 m height~~ (°C), u_2 is wind speed ~~at 2 m height~~ (m s^{-1}), e_s is saturation vapour pressure (kP$_a$), e_a is actual vapour pressure (kP$_a$), e_s–e_a is the saturation vapour pressure deficit (kP$_a$), Δ is slope of saturation vapour pressure curve (kP$_a$ °C^{-1}), and γ is the psychrometric constant (kP$_a$ °C^{-1}).

The monthly crop coefficient (Kc) is defined as the ratio of the measured total monthly AET and the ~~ET_0~~total monthly PET calculated by ~~equation (~~(Equation 1~~)~~ varies by month and vegetation types (Equation 2). The average annual *Kc* were calculated using mean monthly *Kc* from January to December for the special sites.

$$\cancel{K_c = \frac{ET}{ET_0}}\; Kc = \frac{ET}{ET_0} \qquad (2)$$

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The LAI time series for each tower site were downloaded from the Oak Ridge National Laboratory Distributed Active Archive Center (http://daac.ornl.gov/cgi-bin/MODIS/GR_col5_1/mod_viz.html). MODIS LAI was derived from the fraction of absorbed photosynthetically active radiation (FPAR) that a plant canopy absorbs for photosynthesis and growth in the 0.4–0.7 nm spectral range. ~~LAI is the biomass equivalent of FPAR.~~ The MODIS LAI/FPAR algorithm exploits the spectral information of MODIS surface reflectance at up to seven spectral bands. We extracted monthly LAI data for the time period from 2000 through 2006 across 77 sites using 8-day GeoTIFF data from the Moderate Resolution Imaging Spectroradiometer (MODIS) land subsets' 1-km LAI global fields. We estimated monthly LAI for each flux tower by computing the mean of the 8-day daily values for each month ~~(Fang et al., 2015)~~(Fang et al., 2015).

3. Results

3.1. Seasonal variations and long term means of Kc by land cover

The average monthly *Kc* based on eddy flux data from 2000 to 2007 increased gradually from January to July and then decreased (Fig. 2). EBF had the highest mean monthly *Kc* (1.01±0.17) (mean ± standard error) in August. *Kc* for both EBF and ENF varied less seasonally than other forest types (Fig. 2). Standard errors for GRA, ENF and OS (0.10-

0.17) were larger than other land cover types (0.03-0.10) for April to August. EBF had higher *Kc* for all seasons than other land covers with a peak value of 0.91 (±0.13) in the summer season (Fig. 3). In winter seasons, CRO and OS had the lowest *Kc*, 0.25 (± 0.006) and 0.22 (± 0.004), respectively.

The mean annual *Kc* was 0.39 (± 0.04), 0.47 (± 0.05), 0.79 (± 0.03), 0.45 (± 0.02), 0.57 (± 0.06), 0.45 (± 0.05), and 0.40 (± 0.04) for CRO, ~~DB~~DBF, EBF, ENF, GRA, MF, and OS, respectively. Yearly average ~~AET, ET_0 and~~ precipitation ~~were~~was higher in EBF and DBF than other land covers (Fig. 4). The precipitation ranking by land cover type was DBF> EBF~~> DB~~> MF> GRA> ENF> CRO> OS. Consequently, OS, MF, GRA and ENF had relatively low AET (376-425 mm). In contrast, CRO had relatively low precipitation with a high ~~ET_0~~PET.

3.2. Environmental controls on Kc

~~At~~As indicated in Equation 1, factors such as temperature and solar radiation were using for PET calculation, and were not independent to AET/PET. Therefore, we chose other independent factors to simulate AET/PET. Since site latitude is a readily available variable for a particular location, but is crucial to determine the ~~annual temporal scale,~~day length and incoming radiation over the year in the same land cover types, so we explored the relationship between *Kc* and site latitude.

The results show that annual *Kc* was negatively (p<0.05) correlated with the latitude of the sites (Fig.5) for CRO, ~~DB~~DBF, ENF, GRA and MF with a determination coefficient (R^2) of 0.83, 0.59 and 0.21, 0.72 and 0.52, respectively. For ~~other sites~~OS, annual mean *Kc*

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also decreased with the increase in site latitude. Most of the study site latitudes fell between ~~30^0N to 60^0N except some EBF sites~~30 °N to 60 °N.

At the seasonal scale, the linear relationships between monthly *Kc* and total monthly precipitation differed among different land cover types (Fig. 6). Monthly *Kc* increased with monthly precipitation in the same ecosystem type with the R^2 ranking from high to low: OS>MF>~~-~~GRA>~~-~~ENF>CRO>~~DB~~DBF. The monthly *Kc* for open shrublands (OS) was especially sensitive to precipitation (R^2= 0.69, p<0.001). The monthly *Kc* for EBF was not as sensitive to precipitation because EBF was generally found in a wet environment with a peak monthly precipitation of 468 mm. Moreover, *Kc* for OS, GRA and MF in relatively drier environments had lower values (Fig. 2). Therefore, *Kc* was closely related to the monthly precipitation.

~~Growing~~In addition to growing season, site latitude and monthly precipitation~~-~~, leaf area index affected the monthly *Kc*~~, in addition to leaf area index~~ (Fig. 7). *Kc* was obviously influenced by the leaf area index (LAI) for all land covers~~ except EBF~~. The determination coefficients for different land covers were OS> MF~~>~~=GRA> ENF>~~DB~~DBF>CRO>EBF. The LAI ~~could reach~~range was up to 6 m^2 m^{-2} in most land covers, while ~~in OS and CRO the LAI were~~it only reached 3-4 m^2 m^{-2} in OS and CRO.

~~*3.3.*~~ *3.3. Kc models*

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A series empirical *Kc* model ~~were~~was developed using a multiple linear regression approach with precipitation, leaf area index (LAI), and site latitude as independent variables (Table 1).The monthly precipitation, LAI and site latitude influenced *Kc* (p<0.1) for most ecosystems studied in different seasons except at EBF in ~~summer~~spring, fall and

~~fall~~winter, and for OS in the spring. As annual precipitation increases, total leaf area increases, therefore *Kc* increases for ENF in all seasons and most of the time for ~~DB~~DBF and MF. As site latitude increases, *Kc* values were found to decrease in some periods at CRO, ~~DB, EBF~~DBF and MF sites. In addition, *Kc* was closely correlated to LAI, site latitude, and monthly precipitation at ENF in fall and OS in winter with R^2 0.55 and 0.99. All land covers had a peak values (0.53 ~~(~~± 0.04~~)~~ - 1.01 ~~(~~± 0.17) in the summer months. Except for EBF and GRA, *Kc* values had a close relationship with the monthly precipitation in the summer with R^2 ranging from 0.21 to 0.90. The linear relationships were significant for most vegetation types, suggesting the regression models (Table 1) can be used to estimate monthly *Kc* if LAI and precipitation ~~are~~ for a specific ecosystem are available.

3.4. The validation of the regression models of Kc

All *Kc* multiple regression models for different seasons were validated byecosystem type (Fig. 8). The validation was carried out for 30 sites at a monthly scale. The results showed that the modeled AET calculated from the multiple *Kc* models compared well with measurmentswith R^2 ranging 0.28-0.56. Among the ecosystems, the model for DBF appeared to be the most accurate one with a R^2 of 0.56.

4. Discussion

Our study estimated annual and seasonal crop coefficient (*Kc*) for seven land cover types using measured global eddy flux data. We comprehensively evaluated environmental controls (i.e., precipitation, LAI, and site latitude) on annual and growing seasons *Kc* and developed a series of multiple linear regression models that can be used for estimating monthly AET over time and space.

4.1. Crop coefficient variation in different seasons

Several recent studies had shown that *Kc* reached the maximum value in middle of the growing season in many ecosystems, such as a *P. euphratica* forest in the riparian area ~~(Hou et al., 2010)~~(Hou et al., 2010)in a desert environment, a watermelon crop covered with plastic mulch in Florida ~~(Shukla et al., 2014a;Shukla et al., 2014b)~~(Shukla et al., 2014b;Shukla et al., 2014a), soybean in Nebraska ~~(Irmak et al., 2013b)~~(Irmak et al., 2013b), a temperate desert steppe in Inner Mongolia(Zhang et al., 2012). As Fig. 2 shows, most of the land covers had peak *Kc* during June to August, while the seasonal patterns of ENF and EBF varied less than other surfaces. Vegetation growth for both the ENF and EBF sites is active throughout the year~~ and some EBF sites distributed in the southern hemisphere lead to the stable *Kc* that varied little~~. The crop coefficients for early period mid-density fruit trees is about 0.5 ~~(Allen and Pereira, 2009;Allen et al., 1998)~~(Allen et al., 1998;Allen and Pereira, 2009) which is similar to those found for ~~DB~~DBF or MF during April and May. In addition, the middle season *Kc* values for apple and peach trees with active ground cover were higher than *Kc* for ~~DB~~DBF sites during the summer. It is likely that the orchards had higher evapotranspiration rates than natural forests due to irrigation in orchards.

4.2. Environmental control factors for Kc

The ecosystem covers and the distributions of the vegetation classes were determined by the latitude ~~(Potter et al., 1993). Crop coefficient varied predominately by ecosystems, *Kc* increased~~(Potter et al., 1993). Crop coefficient varies predominately by ecosystems, *Kc* will in most cases increase as the site latitude decreased for the same land cover (Fig. 5). As the latitude decreased, the temperature and the solar radiation increased and the vegetation characteristics would be different for the same land cover type. Models developed from the FLUXNET data may be best used on flat areas for a given latitude given that eddy covariance towers were generally installed on flat lands ~~(Baldocchi et al., 2001)~~(Baldocchi et al., 2001). For areas with complex topography, the relationship between *Kc* and site latitude may be more complicated.

Spatial variations of *Kc* are characteristic of ecosystems, but *Kc* is also affected by climate factors such as rainfall~~ and temperature.~~. For example, *Kc* was highly correlated with precipitation for most land covers (Fig. 6).The rainfall is the major source of soil water and AET in natural ecosystems ~~(Parent and Anctil, 2012)~~(Parent and Anctil, 2012). During dry years or periods, a lack of precipitation may cause a reduction of the leaf area index and *Kc* will decrease to response the ecosystem function. During rainy seasons, as, leaf area index and stomatal conductance of trees and rain-fed crops increases, so does *Kc* ~~(Kar et al., 2006~~(Kar et al., 2006;Zeppel et al., 2008). Irrigation of cropland is a primary mechanism for increasing yield ~~(Du et al., 2015;Fereres and Soriano, 2007)~~(Du et al., 2015;Fereres and Soriano, 2007), so the CRO may have a high monthly *Kc* even at sites with a low precipitation. In contrast, *Kc* does not have a close relationship with precipitation under a wet environment. For example, the EBF site had a monthly precipitation as high as 468 mm/month and generally exceeded monthly AET. In an opposite case for the OS sites, monthly precipitation values were between 0.7 to 69 mm, and *Kc* was highly correlated to monthly precipitation. Moreover, the soil moisture could be a limiting factor to AET, and would affect *Kc* in dry periods. When the time lag between precipitation and soil moisture might cause errors in modeling *Kc* in the long dry or wet season. However, at the monthly scale, previous modeling work (Fang et al., 2015) suggest that considering a time lag does not increase the prediction power dramatically (G. Sun Personal communication).

Besides precipitation, leaf area index (LAI) also ~~impacted~~affects *Kc* in dry and semi-humid area ~~(Kang et al., 2003;Zhang et al., 2012)~~(Zhang et al., 2012;Kang et al., 2003). Unlike precipitation, LAI directly affects *Kc* in AET calculations ~~(Novák, 2012;Tolk and Howell, 2001).~~(Novák, 2012;Tolk and Howell, 2001). Inter-annual *Kc* values are stable at the GRA and OS sites due to the steady seasonal LAI between years while the plantation forest sites had a more dynamic LAI pattern~~(Marsal et al., 2014a)~~(Marsal et al., 2014a). As the growth rate of the perennial plants could have large effects on relationship between *Kc* and LAI, long term data are needed to estimate *Kc* as a function of all environmental factors.

4.3. Modeling the dynamics of Kc

Our study results are consistent with previous studies that show that the growing stage is a key factor for estimating *Kc* in agricultural crops (~~Alberto et al., 2014~~Allen et al., 1998;~~Allen et al., 1998~~Zhang et al., 2013;Wei et al., 2015;~~Zhang et al., 2013~~Alberto et al., 2014), fruit trees (Abrisqueta et al., 2013~~;Marsal et al., 2014b);~~Marsal et al., 2014b), salt grass (Bawazir et al., 2014) and *Populus euphratica Oliv* forest ~~(Hou et al., 2010)~~(Hou et al., 2010). Additionally, our study showed that *Kc* fluctuated more dramatically in ~~DB~~DBF, GRA, and MF than other land covers in different seasons (Table 1). Studies also show that monthly leaf resistance that varies over time is important in estimating the seasonal crop coefficient ~~fora~~for a citrus orchard ~~(Taylor et al., 2015)~~(Taylor et al., 2015). ~~The LAI and total monthly precipitation varied in both time and space while the site latitude only represents spatial influences on *Kc*.~~The LAI and total monthly precipitation were

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considered as independent factors (Bond-Lamberty and Thomson, 2010) and both of them varied in both time and space while the site latitude only represents spatial influences on *Kc*. The modeled AET was acceptable for the different land cover types (Fig. 8), and could be used for monthly AET calculation for large spatial scale and homogeneous ecosystems. Thus, the multiple linear regression equations developed from this study take account of both spatial and temporal changes in land surface characteristics and offer a powerful tool to estimate of seasonal dynamic *Kc* for different ecosystems (Table 1).

5. Conclusions

To seek a convenient method to calculate monthly AET in large spatial scale, we comprehensively examined the relations between *Kc* and environmental factors using eddy flux data from 81 sites with different land covers. We found that *Kc* values varied largely among CRO, ~~DB~~DBF, EBF, GRA and MF and over seasons. Precipitation determined *Kc* in the growing seasons (such as summer), and was chosen as a key variable to calculate *Kc*. We established multiple linear equations for different land covers and seasons to model the dynamics of *Kc* as function of LAI, site latitude and monthly precipitation. These empirical models could be helpful in calculating monthly AET at the regional scales with readily available climatic data and vegetation structure information. Our study extended the applications of the traditional *Kc* method for estimating crop water use to estimating AET rates and evaporative stress for natural ecosystems. Future studies should further test the applicability of the empirical *Kc* models under extreme climatic conditions.

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Table 1 Multiple linear regression relationships among crop coefficient and LAI, precipitation and site latitude in different seasons.

IGBP	season	*N*	R^2	*Kc*	*b*	a_1	a_2	a_3
CRO	Spring	24	0.16	0.31	0.242***	0.141*		
	Summer	24	0.21	0.57	0.331**			0.0033*
	Fall	23	0.78	0.48	0.036	0.472***		
	Winter	21	0.36	0.26	0.920***		-0.0141**	
~~DB~~DBF	Spring	39	0.49	0.30	0.479**		-0.0076*	0.0022***
	Summer	39	0.42	0.65	0.536***			0.0011***
	Fall	39	0.13	0.60	0.462***			0.0014*
	Winter	39	0.15	0.30	0.713***		-0.0094*	
EBF	Spring	~~15~~6	~~0.25~~-	0.~~746~~6	0.~~875~~663***		~~-0.0050*~~	
	Summer	~~15~~6	~~-~~0.93	0.~~919~~7	~~0.911***~~-2.10**		0.059**	
	Fall	~~15~~4	-	0.~~807~~7	0.~~798***~~772**			
	Winter	~~15~~3	~~0.42~~-	0.~~725~~2	0.~~676***~~519**	~~0.050*~~	~~-0.0050*~~	
ENF	Spring	96	0.39	0.37	0.225***	0.060***		0.0017***
	Summer	99	0.59	0.49	0.211***	0.053***		0.0020***
	Fall	98	0.55	0.52	-0.040	0.066***	0.0049*	0.0025***
	Winter	92	0.21	0.44	0.293***	0.084*		0.0010*
GRA	Spring	27	0.48	0.45	0.237***			0.0052***
	Summer	27	0.23	0.86	0.572***	0.110*		
	Fall	27	0.30	0.76	0.499***	0.123**		
	Winter	27	0.26	0.41	0.256**			0.0038**
MF	Spring	30	0.67	0.31	0.099**	0.188***		0.0012***
	Summer	30	0.40	0.61	0.372***			0.0029***
	Fall	30	0.54	0.58	0.250***	0.071***		0.0018***
	Winter	30	0.13	0.33	0.961**		-0.0136*	
OS	Spring	6	-	0.23	0.230***			

Summer	6	0.90	0.35	-5.419*		0.1005*	0.0026*
Fall	6	0.88	0.42	-9.921*	0.051*	0.1828*	
Winter	6	0.99	0.14	-4.919*	0.629*	0.0882*	0.0032*

Note: *N* is the number of observations used, R^2 the determination coefficient, Kc_{Ave} is the average *Kc* for seasons. *b* is the intercept of the multiple linear equation, a_1 the coefficient of LAI, a_2 the coefficient of site latitude (Absolute values), a_3 the coefficient of precipitation. IGBP is the International Geosphere-Biosphere Program land cover classification system: cropland (CRO), deciduous broad leaf forest (~~DB~~DBF), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). ***, **, * stand for p<0.001, p<0.01, p<0.1. Spring is the month of February, March and April; Summer is the month of May, June and July; Fall is August, September and October; Winter is November, December and January.

Figure captions

Fig. 1 Location of eddy flux sites from which climate and evapotranspiration data are collected.

Fig. 2 The variation of *Kc* for the different IGBP_code. The error bras are stand errors among different sites.

Fig.3 Average *Kc* at spring, summer, fall and winter in different vegetation types. The error bras are stand errors among different sites. Spring is the month of February, March and April; Summer is the month of May, June and July; Fall is August, September and October; Winter is November, December and January.

Fig. 4 Annual total precipitation (P), ~~ET~~AET and ~~ET_0~~PET in different vegetation types The error bras are stand errors among different sites.

Fig. 5 ~~The average~~Variation of annual *Kc* ~~variation~~ at different latitude~~.~~ (Lat). (a) stand for cropland (CRO), deciduous broad leaf forest (~~DB~~DBF), evergreen broad leaf forest (EBF), and (b) evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). The absolute values of the latitude were used in EBF in the southern hemisphere sites and all the determination coefficient (R^2) listed in the figure were significant (p<0.05).

Fig. 6 Relationships between the average monthly *Kc* and the total monthly precipitation (P, mm) for different vegetation surfaces. (a)~(g) represent for cropland (CRO), deciduous broad leaf forest (~~DB~~DBF), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). All the determination coefficient (R^2) listed in the figure were significant (p<0.001)

Fig. 7 Relationships between the average monthly *Kc* and leaf area index for different vegetation surfaces. (a)~(g) stand for cropland (CRO), deciduous broad leaf forest (~~DB~~DBF), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). All the determination coefficient (R^2) listed in the figure were significant (p<0.001)

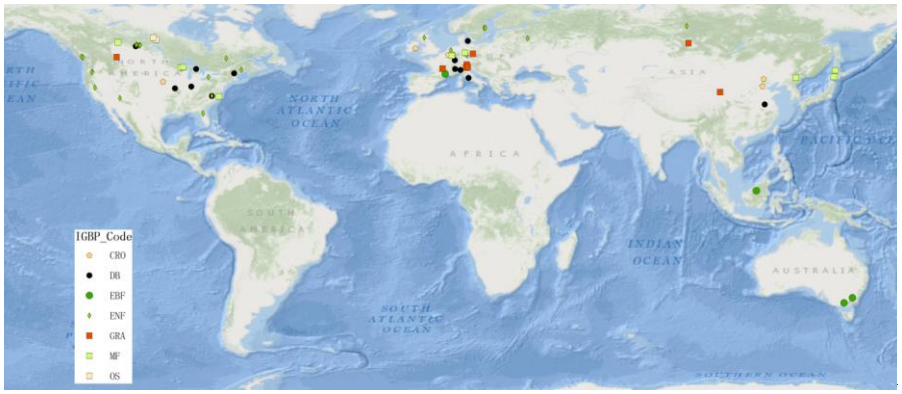


Fig. 8 Relationships between the simulated ET using *Kc* from Table 1 (SET) and the measured ET (AET) for different vegetation surfaces. (a)~(f) stand for cropland (CRO), deciduous broad leaf forest (DBF), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland(OS). All the determination coefficient (R^2) listed in the figure were significant (p<0.001).

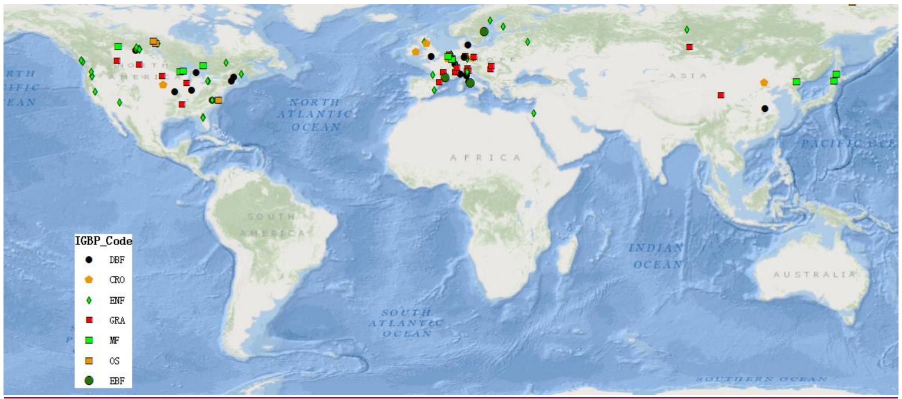
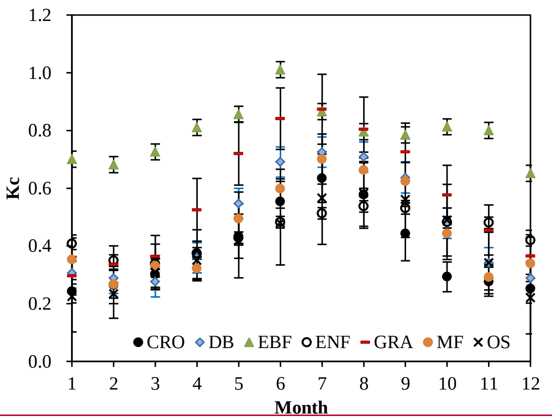
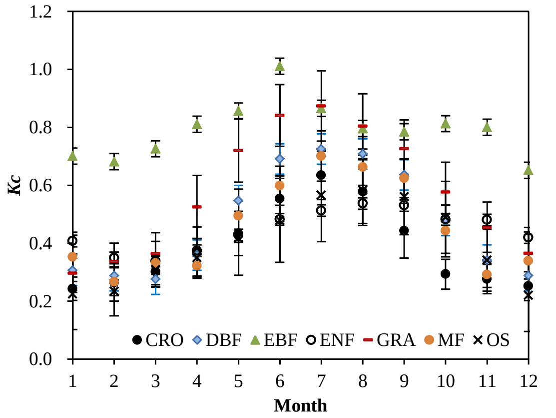
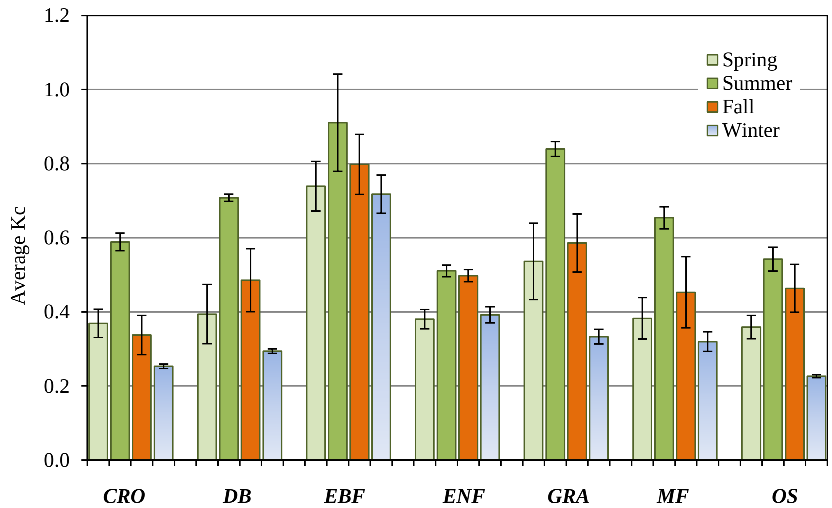


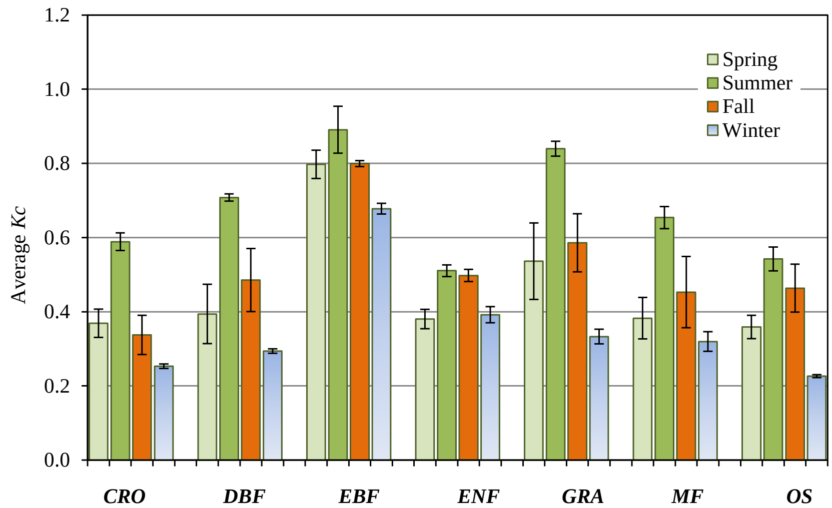
Fig. 1 Location of eddy flux sites from which climate and evapotranspiration data are collected.



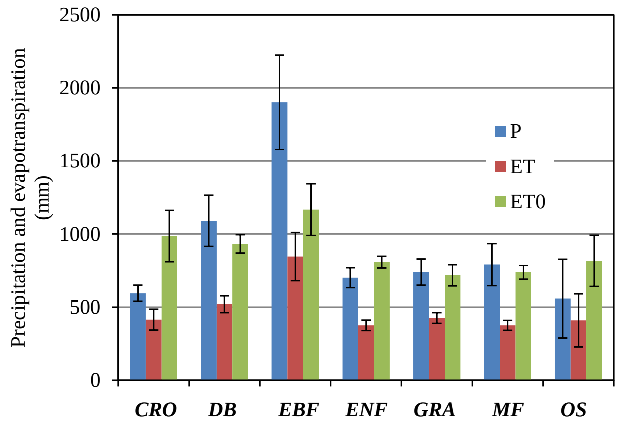


575 Fig. 2 The variation of *Kc* for the different IGBP_code. The error bras are stand errors among different sites.





580 Fig.3 Average *Kc* at spring, summer, fall and winter in different vegetation types. The error bras are stand errors among different sites. Spring is the month of February, March and April; Summer is the month of May, June and July; Fall is August, September and October; Winter is November, December and January.



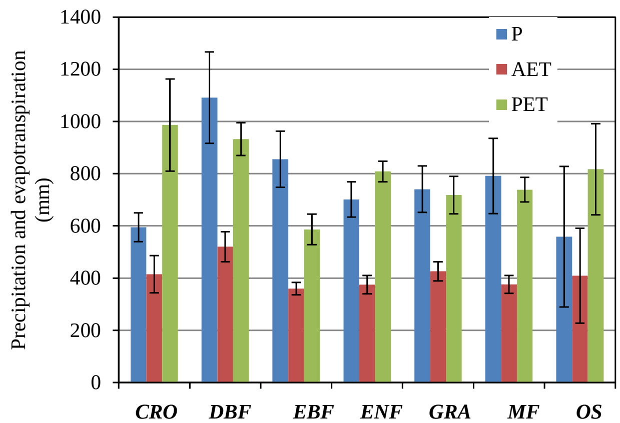


Fig.4 Annual total precipitation (P), ~~ET~~AET and ~~ET$_0$~~PET in different vegetation types. The error bras are stand errors among different sites.

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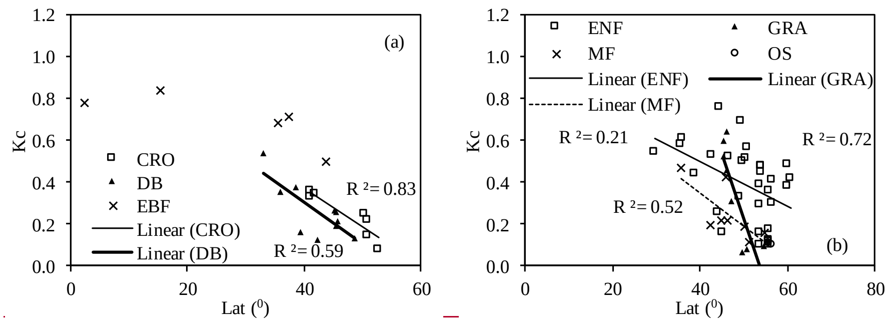

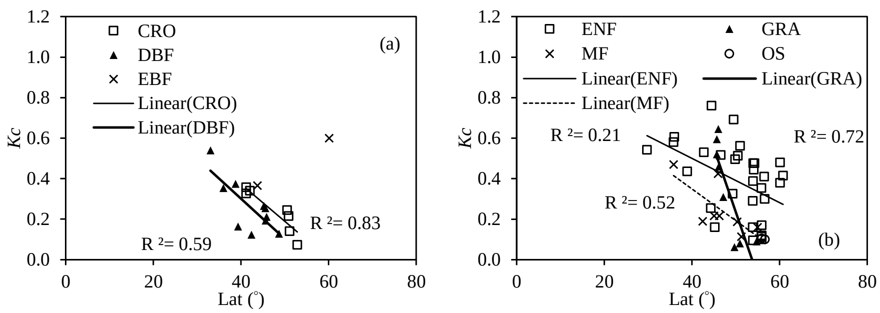

Fig. 5 ~~The average~~Variation of annual *Kc* ~~variation~~ at different latitude~~.~~ (Lat). (a) stand for cropland (CRO), deciduous broad leaf forest (~~DB~~DBF), evergreen broad leaf forest (EBF), and (b) evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). The absolute values of the latitude were used in EBF in the southern hemisphere sites and all the determination coefficient (R^2) listed in the figure were significant (p<0.05).

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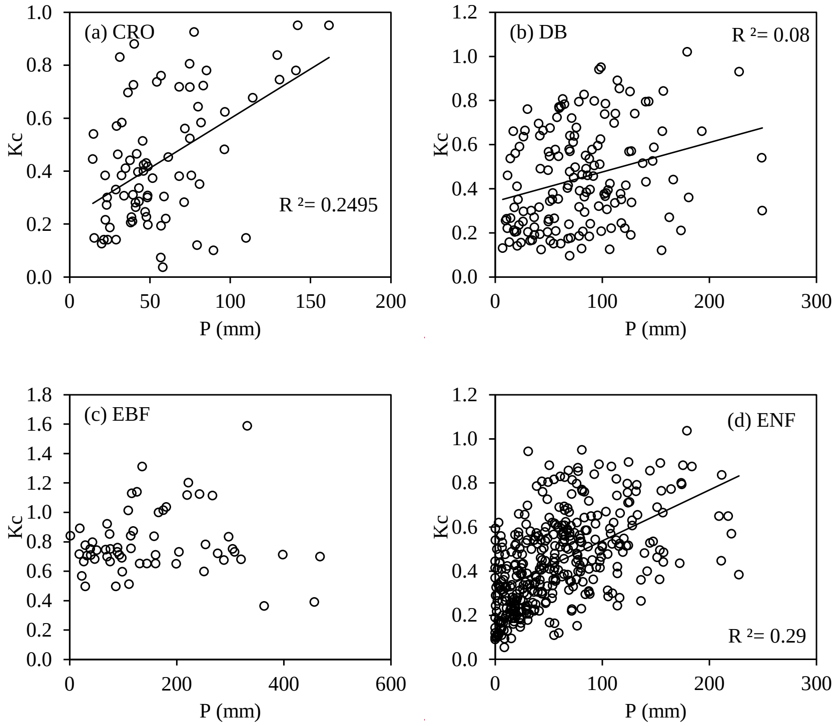
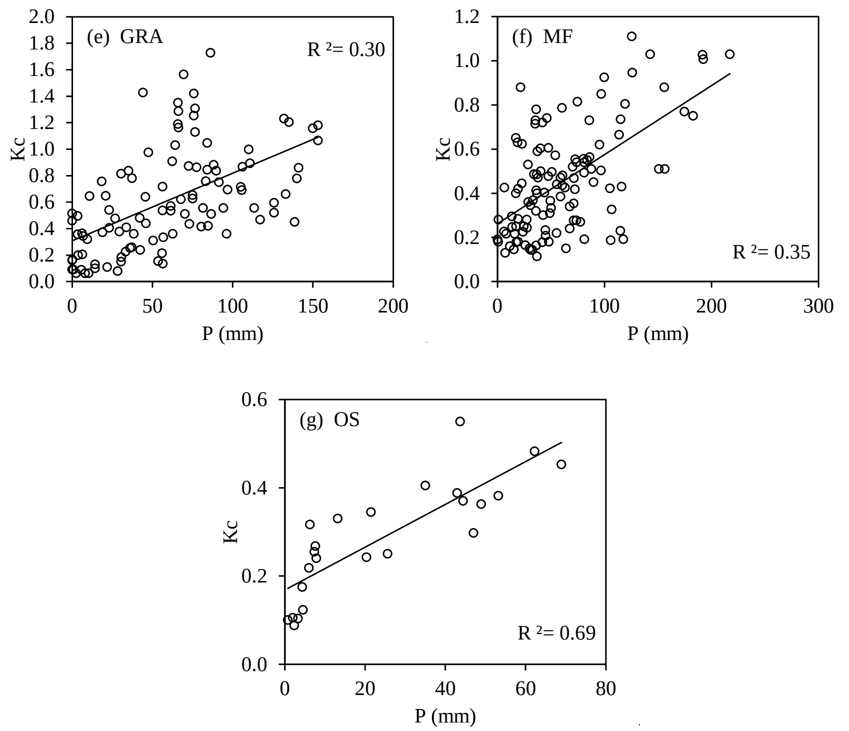
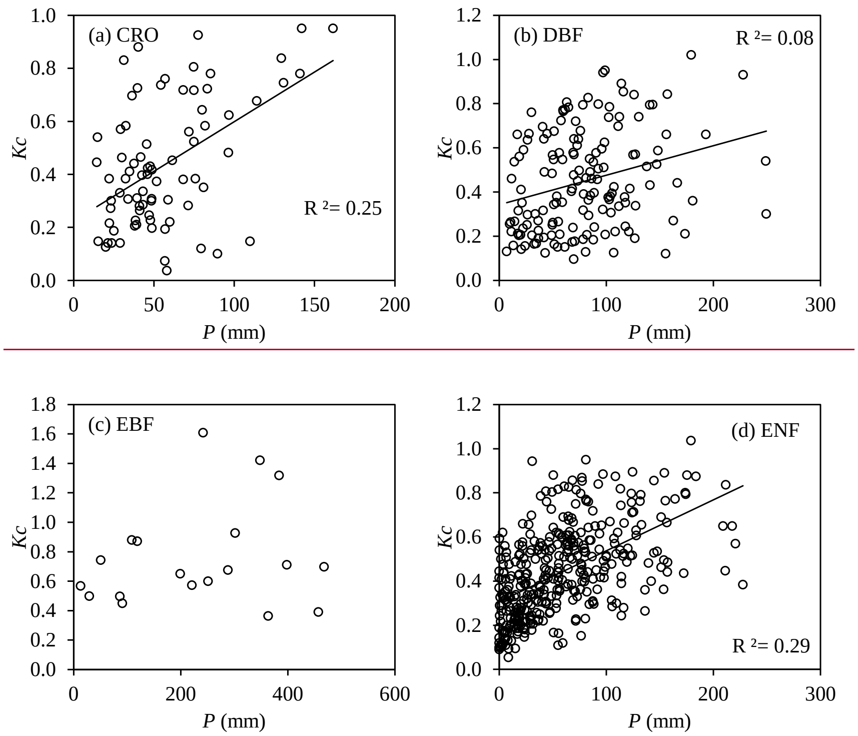

(a) CRO
R ²= 0.2495
Kc
P (mm)
(b) DB
R ²= 0.08
Kc
P (mm)
(c) EBF
Kc
P (mm)
(d) ENF
R ²= 0.29
Kc
P (mm)


(e) GRA
R ²= 0.30
Kc
P (mm)
(f) MF
R ²= 0.35
Kc
P (mm)
(g) OS
R ²= 0.69
Kc
P (mm)



(a) CRO
R ²= 0.25
Kc
P (mm)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
(b) DBF
R ²= 0.08
Kc
P (mm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
(c) EBF
Kc
P (mm)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
(d) ENF
R ²= 0.29
Kc
P (mm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300

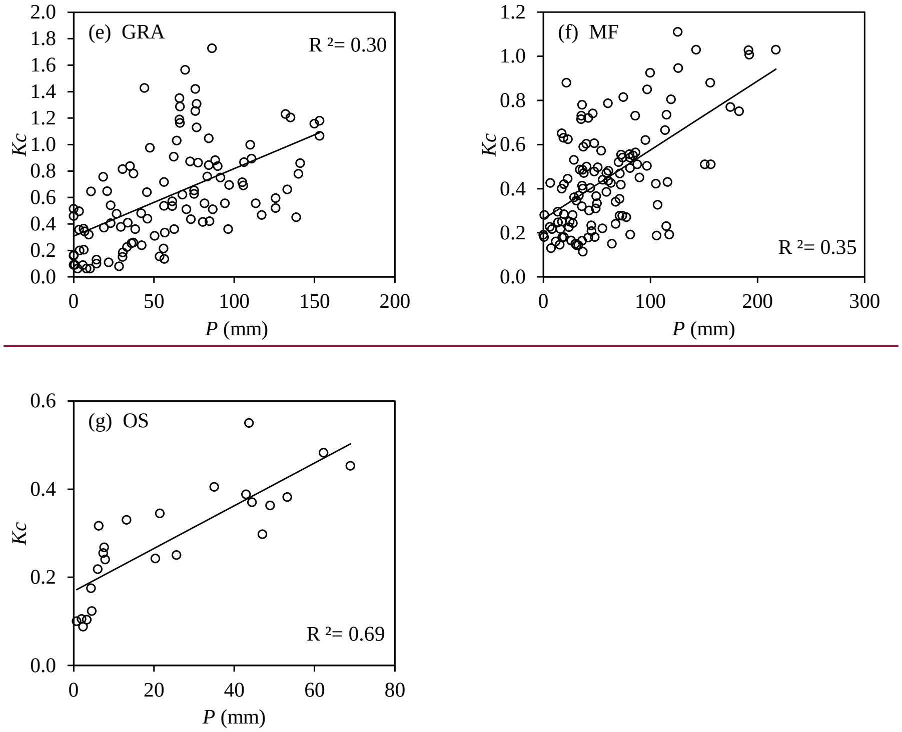
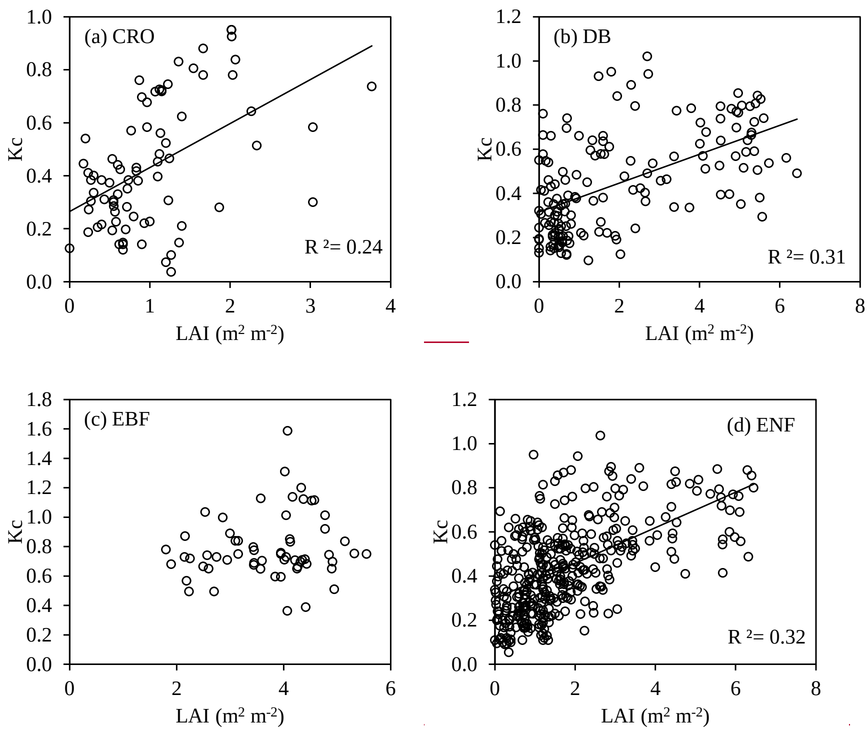
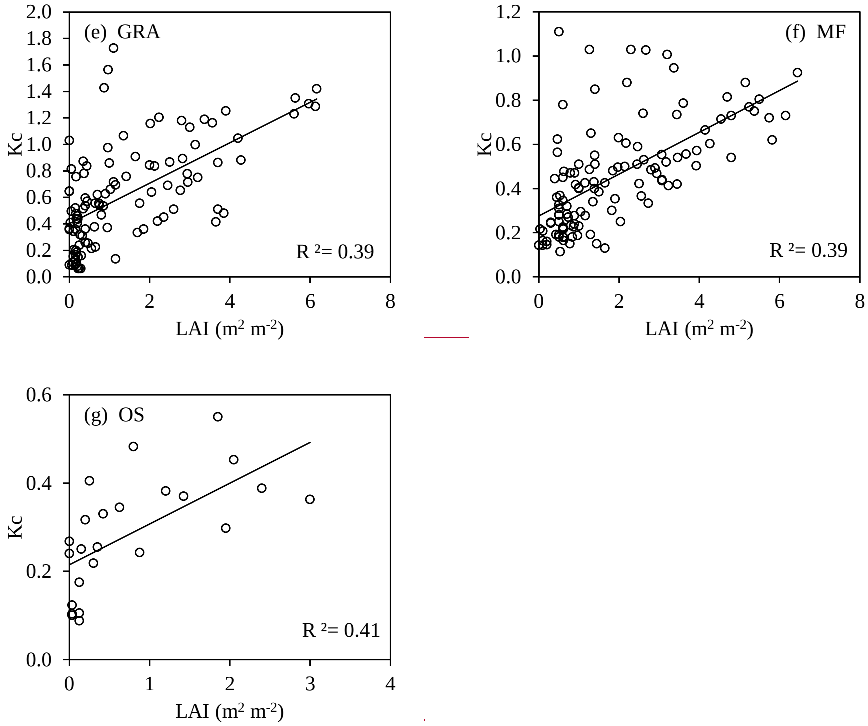
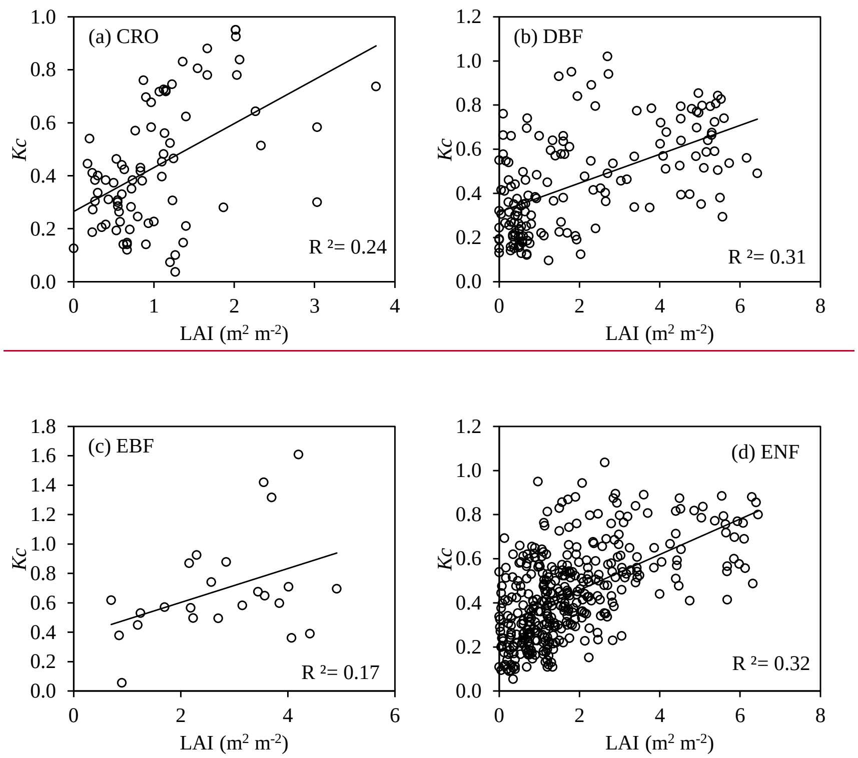


Fig. 6 Relationships between the average monthly *Kc* and the total monthly precipitation (P, mm) for different vegetation surfaces. (a)~(g) represent for cropland (CRO), deciduous broad leaf forest (~~DB), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). All the determination coefficient (R^2) listed in the figure were significant (p<0.001)~~


(a) CRO
(b) DB
(c) EBF
(d) ENF
Kc
LAI (m² m⁻²)
R ²= 0.24
R ²= 0.31
R ²= 0.32



DBF~~Fig. 7 Relationships between the average monthly *Kc* and leaf area index for different vegetation surfaces. (a)~(g) stand for cropland (CRO), deciduous broad leaf forest (DB~~), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). All the determination coefficient (R^2) listed in the figure were significant (p<0.001)


(a) CRO
R ²= 0.24
Kc
LAI (m² m⁻²)
(b) DBF
R ²= 0.31
Kc
LAI (m² m⁻²)
(c) EBF
R ²= 0.17
Kc
LAI (m² m⁻²)
(d) ENF
R ²= 0.32
Kc
LAI (m² m⁻²)

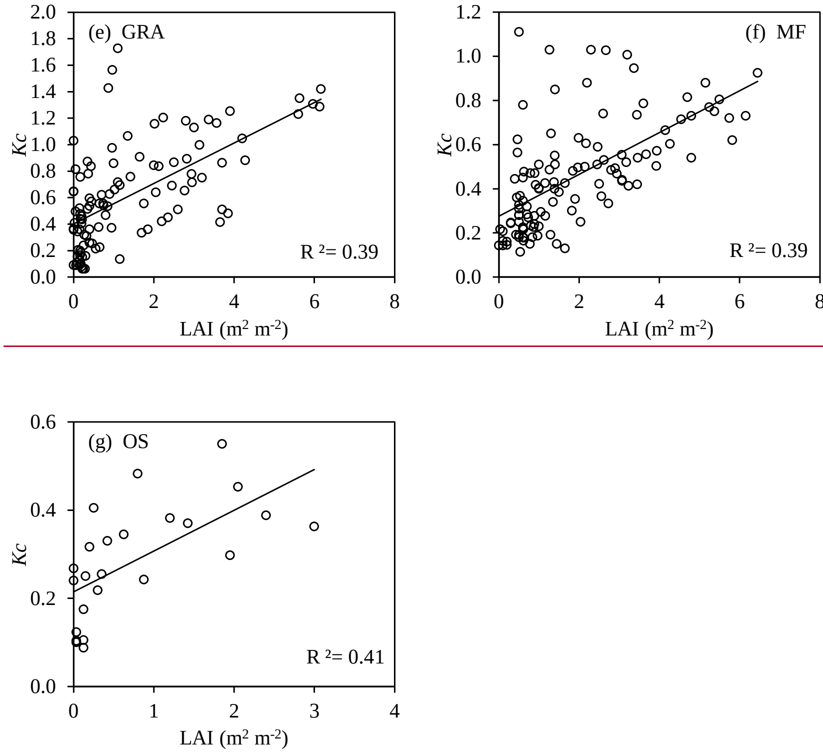
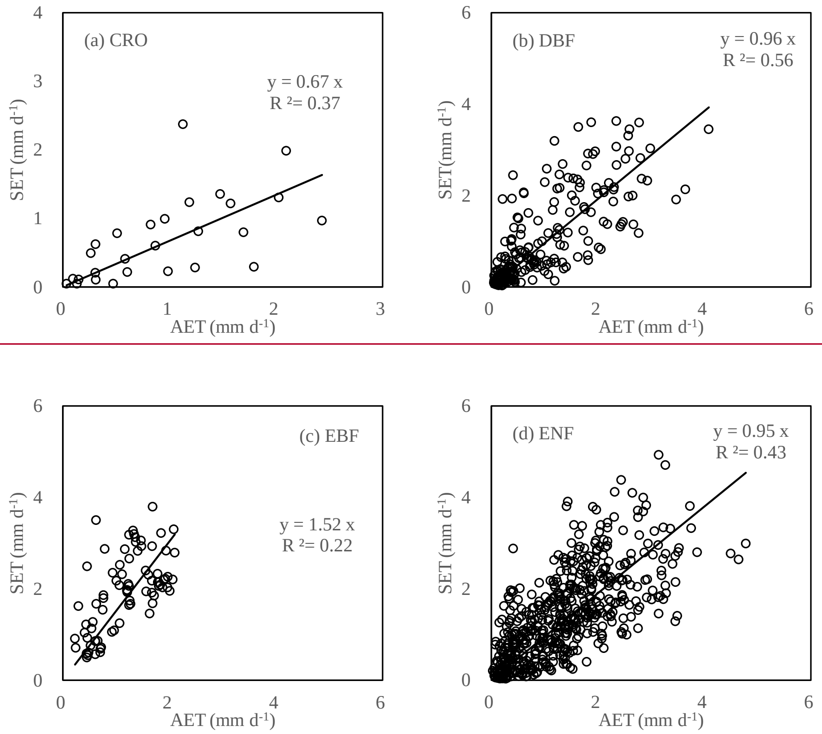


Fig. 7 Relationships between the average monthly *Kc* and leaf area index for different vegetation surfaces. (a)~(g) stand for cropland (CRO), deciduous broad leaf forest (DBF), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). All the determination coefficient (R^2) listed in the figure were significant (p<0.05)


(a) CRO
y = 0.67 x
R ²= 0.37
SET (mm d-1)
AET (mm d-1)
(b) DBF
y = 0.96 x
R ²= 0.56
SET(mm d-1)
AET (mm d-1)
(c) EBF
y = 1.52 x
R ²= 0.22
SET (mm d-1)
AET (mm d-1)
(d) ENF
y = 0.95 x
R ²= 0.43
SET (mm d-1)
AET (mm d-1)

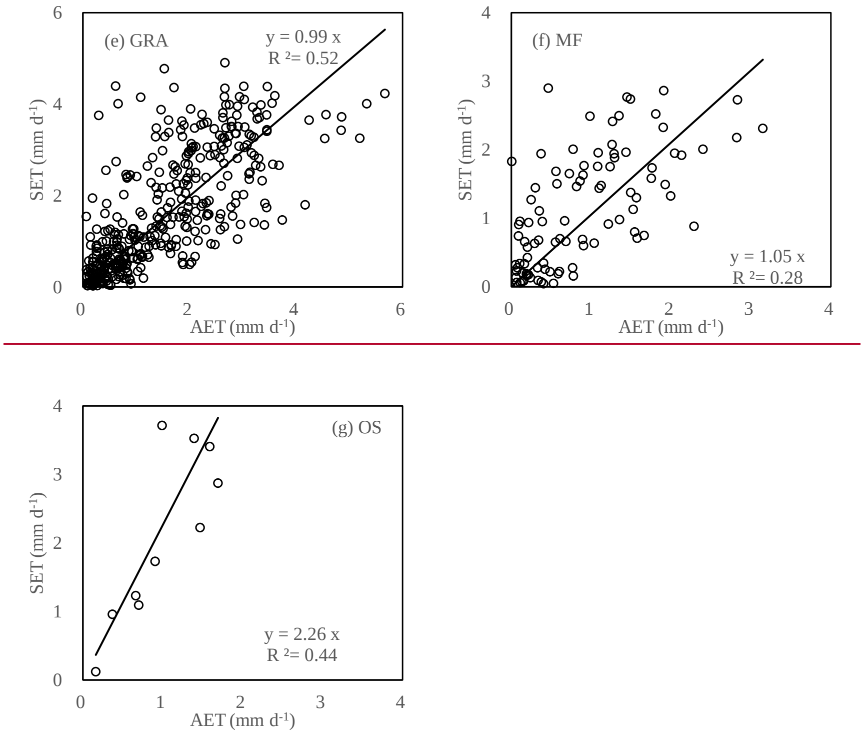


Fig. 8 Relationships between the simulated ET using *Kc* from Table 1 (SET) and the measured ET (AET) for different vegetation surfaces. (a)~(f) stand for cropland (CRO), deciduous broad leaf forest (DBF), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland(OS). All the determination coefficient (R^2) listed in the figure were significant (p<0.001).