DOI: 10.1007/s11430-006-8241-2

A comparison between simulated and measured CO_2 and water flux in a subtropical coniferous forest

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Received October 27, 2005; accepted March 10, 2006

Abstract Using data from eddy covariance measurements in a subtropical coniferous forest, a test and evaluation have been made for the model of Carbon Exchange in the Vegetation-Soil-Atmosphere (CEVSA) that simulates energy transfers and water, carbon and nitrogen cycles based on ecophysiological processes. In the present study, improvement was made in the model in calculating LAI, carbon allocation among plant organs, litter fall, decomposition and evapotranspiration. The simulated seasonal variations in carbon and water vapor flux were consistent with the measurements. The model explained 90% and 86% of the measured variations in evapotranspiration and soil water content. However, the modeled evapotranspiration and soil water content were lower than the measured systematically, because the model assumed that water was lost as runoff if it was beyond the soil saturation water content, but the soil at the flux site with abundant rainfall is often above water saturated. The improved model reproduced 79% and 88% of the measured variations in gross primary production (*GPP)* and ecosystem respiration (R_e), but only 31% of the variations in measured net ecosystem exchange (*NEP*) despite the fact that the modeled annual *NEP* was close to the observation. The modeled *NEP* was generally lower in winter and higher in summer than the observations. The simulated responses of photosynthesis and respiration to water vapor deficit at high temperatures were different from measurements. The results suggested that the improved model underestimated ecosystem photosynthesis and respiration in extremely condition. The present study shows that CEVSA can simulate the seasonal pattern and magnitude of CO_2 and water vapor fluxes, but further improvement in simulating photosynthesis and respiration at extreme temperatures and water deficit is required.

Keywords: ecosystem CO_2 and water flux, CEVSA, eddy covariance, subtropical coniferous forest.

Accurate estimates of carbon and water fluxes between ecosystem and atmosphere are important in assessing the role of terrestrial ecosystem in the global carbon and water cycle. Process-based ecosystem models are one of the important approaches and tools for studying ecosystem carbon and water cycles and their responses to the ongoing environmental changes. Farquhar and Caemmerer's photosynthesis model [1] and its linkage to a photosynthetically dependent stomatal conductance algorithm [2,3] provide a theoretical framework for the ecosystem mechanical models to simulate ecosystem carbon and water cycle based on the experiments of leaf and plant levels. However, the models had been used in regional and global scales, and the validation at the levels of canopy and ecosystem is lacking before the early 1990s. Since the mid-1990s, large environment-controlled experiments and the use of eddy covariance technique provided continuous and long-term carbon and water flux data in vegetation canopy level [4−11]. These data can be used in the improvement and validation of ecosystem mechanical models. In FLUXNET, there are about 10 sites with continuing measurements over 10 years, and over 100 sites with over 5 years records of eddy fluxes [12]. In China Terrestrial Ecosystem Flux Research Network (ChinaFLUX), over 3 years of carbon and water fluxes for 8 typical ecosystems have been measured by using eddy covariance technique [13]. While the comparison between flux measurement and model simulation is still in its initial stage[14−16], more attention should be paid to the understanding of the mechanisms that couple the carbon and water cycle in vegetation canopy level and could be served as the foundation for developing new generation mechanistic models. The objective of this study is to provide a basis for accurately evaluating and assessing canopy scale variations of terrestrial carbon and water fluxes in space and time and possible mechanisms of their control and management by using mechanical ecosystem models.

CEVSA is an ecosystem mechanical model to simulate energy transfers and water, carbon and nitrogen cycles based on eco-physiological processes. It has been used to simulate the spatio-temporal variation of terrestrial ecosystem carbon cycle and its response to climate change at the scales of regional and global[17−21]. The CEVSA model has been validated by using the data obtained from leaf and plant physiological experiments, primary production observation in plots and remote sensing data; however, the description of water and carbon fluxes have not yet been evaluated and validated at canopy and ecosystem levels. Now, the available long-term and continuous eddy covariance flux measurements have made such an evaluation and validation possible. To improve the reliability and credibility of the model simulation, two issues need to be examined: whether the model based on the leaf ecophysiological processes could calculate accurately the photosynthesis and evapotranspiration in canopy level by integration, and whether it could simulate the component fluxes of carbon and water cycle (e.g. carbon assimilation by photosynthesis, respiration, evapotranspiration and latent and sensible heat). The planted coniferous forest ecosystem in Qianyanzhou Observation Station was selected for this study. The Station located within the typical subtropical monsoon climate region; however, the precipitation and temperature in growing season are not synchronized. The forest ecosystem has been affected by frequent drought from June to August, and the lower precipitation from June to August in 2003 was obviously lower than the precipitation in the same period of past previous years. The stress from high temperature and drought was severe in Qianyanzhou in 2003[22]. It has been a great challenge for simulating the processes in ecosystems that have a substantial amount of carbon uptake during the none-growing season and their photosynthesis in growing season is limited by the stomatal closure controlled by water deficit[23]. In this paper, we present improvements of the model and associated parameterization, validate the improved model through a comparison between eddy covariance measurements and simulated canopy scale carbon and water exchange, and discuss the possible future improvement of the model.

1 Model description

The CEVSA incorporates three submodels: (1) the biophysical submodel calculating evapotranspiration, soil moisture, and stomatal conductance; (2) the vegetation submodel estimating vegetation distribution and calculating net primary production (*NPP*), carbon allocation and litter production; and (3) the biogeochemical submodel simulating the decay of litter, the transformation and decomposition of soil organic carbon, and nitrogen mineralization[18]. The CEVSA model simulates synthesis of the biophysical and biogeochemical processes between vegetation, soil and the atmosphere. The CEVSA model is driven by climate and soil variables with a 10-day time step and needs only a small number of parameters. A description of the improved model and its parameterization is presented in the following sections.

1.1 Photosynthesis and stomatal conductance

The model simulates plant CO_2 assimilation that is determined by the efficiency of the photosynthetic enzyme system and the stomatal conductance to CO_2. The stomatal behavior is described by the improved Ball-Berry model that includes the effect of soil moisture.

$$A_b = \min(W_c, W_j, W_p)\left(1 - \frac{0.5P_0}{\tau P_c}\right) - R_d, \quad (1)$$

$$A_d = \frac{g_s}{160}(P_a - P_c), \quad (2)$$

$$g_s = \left(g_0(T) + g_1(T)\frac{AR_h}{P_a}\right)k_g(w_s), \quad (3)$$

where A_b and A_d represent the assimilation rate determined by enzyme system and stomatal conductance, respectively; g_s is stomatal conductance to water vapor; W_c is the carboxylation rate controled by Rubisco, and W_j is the carboxylation rate depended on the rate of electron transport, and W_p is the carboxylation rate limited by triose phosphate utilization. The variables P_0 and P_c are the internal partial pressures of O_2 and CO_2 respectively; τ is the specificity factor of Rubisco for CO_2 relative to O_2, and R_d is the rate of respiration in light due to processes other than photorespiration. P_a is the partial pressure of CO_2 in the leaf surface. R_h is relative humidity of the air surrounding the leaf. The parameter g_0 is the stomatal conductance when A_d is zero at the light compensation point, and g_1 is an empirical sensitivity coefficient. $k_g(w_s)$ is a hyperbolic response function which describes the influence of soil water content w_s on stomatal conductance g_s.

1.2 Evapotranspiration and soil water dynamics

Penman-Monteith equation was used to calculate the canopy evapotranspiration. Soil water content variation is the balance of precipitation income and evapotranspiration loss in the soil. The model took into account of the effect of runoff, soil characteristics, and canopy interception on soil water content.

$$ET = \frac{sR_n + c_p \rho g_a D}{\lambda(s + \gamma(1 + g_a / g_n))}, \quad (4)$$

$$\frac{dw_s}{dt} = Rain - ET - Runoff, \quad (5)$$

where c_p is the specific heat of air; g_n is the stomatal conductance; g_a is the boundary layer conductance; R_n is the net radiation; γ is the psychrometric constant; λ is the latent heat of vaporization; ρ is the mean air density at constant pressure; D is vapor pressure deficit; s is the slope of saturation vapour pressure curve under standard air temperature; w_s is the soil water content; *Rain*, *ET* and *Runoff* are the rainfall reaching the ground, evapotranspiration and runoff, respectively.

1.3 Carbon allocation

Plant carbon allocation is simulated based on the assumption that ecosystems acclimate to environmental conditions in the direction of enhancing the acquisition of the most limiting resources resulting in a maximization of growth. We modified the allocation submodel according to the CTEM model[24] that took into account of the effect of light and water stress on carbon allocation. We also adjusted the allocation regime in different growth periods based on the seasonal change of evergreen coniferous forest growth in Qianyanzhou station [25]. All NPP is allocated to leaves during a leaf onset season, and the allocation during a growing season is shared among leaves, stem and roots. The carbon allocation to leaves ceases at the beginning of leaf offset [24].

The allocation of assimilated product to stem (a_S), root (a_R) and leaf (a_L) is calculated as follows:

$$a_S = \frac{\varepsilon_S + \omega(1 - L)}{1 + \omega(2 - L - W)}, \quad (6)$$

$$a_R = \frac{\varepsilon_R + \omega(1 - W)}{1 + \omega(2 - L - W)}, \quad (7)$$

$$a_L = \frac{\varepsilon_L}{1 + \omega(2 - L - W)} = 1 - a_S - a_R, \quad (8)$$

where ε_S, ε_R, ε_L and ω are plant function type (PFT) dependent parameters following the rule of $\varepsilon_S + \varepsilon_R + \varepsilon_L = 1$. L and W represent light and water availability, respectively.

Plant must have sufficient woody biomass to support the mass of leaves, and the structure needs to be maintained by the proper allocation of carbon among leaves, stem, and roots. The relationship between green biomass (leaves) and the remaining biomass (stems and roots) is[24]

$$(C_S + C_R) = \varepsilon C_L^k, \quad (9)$$

where C_S, C_L and C_R are the carbon in the stems, leaves and roots, respectively; and ε and k are PFT-dependent constants. Roots uptake water and nutrients but also provide mechanical support and stability to the plant and carbon is allocated to roots at the expense of stem and leaves in order to maintain this structural feature, so it needs a minimum root : shoot ratio[24].

1.4 The simulation of leaf area index (LAI)

In previous version of CEVSA model, the simulation of LAI dynamics was the same as in DOLY model[26], in which LAI was adjusted to reach the maximum value such that both hydrological and primary productivity constraints are satisfied. This method, however, cannot reflect the seasonal change of canopy LAI. In this study, we simulate the temporal variation of LAI by calculating the carbon balance of leaves. The LAI value in a ten-day period is

$$LAI_n = LAI_{n-1} + m_l \times SLA, \quad (10)$$

where LAI_n and LAI_{n-1} are leaf area index at the nth and $n-1$th ten-day, respectively; SLA is specific leaf area; and m_l is the net increase of biomass at the nth ten-day calculated as the difference between the biomass allocated to leaves and biomass loss due to litter fall.

1.5 Soil carbon and nitrogen dynamics

The CEVSA model divided litter and soil organic matter into 8 carbon pools. Each pool has its own decay rate that is determined by soil carbon characteristic, temperature, moisture, nitrogen availability, and texture. The heterotrophic respiration (R_h) and nitrogen mineralization (N_a) are given as

$$R_h = \sum_1^8 SOC_i K_i (1 - a_i), \quad (11)$$

$$N_a = \sum_1^8 SOC_i K_i ((N/C)_i), \quad (12)$$

where $i = 1, 2, \cdots, 8$, refers to the 8 different carbon pools; SOC is the size of the carbon pools; K is the potential decay rate; a is the assimilation efficiency and N/C is the ratio of N to C.

1.6 Parameterization of the model

The CEVSA model parameterization was based on the data observed in Qianyanzhou site and related literatures. The CEVSA model needs vegetation parameters such as vegetation type, vegetation carbon, and initial LAI; soil parameters such as soil N : C ratio, soil carbon, initial soil water content, and the composition of soil particles. When the model is applied in regional and global scales, parameters will come from the output of the static version of the CEVSA model. When the model is validated using eddy covariance measurements, the site observation should be used as model input and parameters. The parameters determined by soil texture such as soil moisture at field capacity, saturated soil moisture, soil moisture at wilt point, and soil optimum moisture for decomposition will also be needed. We estimated these parameters based on the data provided by McGuire *et al.* [27] and Cao & Woodward [18]. Table 1 lists the main model parameter values.

2 Site characteristics and data collection

The experimental site is located in Qianyanzhou Experimental Station (115°04′13″E, 26°44′48″N) of Red Earth Hilly Comprehensive Development of Chinese Ecosystem Research Network (CERN), Chinese Academy of Sciences. It belongs to a typical red soil hill region in the sub-tropical monsoon climate zone. Mean annual air temperature is 18.6℃. Mean annual precipitation is 1488.8 mm, and evapotranspiration is 1110.3 mm. The site contains a coniferous mixed forest, which was planted in 1983. The dominant species are *Pinus elliottii*, *Pinus massoniana*, *Cunninghamia lanceolata,* and *Schima superba*. The mean stumpage height is about 10.8 m. Because of the high degree of crown closure, the vegetation under canopy is poorly developed [22, 28, 32]. The observation tower is 42.0 m high, and we validated the carbon and water flux simulation of CEVSA model by using the open-path eddy covariance (OPEC) system observation data installed at the height of 39.6 m. The eddy flux measurements and data processing procedure can be found in Wen [22].

Fig.1 shows that Qianyanzhou site has experienced high temperature and severe drought in 2003 summer, and the annual precipitation is only about 60% of historical mean value. In the growing season, abundant rainfall occurred only in May and August but not in

Table 1 Main parameters in CEVSA model

Parameter	Description	Value	Source
Lon	longitude	115.07	[28]
Lat	latitude	26.73	[28]
VGTY	vegetation type	evergreen coniferous forest (1)	CERN
VEGC ($gC \cdot m^{-2}$)	vegetation carbon	10931	CERN, [29]
iLAI ($m^2 \cdot m^{-2}$)	initial LAI	3.2	[30], Modis
YSMC ($gC \cdot m^{-2}$)	soil carbon	12949	CERN, [29]
YSAN ($gN \cdot m^{-2}$)	soil available nitrogen	22.0	CERN
rato	soil N:C ratio	0.063	CERN
INSWC (mm)	initial soil water content	429	flux data
SAND, SILT, CLAY (%)	percent of soil particle	0.20, 0.62, 0.18	CERN
MSAT (mm)	saturated soil water content (volume)	0.42	CERN
whc (mm)	soil moisture at field capacity (volume)	0.25	CERN
Wilt (mm)	soil moisture at Wilt point (volume)	0.12	CERN
WFC (%)	soil moisture at field capacity (mass)	61.0	CERN
SMOPT (%)	soil optimum moisture for decomposition	68.0	CERN
SMIE	parameter	−0.29	CERN
SMAT	parameter	0.53	CERN
SLA ($m^2 \cdot gC$)	specific leaf area	0.025	[31]
ω	allocation parameter	0.50	[24]
ε_L	allocation parameter	0.06	[24]
ε_S	allocation parameter	0.05	[24]
ε_R	allocation parameter	0.89	[24]

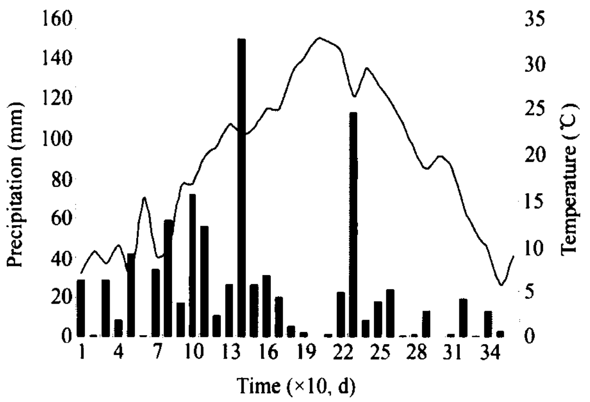

Fig.1. Seasonal change of temperature and precipitation in Qianyanzhou site in 2003.

other months such as only 3.2 mm precipitation in July. So the growth of plant is heavily constrained by the severe drought and high temperature.

3 Results and discussion

3.1 Comparison between simulated and measured carbon and water fluxes

Table 2 shows the main variables measured by eddy covariance and modeled by CEVSA. While modeled evapotranspiration (*ET*) is lower than the observation, the simulated gross primary productibity (*GPP*), ecosystem respiration (R_e) and net ecosystem productivity (*NEP*) are all slightly higher than the measured.

In 2003, *ET* showed a two-peak pattern because of summer drought, and soil water content (*SWC*) continues to decrease after June. We compared the simulated *SWC* with the measurements within 50cm depth. Our results showed that the simulated *ET* and *SWC* are consistent with the observations (Fig. 2). The model explained 90% and 86% of the measured variations in *ET* and *SWC*, respectively, and represented well the seasonal change of water flux. The modeled *ET* values were lower than observations after later July and displayed a time-lag of two ten-day period from the observation. After the rain process in August, the increase of simulated *ET* synchronized with the observed water flux data. The increase and decrease of model calculation of *SWC* is also compared well with measurements.

The net ecosystem productivity (*NEP*) is the difference between gross primary productivity (*GPP*) and ecosystem respiration (R_e), namely $NEP = GPP - R_e$. Model test is not only on the accuracy in simulated CO_2 flux, but also in the simulated CO_2 flux components *GPP* and R_e. The simulated and measured *GPP*

Table 2 Calculation of main variables in CEVSA and compared with flux measurements

Variable	Description	CEVSA	Measured
GPP ($gC \cdot m^{-2}$)	annual gross primary productivity	1710.00	1610.38
NPP ($gC \cdot m^{-2}$)	annual net primary productivity	817.30	–
R_g ($gC \cdot m^{-2}$)	growth respiration	204.33	–
R_{ml} ($gC \cdot m^{-2}$)	leaf maintenance respiration	62.43	–
R_{ms} ($gC \cdot m^{-2}$)	sapwood maintenance respiration	637.32	–
R_a ($gC \cdot m^{-2}$)	autotrophic respiration	904.07	–
R_h ($gC \cdot m^{-2}$)	heterotrophic respiration	423.3	–
R_e ($gC \cdot m^{-2}$)	annual ecosystem respiration	1327.37	1223.24
NEP ($gC \cdot m^{-2}$)	annual net ecosystem productivity	394.00	387.15
LTTFC ($gC \cdot m^{-2}$)	annual liferfall	303	–
YRETA (mm)	annual evapotranspiration	599.47	815.69
YRGSN ($mm \cdot s^{-1}$)	annual average canopy stomatal conductance	7.26	–

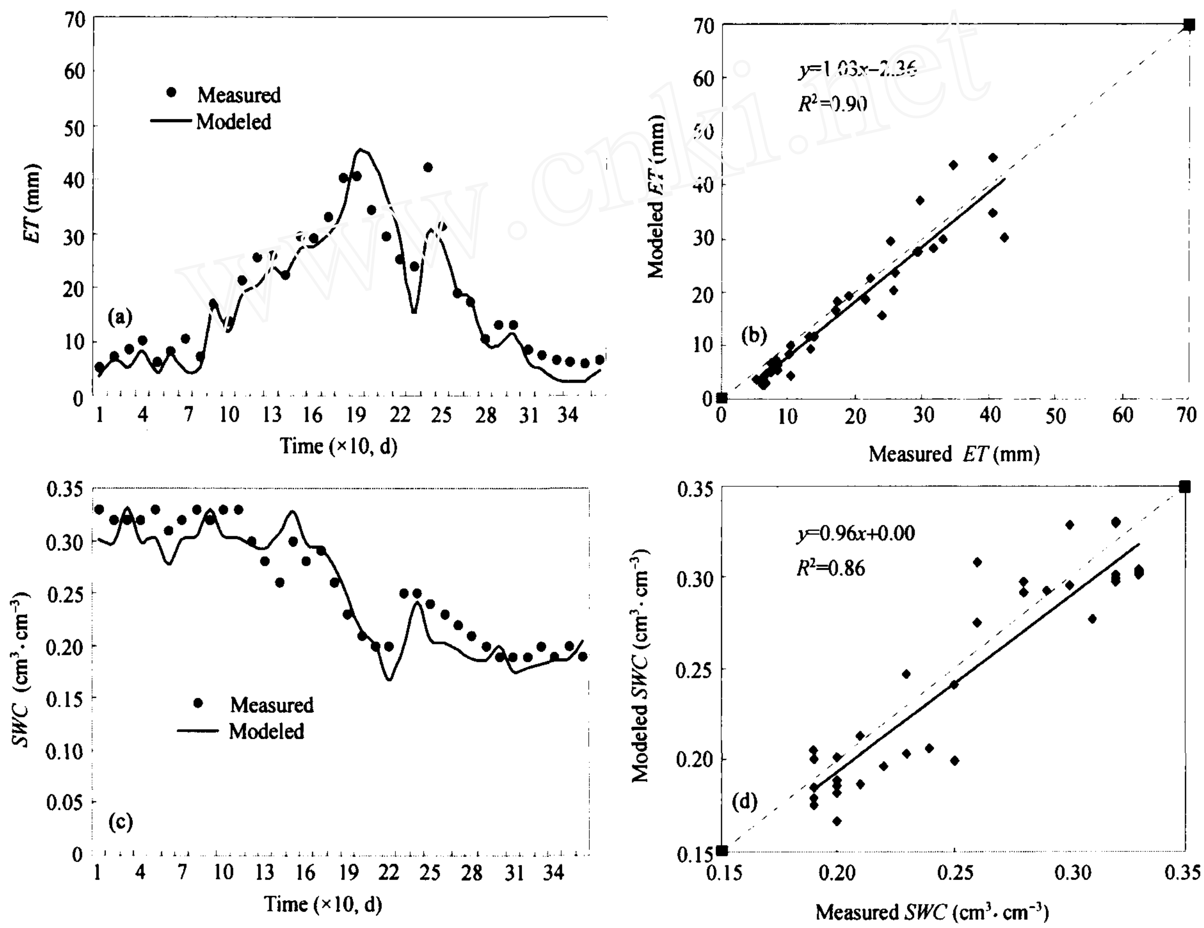

Fig. 2. Comparison between modeled and measured ten-day ecosystem *ET* (a) and *SWC* (c) in Qianyanzhou in 2003. (b) and (d) show the modeled and measured ten-day *ET* and *SWC* and the 1:1 lines, respectively.

and R_e compared well on the pattern of seasonal change (Fig. 3 (a), (c)), and the model reproduced 79% and 88% of the observed variations in *GPP* and R_e respectively (Fig. 3 (b), (d)). However, the model predictions underestimated *GPP* and R_e in winter and overestimated the flux in summer. A time-lag was showed between the simulated and observed responses of modeled *GPP* and R_e to water deficit. Simulated *GPP* and *NEP* decrease in early July and the simulated R_e decreases in later July, which were 1 and 2 ten-day period delayed in comparing with the measurements, respectively. However, the increase of *GPP* and R_e following the rain day is consistent with the increase of flux measurements.

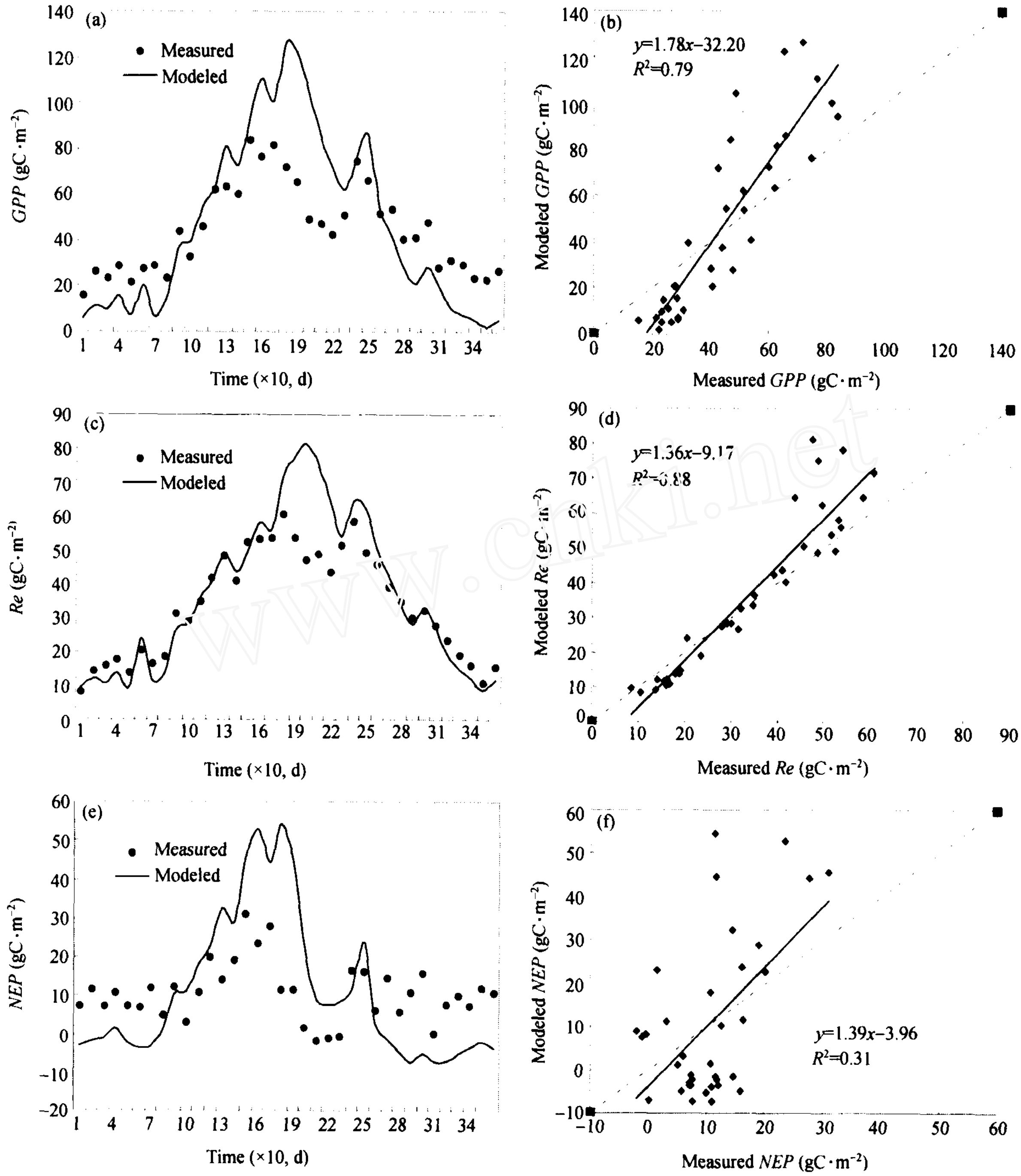

Fig. 3. Comparison between modeled and measured ten-day *GPP* (a), R_e (c) and *NEP* (e) in Qianyanzhou in 2003. (b), (d) and (f) show the modeled and measured ten-day *GPP*, R_e and *NEP* and the 1∶1 lines, respectively.

Simulated by using the CEVSA model, *NEP* in Qianyanzhou in 2003 was calculated as 394 $gC·m^{-2}$, which is very close to the measured value of 397.15 $gC·m^{-2}$. Fig. 3(e) shows that the season change patterns of *NEP* to the variations of temperature and precipitation were well represented by the CEVSA simulation results. However, the simulated results only explained 31% of the observed variation in *NEP* (Fig. 3 (f)), and there is more scatter in calculated and observed *NEP*. Similar to the estimates of *GPP* and R_e presented previously, the model underestimated *NEP* in winter and overestimated it in summer. The model predicted the summer drought effect on carbon exchange, but underestimated *NEP* due to the time-lag in predicting summer water deficit. Thus there is a need to improve the representation of response of CO_2 flux to environmental change in CEVSA model. There is greater disparity between measured and modeled ten-day *NEP* resulting from errors in estimates of the photosynthesis and respiration components also because the values of *NEP* is much smaller than *GPP* and R_e[23,33].

3.2 Sources of errors in simulation

According to Baldocchi & Wilson[4] and Dufrene *et al.*[33], there are five major sources of errors in any models: (1) model parameters; (2) meteorological driving variables; (3) functional representation of the biophysical system; (4) time and space resolution of the model, and (5) errors in the flux observations being used for model validation. In this paper, we mainly discussed the accuracy of representation of ecophysiological processes in CEVSA model by comparing the simulated carbon and water vapor exchange with the observed. At the same time we discussed the sources of difference between simulated and observed carbon and water fluxes.

In order to find the sources of errors, we compared the responses of simulated and observed *ET*, *GPP* and R_e to temperature and vapor pressure deficit (*VPD*), respectively. The simulated *ET* and *SWC* showed a general trend of underestimation in comparison with observations. The comparison between response of simulated and observed of *ET* to temperature and *VPD* indicated a consistent trend with a systematic error (Fig. 4). This is because the model employed an assumption that water was lost as runoff if it was beyond the soil saturation water content, but this assumption was unfit to the soil condition at the flux site where abundant rainfall often results in over-saturated water content. Fig. 2(a) showed when there is large amount of precipitation following the severe summer drought and high temperature, the observed *ET* is higher than the model predicted. Thus, the model was unable to simulate the rapid change in *ET* that occurs following rain[34], and this is consistent with Law *et al.*[23]. This needs to be addressed in the further improvement of the model. In addition, the accuracy of flux measurements during and following rain could also be a problem with open-path infrared gas analyzers[23].

We also compared the responses of simulated and observed *GPP* and R_e to temperature and *VPD*. The result indicated that an exponential curve could explain the relationships of *GPP*, and R_e vs. temperature and a logarithm curve could explain the relationships of *GPP*, and R_e vs. *VPD* under the conditions that temperature is lower than 30℃ and *VPD* is under 1.5kPa (Fig. 5). Under high temperature and severe drought conditions, the observed *GPP* and R_e decreased with increasing *VPD* and temperature, and the main limiting factor to the carbon exchange between ecosystem and atmosphere is water deficit. However, the simulated *GPP* and R_e increased still with increasing *VPD* and temperature at this time, and the model did not simulate the influence of high temperature and water deficit on photosynthesis and respiration. Otherwise, the model underestimated the *GPP* under low temperature and *VPD*. Law *et al.*[23] repoted that some coniferous forests were capable of taking in carbon even when the freezing temperature is approached.

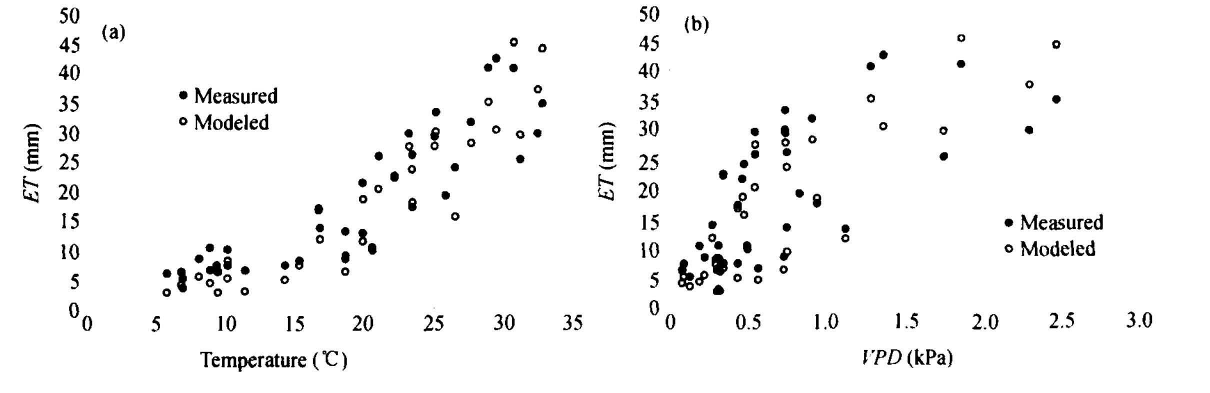

Fig. 4. The difference in response of simulated and observed *ET* to temperature (a) and *VPD* (b).

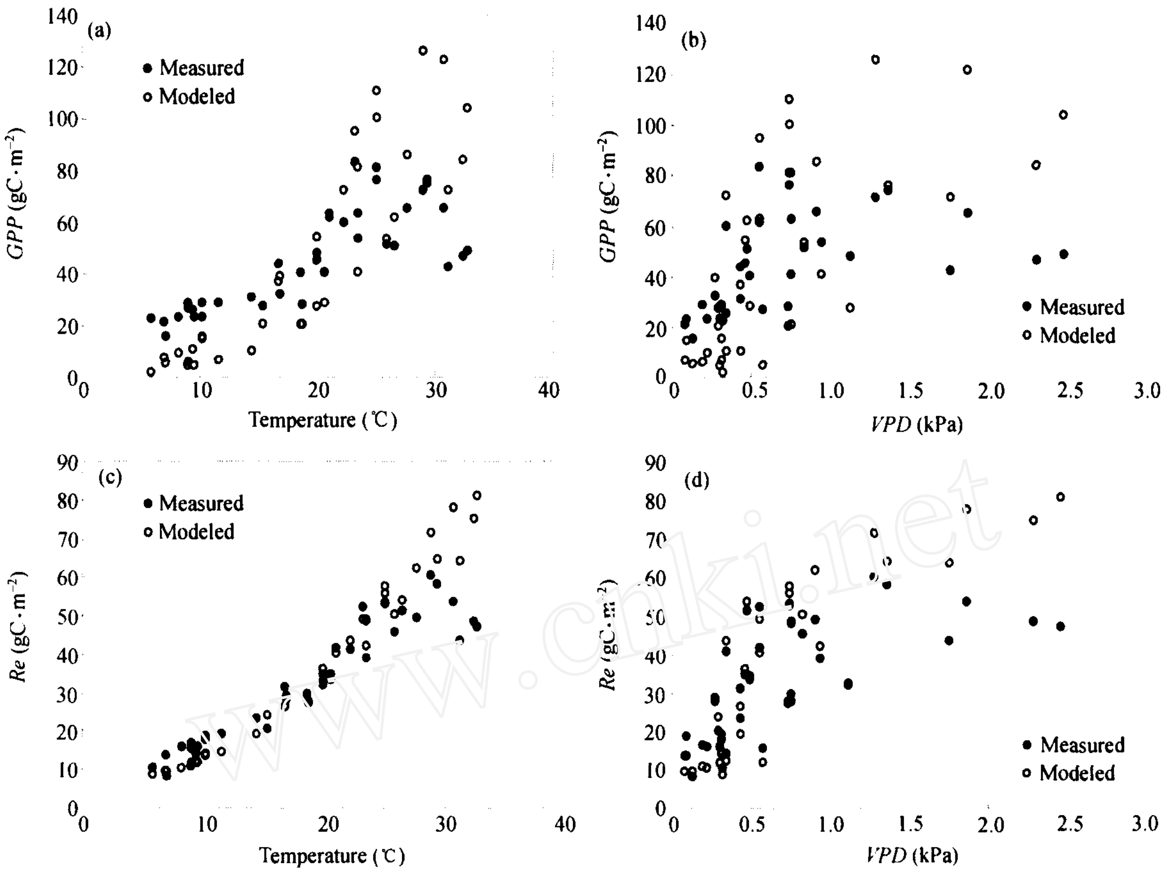

Fig. 5. The difference in response of simulated and observed *GPP* and R_e to temperature ((a), (b)) and *VPD* ((c), (d)), respectively.

Lowering the temperature optimum in winter and spring assumes that more photosynthesis can occur at lower temperature, and this could result in increased carbon uptake under low temperature when we changed the temperature optimum with change of daily temperature[23]. In the present version of CEVSA, temperature optimum for photosynthesis was constant throughout the year, so that the model could underestimate the ecosystem assimilation in winter. However, the seasonal change of temperature optimum for photosynthesis requires detailed ecophysiological studies. Consequently, more attention needs to be paid in seasonal change in temperature optimum for photosynthesis.

All the above analyses indicated that the CEVSA model represented well the seasonal change of carbon and water vapor exchange. However, the model could overestimate the net carbon uptake under high temperature and severe drought conditions in summer, and the model might be less capable in simulating the influence of water deficit on photosynthesis, respiration and stomatal behavior. Furthermore, the simulated responses of carbon and water flux to high temperature and water deficit had a time-lag with regard to the measured ones. These results indicated there are some errors in model representation of response of photosynthesis, respiration to temperature and water deficit, especially in extreme environmental conditions with high temperature and severe drought. The ability to simulate the sensitivity of mass and energy exchange to increasing temperature and water deficit is an important attribute in models used to predict climate change impacts on forest carbon and water exchange[35]. However, most ecosystem models are based on average of experimental results, and thus biased estimates are hardly eliminated especially under extreme environmental conditions. For example, Law *et al.*[23] and Grant *et al.*[35] reported that most of the models (such as SPA, CANPOND, BEPS, CLASS, etc.) were able to simulate the carbon and water exchange accurately in years which have normal precipitation and temperature, but these model underestimated the net loss of carbon under rising temperature and severe drought if the models were less capable of describing the influence of high temperature and water deficit on photosynthesis, respiration and stomatal behavior. We thus suggest that future model improvement should focus on the accurate representation on how the photosynthesis, stomatal conductance and respiration processes could respond to drought.

4 Summary

We adjusted and re-estimated CEVSA model parameters using the eddy flux and ecological measurements in Qianyanzhou to improve the simulation of allocation, litterfall, LAI dynamics. The results indicated that CEVSA can simulate the seasonal pattern and magnitude of CO_2 and water vapor fluxes; however, there is systematic bias between simulated and observed fluxes. The results suggested that further model improvement should be made in simulating the response of photosynthesis, stomatal conductance and respiration to water deficit at extreme temperatures, and the rapid evapotranspiration change following rain days. In the future, we should use eddy covariance measurements in different types of ecosystems to validate the CEVSA model. To test and validate the mechanistic models in canopy level provide basis for building new generation mechanistic ecosystem models for simulating cross-scale interactions and evaluating accurately carbon and water balance and spatial and temporal pattern of carbon sinks in regional and global scales.

Acknowledgements The authors are grateful to Chinese Ecosystem Research Network (CERN) and ChinaFLUX for their data provision, and to Dr. Huang Mei for the help with the improvement of the model. This study was supported by Chinese Academy of Sciences "Hundred Talents" Project, the National Key Research and Development Program (Grant No. 2002CB412501) and the Knowledge Innovation Program of the Chinese Academy of Sciences (Grant No. KZCX1-SW-01-01A).

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