

Abstract

Typhoons are very unpredictable natural disturbances to subtropical mangrove forests in Asian countries, but litter information is available on how these disturbances affect ecosystem level carbon dioxide (CO₂) exchange of mangrove wetlands. In this study, we examined short-term effect of frequent strong typhoons on defoliation and net ecosystem CO₂ exchange (NEE) of subtropical mangroves, and also synthesized 19 typhoons during a 4-year period between 2009 and 2012 to further investigate the regulation mechanisms of typhoons on ecosystem carbon and water fluxes following typhoon disturbances. Strong wind and intensive rainfall caused defoliation and local cooling effect during typhoon season. Daily total NEE values were decreased by 26–50 % following some typhoons (e.g. W28-Nockten, W35-Molave and W35-Lio-Fan), but were significantly increased (43–131 %) following typhoon W23-Babj and W38-Megi. The magnitudes and trends of daily NEE responses were highly variable following different typhoons, which were determined by the balance between the variances of gross ecosystem production (GEP) and ecosystem respiration (RE). Furthermore, results from our synthesis indicated that the landfall time of typhoon, wind speed and rainfall were the most important factors controlling the CO₂ fluxes following typhoon events. These findings not only indicate that mangrove ecosystems have strong resilience to the frequent typhoon disturbances, but also demonstrate the damage of increasing typhoon intensity and frequency on subtropical mangrove ecosystems under future global climate change scenarios.

1 Introduction

Although mangrove ecosystems only cover a small fraction of world forests, they are highly important component in coastal and global carbon cycle (Bouillon et al., 2008a; Kristensen et al., 2008; Donato et al., 2011). They could provide numerous ecological services, such as coastal protection, fisheries production, biodiversity maintenance and

BGD

11, 9421–9449, 2014

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



nutrient cycling (Tomlinson, 1986; Gilbert and Janssen, 1998). But due to aquaculture, urbanization and other human activities, the global mangrove area has been reduced by 1–2 % per year, and the mangrove areas in China has greatly lost since 1980s with only 22 700 ha remained (Alongi, 2002; Duke et al., 2007; Chen et al., 2009). Changes in tropical cyclone activities are one important component of global climate change, and the characteristics of tropical cyclones will change in a warming climate (Webster et al., 2005; Emanuel, 2007; IPCC, 2007; Knutson et al., 2010). Knutson et al. (2010) predicted that the global mean maximum wind speed of tropical cyclones would increase by 2–11 % in 2100, and the frequency likely to decrease by 6–34 %. Coastal mangrove ecosystems are especially vulnerable to tropical cyclones due to their location along coastlines (Kovacs et al., 2004; Milbrandt et al., 2006; Amiro et al., 2010; Barr et al., 2012). Although mangrove ecosystems exhibit a high degree of ecology stability to these disturbances, the increased intensity and frequency of storms may increase damage to mangroves through defoliation and tree mortality (Alongi, 2008; Gilman et al., 2008). Dietze and Clark (2008) investigated the detailed dynamics of vegetation to hurricane disturbance using designed experimental gaps, and found that sprouts which constitute 26–87 % of early gap regeneration played important role in the maintenance of diversity. However, litter information is available on how these disturbances affect carbon dioxide (CO₂) exchange of mangrove ecosystem, partly due to few direct measurements of canopy level CO₂ fluxes of mangrove ecosystem before and after tropical cyclone disturbances (Amiro et al., 2010; Barr et al., 2010, 2012).

A synthesis of FLUXNET underscored the importance of stand-replacing disturbance regulation on carbon budgets of ecosystem (Baldocchi, 2008). Running (2008) also illustrated the less extreme disturbances should be incorporated in future climate change studies. Disturbances such as tropical cyclones (typhoons, hurricanes or cyclones), which have strong impacts on forest structures and functions, are very common but unpredictable to coastal ecosystems (Turner and Dale, 1998; Greening et al., 2006). The most fundamental impact of such disturbances is the redistribution of organic matter from trees to the forest floor, including defoliation and uprooting stems

(Kovacs et al., 2004; Milbrandt et al., 2006; Li et al., 2007; Barr et al., 2012). Defoliation not only could greatly reduce LAI (leaf area index) and the daytime carbon uptake, but also increase litter decomposition and result in large ecosystem respiration (RE) following this disturbance (Ostertag et al., 2003; Ito, 2010).

In recent years, several studies examined possible impact of typhoon or hurricane disturbances on net ecosystem CO₂ exchanges (NEE) (Li et al., 2007; Ito, 2010; Barr et al., 2012). After 10 typhoons struck Japan, the canopy carbon gain of forests was decreased by 200 g C m⁻² yr⁻¹ (Ito, 2010). Li et al. (2007) reported a 22 % decrease of GPP (gross primary production) and a 25 % decrease of RE of a scrub-oak ecosystem after Hurricane France, resulted in no significant change in NEE. Stand-replacing hurricane disturbances generally cause large defoliation and tree mortality, and hence large reduction in CO₂ uptake over a long time period (Amiro et al., 2010; Barr et al., 2012), whereas less extreme disturbances that do not have significant damage to stems have negligible effects on NEE (Li et al., 2007; Powell et al., 2008).

The complex variations of NEE depend on the balance between two interactive processes, GEP (gross ecosystem production) and RE (Valentini et al., 2000; Wen et al., 2010; Zhang et al., 2010). GEP is mainly controlled by PAR (photosynthetically active radiation), and high VPD (vapor pressure deficit) and T_a (air temperature) limit daily photosynthetic rates (Goulden et al., 2004; Powell et al., 2008; Keith et al., 2012). GEP and RE respond independently to microclimate, but Re is regulated by T_s (soil temperature), soil water content and debris on the forest floor (Li et al., 2007; Kwon et al., 2010; Barr et al., 2012). Kwon et al. (2010) observed that NEE depression is produced with different timing, magnitude and mechanism in a deciduous forest and farmland during Asian monsoon. These results indicate that the relative effects of these microclimatic factors determine the balance between GEP and RE, and hence the different trends and magnitudes in NEE responses following disturbances. Furthermore, previous studies could be better convinced if they consider the relationships among different tropical cyclone disturbances, microclimates and the carbon budgets of ecosystems. Moreover,

BGD

11, 9421–9449, 2014

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



it is essential to investigate typhoon characteristics regulations (including wind speed, landfall point, frequency and duration) on CO₂ exchange of mangrove ecosystem.

The main objective of this study was to examine short-term effects of frequent strong typhoon on microclimate, defoliation and net ecosystem CO₂ exchange of two subtropical mangroves in China. We also synthesize 19 typhoons during a four year period between 2009 and 2012 to further investigate possible mechanisms for the regulations of typhoon characteristics on variations of ecosystem carbon dynamics following typhoon disturbances.

2 Materials and methods

2.1 Site description

The measurements were made in two subtropical mangrove ecosystems located in Gulei Gulf, Fujian Province and Yingluo Bay, Guangdong Province, south of China. The first site, Yunxiao mangrove study site (thereafter YX), is situated in Zhangjiangkou National Mangrove Nature Reserve (23°55′14.59″N, 117°25′4.9″E). This nature reserve was established in 1997 as a provincial nature reserve, and has been include into the Ramsar List in 2008. This site was dominated by *Kandelia obovata*, *Avicennia marina* and *Aegiceras corniculatum*, with the canopy height of 3–4 m. Based on China Meteorological Administration, the 1981–2011 mean annual temperature and precipitation were 21.1 °C and 1285 mm, respectively. For YX, tides were irregular semidiurnal and the high tides can reach up to 1.0 m above the sediment, with tide water salinity range between 1–22 ppt. The second site, Gaoqiao mangrove study site (thereafter GQ), is located in Zhanjiang National Mangrove Nature Reserve (21°34′3.04″N, 109°45′22.33″E). This nature reserve is the largest mangrove nature reserve in China, and it also has been include into the Ramsar List in 2002. This site was dominated by *Bruguiera gymnorrhiza*, *A. corniculatum* and *A. marina*, and the canopy height was about 3 m. The 1981–2011 mean annual temperature and precipitation were 22.9 °C

BGD

11, 9421–9449, 2014

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



and 1 770 mm, respectively. Tides of GQ were regular diurnal and the high tides can reach up to 1.8 m above the sediment, with tide water salinity range between 1–30 ppt.

2.2 Eddy covariance and microclimatic measurements

The eddy covariance measurement systems were established in 2008 and 2009 at YX and GQ site. Each system was equipped with a three-dimensional sonic anemometer (CSAT3; Campbell Scientific, Inc., USA) and an open-path infrared gas analyzer (LI-7500; Li-Cor, Inc., USA). The CSAT3 and LI-7500 were mounted at heights of 5.4 m for YX and 8.6 m for GQ. The footprint was in the direction of the local prevailing winds, which is southeast wind for YX and northeast wind for GQ. The eddy flux data were sampled at 10 Hz, and their mean, variance and covariance values were calculated and logged at 30 min intervals using a digital micrologger (CR1000 for YX, CR3000 for GQ; Campbell Scientific, Inc., USA).

Air temperatures and relative humidity were measured with temperature and relative humidity probes (HMP45AC; Vaisala, Inc., Finland) at heights of 3.0 m, 12.6 m for YX and 2.6 m, 7.4 m, 8.6 m, 14.0 m for GQ. Soil temperatures were measured using temperature probes (109; Campbell Scientific, Inc., USA) at three sediment layers (5 cm, 10 cm, 20 cm) for YX and at two sediment layers (10 cm, 20 cm) for GQ, and the average soil temperatures were also measured using averaging soil TC probe (TCAV; Campbell Scientific, Inc., USA) at 10–20 cm sediment layer. Solar radiation, PAR and net radiation were determined with pyranometer sensor (LI-200SZ; Li-Cor, Inc., USA), PAR quantum sensor (LI-190SZ; Li-Cor, Inc., USA) and four-component net-radiation sensor (NR01; Hukseflux Thermal Sensors, Inc., USA), respectively. Soil heat flux was measured with soil heat flux plate (HFP01SC; Hukseflux Thermal Sensors, Inc., USA). Wind speeds (010C; Met One Instruments, Inc., USA) and wind direction (020C; Met One Instruments, Inc., USA) were measured at heights of 3.0 m, 12.6 m for YX and 2.6 m, 7.4 m, 14.0 m for GQ. Precipitation was measured using a tripping bucket rain gauge (TE525MM; Campbell Scientific, Inc., USA). The meteorological data were

BGD

11, 9421–9449, 2014

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



sampled at 1 s intervals and averaged values were recorded at 30 min intervals with a CR1000 data logger (Campbell Scientific, Inc., USA).

2.3 Flux data processing and gap filling

The eddy covariance data were processed with the EC_PROCESSOR software package (<http://www4.ncsu.edu/~anoorme/ECP/>) (Noormets et al., 2007), using the 2-axis rotation and the Webb–Pearman–Leuning expression (Paw U et al., 2000; Mauder and Foken, 2006). Sonic temperatures were corrected for changes in humidity and pressure (Schotanus et al., 1983). The 30 min fluxes were corrected for the warming of IRGA according to Burba et al. (2006). We also removed anomalous or spurious data that were caused by rainfall events, instrument malfunction, power failure or IRGA calibration. These introduced data gaps that were filled following the methods of Falge et al. (2001). Mean diurnal variation method was used to fill short gaps by calculating the mean values of the same half-hour flux data within 14 days moving window. Larger data gaps were filled using look-up tables. For each site, daytime and nighttime look-up tables were created for each two months interval, which sorted by PPF and T_a . After gap filling the data for corresponding days, data were extracted and analyzed with the micrometeorological data.

2.4 Typhoon impacts on mangrove ecosystem

In this study, we selected typhoons that were stronger than Category 8 (wind speed > 17.2 m s^{-1}), and landed at a distance less than 300 km from the YX or GQ site based on data from China Meteorological Agency, which resulted in a total of 19 typhoons passed over the YX and GQ site (Fig. 1) during a 4-year period between 2009 and 2012. Characteristics of each typhoon including typhoon name, DOY_{Land} (the time of year that typhoon made landfall), duration (the length of time when the typhoon occurred at a distance less than 300 km from our study site), category (Beaufort wind force scale), $\text{wind}_{\text{Land}}$ (the maximum wind speed of typhoon when made landfall), $\text{wind}_{\text{min distance}}$ (the

BGD

11, 9421–9449, 2014

Typhoon impact on CO_2 flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



species around the eddy tower, with litter collected monthly, oven-dried, sorted and weighted as leaf, twig, flower and fruit (including hypocotyle).

2.6 Statistical analysis

Eddy covariance data were processed using software SAS version 9.0 (SAS Institute Inc., USA). All measured parameters before and after typhoon were presented as mean \pm standard deviation for seven replicates. The differences in microclimatic factors, carbon and water fluxes between before and after typhoon were tested using independent sample *t* test. The differences in daily carbon and water fluxes among typhoons were analyzed by one-way Analysis of Variance (ANOVA). Then Duncan post hoc tests were applied to examine the differences after ANOVA. The relationships between typhoon characteristics and microclimatic factors, carbon and water fluxes were also analyzed by linear regression. The statistical analyses were conducted with software SPSS version 16.0 (SPSS Inc., USA).

3 Results

3.1 Typhoons and microclimatic data

From 1945 to 2012, the annual typhoon initiation frequency was 25.27 ± 6.10 , and the frequency of landfalls on China was 9.26 ± 2.65 . During 2009 and 2012, the typhoon initiation and landfall frequency was not very high. There were three and one typhoon made landfall particularly near YX and GQ (Fig. 1a, Supplement Table S1). Among them the minimum distance from YX and GQ was 9 km and 29 km, respectively (Supplement Table S1). Duration of each typhoon when it occurred at a distance less than 300 km from YX or GQ was 28.79 ± 15.44 h, ranging from 9 to 74 h.

From June to October, typhoon brought strong wind accompanied with torrential rain (Fig. 2, Supplement Table S1). The monthly total rainfall showed significant correlation with monthly maximum wind speed for our study sites ($P < 0.001$ for YX, $P = 0.017$ for

BGD

11, 9421–9449, 2014

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



GQ). During typhoon period, the strongest wind speed of typhoon reached 40 m s^{-1} , and the strongest observed wind speed near our study site can exceed 35 m s^{-1} . The magnitude of total rainfall during typhoon period ranged from 3 mm to 85.8 mm for YX, and from 0.2 mm to 115.8 mm for GQ during 2009 and 2012. Rainfall showed significant correlation with duration of typhoon for our study sites ($P = 0.014$ for YX, $P = 0.029$ for GQ). Both daily mean and maximum T_a were significantly decreased after most of strong typhoon landfalls, while their variations were larger than that before typhoon (Table 1). The cooling effect of typhoon was less apparent in T_s , which led to smaller differences in T_s and $T_{s_{\max}}$ following typhoon. With a few exceptions, significant decreases in daily mean total PAR were observed (Table 1).

3.2 Litterfall production

Mean annual litterfall production was $848.44 \text{ g m}^{-2} \text{ yr}^{-1}$ and $728.62 \text{ g m}^{-2} \text{ yr}^{-1}$ for YX and GQ from 2009 to 2012. Leaf and twig litter were the largest components of total litterfall, accounting for more than 75 % of total litterfall for our mangrove site. Except for leaf litter of *A. corniculatum*, monthly litterfall varied seasonally with two peaks, one in April to May and the other in July to August (Fig. 3). Typhoon with strong wind and heavy rain could cause defoliation. In the typhoon season, the highest monthly litter production represented 30 % and 13 % of annual litterfall for YX and GQ. Moreover, about 5 % to 25 % green leaves and twigs appeared in litter traps after typhoon made landfall. For *K. obovata* at YX site, monthly twig litter production was significantly correlated with monthly maximum wind speed ($P = 0.015$) and monthly total rainfall ($P = 0.041$). For *B. gymnorhiza* at GQ site, monthly leaf litter production was significantly correlated with monthly maximum wind speed ($P = 0.004$), and monthly twig litter production also showed significant correlation with monthly maximum wind speed ($P = 0.001$) and monthly total rainfall ($P = 0.005$). For *A. corniculatum* at GQ site, only monthly twig litter production showed significant correlation with monthly maximum wind speed ($P = 0.045$).

3.3 Net ecosystem CO₂ exchange

For typhoon effect on carbon and water flux values of mangrove ecosystems, only six strong typhoons that made significant changes on them were taken into account (Fig. 4). Daily total NEE values were reduced following typhoon W28-Nockten (26 %), W35-Molave (39 %) and W35-Lio-Fan (50 %), but were significantly increased following typhoon W23-Parma (12 %), W23-Babj (43 %) and W38-Megi (131 %) (Fig. 4a). Daily total GEP values were all reduced significantly following typhoon W28-Nockten (15 %) and W35-Molave (8 %), but no change in daily total GEP was observed following the typhoon W23-Babj (Fig. 4b). Typhoon W23-Parma and W38-Megi significantly suppressed daily total RE values, but typhoon W23-Babj increased the daily RE (Fig. 4c). Typhoon W23-Parma also reduced daily total ET after typhoon landfalls, but typhoon Parma caused the opposite (Fig. 4d).

Table 2 summarized light response curve parameters before and after strong typhoons made landfall near our study sites during the four year period between 2009 and 2012. The apparent quantum yields (α value) were slightly decreased following typhoon, but there was no significant difference in α before and after each typhoon. After typhoon W38-Megi made landfall, GEP₂₀₀₀ value was smaller than before typhoon values ($P < 0.001$). Ecosystem respiration rate (the R value) before typhoon was more than twice the value after typhoon W38-Megi made landfall. However, after typhoon W23-Babj, GEP₂₀₀₀ value was greater than before typhoon values ($P = 0.035$).

PAR was the most important control over daytime NEE, although VPD and T_a also exerted strong controls over daytime NEE (Figs. 5 and 6). VPD above 1.5 kPa suppressed daytime NEE (Fig. 5a and e). After typhoon W28-Nockten landed, daytime NEE values were reduced by high VPD, while they were not been affected by VPD before the typhoon (Fig. 5e). Although high T_a also reduced daytime NEE values after typhoon W28-Nockten, it had litter effect on daytime NEE before this typhoon made landfall (Fig. 5f). After typhoon W38-Megi landed, significant reduction in T_a increased daytime NEE (Fig. 5l).

BGD

11, 9421–9449, 2014

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



3.4 Relationships between carbon, water fluxes and typhoon properties

Variations in daily carbon fluxes and the model parameters were explained by variations in typhoon properties (Table 3). ΔGEP values did not show significant relationships with typhoon properties for YX and GQ. However, ΔNEE values were strong correlated with DOY_{Land} ($P = 0.025$), indicating that typhoon made landfall later in the year could increase daily NEE. $\Delta\alpha$ values were negatively correlated with DOY_{Land} ($P = 0.039$) and rainfall ($P = 0.022$). And ΔRE values were also negatively related to $\text{wind}_{\text{min.distance}}$ ($P = 0.030$), showing that typhoon with strong wind led to lower daily RE.

4 Discussion

4.1 Impact of typhoons on defoliation of mangrove forests

We observed significant increase in litter production in both mangrove forests in China following most typhoon events (Fig. 3), suggesting great defoliation occurred due to typhoon disturbances. The immediate impacts of typhoon disturbance on canopy included defoliation and twig losses (Xu et al., 2004; Li et al., 2007; Ito, 2010), which led to obvious changes in LAI and albedo values (Barr et al., 2012; O'Halloran et al., 2012). The positive relationship between monthly litter productions and monthly mean wind speed observed here for GQ (Fig. 3) also indicated a strong impact of wind disturbance on defoliation. This is consistent with the results from several previous studies, which demonstrated higher monthly litter production during typhoon season (Tam et al., 1998; Zheng et al., 2000). Milbrandt et al. (2006) observed no significant differences of hurricane impacts on litter production among mangrove species, but they found a negative correlation between canopy loss and the distance to hurricane eyewall. Moreover, typhoon-derived litters could immediate decompose on the forest floor, which increase litter decomposition and nutrient inputs (Ostertag et al., 2003). Thus, significant in-

BGD

11, 9421–9449, 2014

Typhoon impact on CO_2 flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



creases in mangrove litter production following typhoon events are very common, and will increase ecosystem respiration and nutrient supplies for mangrove forest recovery.

4.2 Impacts of typhoons on mangrove daytime NEE

We found inconsistent changes in daytime NEE following typhoon events, with some typhoons (e.g. W23-Babj, W38-Megi) increasing daytime NEE, some typhoons (W28-Nockten, W35-Molave, W35-Lio-Fan) having the opposite effect and one typhoon (W23-Parma) having no effect (Fig. 4). Ito (2010) observed that defoliation caused by typhoon greatly reduce CO₂ uptake of a deciduous broad-leaf forest. Li et al. (2007) also reported a decrease in GPP because of the reduction in LAI after hurricane disturbance. In our study, after typhoon W28-Nockten, W35-Molave and W35-Lio-Fan made landfall, the decreased magnitudes of GEP were larger than that of RE, which resulted in significant decrease in NEE. Although typhoon W38-Megi caused a reduction in GEP, the large reduction of RE resulted in increased NEE. Kwon et al. (2010) also reported that intensive rainfalls could reduce respiration during Asian monsoon. Different variations and magnitudes of GEP and RE also controlled the NEE values after typhoon W23-Parma and W23-Babj (Fig. 4). However, Barr et al. (2012) demonstrated that local heating effect following stand-replacing hurricane disturbances caused high respiration. Therefore, possible effects of typhoons on daytime NEE depend on forest types, forest locations and various changes in micromet conditions due to typhoon events.

VPD and T_a were important secondary factors controlling daytime NEE values, especially after typhoon made landfall (Fig. 5). The less negative GEP₂₀₀₀ values following typhoon likely due to carbon assimilation suppressed by high VPD and T_a . Our results for VPD also have been reported in previous studies (Goulden et al., 2004; Powell et al., 2008; Keith et al., 2012). Daytime photosynthetic rates of leaves could be limited by lower stomatal conductance as a result of high VPD (Sano et al., 2010). Additionally, the daytime NEE was much more sensitive to VPD following typhoon W28-Nockten. Although T_a values were reduced following typhoon, high T_a also could caused de-

BGD

11, 9421–9449, 2014

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



pression in daytime NEE. This regulation can be explained by temperature controls on both photosynthesis and respiration (Powell et al., 2008). Goulden et al. (2004) also demonstrated positive correlation between $NEE_{residual}$ and T_a in the afternoon, which may cause by high T_a , high VPD, or a circadian rhythm.

4.3 Regulation mechanisms of typhoons on ecosystem carbon and water fluxes in mangrove forests

Although many studies have examined extreme typhoon or hurricane disturbances impacts on CO_2 fluxes in various ecosystems, few have attempted to find the regulation mechanisms of typhoon characteristics on mangrove carbon fluxes (Li et al., 2007; Ito, 2010; Sano et al., 2010; Barr et al., 2012; Vargas, 2012). Results from our synthesis indicated variations of carbon fluxes following typhoon were strongly controlled by DOY_{Land} , $wind_{min.distance}$ and rainfall (Table 3). Rainfall controls on RE was consistent with Kwon et al. (2010), who found intensive and consecutive rainfall reduced respiration during summer monsoon. $wind_{min.distance}$ regulations on RE could be explained by wind damage on canopy loss immediately after typhoon (Ito, 2010). Though we did not measure the changes in leaf area following typhoon, the large litter production and their correlations between wind speed and rainfall during typhoon season confirmed the damage of typhoon on mangrove forest. These differ from findings of extreme disturbance, which stand-replacing damages cause significant large RE in a long term (Amiro et al., 2010; Barr et al., 2012). However, no difference in RE after typhoon W28-Nockten, W28-Molave and W35-Lio-Fan observed in this study was consistent with Li et al. (2007) who found that less extreme disturbance did not increase respiration of forest ecosystem.

The variations of daily NEE before and after typhoon were complex, because NEE depends both on photosynthesis and respiration processes. They are interacted with each other, and were controlled by relative independently environmental factors (Li et al., 2007; Wen et al., 2010). Extreme hurricane disturbances generally caused significant defoliation and plant uprooting, and then resulted in significant reduction in

BGD

11, 9421–9449, 2014

Typhoon impact on CO_2 flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



GEP and increase in RE of mangrove ecosystem (Barr et al., 2012). Reduced NEE values also have been reported by Lindroth et al. (2008), who observed the reduction of NEE were caused by increased RE. However, less extreme disturbances have negligible effects on NEE (Li et al., 2007). Hurricane disturbance have no significant effects on NEE due to the compensatory reduction in GEP and RE (Li et al., 2007). Actually, there is great agreement with previous studies, who indicate climatic drivers on the balance between carbon and uptake (Powell et al., 2008; Wen et al., 2010; Zhang et al., 2010). These indicated typhoon disturbances reduced NEE or do not have significant impact on our mangrove study sites. However, our study also observed significant increase in NEE after typhoon W38-Megi in early autumn, which was due to decrease in T_a and RE. In this case, the strong correlation between ΔNEE values and DOY_{Land} conformed that the timing of typhoon made landfall was also very important control on carbon exchange of mangrove ecosystems. Though only six typhoons caused significant changes in carbon flux of mangrove ecosystem, these results indicated that carbon flux dynamics were highly variable following typhoon.

5 Conclusions

Typhoon disturbances frequently influenced the subtropical mangrove ecosystems in China. Strong wind and intensive rainfall caused defoliation and local cooling effect during typhoon periods. The magnitudes and trends of daily NEE responses were highly variable following different typhoons, which were dependent of the balance between the variances of GEP and RE. Furthermore, results from our synthesis of 19 typhoons demonstrated that DOY_{Land} , $wind_{min.distance}$ and rainfall were the most important factors controlling the carbon fluxes following typhoon. These findings not only indicated that mangrove ecosystems have strong resilience to typhoon disturbances, but also demonstrated the damage of increased typhoon intensity and frequency on subtropical mangrove ecosystems under climate change.

BGD

11, 9421–9449, 2014

Typhoon impact on CO_2 flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The Supplement related to this article is available online at
doi:10.5194/bgd-11-9421-2014-supplement.

Acknowledgements. This study was supported financially by the National Natural Science Foundation of China (30930017) and the National Basic Research Program of China (2013CB956601). We thank the Zhangjiang and Zhanjiang Mangrove National Nature Reserve for allowing the study in the field. We appreciated Jiquan Chen, Bin Zhao, Haiqiang Guo, Dan Yakir for their help with eddy tower construction and flux data processing. We also thank Yihui Zhang, Luzhen Chen, Jingfeng Xiao, Wenjiao Zheng, Yue-Joe Hsia for their valuable suggestions on our earlier version of the manuscript.

References

- Alongi, D. M.: Present state and future of the world's mangrove forests, *Environ. Conserv.*, 29, 331–349, doi:10.1017/s0376892902000231, 2002.
- Alongi, D. M.: Mangrove forests: resilience, protection from tsunamis, and responses to global climate change, *Estuar. Coast. Shelf S.*, 76, 1–13, doi:10.1016/j.ecss.2007.08.024, 2008.
- Alongi, D. M.: *The Energetics of Mangrove Forests*, Springer, Dordrecht, 2009.
- Amiro, B. D., Barr, A. G., Barr, J. G., Black, T. A., Bracho, R., Brown, M., Chen, J., Clark, K. L., Davis, K. J., and Desai, A. R.: Ecosystem carbon dioxide fluxes after disturbance in forests of North America, *J. Geophys. Res.*, 115, G00K02, doi:10.1029/2010jg001390, 2010.
- Baldocchi, D.: “Breathing” of the terrestrial biosphere: lessons learned from a global network of carbon dioxide flux measurement systems, *Aust. J. Bot.*, 56, 1–26, doi:10.1071/bt07151, 2008.
- Barr, J. G., Engel, V., Fuentes, J. D., Zieman, J. C., O’Halloran, T. L., Smith III, T. J., and Anderson, G. H.: Controls on mangrove forest-atmosphere carbon dioxide exchanges in western Everglades National Park, *J. Geophys. Res.*, 115, G02020, doi:10.1029/2009jg001186, 2010.
- Barr, J. G., Engel, V., Smith, T. J., and Fuentes, J. D.: Hurricane disturbance and recovery of energy balance, CO₂ fluxes and canopy structure in a mangrove forest of the Florida Everglades, *Agr. Forest Meteorol.*, 153, 54–66, doi:10.1016/j.agrformet.2011.07.022, 2012.

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Bouillon, S., Borges, A. V., Castañeda-Moya, E., Diele, K., Dittmar, T., Duke, N. C., Kristensen, E., Lee, S. Y., Marchand, C., and Middelburg, J. J.: Mangrove production and carbon sinks: a revision of global budget estimates, *Global Biogeochem. Cy.*, 22, GB2013, doi:10.1029/2007gb003052, 2008a.
- 5 Bouillon, S., Connolly, R. M., and Lee, S. Y.: Organic matter exchange and cycling in mangrove ecosystems: recent insights from stable isotope studies, *J. Sea Res.*, 59, 44–58, doi:10.1016/j.seares.2007.05.001, 2008b.
- Burba, G. G., Anderson, D. J., Xu, L., and McDermitt, D. K.: Correcting apparent off-season CO₂ uptake due to surface heating of an open path gas analyzer: progress report of an ongoing study, 27th Conference on Agricultural and Forest Meteorology, P4.4, San Diego, California, 24 May 2006, 2006.
- 10 Chen, L. Z., Wang, W. Q., Zhang, Y. H., and Lin, G. H.: Recent progresses in mangrove conservation, restoration and research in China, *J. Plant Ecol.-UK*, 2, 45–54, doi:10.1093/jpe/rtp009, 2009.
- 15 Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., and Kanninen, M.: Mangroves among the most carbon-rich forests in the tropics, *Nat. Geosci.*, 4, 293–297, doi:10.1038/ngeo1123, 2011.
- Dietze, M. and Clark, J. S.: Changing the gap dynamics paradigm: vegetative regeneration control on forest response to disturbance, *Ecol. Monogr.*, 78, 331–347, doi:10.1890/07-0271.1, 2007.
- 20 Duke, N. C., Meynecke, J. O., Dittmann, S., Ellison, A. M., Anger, K., Berger, U., Cannicci, S., Diele, K., Ewel, K. C., and Field, C. D.: A world without mangroves?, *Science*, 317, 41–42, doi:10.1126/science.317.5834.41b, 2007.
- Emanuel, K.: Environmental factors affecting tropical cyclone power dissipation, *J. Climate*, 20, 5497–5509, doi:10.1175/2007jcli1571.1, 2007.
- 25 Falge, E., Baldocchi, D., Olson, R., Anthoni, P., Aubinet, M., Bernhofer, C., Burba, G., Ceulemans, R., Clement, R., and Dolman, H.: Gap filling strategies for long term energy flux data sets, *Agr. Forest Meteorol.*, 107, 71–77, doi:10.1016/S0168-1923(00)00235-5, 2001.
- Gilbert, A. J. and Janssen, R.: Use of environmental functions to communicate the values of a mangrove ecosystem under different management regimes, *Ecol. Econ.*, 25, 323–346, doi:10.1016/s0921-8009(97)00064-5, 1998.
- 30

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Gilman, E. L., Ellison, J., Duke, N. C., and Field, C.: Threats to mangroves from climate change and adaptation options: a review, *Aquat. Bot.*, 89, 237–250, doi:10.1016/j.aquabot.2007.12.009, 2008.

Goulden, M. L., Miller, S. D., Da Rocha, H. R., Menton, M. C., de Freitas, H. C., de Silva Figueira, A. M., and de Sousa, C. A. D.: Diel and seasonal patterns of tropical forest CO₂ exchange, *Ecol. Appl.*, 14, S42–S54, doi:10.1890/02-6008, 2004.

Greening, H., Doering, P., and Corbett, C.: Hurricane impacts on coastal ecosystems, *Estuar. Coast.*, 29, 877–879, doi:10.1007/bf02798646, 2006.

IPCC: Fourth Assessment Report (AR4 SYR Summary for Policymakers), Cambridge University Press, Washington, 2007.

Ito, A.: Evaluation of the impacts of defoliation by tropical cyclones on a Japanese forest's carbon budget using flux data and a process-based model, *J. Geophys. Res.*, 115, G04013, doi:10.1029/2010jg001314, 2010.

Keith, H., van Gorsel, E., Jacobsen, K., and Cleugh, H.: Dynamics of carbon exchange in a Eucalyptus forest in response to interacting disturbance factors, *Agr. Forest Meteorol.*, 153, 67–81, doi:10.1016/j.agrformet.2011.07.019, 2012.

Knutson, T. R., McBride, J. L., Chan, J., Emanuel, K., Holland, G., Landsea, C., Held, I., Kossin, J. P., Srivastava, A., and Sugi, M.: Tropical cyclones and climate change, *Nat. Geosci.*, 3, 157–163, doi:10.1038/ngeo779, 2010.

Kovacs, J. M., Malczewski, J., and Flores-Verdugo, F.: Examining local ecological knowledge of hurricane impacts in a mangrove forest using an analytical hierarchy process (AHP) approach, *J. Coastal Res.*, 20, 792–800, doi:10.2112/1551-5036(2004)20[792:elekoh]2.0.co;2, 2004.

Kristensen, E., Bouillon, S., Dittmar, T., and Marchand, C.: Organic carbon dynamics in mangrove ecosystems: a review, *Aquat. Bot.*, 89, 201–219, doi:10.1016/j.aquabot.2007.12.005, 2008.

Kwon, H., Kim, J., Hong, J., and Lim, J.-H.: Influence of the Asian monsoon on net ecosystem carbon exchange in two major ecosystems in Korea, *Biogeosciences*, 7, 1493–1504, doi:10.5194/bg-7-1493-2010, 2010.

Li, J. H., Powell, T. L., Seiler, T. J., Johnson, D. P., Anderson, H. P., Bracho, R., Hungate, B. A., Hinkle, C. R., and Drake, B. G.: Impacts of Hurricane Frances on Florida scrub-oak ecosystem processes: defoliation, net CO₂ exchange and interactions with elevated CO₂, *Glob. Change Biol.*, 13, 1101–1113, doi:10.1111/j.1365-2486.2007.01358.x, 2007.

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



Lindroth, A., Lagergren, F., Grelle, A., Klemedtsson, L., Langvall, O., Weslien, P., and Tuulik, J.: Storms can cause Europe-wide reduction in forest carbon sink, *Glob. Change Biol.*, 15, 346–355, doi:10.1111/j.1365-2486.2008.01719.x, 2008.

Mauder, M. and Foken, T.: Impact of post-field data processing on eddy covariance flux estimates and energy balance closure, *Meteorol. Z.*, 15, 597–609, doi:10.1127/0941-2948/2006/0167, 2006.

Milbrandt, E. C., Greenawalt-Boswell, J. M., Sokoloff, P. D., and Bortone, S. A.: Impact and response of southwest Florida mangroves to the 2004 hurricane season, *Estuar. Coast.*, 29, 979–984, doi:10.1007/bf02798659, 2006.

Noormets, A., Chen, J., and Crow, T. R.: Age-dependent changes in ecosystem carbon fluxes in managed forests in northern Wisconsin, USA, *Ecosystems*, 10, 187–203, doi:10.1007/s10021-007-9018-y, 2007.

O'Halloran, T. L., Law, B. E., Goulden, M. L., Wang, Z., Barr, J. G., Schaaf, C., Brown, M., Fuentes, J. D., Göckede, M., and Black, A.: Radiative forcing of natural forest disturbances, *Glob. Change Biol.*, 18, 555–565, doi:10.1111/j.1365-2486.2011.02577.x, 2012.

Ostertag, R., Scatena, F. N., and Silver, W. L.: Forest floor decomposition following hurricane litter inputs in several Puerto Rican forests, *Ecosystems*, 6, 261–273, doi:10.1007/s10021-002-0203-8, 2003.

Paw U, K. T., Baldocchi, D. D., Meyers, T. P., and Wilson, K. B.: Correction of eddy-covariance measurements incorporating both advective effects and density fluxes, *Bound.-Lay. Meteorol.*, 97, 487–511, doi:10.1023/a:1002786702909, 2000.

Powell, T. L., Gholz, H. L., Clark, K. L., Starr, G., Cropper, W. P., and Martin, T. A.: Carbon exchange of a mature, naturally regenerated pine forest in north Florida, *Glob. Change Biol.*, 14, 2523–2538, doi:10.1111/j.1365-2486.2008.01675.x, 2008.

Running, S. W.: Ecosystem disturbance, carbon, and climate, *Science*, 321, 652–653, doi:10.1126/science.1159607, 2008.

Sano, T., Hirano, T., Liang, N., Hirata, R., and Fujinuma, Y.: Carbon dioxide exchange of a larch forest after a typhoon disturbance, *Forest Ecol. Manag.*, 260, 2214–2223, doi:10.1016/j.foreco.2010.09.026, 2010.

Tam, N. F. Y., Wong, Y. S., Lan, C. Y., and Wang, L. N.: Litter production and decomposition in a subtropical mangrove swamp receiving wastewater, *J. Exp. Mar. Biol. Ecol.*, 226, 1–18, doi:10.1016/s0022-0981(97)00233-5, 1998.

Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Table 1. Daily average microclimatic factors before and after typhoon made landfall for Yunxiao (YX) and Gaoqiao (GQ) in 2010, including daily means of air temperature (T_a), maximum air temperature ($T_{a_{\max}}$), soil temperature (T_s), maximum soil temperature ($T_{s_{\max}}$) and total photosynthetically active radiation (PAR).

Typhoon		T_a (°C)	$T_{a_{\max}}$ (°C)	T_s (°C)	$T_{s_{\max}}$ (°C)	PAR (mol m ⁻² d ⁻¹)
W23-Parma	Before	28.29 ± 0.65	32.05 ± 1.37	27.68 ± 0.28	27.90 ± 0.14	28.81 ± 8.35
	After	27.57 ± 0.80	32.11 ± 2.21	26.41 ± 0.51	26.86 ± 0.53	29.65 ± 6.68
W23-Babj	Before	29.28 ± 0.30	33.76 ± 0.90	27.65 ± 0.13	27.81 ± 0.12	38.65 ± 1.94
	After	27.55 ± 0.29	31.10 ± 0.67	26.54 ± 0.13	26.68 ± 0.12	28.67 ± 4.13
W28-Nockten	Before	29.45 ± 0.29	33.34 ± 0.95	28.15 ± 0.28	28.41 ± 0.34	37.08 ± 3.37
	After	28.49 ± 0.86	32.37 ± 1.31	28.47 ± 0.32	28.73 ± 0.29	29.28 ± 7.21
W35-Molave	Before	29.38 ± 0.73	33.43 ± 1.34	27.71 ± 0.56	28.64 ± 0.51	47.40 ± 5.12
	After	29.12 ± 0.14	32.96 ± 1.18	27.99 ± 0.25	28.86 ± 0.28	40.72 ± 8.11
W35-Lio-Fan	Before	29.10 ± 0.49	33.99 ± 0.84	27.91 ± 0.28	29.41 ± 0.32	34.12 ± 6.49
	After	26.52 ± 0.51	32.95 ± 0.92	26.26 ± 0.18	27.91 ± 0.38	28.31 ± 7.36
W38-Megi	Before	24.98 ± 0.56	28.51 ± 0.88	24.65 ± 0.15	24.86 ± 0.24	20.78 ± 6.16
	After	19.08 ± 1.38	22.94 ± 0.80	22.05 ± 0.90	22.42 ± 0.89	28.81 ± 5.35

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

Table 3. Linear regression coefficient (Coef.) and significance probability (P) between daily ecosystem carbon fluxes change (Δ NEE, Δ GEP and Δ RE), model parameters change of light response curves ($\Delta\alpha$, Δ GEP₂₀₀₀ and Δ R) before and after typhoon made landfall and typhoon characteristics (DOY_{Land}, duration, category, wind_{Land}, wind_{min.distance}, distance_{min}, rainfall). The daily data from 2009 to 2012 for Yunxiao (YX) and Gaoqiao (GQ) were used. The p value less than 0.05 was marked as bold number.

Factor	Δ NEE		Δ GEP		Δ RE		$\Delta\alpha$		Δ GEP ₂₀₀₀		Δ R	
	Coef.	P	Coef.	P	Coef.	P	Coef.	P	Coef.	P	Coef.	P
DOY _{Land}	0.816	0.025	0.547	0.204	-0.621	0.137	-0.779	0.039	-0.600	0.154	-0.684	0.090
Duration	-0.196	0.674	0.041	0.931	0.147	0.752	-0.481	0.275	-0.099	0.832	-0.303	0.509
Category	0.160	0.732	-0.165	0.724	-0.536	0.214	-0.287	0.533	-0.516	0.235	-0.307	0.503
Wind _{Land}	0.100	0.831	-0.226	0.626	-0.506	0.246	-0.238	0.608	-0.501	0.252	-0.289	0.530
Wind _{min.distance}	0.314	0.493	-0.281	0.541	-0.802	0.030	-0.043	0.927	-0.514	0.238	-0.320	0.485
Distance _{min}	-0.371	0.412	-0.301	0.511	0.381	0.399	0.518	0.233	0.274	0.552	0.507	0.245
Rainfall	0.006	0.989	0.111	0.813	-0.061	0.897	-0.826	0.022	-0.473	0.284	-0.627	0.132

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

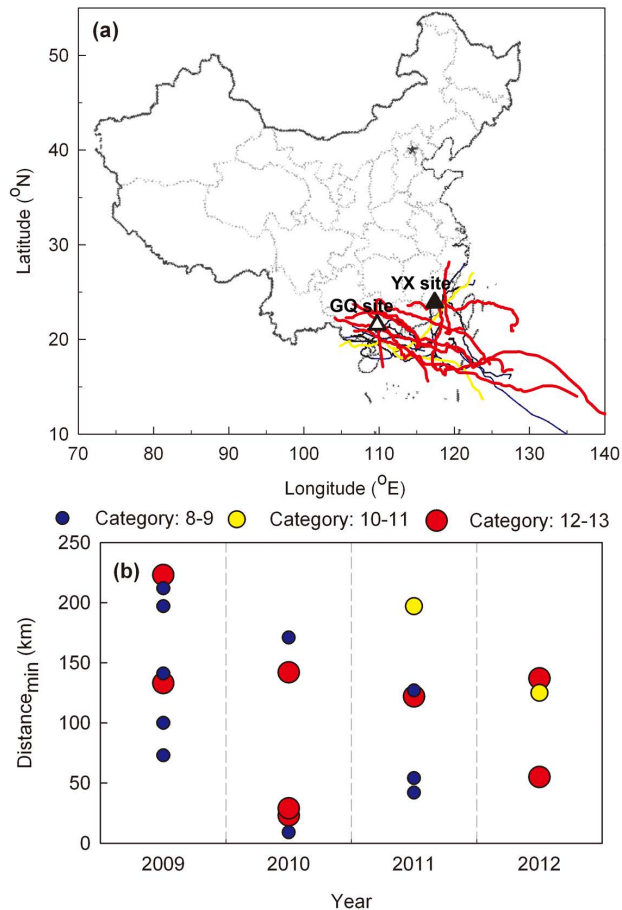


Figure 1. (a) Paths of the 19 typhoons that passed over Yunxiao (YX) and Gaoqiao (GQ) mangrove sites during a four year period between 2009 and 2012, and (b) category of each typhoon and its distance_{min} (the minimum distance from mangrove sites) during 2009 and 2012.

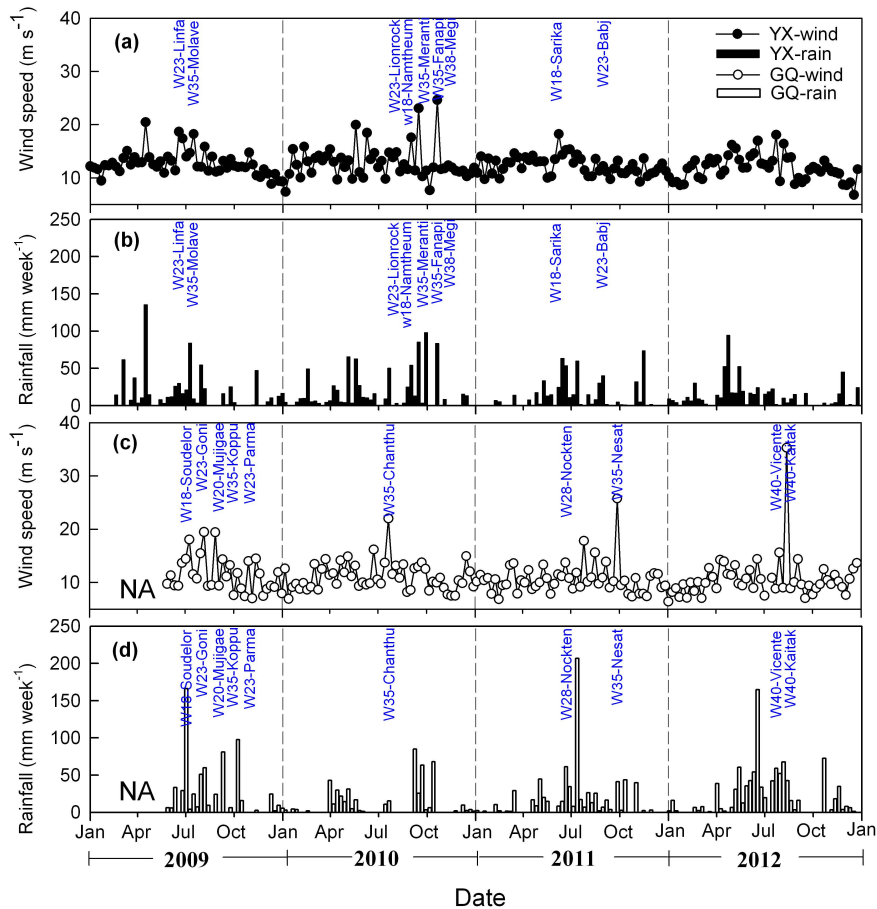


Figure 2. (a, c) Maximum weekly wind speed, (b, d) total weekly rainfall for Yunxiao (YX) and Gaoqiao (GQ) during a four year period between 2009 and 2012. The name and occurrence date of each typhoon are also shown.

Typhoon impact on
CO₂ flux of mangrove
ecosystem

H. Chen et al.

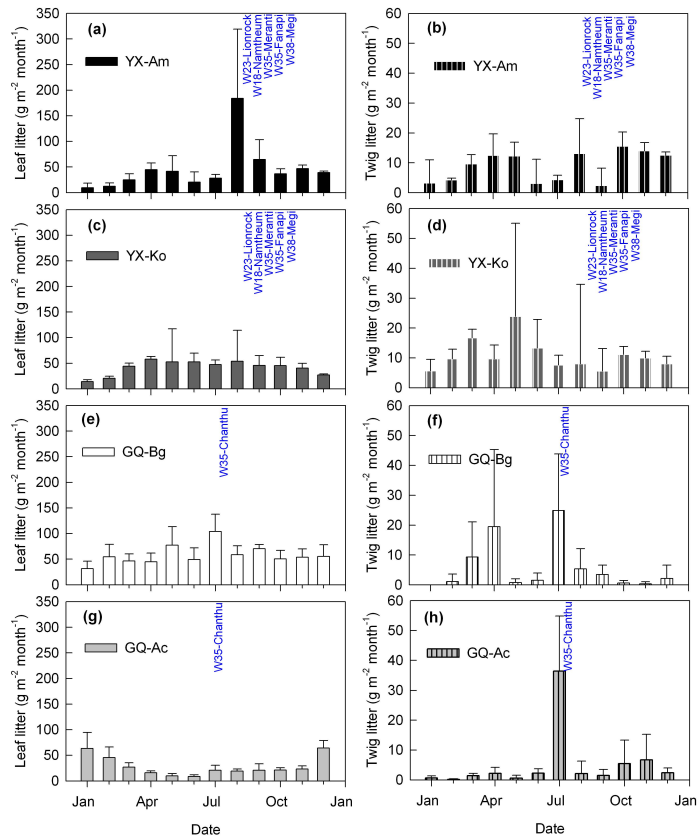


Figure 3. Monthly (a, c, e, g) leaf litter and twig litter (b, d, f, h) production for Yunxiao (YX) and Gaoqiao (GQ) in 2010. YX-Am: *Avicennia marina* at YX, YX-Ko: *Kandelia obovata* at YX, GQ-Bg: *Bruguiera gymnorrhiza* at GQ, GQ-Ac: *Aegiceras corniculatum* at GQ. The name and occurrence date of each typhoon are also shown.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Typhoon impact on CO₂ flux of mangrove ecosystem

H. Chen et al.

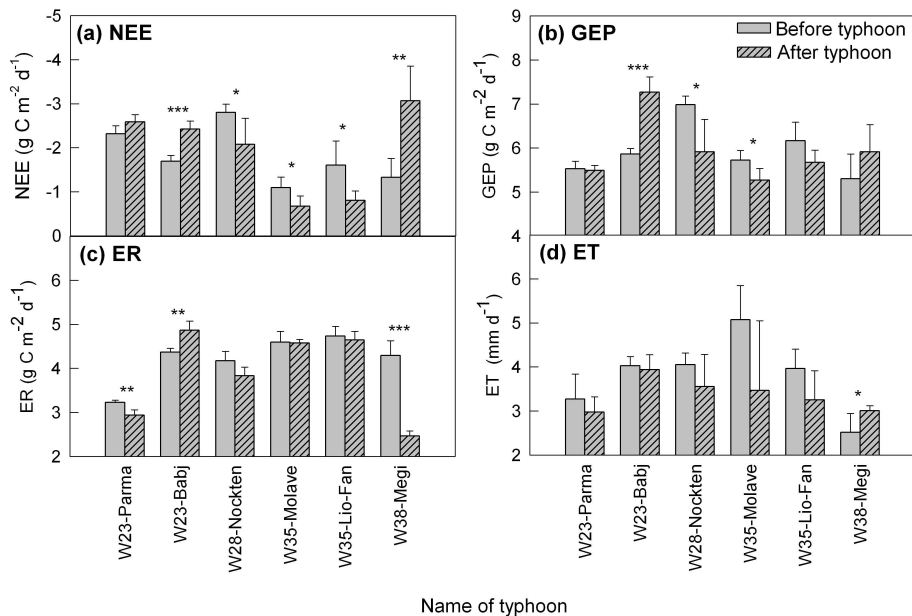


Figure 4. Average daily (a) net ecosystem CO₂ exchange (NEE), (b) gross ecosystem production (GEP), (c) ecosystem respiration (RE), and (d) evapotranspiration (ET) before and after six typhoons made landfall near Yunxiao (YX) and Gaoqiao (GQ).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Typhoon impact on
CO₂ flux of mangrove
ecosystem

H. Chen et al.

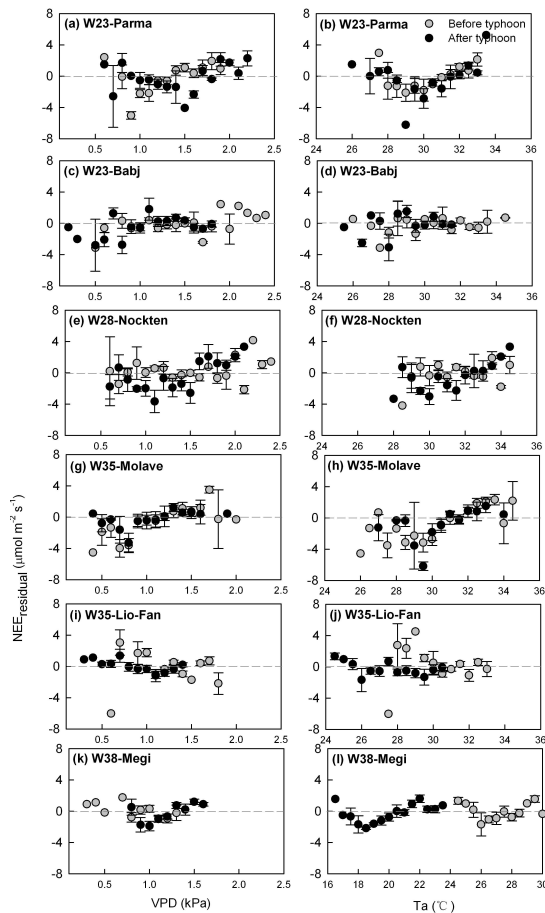


Figure 5. Residuals of daytime net ecosystem CO₂ exchange (NEE) at photosynthetically active radiation (PAR) as a function of vapor pressure deficit (VPD) and air temperature (T_a) before and after a typhoon made landfall.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Typhoon impact on
CO₂ flux of mangrove
ecosystem

H. Chen et al.

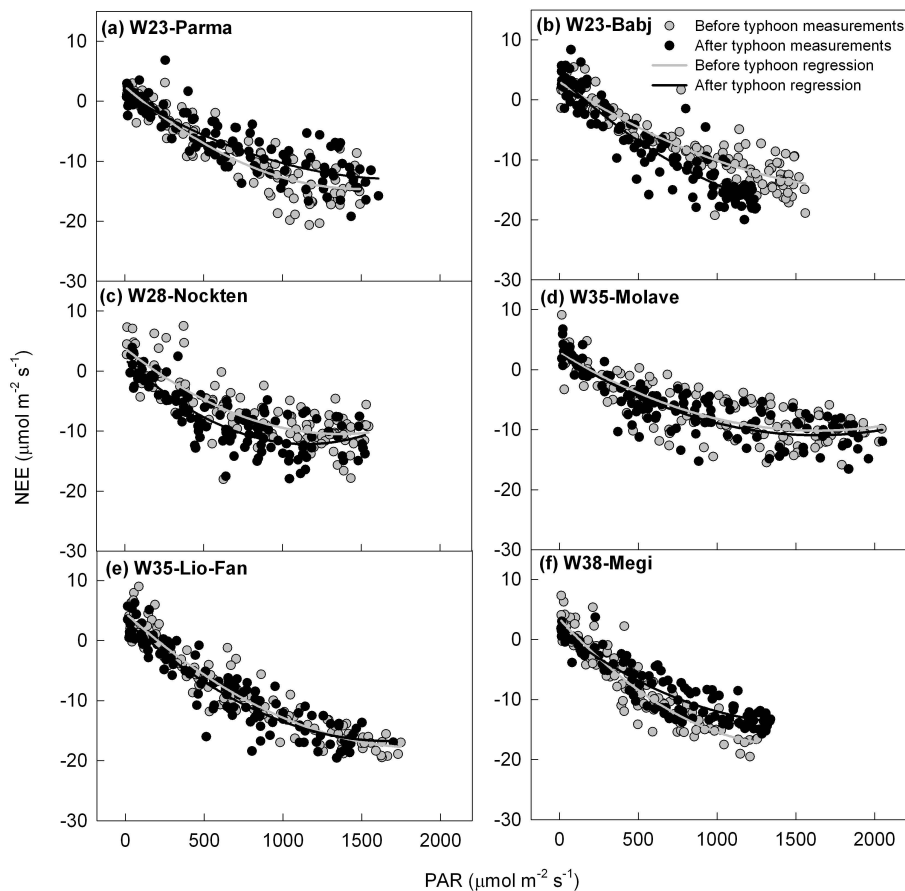


Figure 6. Light response curves before (grey circles) and after (dark circles) 6 typhoons made landfall.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)