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# Effects of Changes in Aerosol Loading and Cloudiness on Forest Ecosystem Net Carbon Uptake

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2013.8.30

# Outline

- Introduction
- Objectives
- Methods
- Results
- Key questions

# 1. Introduction

- Solar radiation received on the ground surface is an important factor driving global carbon cycle (*Urban et al., 2007; Baldocchi, 2008; Mercado et al., 2009*).
- Changes in cloudiness and aerosol content in the atmosphere can influence solar radiation received on the ground surface, balance of direct and diffuse components of the solar radiation received on the ground surface, and even regional climate (*Gu et al., 2003; Niyogi et al.,2004; Urban et al., 2007; Olivera et al., 2007; Matsui et al., 2008; Doughty et al., 2010*).

# 1. Introduction

- Many studies have shown that net ecosystem exchange of carbon dioxide (NEE) of forest ecosystems increase when sky become cloudy (*Gu et al., 1999; Law et al., 2002; Urban et al., 2007; Zhang et al., 2010*), or aerosol content in the atmosphere increase (Niyogi et al., 2004; Procopio et al., 2004; Olivera et al., 2007; Matsui et al., 2008;Doughty et al., 2010).
- Some studies suggest that the effects of changes in aerosol loading on NEE of forest ecosystem may be even more significant than the effects of changes in cloudiness (Niyogi, et al., 2004).

# 1. Introduction

- Affected by Asia monsoon, Temperature and precipitation exhibit apparent latitudinal gradients along the North-South Transect of Eastern China (NSTEC). A forest ecosystem sequence (from cold temperate coniferous forest to tropical rainforest) exists along the NSTEC from the north to the south (*Yu et al., 2008*).

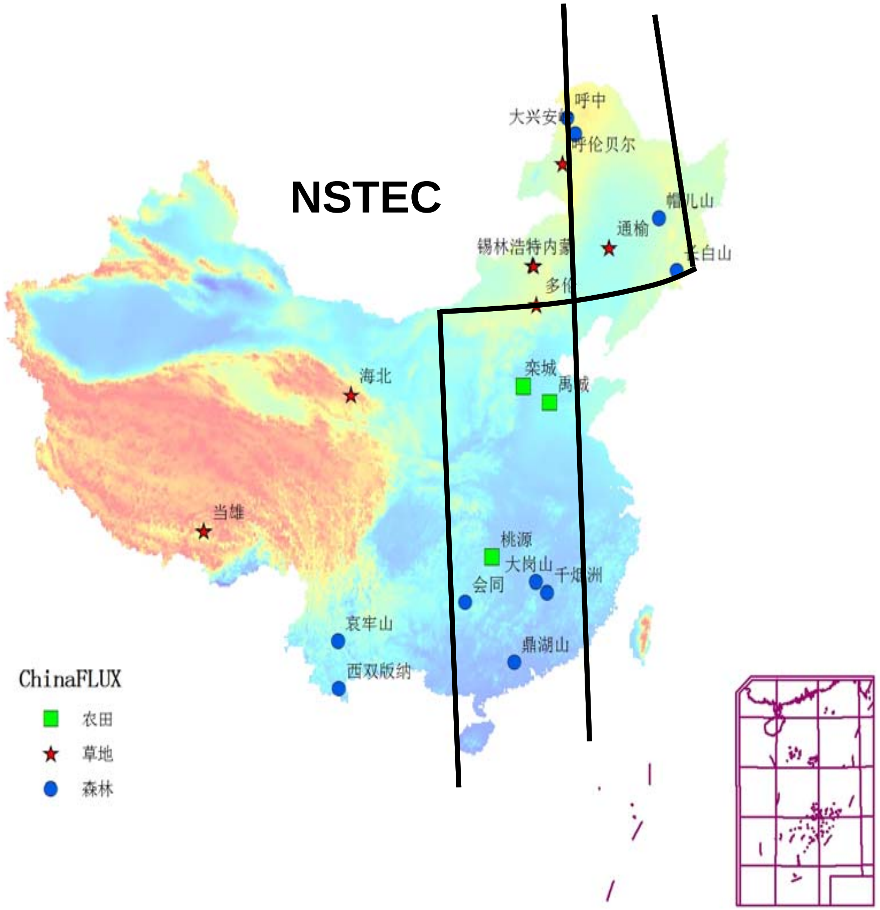


Fig. 1 The location of North-South Transect of Eastern China (NSTEC).

# 1. Introduction

- How do changes in cloudiness and aerosol content in the atmosphere impact NEE in different forest ecosystems along NSTEC?
- Which effect may be more significant, the changes in cloudiness or aerosol content in the atmosphere?
- What are the mechanisms that control effects of changes in cloudiness and aerosol content in the atmosphere on NEE of different forest ecosystems?

# 2. Objectives

- To characterize the impacts of changes in aerosol loading and cloudiness on NEE of different forest ecosystems, especially the impact of changes in aerosol loading.
- To identify the mechanisms of the impacts of changes in aerosol loading and cloudiness on NEE of different forest ecosystems.

# 3. Methods

## 3.1 Sites descriptions

- We chose three typical forest ecosystems, including Changbaishan temperate mixed forest (CBS), Qianyanzhou subtropical coniferous plantation (QYZ), and Dinghushan subtropical evergreen broad-leaved forest (DHS).

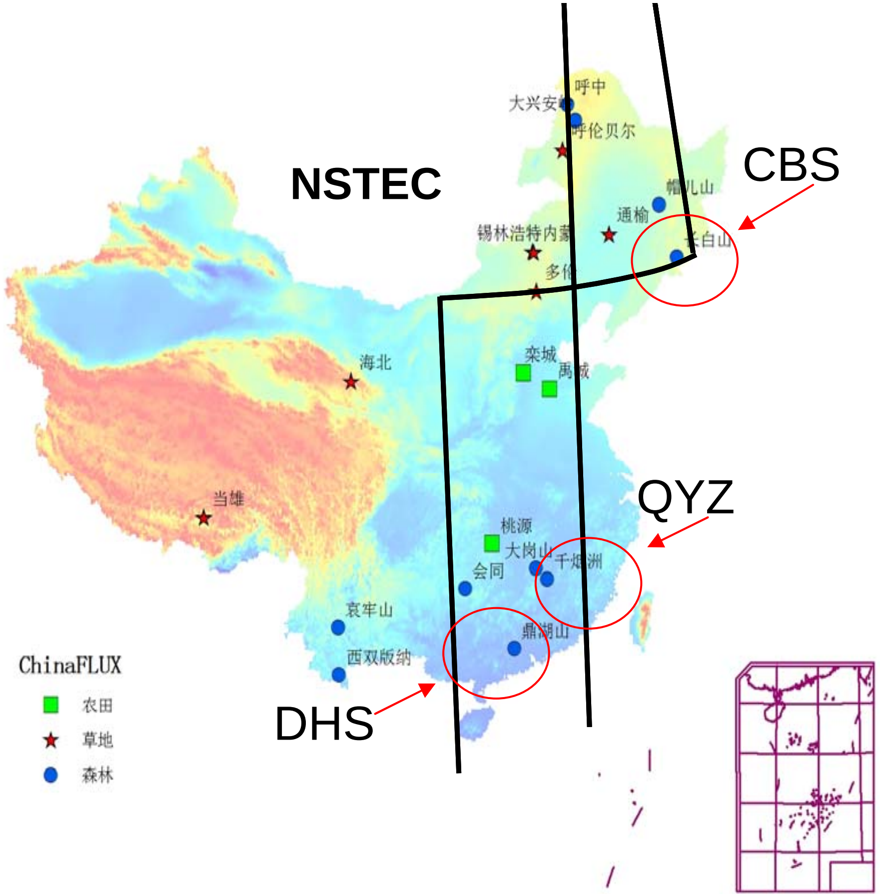


Fig.2 The location of study sites.

# 3.1 Sites descriptions

Table 1 Sites information

| | CBS | QYZ | DHS |
|---|---|---|---|
| Location | 42°24′N<br>128°05′E | 26°44′N<br>115°03′E | 23°10′N<br>112°34′E |
| Altitude(m) | 738 | 102 | 240 |
| MAT(℃) | 3.6 | 17.9 | 21.0 |
| P(mm) | 695 | 1485 | 1956 |

# 3.2 Measurement

- Based on measurements of eddy covariance and microclimate, 30 min NEE and routine meteorological variables (e.g Solar radiation received by ecosystem surface (*S*), Photosynthetically active radiation (PAR), air temperature ($T_a$), vapor press deficit (VPD)) were obtained.
- the data measured from June to August during study period was used to eliminate the effect of changing leaf area index (LAI).
- Aerosol optical depth (AOD) was obtained from sun hazemeter ground-based network and MODIS.

# 3.3 Key indexes

- Clearness index ($k_t$) was applied to describe the effects of changes in sky condition (including changes in cloudiness and aerosol content in the atmosphere) on global solar radiation received at ground surface (*Gu et al., 1999*).

$$k_t = \frac{S}{S_e}$$

$$S_e = S_{sc}[1 + 0.033\cos(360 t_d / 365)]\sin\beta$$

$S$ : global solar radiation received at the Earth's surface.

$S_e$ : the extraterrestrial irradiance at a plane parallel to the Earth's surface.

$S_{sc}$: the solar constant (1370 W·m$^{-2}$).

$t_d$: the day of year. $\beta$*:* the solar elevation angle

# 3.3 Key indexes

- Relative irradiance (*f*) can describe the effects of changes in aerosol particles and clouds in the atmosphere on total downward solar flux, compared with the clean atmosphere (*Oliveira et al., 2007*).

$$f = \frac{S_{means}[AOD, clouds \quad aerosols]}{S_0[AOD = 0.05 \quad cloudless]}$$

$S_{meas}$ [AOD, clouds and aerosols] : the total downward solar irradiance measured in actual sky conditions.

$S_0$[AOD=0.05, cloudless] : the total downward solar irradiance in cloudless and background aerosol (AOD=0.05) condition, calculated from solar radiative model.

# 3.3 Key indexes

- Relative irradiance ($f_s$) only identify the aerosol effect (*Oliveira et al., 2007*).

$$f_s = \frac{S_{sim}[AOD, cloudless]}{S_0[AOD = 0.05 \quad cloudless]}$$

$S_{sim}$: modeled or measured total downward solar irradiance in completely cloudless conditions, for any AOD value.

# 3.4 Key models

- Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) (*Ricchiazzi et al., 1998, Oliveira et al., 2007*) was applied to calculated $S_0$[AOD=0.05, cloudless] .
- Multilayer photosynthetic productivity model was used to identify the environmental controls on NEE, which are affected by changes in aerosol content in the atmosphere and cloudiness.

# 4. Results

## 4.1 Seasonal variation of environmental variables

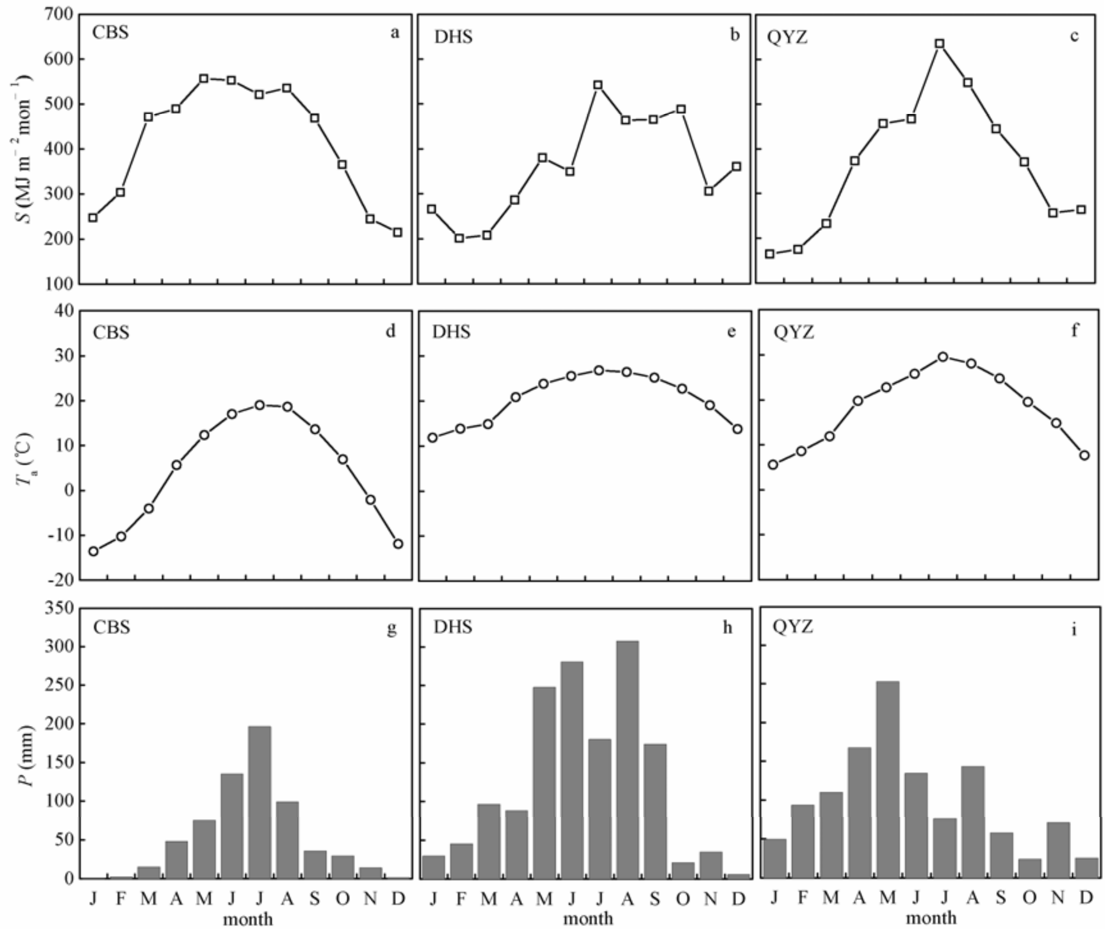


Fig.3 The seasonal variations of global solar radiation ($S$) (a-c), air temperature ($T_a$) (d-f) and precipitation ($P$) (g-i) at CBS, DHS, and QYZ.

# 4. Results

## 4.2 Frequency distribution of clearness index value in the three forest ecosystems

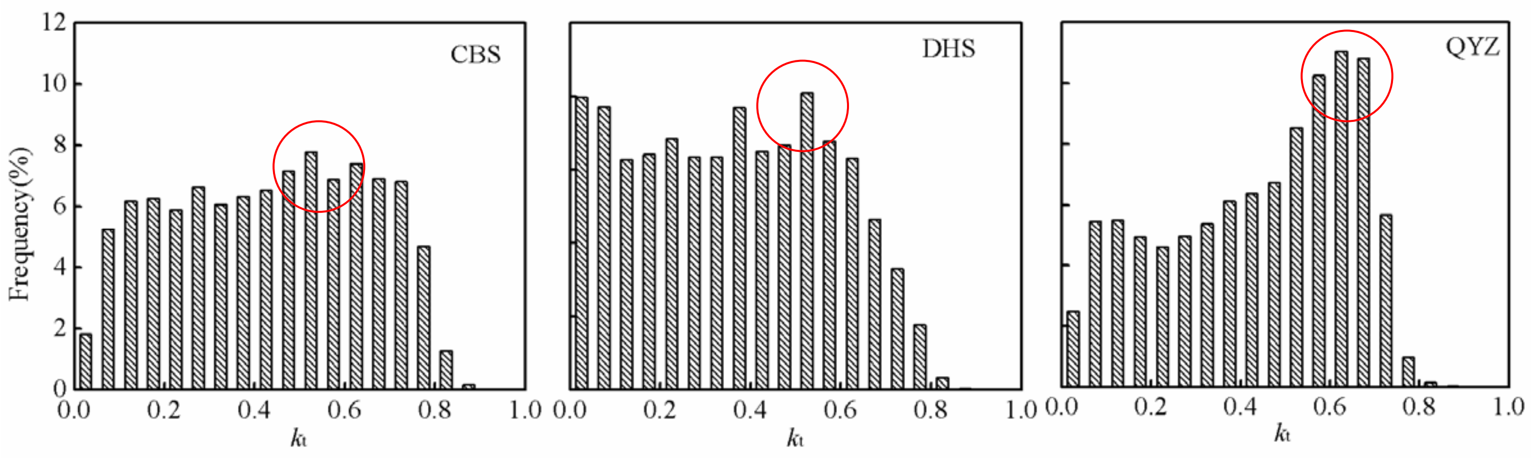


Fig.4 Histograms of the clearness index ($k_t$) value for solar elevation angle >20° at the three sites from June to August in the year from 2003 to 2006.

# 4.3 Change in NEE with clearness index

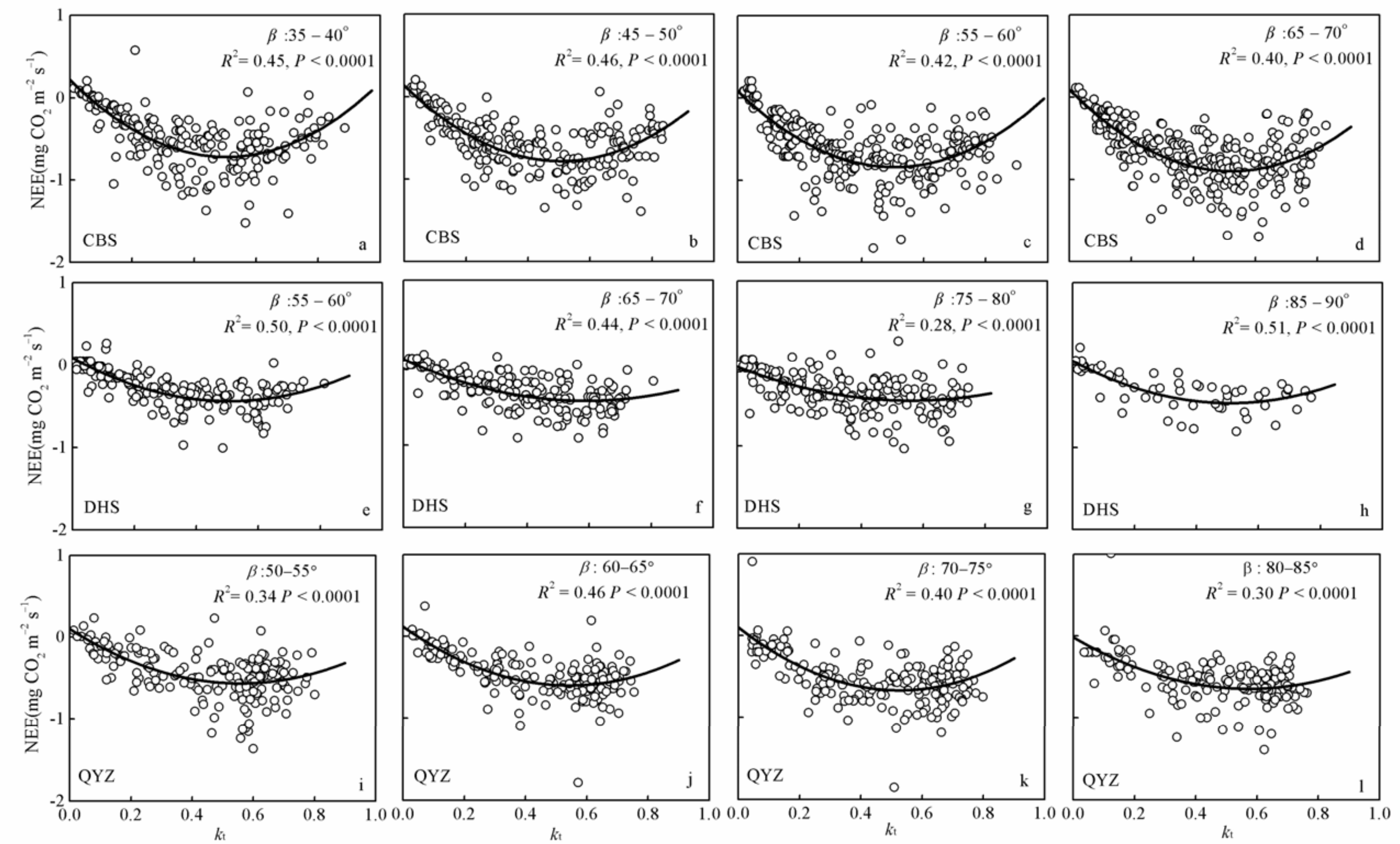


Fig.5 Relationship between NEE and the clearness index ($k_t$ ) at CBS (a-d), DHS (e-h), and QYZ (i-l) for different intervals of solar elevation angles from June to August in 2005.

# 4.3 Change in NEE with clearness index

Table 2 The optimal $k_t$ making NEE reach maximum at CBS, DHS, and QYZ for different intervals of solar elevation angles from June to August in 2005

| CBS | | DHS | | QYZ | |
|---|---|---|---|---|---|
| $\beta$ | $k_t$ | $\beta$ | $k_t$ | $\beta$ | $k_t$ |
| 34-40° | 0.50 | 55-60° | 0.51 | 50-55° | 0.56 |
| 45-50° | 0.51 | 65-70° | 0.59 | 60-65° | 0.54 |
| 55-60° | 0.51 | 75-80° | 0.56 | 70-75° | 0.53 |
| 65-70° | 0.52 | 85-90° | 0.51 | 80-85° | 0.57 |
| Average | 0.51 | Average | 0.54 | Average | 0.55 |

# 4.4 Changes in environmental variables with clearness index

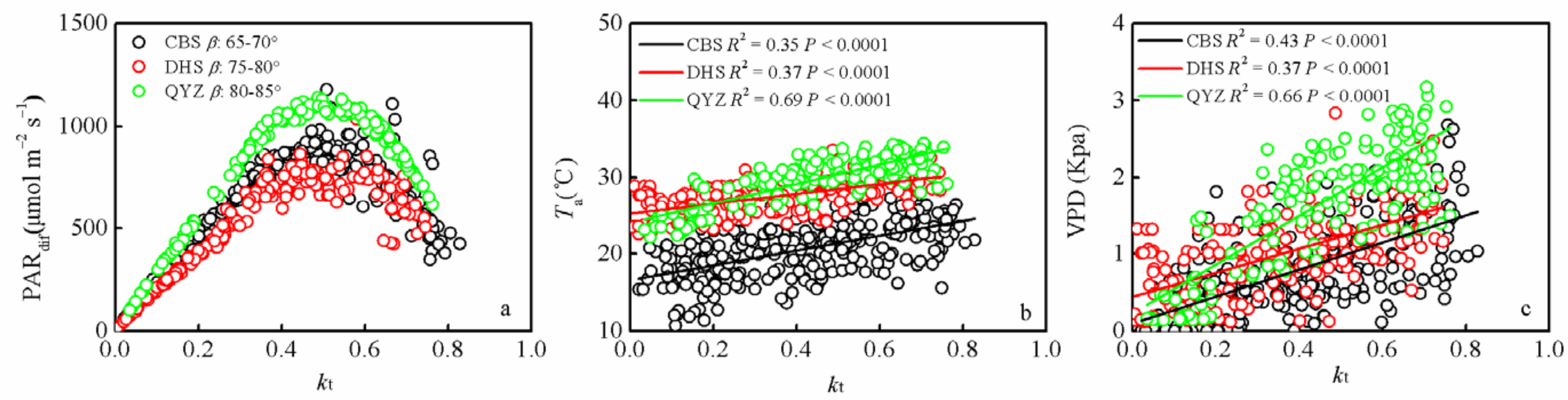


Fig.6 Relationship between diffuse PAR received by ecosystem ($PAR_{dif}$) (a), air temperature ($T_a$) (b), and vapor press deficit (VPD) (c) and the clearness index ($k_t$) for selected interval of solar elevation angles at CBS, DHS, and QYZ sites from June to August in 2005.

# 4.5 the responses of carbon budget to changes in environmental variables

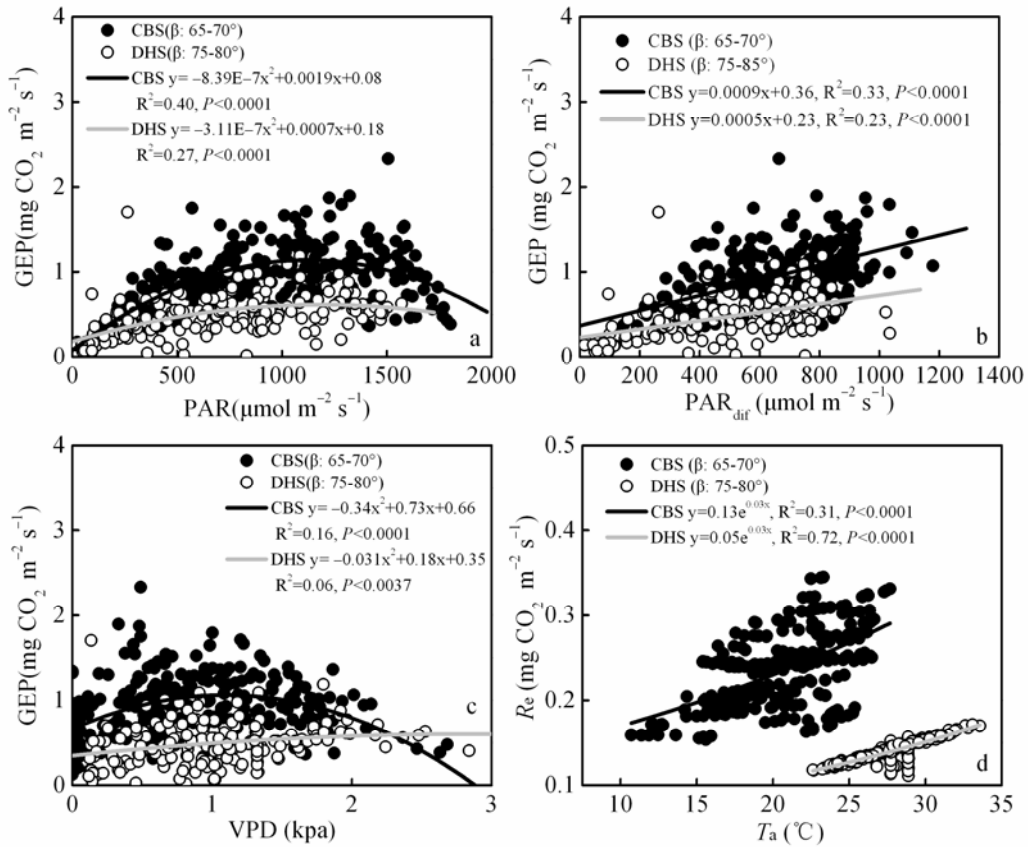


Fig.7 Changes of gross ecosystem photosynthesis (GEP) with (a) PAR, (b) diffuse PAR ($PAR_{dif}$) and (c) vapor pressure deficit (VPD) and Changes of ecosystem respiration ($R_e$) with air temperate ($T_a$) (d) for selected intervals of solar elevation angles at CBS and DHS from June to August in 2005.

# 4. Results

- The NEE of the three different forest ecosystems reached maximum when $k_t$ was between 0.5-0.6.
- The $k_t$ value at CBS, DHS, and QYZ had the highest frequency around 0.55, 0.55, and 0.60, respectively. The result suggested that currently sky conditions were better for the net carbon uptake of the three forest ecosystems.
- In three forest ecosystems, diffuse PAR reached maximum when $k_t$ was between 0.4~0.6, and $T_a$ and VPD decreased linearly with decrease in $k_t$.
- The changes in GEP of temperate forest at CBS with PAR and VPD were more significant than that at DHS.

# 5. Key question

- Applying SBDART to simulate $S_0$[AOD=0.05, cloudless] and calculate $S$ and $S_f$ in order that the effect of aerosol loading can be isolated.
- Combining AOD ground-based measurement with remote sensing monitor to obtain the real time changes in AOD at the three sites.
- Applying multilayer model to test the sensitivity of responses of photosynthesis to changes in environmental variable in the three forest ecosystems.

Thank you for your attention!