Aerosol and Air Quality Research, 16: 3302–3311, 2016

ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2016.07.0309

Estimation of CO_2 Assimilation and Emission Flux of Vegetation in Subtropical Island - Taiwan

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ABSTRACT

The goal of the present study is to provide a comprehensive model to estimate CO_2 assimilation and emission flux in Taiwan. In addition to metrological data, the model consists of (1) 83 land-use types including 68 vegetations, (2) NDVI-LAI transfer functions for various vegetations, (3) leaf width database for 68 vegetations, and (4) LEAFC3 module. The model output includes 2D hourly CO_2 assimilation flux for 68 vegetations with 1 km × 1 km resolution in Taiwan. The results of model evaluation with observed data of 26-day (Nov 12–Dec 7, 2009) CO_2 flux field experiment include: (1) predicted hourly CO_2 uptake fluxes on the daytime match rather well with observed data variations but CO_2 release fluxes on the nighttime show significant underestimate; (2) predicted CO_2 uptake and release fluxes show a relatively good correlation with observed data ($R^2 = 0.67$); (3) predicted CO_2 assimilation fluxes and isoprene emission fluxes are highly correlated with trends of variation due to photosynthesis.

Based on the meteorological data in 2009, the annual total amount of CO_2 assimilation about 115.3 million ton in Taiwan with 79.6 million ton for forests and 35.7 million ton for non-forest vegetations. The CO_2 assimilation amount is higher in the third quarter (July–September) and lower in the first quarter (January–March) for 44.3% and 16.4% of the annual total amount respectively. The spatial distribution of annual CO_2 assimilation amounts are higher in lower and medium altitude mountain areas with an average of around 6–10 thousand ton km^{-2} y^{-1}. The implication of the other results is also discussed.

Keywords: Flux simulation; Flux observation; CO_2 assimilation; Spatial distribution.

INTRODUCTION

Climate change is recognized as an unprecedented challenge worldwide. Among these greenhouse gases, CO_2 contributes over 60% to global warming due to its huge emission amount (Albo *et al.*, 2010; IEA, 2012). CO_2 mitigation presents both a challenge and an opportunity to the world for sustainability of energy and environment (Huang and Tan, 2014). A reduction in fossil fuel energy use would reduce CO_2 emissions but would also be accompanied with a slowdown in economic growth as prices increase without changes in production technology and efficiency (Liou, 2015; Lin, 2015). That is why the studies of carbon sequestration via anthropogenic and natural processes are interested in many countries for reducing CO_2 emissions. many CO_2 capture technologies have been proposed for various CO_2 emission sources (Yu *et al.*, 2015). The forest ecosystem, the largest carbon reservoir of the terrestrial ecosystem, accommodated over 75% of carbon on the Earth's surface (Hamilton *et al.*, 2002). Study showed that tropical forests could be an important carbon reservoir, helping mitigate the rising rate of atmospheric CO_2 concentration (Phillips *et al.*, 1998). CO_2 capture via photosynthesis to directly fix carbon into microalgae has also been recognized as another way to mitigate atmospheric CO_2 concentration in water area. The harvested microalgal biomass can be converted into biofuel products. Thus, microalgal cultivation can contribute to CO_2 fixation and can be a source of biofuels (Klinthong *et al.*, 2015). Terrestrial net primary production (NPP) refers to the net amount of carbon captured by plants through photosynthesis and is a key component of energy and mass transformation in terrestrial ecosystems. NPP represents the net carbon retained by terrestrial ecosystems after assimilation through photosynthesis and losses due to autotrophic respiration (Pan *et al.*, 2014). Therefore, NPP is a measure for the carbon flux which describes the carbon

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uptake by vegetation through photosynthesis (Neumann *et al.*, 2015). Thus forests are important to the global carbon cycle that is linked to global climate. Therefore, better understanding of environmental controls on forest CO_2 is needed to improve regional and global climate models as well as reduce uncertainty about effects of environmental change on forest (Sellers *et al.*, 1997).

Seasonal variability of photosynthesis and respiration is significant in different area for various type of plants, which broad-leaved forest is one of the forests that have large NPP (Falge *et al.*, 2002). Broad-leaved forests occupied about 6–13% of global land (Sellers *et al.*, 1997) and produced 5–8% of global NPP (Ajtay *et al.*, 1979; Olson *et al.*, 1983). The ratio covered by forests is over 60% of terrestrial area, in which the broad-leaved forests account for about 35% in Taiwan (Chang *et al.*, 2009). It shows that the plants of Taiwan have great potential for assimilating a considerable amount of CO_2. Taiwan had established air quality enhancement zones (AQEZs) by planting trees, aiming to improve air quality and ecological environment (Wang and Lin, 2012). Wang *et al.* (2015) furthermore indicated that trees in the AQEZs reduce the amount of CO_2 in the atmosphere by storing carbon in their tissues with average annual CO_2 sequestration of 4.92 tons ha^{-1} yr^{-1}. The carbon sequestration benefits will increase yearly during the growing period of trees. However, carbon sequestration varied greatly among individual trees, species, and regions in Taiwan. Therefore, a model can account for the CO_2 assimilation through photosynthesis effect and loss by respiration for various trees, species, and regions should be needed.

Amthor *et al.* (2001) indicated the importance of developing a ecosystem process model to simulate CO_2 exchange and evapotranspiration process of boreal forest, because plant plays a key role for global carbon balance due to CO_2 uptake and release. Amthor *et al.* (2001) also reviewed and pointed out the major ecosystem process models including BEPS (Liu *et al.*, 1997), BGC (Kimball *et al.*, 1997), CLASS (Verseghy, 1991; Wang, 2000), Ecosys (Grant *et al.*, 1999), FORFLUX (Zeller and Nikolov, 2000), LoTEC (King *et al.*, 1997; Post *et al.*, 1997), NASA-CASA (Potter, 1997; Potter *et al.*, 2001), SPAM (Frolking, 1997), and TEM (McGuire *et al.*, 2000). The time scale considered in such of models can be divided into 30 minutes (CLASS), hours (Ecosys, FORFLUX and LoTEC), days (BEPS, BGC, LoTEC, NASA-CASA, and SPAM), and months (TEM). According to the simulation method, the models can be classified into two types of photosynthetic algorithm and parameterized equation. The models of BEPS, BGC, CLASS, Ecosys, FORFLUX, and LoTEC employed the photosynthetic algorithm proposed by Farquhar and von Caemmerer (1982) to simulate the carbon assimilation, while the models of NASA-CASA, SPAM, and TEM applied the parameterized equation with parameters, such as solar radiation, temperature, CO_2 concentration, humidity variation, and supplement rate of nutrient sodium to calculate the carbon captured.

To estimate the biogenic VOCs (BVOCs) emission for Taiwan, Chang *et al.* (2009) have developed a model, called Taiwan Biogenic Emission Inventory System (TBEIS). The model considered energy balance of leaf temperature and combined 85 types of land-use with seasonal variation of leaf area index (LAI) and leaf wide databases in Taiwan to simulate 33 species of BVOCs and their spatial distributions with 1 km × 1 km resolution. The leaf temperature applied to estimate BVOCs emission in TBEIS is calculated by the leaf energy balance equations used in leaf photosynthesis model (LEAFC3) (Nikolov *et al.*, 1995). There is another function in LEAFC3 to compute the CO_2 assimilation flux due to Leaf-level net photosynthesis of plants (Zeller and Nikolov, 2000). Therefore, based on the photosynthetic algorithm in LEAFC3 and combined with the database in TBEIS, an hourly time step model that couples major processes controlling short-term forest CO_2 exchanges for Taiwan is established in this study. The model, called Taiwan ecosystem process model (TEPM), can be used to simulate hourly CO_2 uptake and release rate of Leaf-level photosynthesis and respiration for each grid in Taiwan, and then the simulation results can be integrated to estimate the temporary variation and spatial distribution of Leaf-level net CO_2 assimilation.

Nevertheless, before the ecosystem model is used with confidence for spatial and/or temporal extrapolation, model accuracy must be systematically evaluated. The evaluation procedure including comparison of model predictions and independent field measurements is also shown later in this study. Consequently, the results of TEPM simulation can provide useful information for assessing CO_2 uptake capacity of various plants and for planting management of various regions in Taiwan.

ESTABLISHMENT OF TEPM

The structure and content of TEPM are illustrated in Fig. 1. Based on LEAFC3 and combined with a land-use database, LAI, and a leaf width database in TBEIS, TEPM is capable of yielding CO_2 uptake and release rates for various forest appearances in each grid by hours, days, months, seasons, and annuals. The LEAFC3 consists of four components: (1) leaf biochemical process, (2) stomatal conduction process (3) electrical conduction process at the leaf boundary, and (4) leaf energy balance process, with the assumption that the total absorption energy of leaves equaled the sum of energies from sensible and latent heat fluxes, long-wave radiation, storage and metabolism (Kurpius *et al.*, 2003). The land-use databases for Taiwan have spatial resolutions of 1 km by 1 km and each grid covers each land-use type (Chang *et al.*, 2009). Incorporated with the land-use database and the leaf area index (LAI), TEPM is capable of simulating seasonal variation of CO_2 flux. The input data to TEPM included temperature, photosynthetic radiation flux, relative humidity, total radiation amount absorbed by leaves, wind speed, atmospheric pressure and CO_2 concentration; the output data included CO_2 net assimilation flux, leaf temperature, stomatal conductance to water vapor and leaf boundary-layer conductance to water vapor.

Land-Use Database

The purpose of incorporating the land-use database was providing data to simulate carbon uptake and release flux

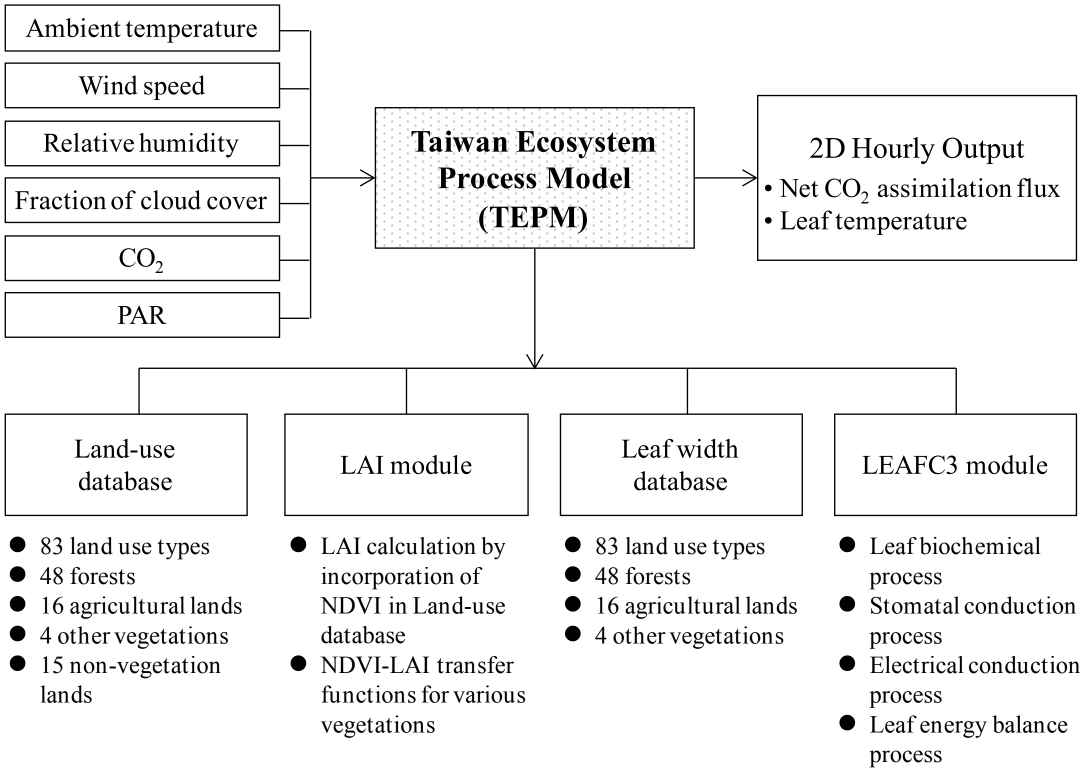

Fig. 1. Configuration of Taiwan ecosystem process model (TEPM).

of different vegetations. Since there are differences among species, the carbon uptake ability of vegetations varied with growth factors such as growth environment, climatic conditions, age, and growth rates. Even in the same species, variation in physiological behaviors was observed. This implied that dissimilarity might exist among the individuals for roles played and effects demonstrated in carbon sequestration (Wang *et al.*, 2002); therefore, the land-use database is of great importance to TEPM. Renewal and accuracy of the land-use database were crucial in the simulation of CO_2 assimilation. Because of the experience of successful application to the estimation of BVOCs emission (Chang *et al.*, 2009), TEPM, during its development, was associated with the land-use database for reflecting variation in spatial distribution of CO_2 uptake and release flux.

According to the land-use database, land-use of Taiwan was divided into 83 types, including 48 forests, 16 agricultural lands, 4 vegetation types, and 15 non-vegetation lands (Chang *et al.*, 2009). The total forest area was about 28,166 km^2, where natural mixed broad-leaved forests occupied the largest portion (21%), and broad-leaved forest came next (18%). Detailed land-use information with 1 km^2 resolution in TEPM would provide simulated data of CO_2 assimilation flux to be evaluated with the data measured by field experiment of CO_2 flux later.

Leaf Area Index

Biomass is another important factor affecting carbon sequestration. Frank and Karn (2003) pointed out there is a high dependency between leaf area index (LAI) and biomass. LAI is the ratio of total leaf area to the area occupied by tree. The higher LAI usually indicates the higher biomass. Thus, a LAI database that can reflect practical biomass for each land area is a crucial information for estimating CO_2 uptake and release flux at each land area of Taiwan in TEPM. The LAI database used in TBEIS-2 (Chang *et al.*, 2009) is also adopted in TEPM.

LAI was demonstrated to be successfully derived from a normalized difference vegetation index (NDVI) (Nemani *et al.*, 1996; Le *et al.*, 2005). To possess the capability of simulation for seasonal variation with LAI change, the NDVI-LAI transfer function, where LAI data are transformed from NDVI, has been also added to TEPM. By combining LEAFC3 with LAI and the land-use databases, TEPM can effectively simulate short-term and long-term variations of CO_2 uptake and release flux for any area in Taiwan.

Leaf Width

Leaf width is an important parameter affecting the uptake of plants. It was shown to directly affect conduction in leaves and energy balance and Larger leaf width implicate the more CO_2 assimilation (Nikolov *et al.*, 1995). A leaf width database for 68 plants of 83 land-use types in Taiwan is established for TEPM. The original leaf width data were acquired from Huang (1994) and the database of biological diversity for national parks of Taiwan (http://npgis.cpami.gov.tw/public/park/park.aspx?park=KT). The data then were set for the 68 kinds of plants by the botanical classification method of Benjamin *et al.* (1996). In addition to that, land-use patterns and LAI were fed to simulate the spatial and temporal variation of CO_2 absorption flux.

Meteorology

The meteorological data required in the model of TEPM include hourly environmental temperature, wind speed, cloud coverage, relative humidity (RH) and photosynthetic available radiation (PAR). To simulate the whole Taiwan's CO_2 flux of assimilation and respiration in subsection 3.3, the meteorological data were originally provided from the weather stations (185 total) around the Taiwan island (Fig. 2) and then the discrete data were processed by a pre-processer and generated a regular dataset of meteorological parameters ready for the model of TEPM. The pre-processer were designed to interpolate hourly meteorological data from 185 weather stations into the hourly meteorological data in each grid of 1 km × 1 km for whole Taiwan. Also, topographic influence during interpolation was considered for the ambient temperature data; wind directions were taken into account for the wind velocity data. It is noted that data on the fraction of cloud coverage were obtained from 25 ground weather stations established throughout the island.

CO_2 Flux Observation

In order to evaluate the model simulation results, the CO_2 flux field experiment was conducted from Nov 12th to Dec 7th, 2009 at the lawn in Gukeng Floriculture Center, Taiwan Agricultural research institute, which was established in response to the needs of the country's thriving floral industry. We chose the lawn, which area is more than 10 hectares and surrounded by various vegetations in the Center as field experiment site of CO_2 flux observation. The disturbance on CO_2 concentration coming from horizontal airflow during observation period could be as low as possible, because the place is located on extensive plain and almost no artificial interference from CO_2 sources. The distance from observation site to each artificial significant CO_2 source such as traffic road is more than two kilometers. Therefore, the artificial influence on CO_2 observation should be low.

An eddy covariance (EC) system was used to measure CO_2 flux for comparison with modeling results later. EC system can measure the variations of atmospheric turbulence and CO_2 concentration to estimate CO_2 flux (Baldocchi *et al.*, 1988). In this study, CO_2 flux measurement was performed by the Open Path Analyzer for ecophysiological research (OP-2, ADC Bioscientific Ltd., Hoddesdon, UK). The OP-2 provides simultaneous measurement of atmospheric fluctuations of CO_2 with open path, absolute and infrared (NDIR) analyzer. It was designed to be used in conjunction with a 3-d sonic anemometer for eddy-covariance studies, where the correlation between fluctuations in CO_2 with vertical wind speed are used to estimate vertical fluxes of CO_2. Positive calculated flux represents that plants release CO_2 into the atmosphere, and vice versa that plants assimilate CO_2 for photosynthesis.

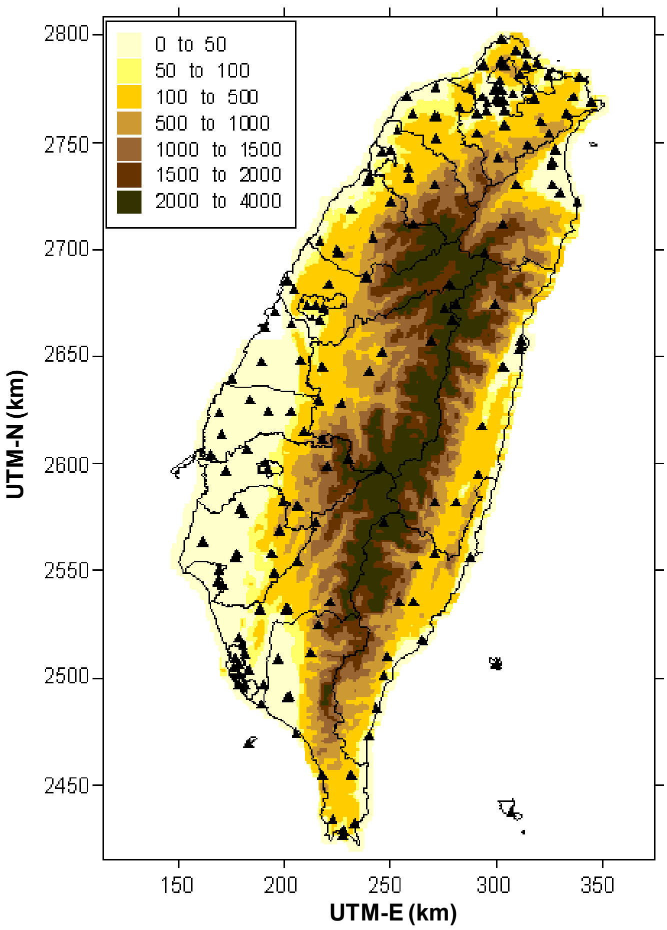

Fig. 2. Spatial distribution of terrain height and 185 meteorological stations in Taiwan.

Besides the CO_2 observation, some meteorological parameters such as ambient temperature and RH measured by the probe of HMP45C (Campbell Scientific Inc., Logan UT, USA), and bi-directional absorbed short and long-wave radiation measured by a net radiometer (CNR1, Kipp & Zonen B.V. Delft, The Netherland) were also observed together with OP-2. The meteorological data were provided to TEPM for simulation of CO_2 flux, and then compared with the observation of CO_2 flux later for model evaluation.

RESULTS AND DISCUSSION

Model Evaluation

Model evaluation is important not only to establishing confidence in models and their uses, but also in determining models and model components that need improvement. Ideally, model evaluation would be carried out by direct comparison of field measurements to model output at the temporal and spatial scales of the model. (Amthor *et al.*, 2001) The evaluation of the developed model results was performed in two ways: (1) diurnal pattern comparison of model results with observed data, and (2) correlation analysis of model results with observed data.

The CO_2 flux during the 26 days observation at the lawn in Gukeng Floriculture Center were ranged from –0.35 mg m^{-2} s^{-1} to 0.13 mg m^{-2} s^{-1} with averaged flux of –0.13 mg m^{-2} s^{-1} for net CO_2 assimilation flux in the day time, while the CO_2 flux were ranged from –0.14 mg m^{-2} s^{-1} to 0.23 mg m^{-2} s^{-1} with averaged flux of 0.047 mg m^{-2} s^{-1} for net CO_2 release flux in the night time. The observed CO_2 flux preformed a significantly diurnal variation, the vegetation starts assimilating CO_2 at around 6:00 when sun rises, gradually increases CO_2 assimilation rate with raised sunlight intensity, reaches the maximum around 11:00–13:00, and then gradually decreases CO_2 assimilation rate to close to zero until sun sets. The diurnal variation of CO_2 flux can be explained very well by the CO_2 exchange and evapotranspiration process among vegetation characteristics, wind speed, temperature, and bi-directional absorbed short and long-wave radiation. The correlation analysis showed the effect of absorbed short-wave radiation is greater than that of absorbed long-wave radiation on CO_2 assimilation flux. And, the correlation coefficients of CO_2 assimilation flux with absorbed short-wave and net radiation are all greater than 0.7. It implicates that the absorbed short-wave and net radiation are major parameters in the CO_2 assimilating process.

Whatever the observed and simulated results, the diurnal variation of CO_2 flux presented a significant characteristic that positive flux at nighttime and negative flux at daytime (Fig. 3). The plants usually exhibited a significant CO_2 assimilation flux from as early as 08:00, and increased near noon when PAR became ever abundant due to vigorous photosynthesis and the observed CO_2 assimilation flux can rise as high as more than 0.30 mg m^2 s^{-1}. The assimilation flux usually decreased around 15:00 because PAR declined.

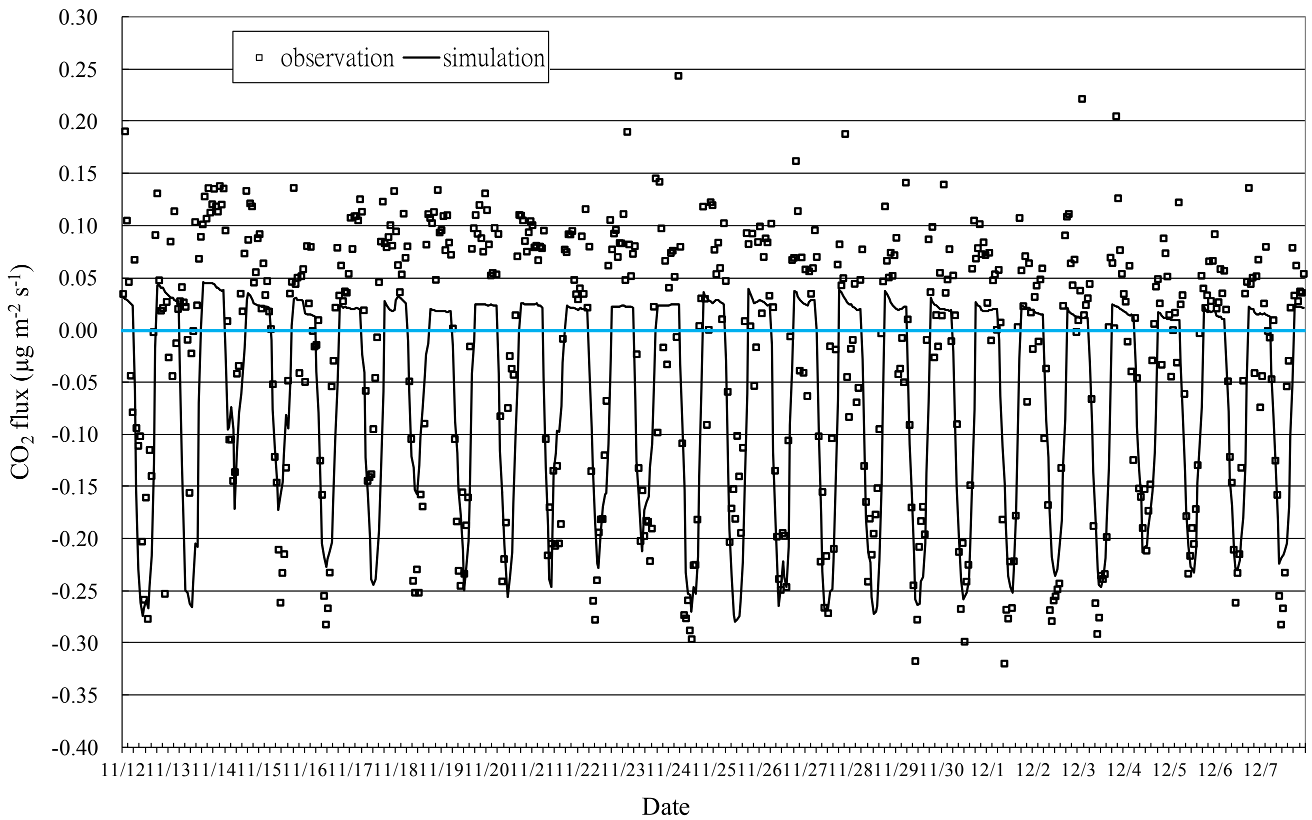

Fig. 3. Time series comparison between observed and simulated CO_2 assimilation fluxes during Nov 12 to Dec 7, 2009 at the lawn in Gukeng floriculture center, Taiwan agricultural research institute.

Kuhn *et al.* (2002) had indicated that CO_2 assimilation flux and PAR had very strong correlation because of photosynthesis. Comparison of the observed and simulated results showed that the simulated results in 07:00–10:00 and 15:00–17:00 were closer to the observed data than the other time. Furthermore, the simulated fluxes were usually underestimated at the noon period (11:00–14:00). During the nighttime the plants exhibited significant CO_2 emission flux due to autotrophic respiration, the observed CO_2 release flux usually varied greatly from 0.05 to 0.15 mg m^2 s^{-1} and possibly rise up to more than 0.20 mg m^2 s^{-1} sometime. In general, the simulated results of TEPM on the daytime showed a slightly underestimated CO_2 uptake flux due to photosynthesis effect with mean normalized bias of 35%, while those on the nighttime presented a significantly underestimated CO_2 release flux due to respiration effect with mean normalized bias of 118%.

The correlation analysis of the simulated results of TEPM with the observed data for CO_2 flux showed a relatively good correlation ($R^2 = 0.67$, Fig. 4). A better correlation occurred at day time (negative flux) specially from 10:00 to 15:00 when photosynthesis increased. The results of correlation analysis, same as time series analysis in Fig. 3, also indicate that TEPM had a better simulation capability for CO_2 uptake flux with photosynthesis effect at daytime than that for CO_2 release flux with respiration effect at nighttime.

CO_2 Assimilation Flux Compared with BVOCs Emission Flux

The emission flux of isoprene from plants varied with CO_2 assimilation flux due to photosynthesis (Kesselmeier *et al.*, 1998), and both of them were highly correlated with trends of variation (Kuhn *et al.*, 2002). Based on the data from the lawn of the Gukeng Floriculture Center, both of Taiwan biogenic VOCs emission inventory system (TBEIS) (Chang *et al.*, 2009) and TEPM simulated hourly isoprene emission and CO_2 assimilation flux, respectively. Fig. 5 shows that at 07:00, isoprene and CO_2 flux gradually increased. At about 13:00, near noon, they reached the maximum fluxes (isoprene flux was 0.35 mg m^2 h^{-1}, and CO_2 flux was about 0.27 mg m^2 s^{-1}), and at 16:00, both of them exhibited downward trends. According to the diurnal variation of the simulation results, the isoprene and CO_2 flux are highly correlated.

Model Inventory Results

The meteorological data of the year 2009 were used to simulate the hourly CO_2 flux of the same year for each grid with 1 km × 1 km resolution in TEPM. The simulated results of hourly CO_2 assimilation flux for each grid were further integrated for an exploration of temporal and spatial characteristics. The estimated CO_2 assimilation amount of forest and non-forest in Taiwan were separated into four seasons so that seasonal effect can be better comprehended. The estimated result shows the annual total amount of CO_2 assimilation was about 115.3 million ton in Taiwan with 79.6 million ton for forest plants and 35.7 million ton for non-forest plants (Table 1). Liao (2009) had ever used the method of GPG (Good Practice Guidance for Land Use, Land Use Change and Forestry) proposed by IPCC (2003) and obtained annual CO_2 assimilation amount of 44.1 million ton for Taiwan's forest plants. Comparing to the result of 44.1 million ton, the amount of 79.6 million ton predicted in this study is higher because of the significantly underestimated CO_2 release flux on the nighttime due to respiration effect whereas the slightly underestimated CO_2 uptake flux on the daytime due to photosynthesis effect mentioned in previous section. The estimated CO_2 assimilation amount reached the highest value in the third quarter (July–September) with 44.3% of the annual total amount, which was attributed to the vigorous photosynthesis effect with higher temperatures/PAR. However, the CO_2 assimilation

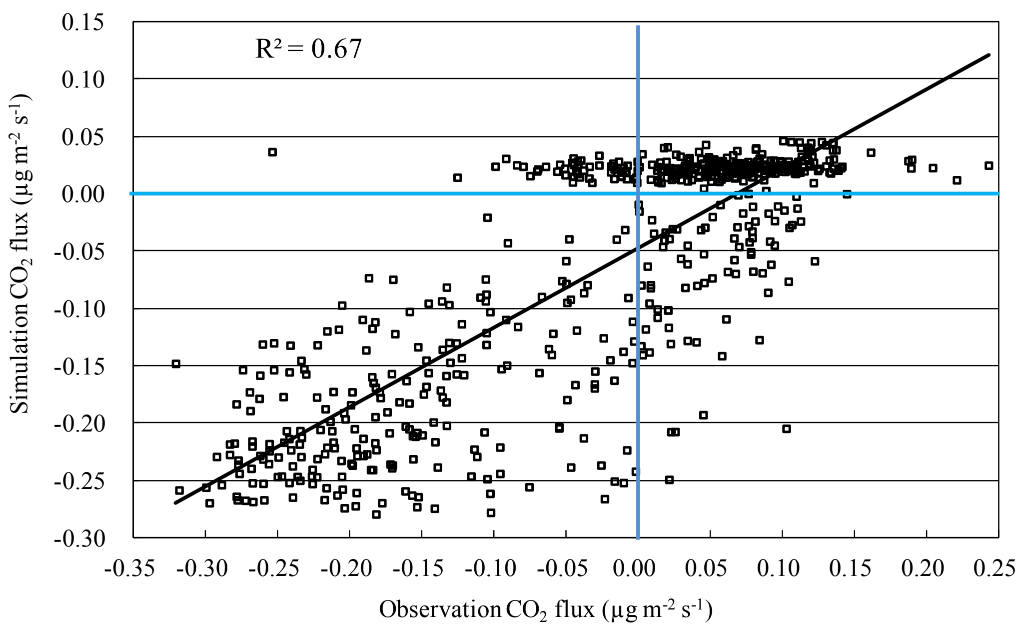

Fig. 4. Scatter plot and correlation analysis between observed and simulated CO_2 assimilation fluxes.

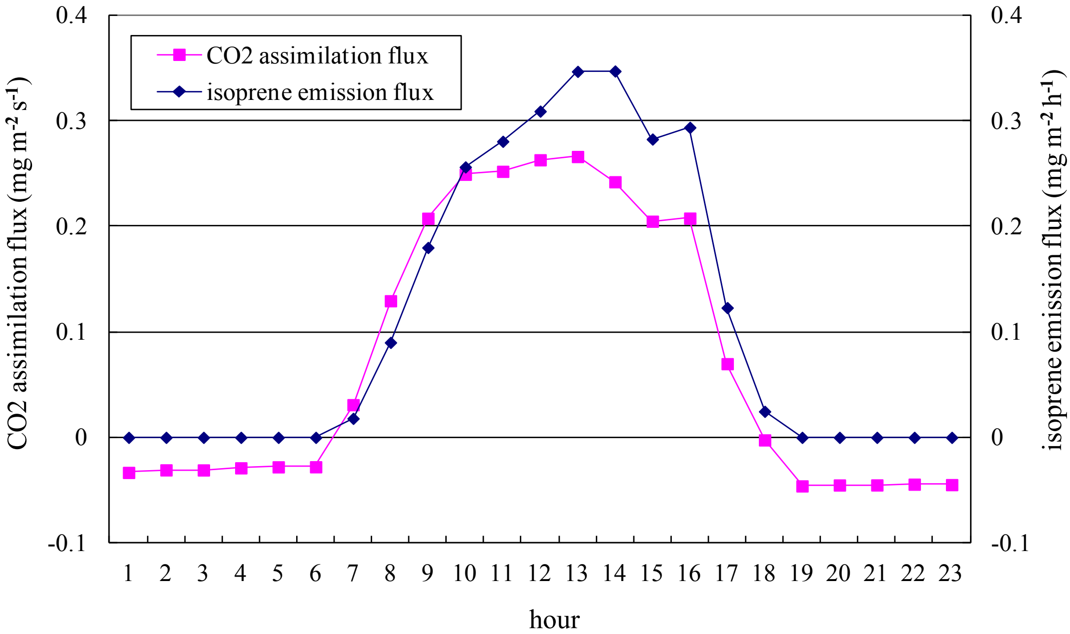

Fig. 5. Diurnal variation of CO_2 assimilation flux and isoprene emission flux predicted by TEPM and TBEIS2 respectively.

Table 1. Net CO_2 assimilation amount in Taiwan (million tons per year).

	Forest	Non-forest	Total	Ratio (%)
1st quarter (Jan.–March)	12.8	6.1	18.9	16.4
2nd quarter (April–June)	16	8.2	24.2	21
3rd quarter (July–Sep.)	36.7	14.4	51.1	44.3
4th quarter (Oct.–Dec.)	14.1	7	21.1	18.3
Annual total	79.6	35.7	115.3	100

amount accounted only 16.4% of the annual total amount in the first quarter (Jan–March) due to lower temperatures and PAR effect. According to the report of 2015 Taiwan Greenhouse Gas Inventory Executive Summary (Taiwan EPA, 2016), Taiwan's total GHG emission amount is 284.5 million ton of CO_2 equivalents in 2013, which is about 2.5 times of net CO_2 assimilation amount of 115.3 million ton due to Taiwan's vegetations. However, a certain part of the CO_2 captured in the vegetation should be released to atmosphere again through biomass combustion and decomposition.

The spatial distribution of total CO_2 assimilation amount in Taiwan in 2003 estimated by TEPM is illustrated in Fig. 6. As can be seen, detailed land-use pattern with 1 km^2 would render good resolution of CO_2 assimilation amount. Annual assimilation amount of CO_2 are higher in lower and medium altitude areas with an average of around 6–10 thousand ton km^{-2}; the highest emission was up to 18 thousand ton km^{-2}, whereas they are 2–3 thousand ton km^{-2} on ground levels. Notice that relatively high CO_2 assimilation amount along the sea shore of the western Taiwan is attributed to the windbreak forests. CO_2 was mostly assimilated in lower and medium altitude mountains (300–1500 m) where the major forest type was broadleaved forests with high assimilation fluxes. And then, the assimilation fluxes decrease progressively with increasing altitude; the total CO_2 assimilation is as lower as below 1 thousand ton km^{-2} on the mountain areas more than 3000 m high. The characteristics of spatial distribution of CO_2 assimilation flux were also presented on the BVOCs emission flux in Taiwan (Chang *et al.*, 2009). With stronger photosynthesis and higher CO_2 assimilation flux, BVOCs emission flux also increased (Kesselmeier *et al.*, 1998; Kuhn *et al.*, 2002; Yaman *et al.*, 2015). Therefore, the spatial distributions between BVOCs emission and CO_2 assimilation flux can be similar. The results imply that CO_2 assimilation flux and BVOCs emission flux in general is strongly dominated by altitude, latitude and coverage ratio of vegetation.

CONCLUSIONS

On the basis of LEAFC3 model and combined with Taiwan's land-use database, NDVI-LAI transfer functions, and leaf width database for 68 vegetations in Taiwan, We have developed a model of TEPM that can be used to estimate hourly CO_2 assimilation and release flux for whole Taiwan with 1 km × 1 km resolution. Therefore, the model can be used to explorer the spatial and temporal distribution of CO_2 assimilation through photosynthesis effect and loss by respiration for various trees, species.

The results of observed data of 26-day (Nov 12–Dec 7, 2009) CO_2 flux field experiment at the lawn in Gukeng Floriculture Center showed the averaged flux of –0.13

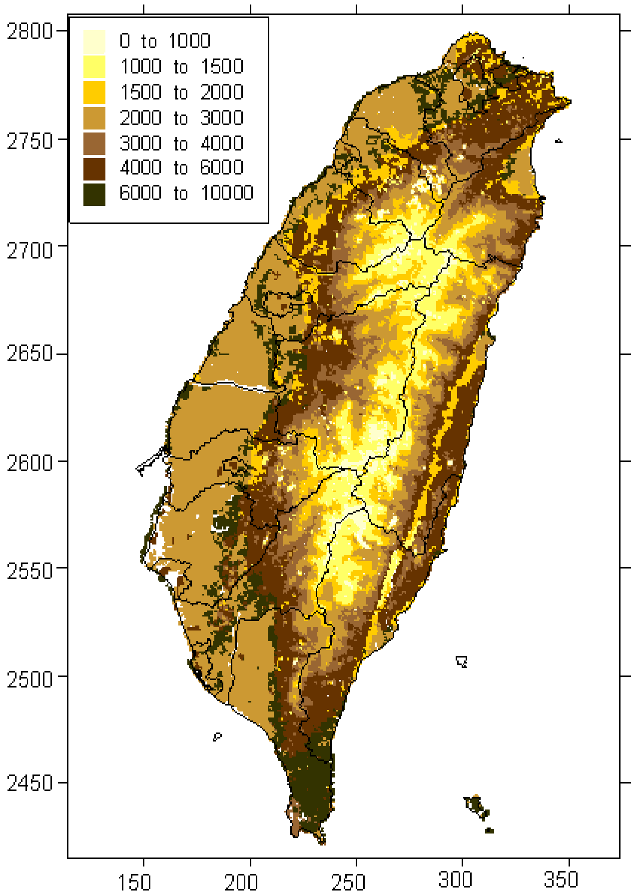

Fig. 6. The spatial distribution of annual CO_2 assimilation amount in Taiwan in 2009 estimated by TEPM (ton CO_2 km^{-2} $year^{-1}$).

mg m^{-2} s^{-1} for net CO_2 assimilation flux in the day time and 0.047 mg m^{-2} s^{-1} for net CO_2 release flux in the night time. The observed CO_2 flux also preformed a significantly diurnal variation. The results simulated by TEPM presented that predicted hourly CO_2 uptake fluxes show match rather well with observed data variations on the daytime; while predicted CO_2 release fluxes show significant underestimate on the nighttime.

The annual total amount of CO_2 assimilation predicted by the model of TEPM was about 115.3 million ton in Taiwan with 79.6 million ton for forests and 35.7 million ton for non-forest vegetations. The CO_2 assimilation amount is higher in the third quarter (44.3%) and lower in the first quarter (16.4%). The predicted amount in the study is higher than that estimated by the past study (Liao, 2009) majorly caused by the significantly underestimated CO_2 release flux on the nighttime due to respiration effect. The spatial distribution of annual CO_2 assimilation amounts are higher in lower and medium altitude mountain areas. It implicates that vegetation type, temperature, and absorbed net radiation are major parameters in the CO_2 assimilating process.

ACKNOWLEDGMENT

Taiwan Ministry of Science and Technology is acknowledged for the financial support (NSC-100-2221-E-224-012-).

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Received for review, July 8, 2016
Revised, September 20, 2016
Accepted, September 21, 2016