1.9 THE SIMULATION OF WATER VAPOR AND CARBON DIOXIDE FLUXES OVER IRRIGATED FARMLAND BY MODIFIED SOIL-PLANT-ATMOSPHERE MODEL(mSPA)

[1]Young-Hee Lee,* [2]Joon Kim and [2]Jinkyu Hong

[1] Department of Astronomy and Atmospheric Sciences, Kyungpook National University, Korea,

[2] Department of Atmospheric Sciences, Yonsei University, Korea

1. INTRODUCTION

Agricultural crop is known as an important carbon sink in the ecosystem. The need to understand carbon exchange between crop and atmosphere leads to many long-term eddy covariance measurements and modeling studies. The process-based models are useful for specifying rates of mass and energy fluxes in and out of the atmosphere and for extrapolating information about trace gas fluxes in time and space. Also, models can identify weaknesses in our understanding of controlling process and can be used to design field experiment. The objectives of this study are i) to parameterize the model ; ii) to examine the sensitivity of diurnal variation of surface fluxes to model parameters in comparison with observations; iii) to investigate the sensitivity of cumulative evaporation and gross primary production (GPP) to model parameters for rice crops during the growing season.

2. MATERIAL AND METHOD

2.1 DATA

The study site is located in a southwestern end of Korean peninsular ($34.55°N$, $126.57°E$, 12.7m above m.s.l) which is part of the Koflux site (Haenam). The landcover is the mixture of rice paddies and various agricultural crops such as beans and sweet potatoes. The soil type is varying from silt loam to loam. The terrain is relatively flat (Lee et al., 2003). The surface flux measurements on a 25 m tower have been made since June in 2002. Eddy covariance system consists of three-dimensional sonic anemometer(CSAT3, Campbell Scientific, USA) and open-path H_2O/CO_2 gas analyzer (LI7500, LICOR, USA) at 21m above the ground. Net radiometer(Kipp & Zonen, Germany) was also installed at 20m above the ground. Meteorological variables measured by Haenam meteorological station (within 50m from the flux tower) are atmospheric pressure, relative humidity, air temperature, precipitation, wind speed and wind direction. The study period is the growing season from June to September in 2003. In August, eddy covariance data are not available.

2.2 MODEL

The mSPA model is a two-layer canopy model. The model is based on the canopy model of Williams et al. (1996), a multilayer soil model with snow and frozen soil physics (Koren et al., 1999, Peters-Lidard et al. 1998) and the surface runoff scheme of Schaake et al. (1996). In the canopy model, plants are assumed to open their stomata until either further opening does not constitute an effective use of stored water in terms of carbon gain per unit loss or further opening causes a drop in leaf wawter potential below the limit that causes xylem cavitation (Williams et al., 1996). Plant water relations are modelled as an analogue to a simple electrical circuit. Water loss is linked to changes in leaf water potential according to the water potential gradient between leaf and soil, liquid-phase hydraulic resistance (R_s: soil resistance, R_p:stem resistance, R_r: root resistance) and the capacitance of the pathways that links soil to leaf. Stomatal conductance varies to maintain evaporation at the rate that keeps leaf water potential from falling below a critical threshold. The sensible and latent heat fluxes for both vegetated and bare soil surfaces are calculated through iteration of the conservation of temperature and water vapor mixing ratio (Lee and Mahrt, 2004). The radiation routines model the incidence, interception, absorption and reflectance of PAR (Photosynthetic Active Radiation), near infrared radiation (NIR) and longwave radiation in each canopy layer (Amthor, 1994, Amthor et al., 1994). A spherical leaf angle distribution is assumed.

2.3 MODEL PARAMETERIZATION

Table 1 shows used parameter in this study. Many parameters are not available at this site and therefore, we used generic values from the literature and some hydraulic parameters were based on the sensitivity test in section 3.2.

*Corresponding author address: Young-Hee Lee, Kyungpook Nat'l Univ., Dept. of Astronomy and Atmospheric Sciences, Daegu, Korea, 702-701; e-mail: young@mail.knu.ac.kr

Table 1.Used parameters in this study. Ψ_{min} is minimum leaf water potential prior to cavitation, V_{cmax} maximum carboxylation capacity, J_{max} maximum electron transport rate, G_p plant hydraulic conductivity and F_{total} total fine root biomass.

Parameter Description	Values
Ψ_{min}	-2.0 MPa
V_{cmax}	$100\mu\mathrm{mol\,m^{-2}\,s^{-1}}$
J_{max}	200 $\mu\mathrm{mol\,m^{-2}\,s^{-1}}$
Maximum LAI	$4.5\mathrm{m^2m^{-2}}$
G_p	$14\mathrm{mmol\,m^{-1}\,s^{-1}\,MPa^{-1}}$
Root resistivity	$10\mathrm{MPa\,s\,g\,mmol^{-1}}$
Rooting depth	0.4m
F_{total}	$200\mathrm{gm^{-2}}$
Mean canopy height	1m
$albedo_{vis}$	0.07
$albedo_{nir}$	0.35

3. RESULTS

3.1 Surface heterogeneity

To examine the influence of surface heterogeneity on turbulent fluxes, we examined evaporative fraction with wind direction. Evaporative fraction is given as follows.

$$EF \equiv \frac{L_v\overline{w'q'}}{R_{net}} \qquad (1)$$

where $\overline{w'q'}$ is the surface moisture flux, R_{net} is the net radiation, L_v is the latent heat of vaporization. The evaporative fraction is known to be relatively time-independent between mid-morning and mid-afternoon over relatively unstressed agricultural regions. Nonetheless, the behavior of the evaporative fraction varies substantially between different surface types. We divided data into 6 classes depending on wind direction (Table 2). Figs. 1a-c show the averaged evaporative fraction during daytime for each month. Daytime is defined as the period from 10LST to 14LST. Relatively uniform ratio is shown in July. It may be due that crop has maximum LAI and soil moisture is ample in July due to large rainfall. Among wind direction groups, classes 2 and 3 show relatively similar ratio throughout the analyzed period. To examine heterogeneity of CO_2 flux, we investigated the relationship between solar radiation and CO_2 flux. Figs. 1d-f show the averaged CO_2 flux for each solar radiation class (Table 2) corresponding wind direction for the analyzed period. Although evaporative fraction is relatively uniform in July, the relationship between CO_2 flux and solar radiation shows directional dependence indicating lower carbon uptake in wind class 4 compared to other classes. It may be due to lower LAI or lower V_{cmax}. For further analysis, we selected the cases with wind class 2 and 3 to avoid directional dependence of surface flux.

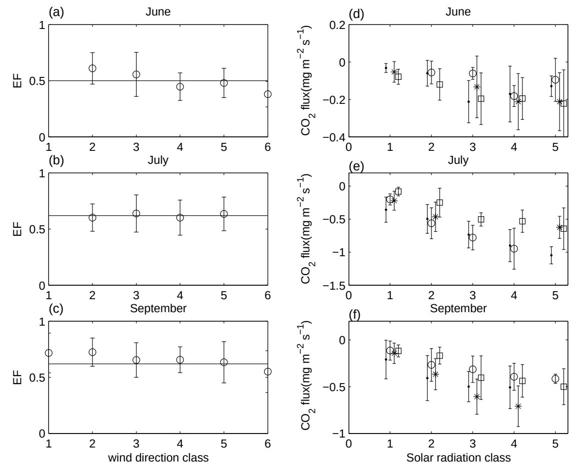

Figure 1: a-c: The evaporative fraction for wind direction class, d-f CO_2 flux with solar radiation class for corresponding wind direction class, dot:wind class 2, circle: wind class 3, star: wind class 4, square: wind class 5

Table 2. The description of wind direction and solar radiation class

Wind direction class	direction range (degree)	solar radiation class	radiation range (Wm^{-2})
1	0-60	1	0-200
2	60-120	2	200-400
3	120-180	3	400-600
4	180-240	4	600-800
5	240-300	5	800
6	300-360	-	-

3.2 Diurnal variation of surface fluxes

Two cases were selected for detailed examination among southeasterly wind cases (classes 2 and 3) during growing season. In the first case (case 1), plant had low LAI and vapor pressure deficit was relatively high. In the second case (case 2), plant had near maximum LAI and vapor pressure deficit was moderately low. Several sensitivity tests were designed to examine diurnal variation of observed fluxes. In both case 1 and 2, simulated latent heat flux showed little sensitivity to LAI and V_{cmax} (Figure is not shown here). The little sensitivity to LAI was due that increased soil evaporation compensated for decreased transpiration. On the other hand, CO_2 flux was sensitive to LAI with higher sensitivity in low LAI(Fig. 2a and 3a). Hydraulic parameters influence latent heat flux and CO_2 flux through plant water transport. We limited water transport by reducing the total fine root biomass and compared the simulated results with observations (Fig. 2b and 3b). When stomatal conductance was lim-

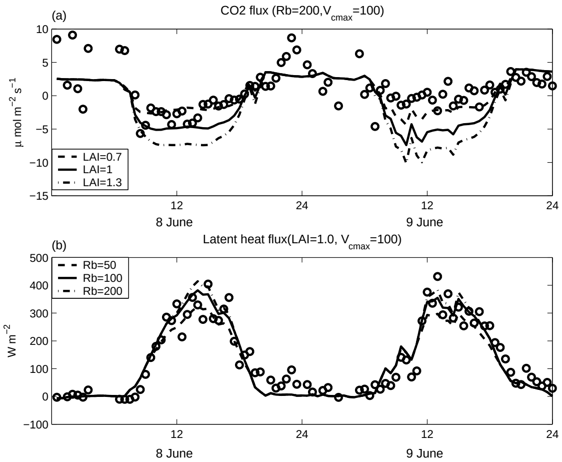

Figure 2: The simulated diurnal cycles (lines) of (a) CO_2 flux with different LAI and (b) latent heat flux with different total fine root biomass(Rb) in comparison with observations (circles) on 8-9 June

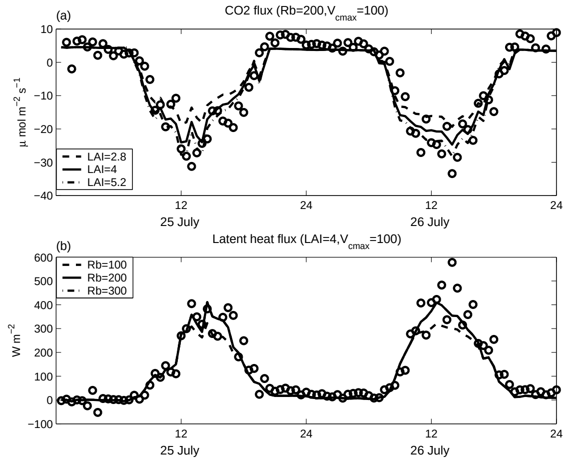

Figure 3: The same as fig. 2 except for 25-26 July

ited by water transport, the latent heat flux was underestimated compared to observation in both cases 1 and 2, which implied that plant water tranport was not limiting factor to stomatal conductance. Possible reason for this is the shortness of crop and ample soil moisture. Although vapor pressure deficit was high in case 1, low LAI resulted in low water loss from the leaf. Current results showed that the used hydraulic parameters and V_{cmax} (Table 1) were reasonable for the simulation of latent heat flux and CO_2 flux in both low and high LAI.

3.3 Sensitivity analysis

In this section, we examined the sensitivity of cumulative GPP (Gross primary production) and evaporation of rice to the model parameters during the growing season, We drive the model with metoerological data and parameters set up in previous section from June to September in 2003. The seasonal variation of LAI was based on the observations that was made in Campbell et al. (2001) and the field managements with rice cultivation in Korea (Moon et al., 2003). During this period, vapor pressure deficit was moderately low and large rainfall occurred. The parameters tested for sensitivity were LAI and maximum carboxylation capacity. The model was rerun for the 122 day, with these parameters varied individually by $\pm 30\%$. Fig.4 showed the sensitivity of cumulative GPP and evaporation to maximum carboxylation capacity and LAI. Cumulative evaporation shows negligible sensitivity to V_{cmax} while cummlative GPP shows 5% increase for a 30 % increase in V_{cmax} and 8% drop for a 30 % decrease in V_{cmax}. Larger sensitivity of GPP is shown for LAI with

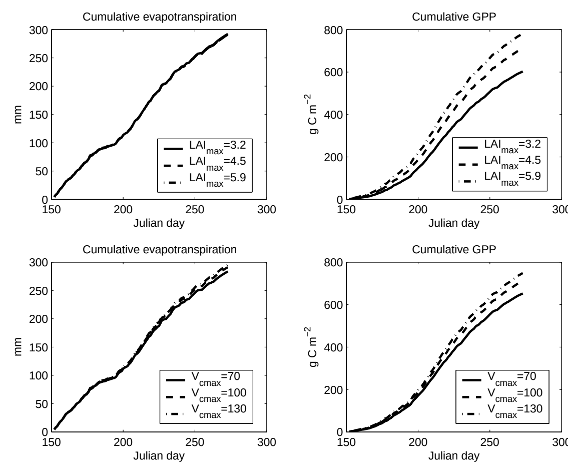

Figure 4: Cumulative daily evaporation and GPP.

9% increase for increased LAI and 15% decrease for decreased LAI.

4. CONCLUSION

We investigated the CO_2 and water vapor exchange with two layer canopy model over the farmland during the growing season. Two cases with contrasting condition were selected and examined in detail with observation. In both cases, when stomatal conductance was limited by water transport, the latent heat flux was underestimated compared to observation, which implied that water stress did not limit transpiration. We examined the sensitivity of cumulative GPP and evaporation to LAI and maximum carboxylation capacity during the growing season. Cumulative GPP shows less sensitivity to V_{cmax} than LAI, which emphasizes the importance of good LAI data for reasonable estimation of carbon uptake.

ACKNOWLEDGEMENTS

This work was supported by Korea Research Foundation Grant (KRF-2005-202-C00336).

5. REFERENCES

Amthor, J. S., 1994: Scaling CO_2-photosynthesis relationships from thee leaf to the canopy, *Photosyn. Res.*, **39**, 320-350.

Amthor, J. S., Goulden, M. L., Munger, J. W., Wofsy, S. C., 1994: Testing a mechanistic model of forest-canopy mass and energy exchange using eddy correlation: Carbon dioxide and ozone uptake by a mixed oak-maple stand, *Aust. J. Plant Physiol.*, **21**, 623-651.

Campbell, C. S., Heilman, J. L., McInnes, K. J., Wilson, L. T., Medley, J. C., Wu, G., Cobos, D. R., 2001: Diel and seasonal variation in CO_2 flux of irrigated rice, *Agric. For. Meteorol.*, **108**, 15-27.

Koren, V. I., Schaake, J., Mitchell, K., Duan, Q.-Y., Chen, F., Bake, J. M., 1999: A parameterization of snowpack and frozen ground intended for NCEP weather and climate models, *J. Geophys. Res.*, **104**, 19,569-19,585.

Lee, Y. H., Mahrt, L., 2004: Comparison of heat and moisture fluxes from a modified soil-plant-atmosphere model with observations from BOREAS, *J. Geophys. Res.*,**109**, D08103.

Lee, H. C., Hong, J. K.., Cho, C.-H., Choi, B.-C., Oh, S.-N., Kim, J., 2003: Surface exchange of energy and carbon dioxide between the atmospehre and a famrland in Haenam, Korea, Korean *J. Agric. For. Meteorol.*, **5(2)**, 61-69.

Moon, B. K., Hong, J. K., Lee, B.-R., Yun, J. I., Park, E. W., Kim, J., 2003: CO_2 and energy exchange in a Rice paddy for the growing season of 2002 in Hari, Korea, *Korean J. Agric. For. Meteorol.*, **5(2)**, 51-60.

Peters-Lidard, C. D., Blackburn, E., Liang, X., Wood, E. F., 1998: The effect of soil thermal conductivity parameterization on surface energy fluxes and temperatures, *J. Atmos. Sci.*, **55**, 1209-1223.

Schaake, J. C., Koren, V. I., Duan, Q. Y., Mitchell, K., Chen, F., 1996: Simple water balance model for estimating runoff at a different spatial and temporal scales, *J. Geophys. Res.*, **101**, 7461-7475.

Williams, M., Rastetter, E. B., Fernades, D. N., Goulden, M. L., Wofsy, S. C., S haver, G. R., Melillo, J. M., Munger, J. W., Fan, S. M. and Nadelhoffer, K. J., 1996: Modelling the soil-plan t-atmosphere continuum in a Quercus-Acerstand at Harvard Forest: the regulation of stomatal conductance by a light, nitrogen and soil/plant hydraulic properties , *Plant Cell and Environment*, **19**, 911-927.