

Evapotranspiration and CO₂ exchange of wet and snow-loaded canopy in an evergreen temperate coniferous forest

¹Linjie Jiao, ¹Yoshiko Kosugi, ^{1,3}Yuichi Sempuku, ^{1,2}Ayaka Sakabe, ¹Ting-Wei Chang,
1Graduate School of Agriculture, Kyoto University, Kyoto, 606-8502, Japan
2Hakubi Center for Advanced Research, Kyoto University, Kyoto 606-8501, Japan
3East Nippon Expressway Co., Ltd., Chiba, 263-0001, Japan
Correspondence to: jiao.linjie.66x@kyoto-u.st.jp

Introduction

● Importance of understanding wet canopy gas exchange regulation

- Tree growing season in temperate evergreen coniferous forest in the Asian monsoon area is typically rainy seasons, unlike the forests in Europe.
- Affected by the Asian monsoon climate, interception took nearly 25% of precipitation in a Japanese cypress forest (Saito et al. 2013)
- However, due to the drawback of closed-path and open-path $\text{CO}_2/\text{H}_2\text{O}$ gas analyzer, there is a **lack of precise CO_2 and H_2O flux measurement from wet canopy**

● Leaf wetness and wet canopy gas exchange relations

- CO_2 uptake during rainfall was sometimes observed (Sumpuku et al., 2018, Japanese cypress)
- The mechanism of leaf wetness effecting plant exchange is complex:
 - ✓ Wet leaf stomatal can be occluded by water droplets or water films, and thus gas exchange gets depressed (Ishibashi and Terashima, 1998)
 - ✓ Leaf wettability (species) influence whether the leaf wetness depress or stimulate gas exchange (Aparecido et al., 2017; Kimaru and Tanakamaru, 1981)
- ❑ **The actual leaf wetness distribution over needle leaf during natural wetting events seldom concerned**

Site information

Kiryu Experimental watershed (FLUXNET member site)

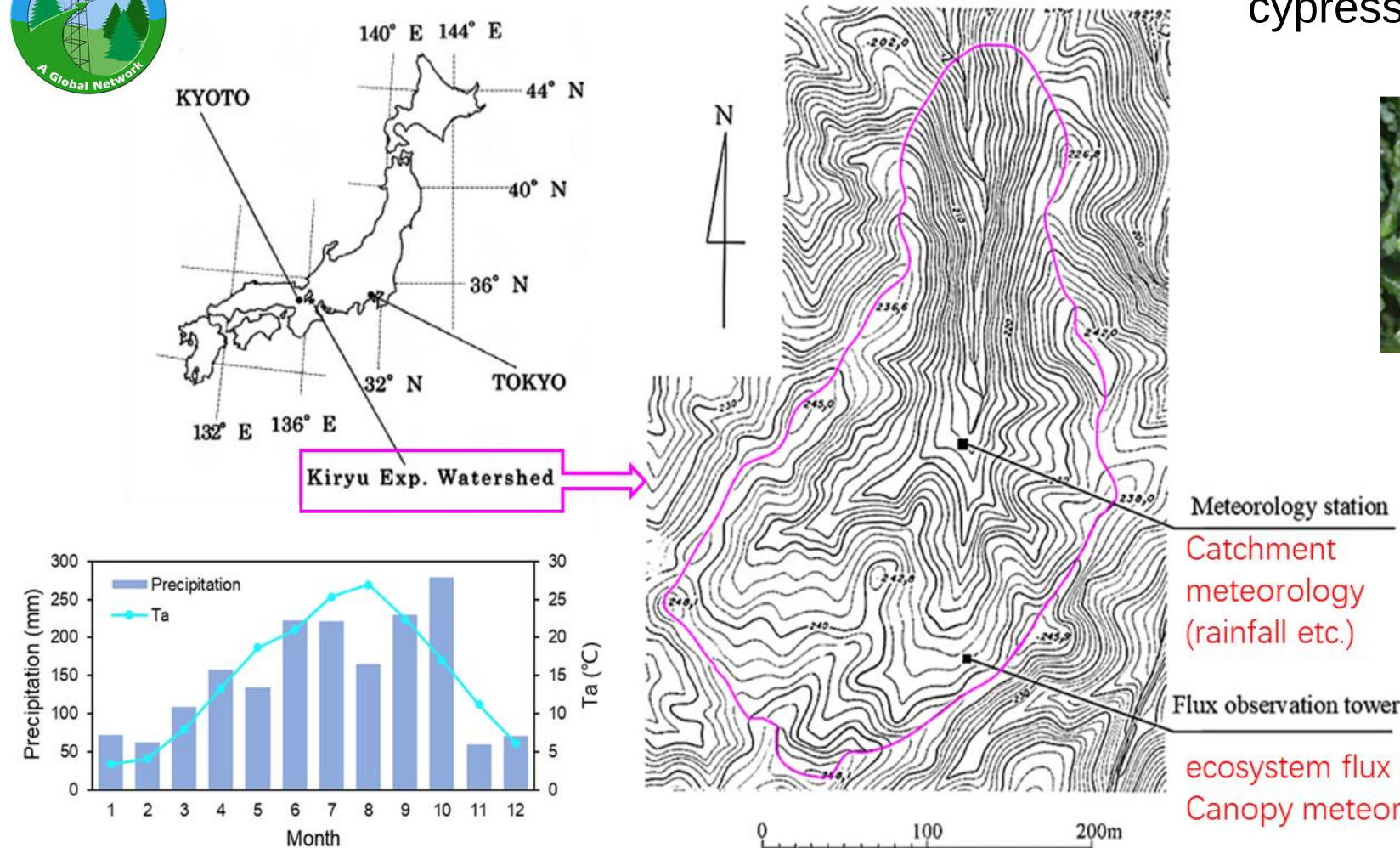


Location: South Shiga, Japan

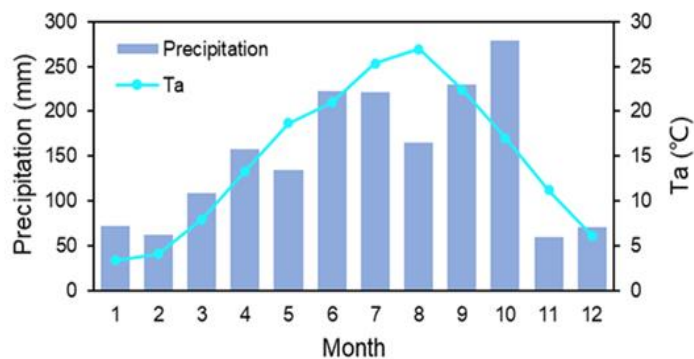
Annual temperature: 13.6°C (2016-2019)

Annual precipitation: 1784.5mm (2016-2019)

Main vegetation: 60-year-old Japanese cypress (20m, hypo-stomatal)



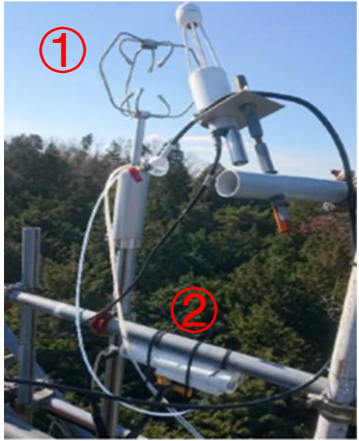
Short snow period in winter
(snow accumulation up to
1-2 days for each event)



Monsoon climate

Measurements

● Eddy covariance measurement



Measurement height: 29m

- ① 3D anemometer (SAT550, Kaijo)
- ② Enclosed path gas analyzer (LI7200, LI-COR, **water-proof sampling cell**)



Latent heat flux (λE)
Net ecosystem exchange (NEE) (15-min interval)

Advantage of CO₂/ H₂O enclosed gas analyzer

- Minimizes data gaps with continuous measurements through precipitation
- Improved optics and temperature controls increase long-term stability and reduce drift

[LI-7200 Enclosed Path CO₂/H₂O Analyzer \(licor.com\)](http://licor.com)

● Leaf wetness measurement

Electric resistance based wetness sensor

Measurement height:

Top, middle and bottom canopy layer
(around 19.4m, 18.6m, 17.4m)

$WD(\text{wetness degree}) = 1 - S_{\text{measured}}/S_{\text{dry}}$

S_{measured} : the sensor signals.

S_{dry} : sensor signal from dry leaves.

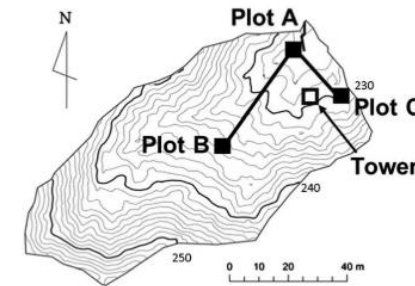
(15-min interval)



● Soil CO₂ flux measurement

Automated chamber system (Sakabe et al., 2015)

Average from three plots near the flux tower



 F_{csoil} (30-min interval)

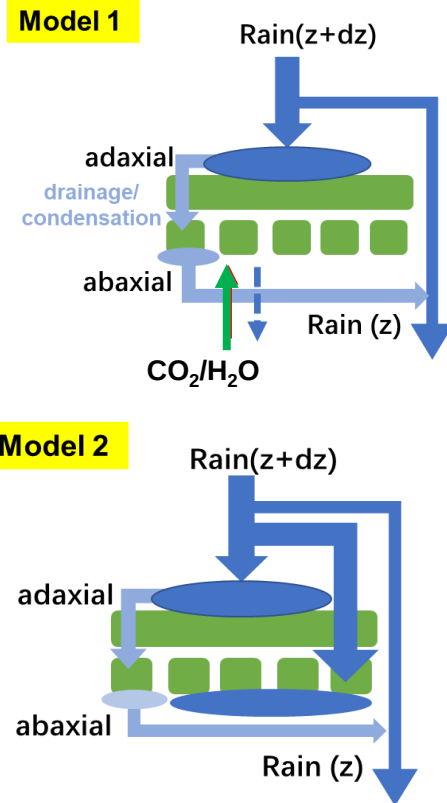
Simulation

SVAT (soil- vegetation-atmosphere transfer) Multi-layer model (Kosugi et al., 2006)

Two interception solutions

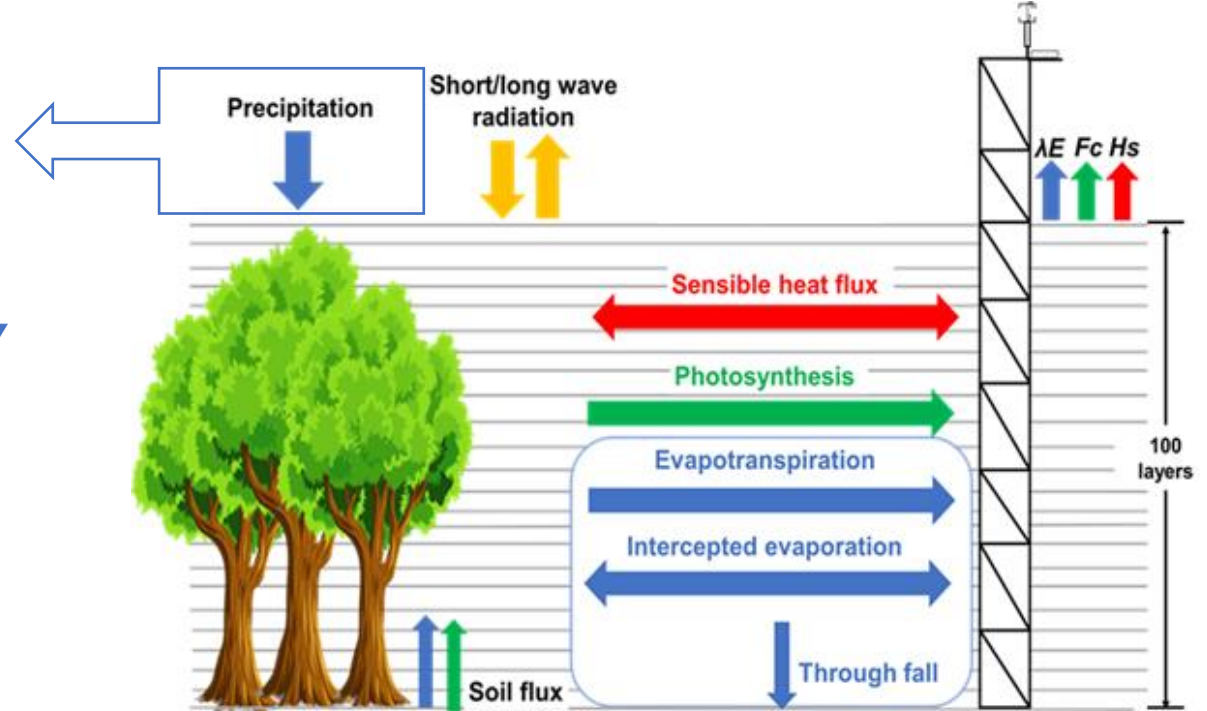
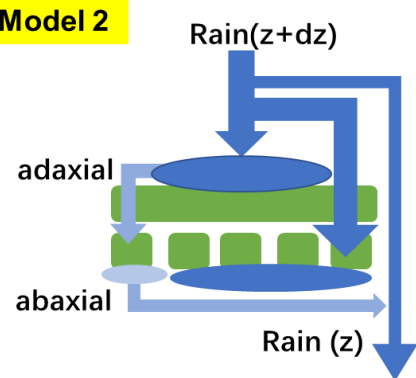
abaxial surface keeps dry during and after rainfall

Model 1



both surfaces get wetted during and after rainfall

Model 2



Coefficient of determination (R^2) (model efficiency index (e.g. Ellis et al., 2010) or Nash–Sutcliffe model efficiency coefficient (NSE) in other study(e.g. Marks et al., 2008))

$$R^2 = 1 - \left[\frac{\sum_{i=1}^n (x_{sim} - x_{obs})^2}{\sum_{i=1}^n (x_{obs} - x_{avg})^2} \right]$$

$R^2 > 0$: better or equal predictive efficiency to the mean of the time series;
the more R^2 is close to 1, the more precise the model is.

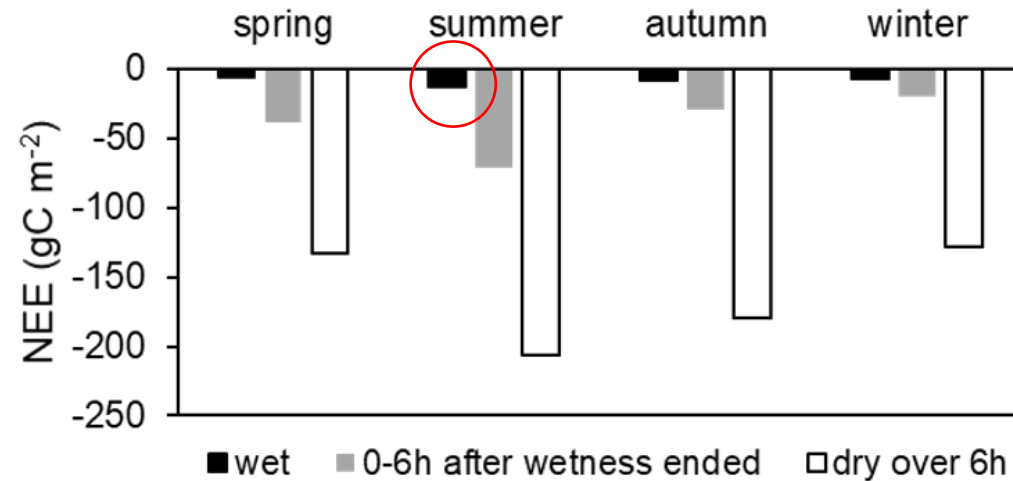
Evaluating wet canopy CO₂ uptake by EC data

- Annual average

	Wet_DR (during rainfall)	Wet_AR (after rainfall)	Wet_total	Snow- loaded	First 6h after wetness ended	usual dry
F_{csoil} ($\mu\text{mol m}^{-2}\text{s}^{-1}$)	2.5	2.6	2.5	0.3	2.9	2.2
NEE ($\mu\text{mol m}^{-2}\text{s}^{-1}$)	0.2	-2.6	-1.9	-0.4	-7.4	-5.3

Soil CO₂ emission during wetting and right after wetness ended was larger than usual dry period

- Seasonal accumulation of NEE



- Wet canopy had contribution to CO₂ uptake , NEE was largest in summer
- NEE was stimulated right after wetness ended

Daytime λE series by observation and simulation (3 representative days)

λE (EC) is close to Model 1

Model1 R^2 0.53

Model2 R^2 -0.43

λE (EC) is close to Model 2

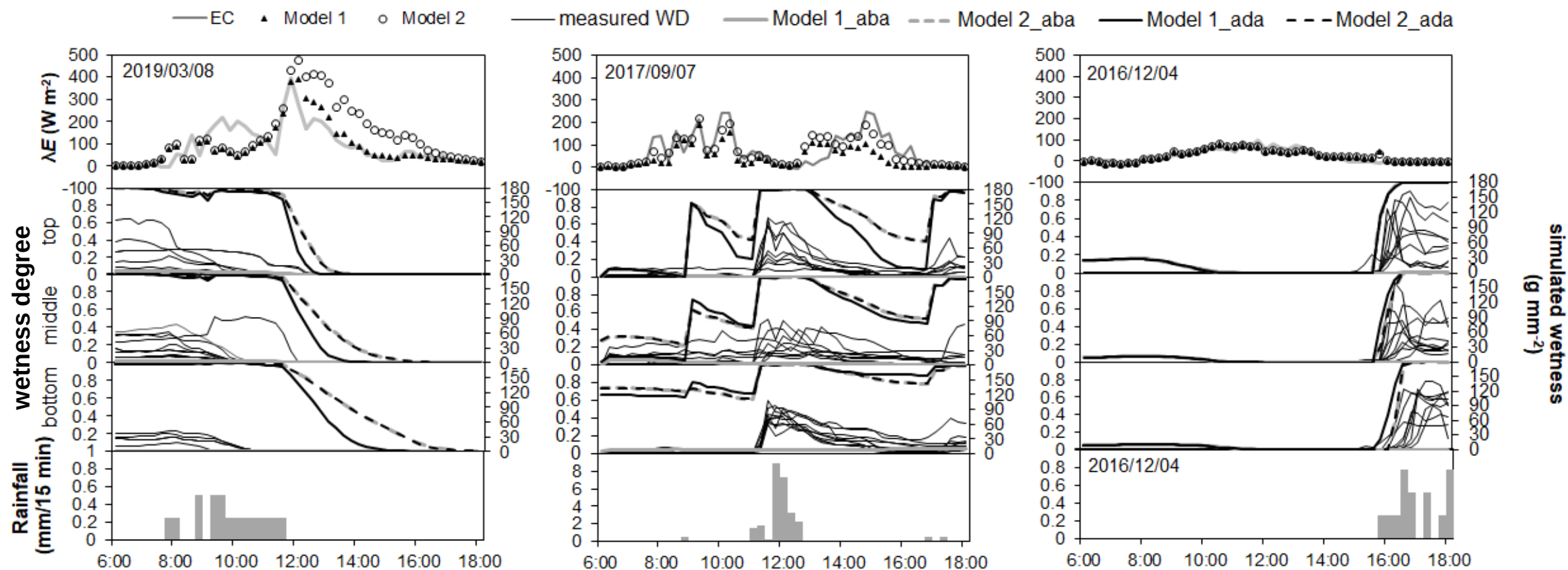
0.34

0.65

λE (EC) is close to both models

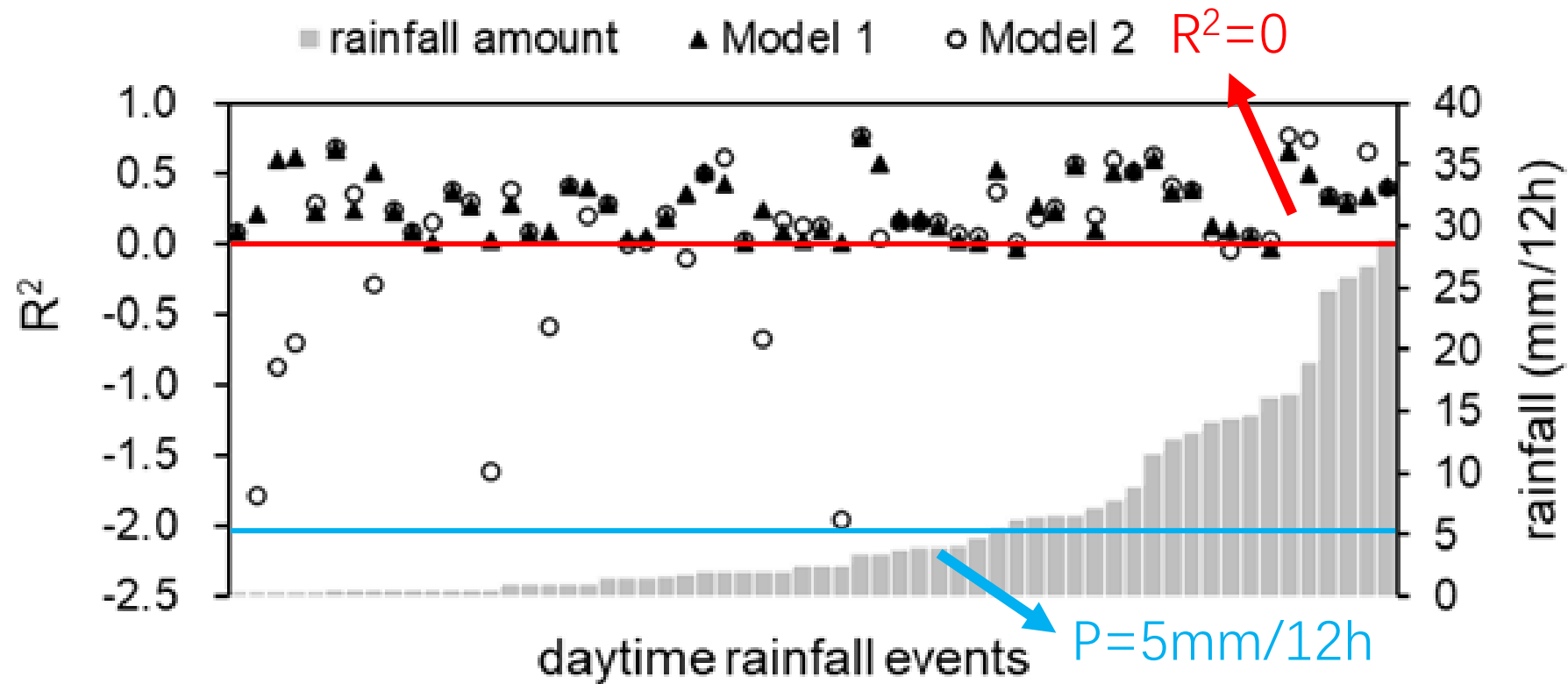
0.75

0.77



Wet day (6:00-18:00) R^2

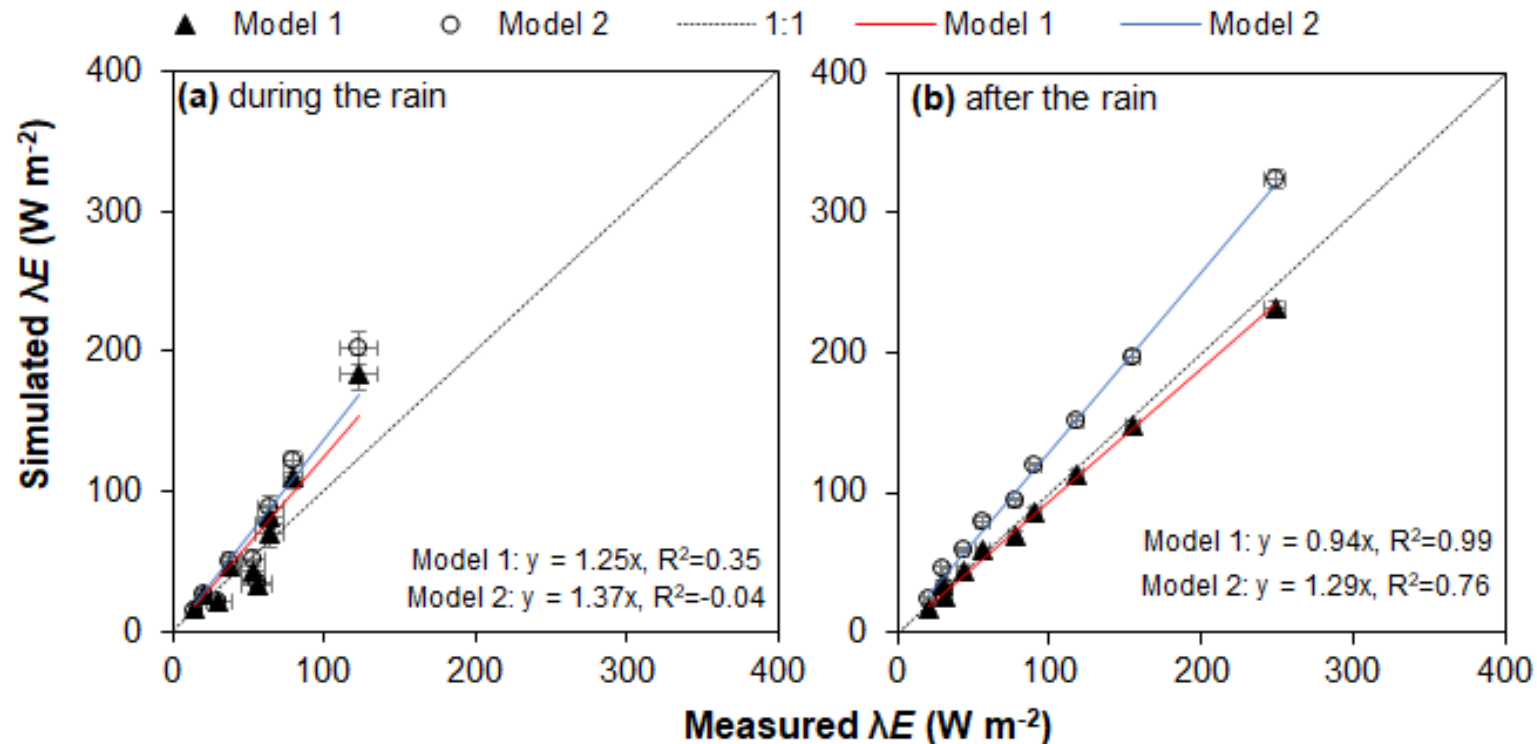
(60 days had wetting in the daytime from 2016 to 2019)



- Model 1 in almost all of the wet days had positive R^2 (equal or even better to the average data)
- Model 2 had several negatives when the accumulated daytime rainfall was less than 5mm (**Model 2 may be less suitable for light rainfall condition**)

Correlation between measured and simulated λE

(15-minute data from 2016-2019)



* R^2 indicates model efficiency, instead of linear correlation)

- **Model 1 had better performance than Model 2 especially after the rainfall** and Model 1 significantly improved after rainfall
- Model 1 had better performance than Model 2 both in relation with available energy and VPD
- Measured λE and simulated λE by both models were close to each other in low available energy and VPD conditions

Conclusion

From measurement:

- CO₂ uptake during the wet was depressed, but the annual accumulated NEE still shows considerable CO₂ uptake;
- CO₂ uptake was stimulated at the first 6 hours after canopy wetness ended
- Both NEE and soil CO₂ flux during the snow-loaded period were very small

From simulation

- Both interception situations are possible to happen, but Model 1 is more suitable for this temperate forest
- Model 1(interception only on adaxial surface) and Model 2 (interception on both surfaces) had similar performance during the rainfall; Model 1 works better after the rainfall (compared to itself during the rainfall and Model 2 after the rainfall).

Future Expectations:

- More abundant precipitation sources (e.g. fog, cloud, short-time snow)
- Species
- Sites with longer snow period

References

- Saito T, Matsuda H, Komatsu M, et al (2013) Forest canopy interception loss exceeds wet canopy evaporation in Japanese cypress (Hinoki) and Japanese cedar (Sugi) plantations. *Journal of Hydrology* 507:287–299. <https://doi.org/10.1016/j.jhydrol.2013.09.053>
- Ishibashi M, Terashima I (1995) Effects of continuous leaf wetness on photosynthesis: adverse aspects of rainfall. *Plant, Cell & Environment* 18:431–438. <https://doi.org/10.1111/j.1365-3040.1995.tb00377.x>
- Aparecido LMT, Miller GR, Cahill AT, Moore GW (2017) Leaf surface traits and water storage retention affect photosynthetic responses to leaf surface wetness among wet tropical forest and semiarid savanna plants. *Tree Physiology* 37:1285–1300. <https://doi.org/10.1093/treephys/tpx092>
- Kimura K, Tanakamaru S (1981) Studies on Plant Response to Rainfall (II) Effect of Mist Treatment on Dry Matter Production on Sunny Days. *Journal of Agricultural Meteorology* 37:231–237. <https://doi.org/10.2480/agrmet.37.231>
- Sempuku Y, Kosugi Y, Iwata H, et al (2018) Evaluation of Canopy Evapotranspiration and Photosynthesis During and Immediately After Rainfall Using Enclosed-Path Eddy Covariance Method. *Journal of Japan Society of Hydrology and Water Resources* 31:190–199. <https://doi.org/10.3178/jjshwr.31.190>
- Sakabe A, Kosugi Y, Takahashi K, et al (2015) One year of continuous measurements of soil CH₄ and CO₂ fluxes in a Japanese cypress forest: Temporal and spatial variations associated with Asian monsoon rainfall. *Journal of Geophysical Research: Biogeosciences* 120:585–599. <https://doi.org/10.1002/2014JG002851>
- Kosugi Y, Takanashi S, Matsuo N, et al (2006) Impact of leaf physiology on gas exchange in a Japanese evergreen broad-leaved forest. *Agricultural and Forest Meteorology* 139:182–199. <https://doi.org/10.1016/j.agrformet.2006.06.009>

Thank you for your attention!

Check us out at
lab homepage 



Facebook 

