Modeling Carbon Fluxes of Forest Ecosystems Using TRIPLEX-FLUX Model

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Topics Outline

I. Overview of TRIPLEX Model Development

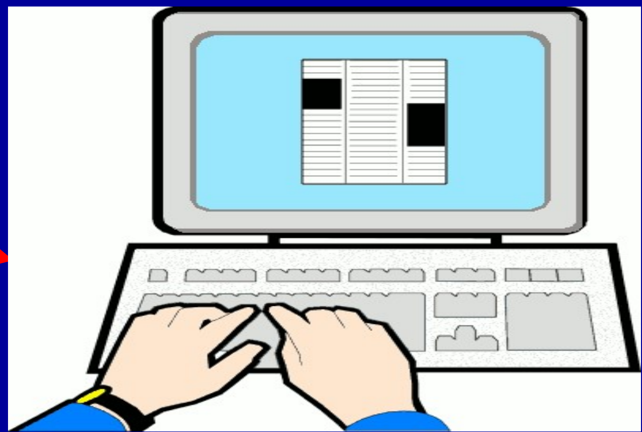
II. Case Studies using TRIPLEX-FLUX:

- Modeling carbon fluxes of Chinese Fir Plantation, China
- Simulating carbon fluxes of boreal forests in Canada

III. Ongoing Challenges: Model-Data Fusion

Three Main Approaches to Investigating Effect of Climate Change on Ecosystems

- Long-term observation
- Experimental manipulation
- Model simulation

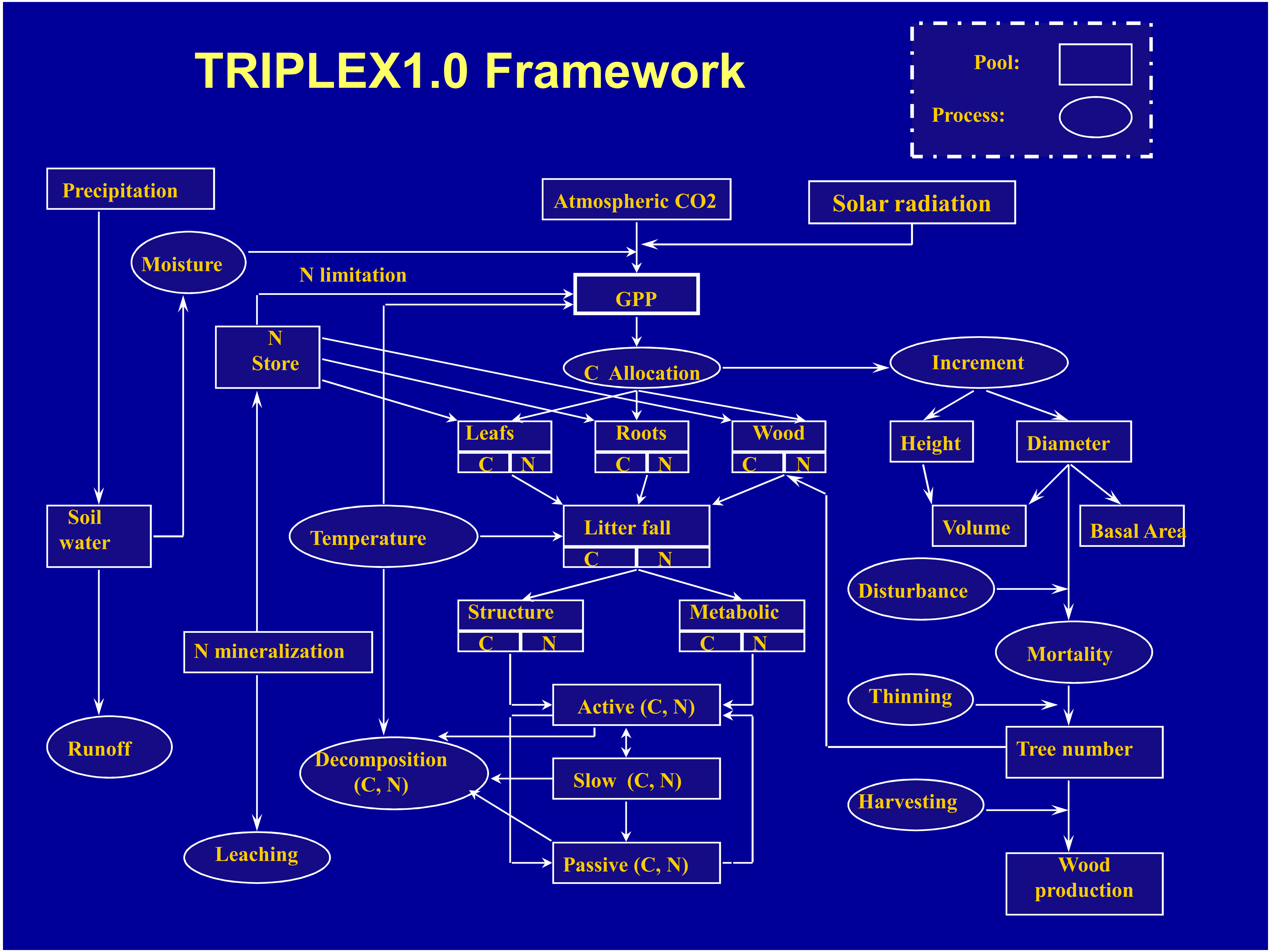


(J.M. Melillo, 1999, Science, 283: 183)

TRIPLEX: A generic hybrid model for predicting forest growth and carbon and nitrogen dynamics *(Peng et al. 2002, Ecol. Model)*

- Developed based on well-established models:
  - 3-PG (Landsberg and Waring, 1997)
  - TREEDYN3.0 (Bossel, 1996)
  - CENTURY4.0 (Parton et al., 1987, 1993)
- Bridges the gap between forest growth and yield and process-based C balance models
- Can be used for:
  1) Making forest management decisions (e.g., G&Y prediction)
  2) Quantifying forest carbon budgets
  3) Assessing the effects of climate change on forest ecosystems

TRIPLEX1.0 Framework



TRIPLEX Model Development History (15 years)

• 2000- 2002: TRIPLEX 1.0 (OFRI, Sault Ste Marie, ON, Canada)

• 2003-2005: TRIPLEX 1.0 Testing and application at stand and landscape Levels (SD, USA; UQAM, Montreal)

2004-2010: Application of TRIPLEX1.0 in China
(Beijing U, Zhejiang U and Central-South U of Forestry & Tech.)

•2006-2008: TRIPLEX-Flux, TRIPLEX-DOC (UQAM)

•2008-present: TRIPLEX-Management (UQAM); TRIPLEX-Aquatic (UQAM and China); TRIPLEX-GHG (UQAM and China)

TRIPLEX Model Development Publications (2002-2016) (www.crc.uqam.ca)

- **TRIPLEX1.0 Model**

- Peng et al, (2002), Ecol. Model ; Liu et al. (2002), CEA

- **TRIPLEX Application in Canada:**

- Zhou et al (2004), EM&S; Zhou et al (2005), CJFR; Zhou et al. (2006), MASGC

TRIPLEX Application in China

- Zhang et al. (2008), EM; Peng et al. (2009), GPC; Zhao et al. EM (2012)

- **New TRIPLEX-Flux, TRIPLEX-Fire, TRIPLEX-DOC**

- Zhou et al (2008), EM; Sun et al. (2008), EM; Two MS (Wu et al. 2014)

- **TRIPLEX-Management, TRIPLEX-Aquatic, TRIPLEX-GHG**

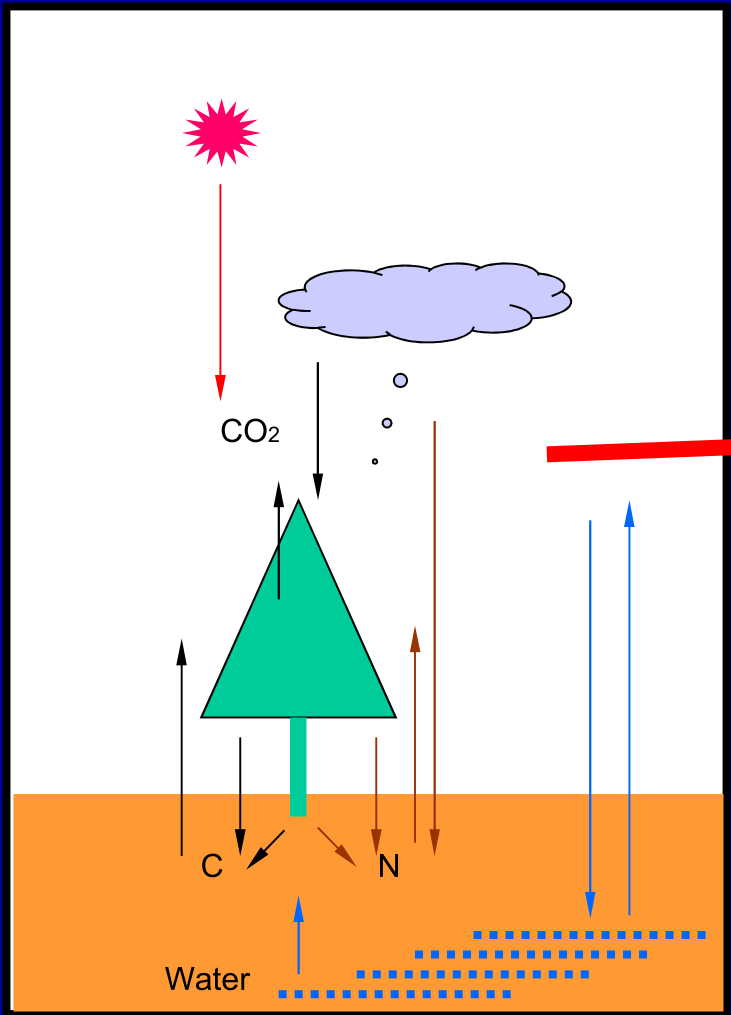
- Wang et al (2010, 2012); Wu et al.(2013); Zhu et al. (2014, 2016)

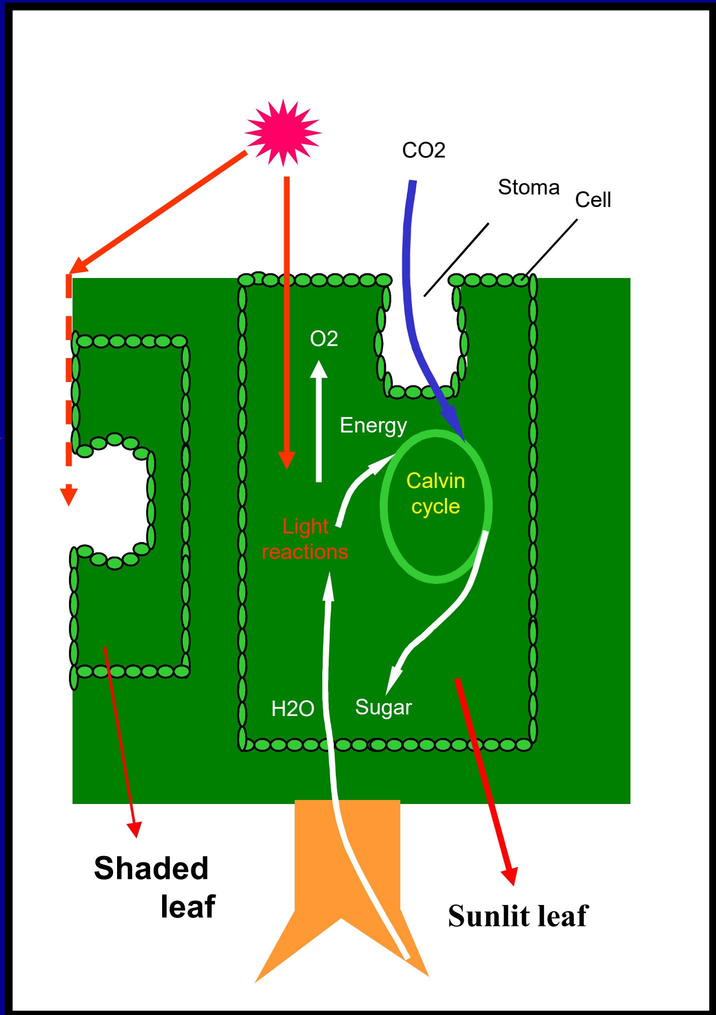
New TRIPLEX-Flux Model Development

(Zhou et al. 2008; Sun et al. 2008)

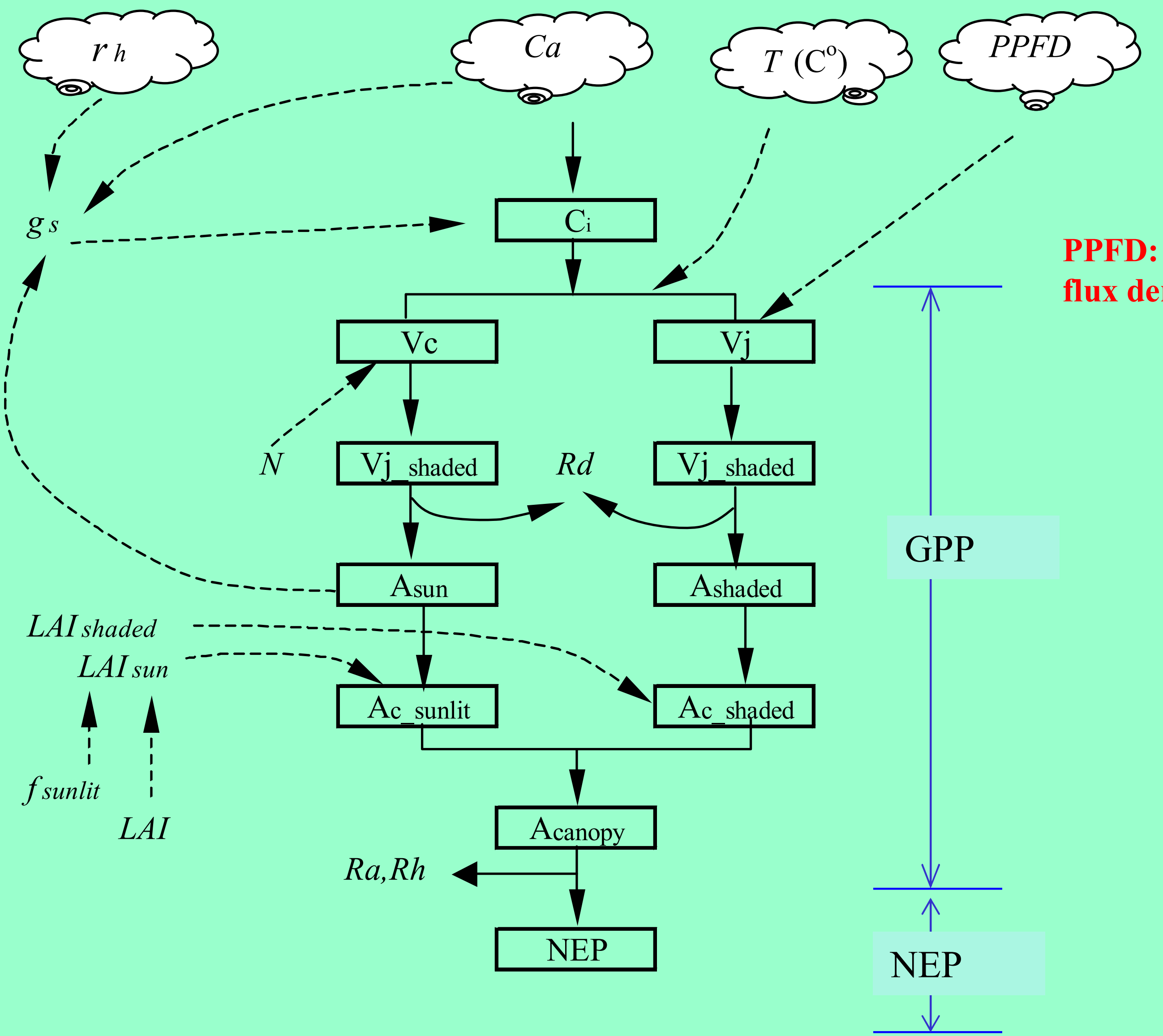
TRIPLEX1.0 (big leaf, monthly)

TRIPLEX-Flux (two leaves, daily)





TRIPLEX-FLUX Model structure



PPFD: photosynthetic photon flux density

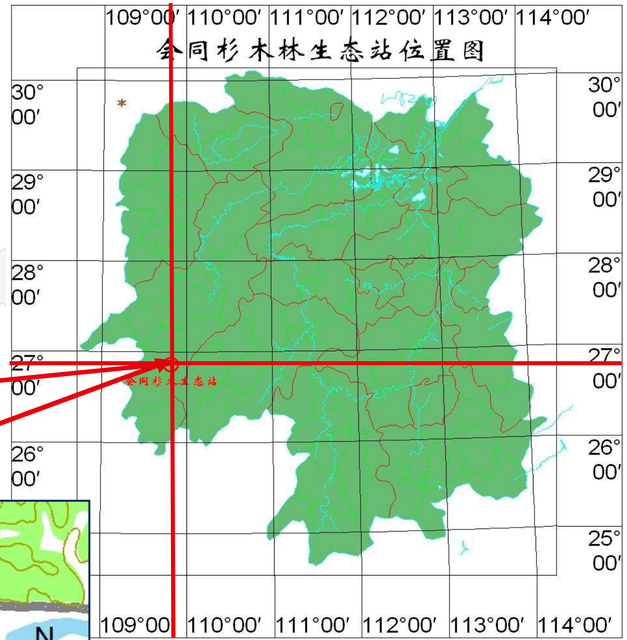
Zhou et al, 2008. Simulating carbon exchange in Canadian Boreal Forests I. Model structure, validation, and sensitivity analysis. EM 219:287-299

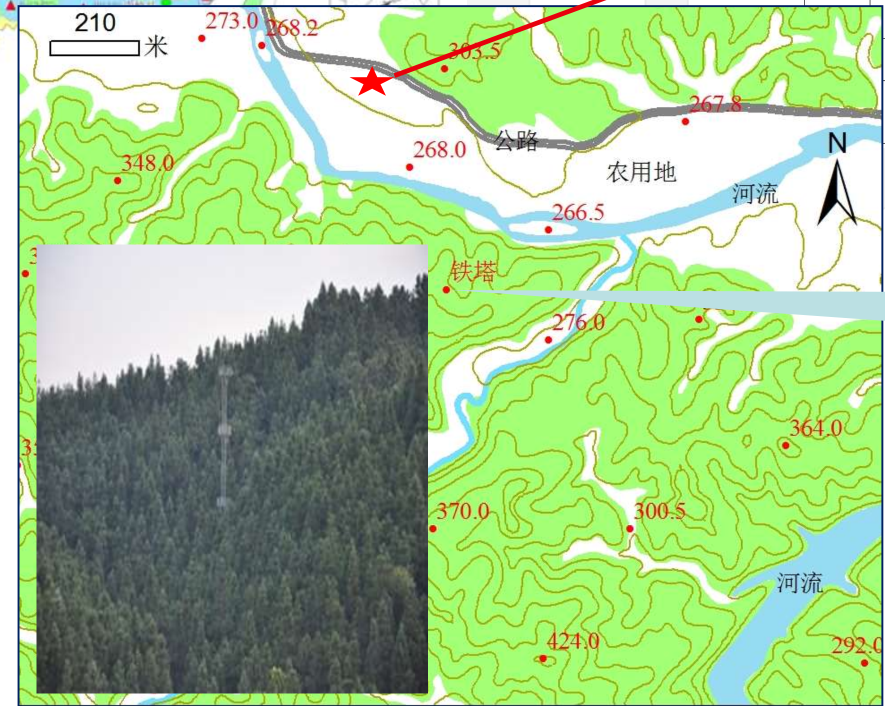
Variables and functions

Symbol	Unit	Description	Equation and Value	Reference
A	μmol $m^{-2} s^{-1}$	net CO_2 assimilation rate for big leaf	$A = \min(V_c, V_j) - Rd$ $A = g_s(C_a - C_i)/1.6$	Farquhar et al. (1980), Leuning (1990)
A_{canopy}	μmol $m^{-2} s^{-1}$	net CO_2 assimilation rate for canopy	$A_{canopy} = A_{sun} LAI_{sun} + A_{shade} LAI_{shade}$	Norman, (1982)
Γ	Pa	CO_2 compensation point without dark respiration	$\Gamma = 1.92 * 10^{-4} O_2 1.75^{(T-25)/10}$	Collatz et al. (1991)
f(N)	-	nitrogen limitation term	$f(N) = N/N_m = 0.8$	Bonan (1995)
f(T)	-	temperature limitation term	$f(T) = (1+\exp((-220{,}000 +710(T+273))/(R_{gas} (T+273))))^{-1}$	Bonan (1995)
g_s	m mol $m^{-2} s^{-1}$	stomatal conductance	$g_s = g_o + m100A\ r_h/Ca$	Ball et al. (1988)
J	μmol $m^{-2} s^{-1}$	electron transport rate	$J = J_{max}\ PPFD/(PPFD + 2.1\ J_{max})$	Farquhar (1982)
Jmax	μmol $m^{-2} s^{-1}$	light-saturated rate of electron transport	$J_{max} = 29.1 + 1.64\ V_m$	Wullschleger (1993)
K	Pa	function of enzyme kinetics	$K = K_c (1 + O_2 / Ko)$	Collatz et al. (1991)
K_c	Pa	Michaelis–Menten constants for CO_2	$K_c = 30 * 2.1^{(T - 25)/10}$	Collatz et al. (1991)
K_o	Pa	Michaelis–Menten constants for O_2	$K_o = 30000 * 1.2^{(T - 25)/10}$	Collatz et al. (1991)
R_a	kg C m^{-2} day^{-1}	autotrophic respiration	$R_a = R_m + R_g$	
R_d	μmol $m^{-2} s^{-1}$	leaf dark respiration	$R_d = 0.015V_m$	Collatz et al. (1991)
R_e	kg C m^{-2} day^{-1}	ecosystem respiration	$R_e = R_a + R_h$	
R_g	kg C m^{-2} day^{-1}	growth respiration	$R_g = r_g\ r_a\ GPP$	Ryan (1991)
R_h	kg C m^{-2} day^{-1}	heterotrophic respiration	$R_h = 1.5\ Q_{10}^{(T-10)/10}$	Lloyd and Taylor 1994
R_m	kg C m^{-2} day^{-1}	maintenance respiration	$R_m = M\ r_m\ Q_{10}^{(T-T_o)/10}$	Running (1988)
V_c	μmol $m^{-2} s^{-1}$	Rubisco-limited gross photosynthesis rates	$V_c = V_m (C_i - \Gamma)/(C_i - K)$	Farquhar et al. (1980)
V_j	μmol $m^{-2} s^{-1}$	Light-limited gross photosynthesis rates	$V_j = J (C_i - \Gamma)/(4.5C_i + 10.5\Gamma)$	Farquhar and von Caemmerer (1982)
V_m	μmol $m^{-2} s^{-1}$	maximum carboxylation rate	$V_m = V_{m25}\ 0.24 (T - 25)\ f(T)\ f(N)$	Bonan (1995)

Zhou et al, 2008. Simulating carbon exchange in Canadian Boreal Forests I. Model structure, validation, and sensitivity analysis.

Testing site: Chinese Fir Plantation of Huitong, Hunan, China

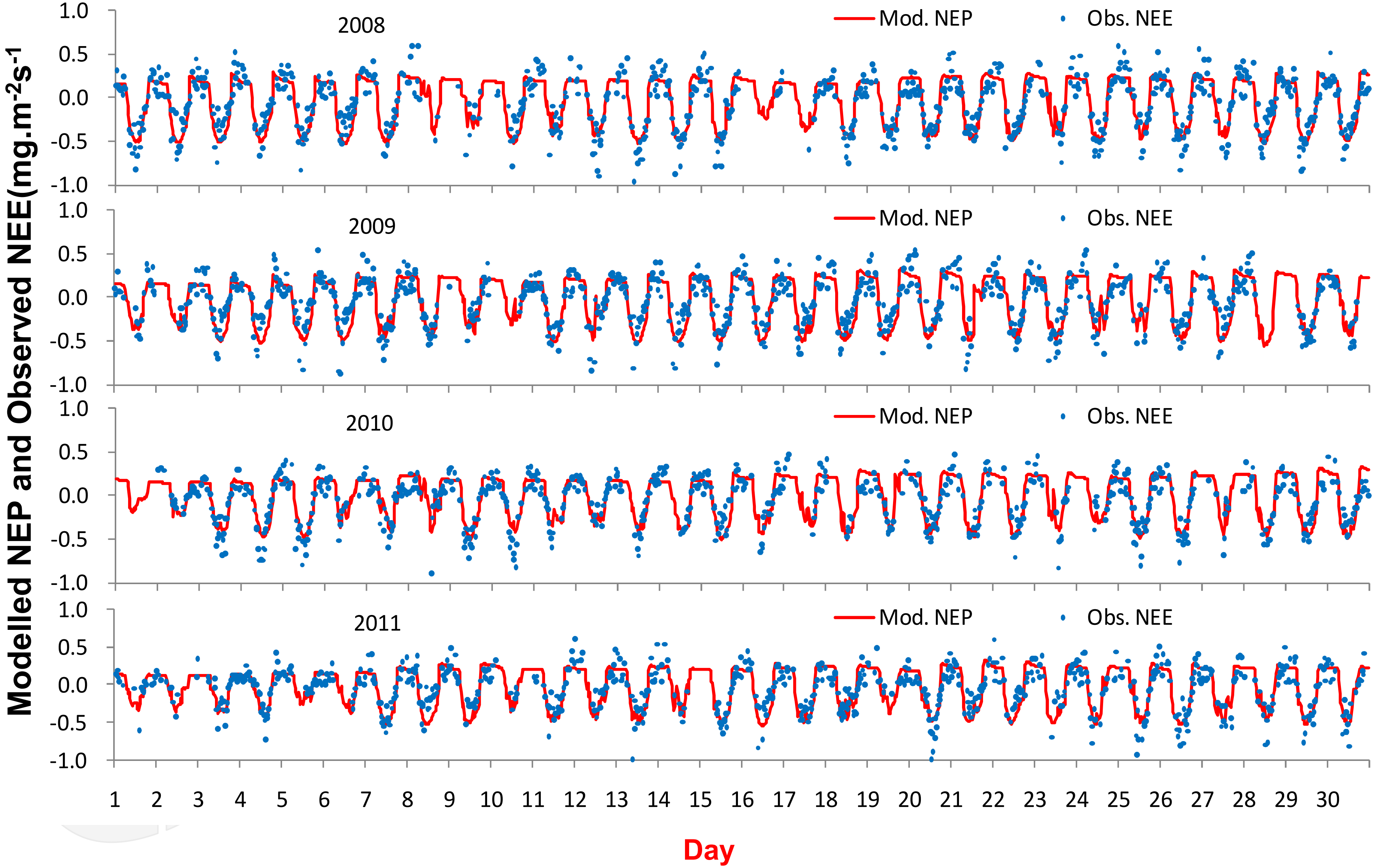




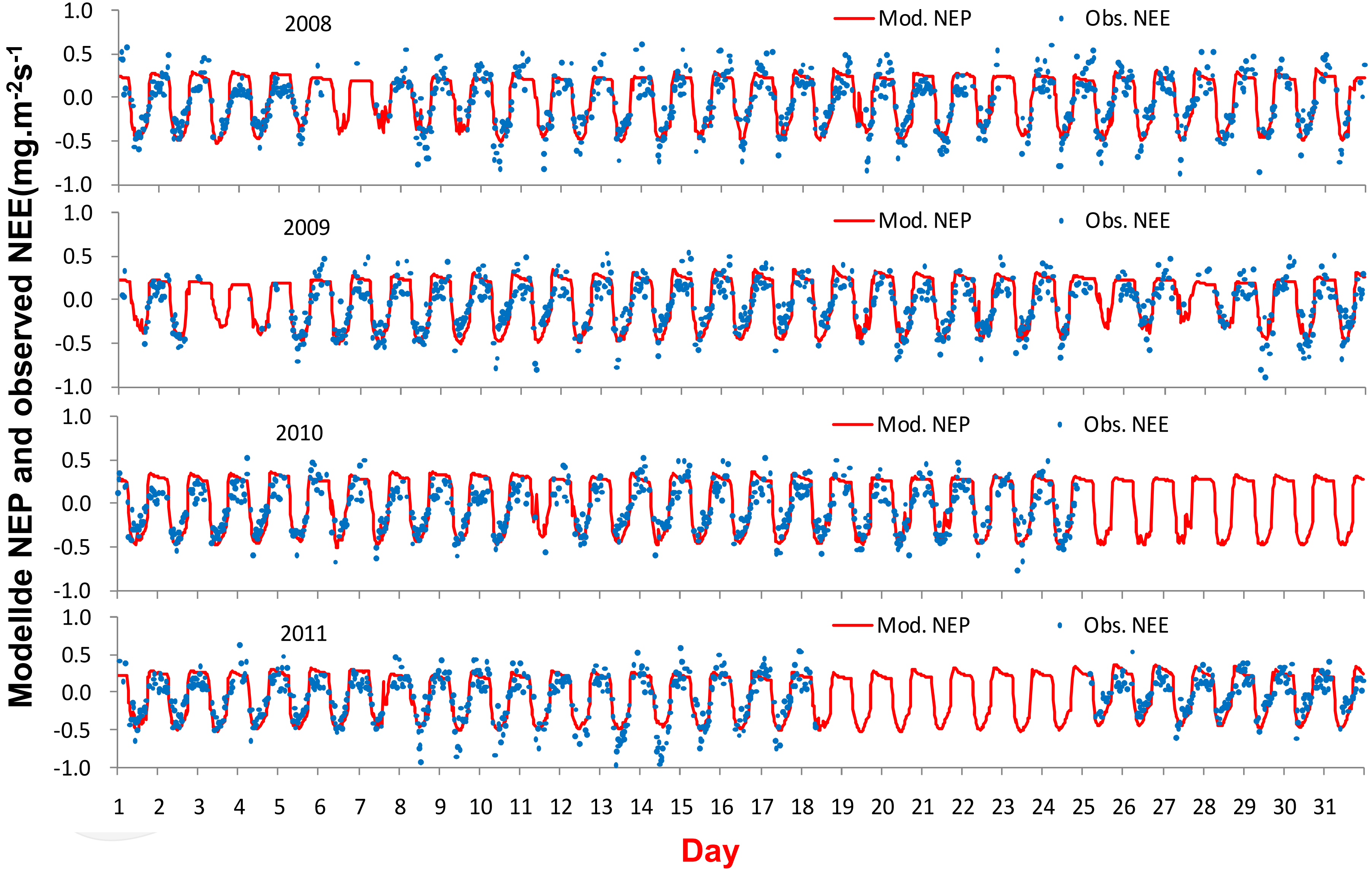
109°35’30.36” E
26°47’8.09” N

Flux Tower since July 2007
about 35m high

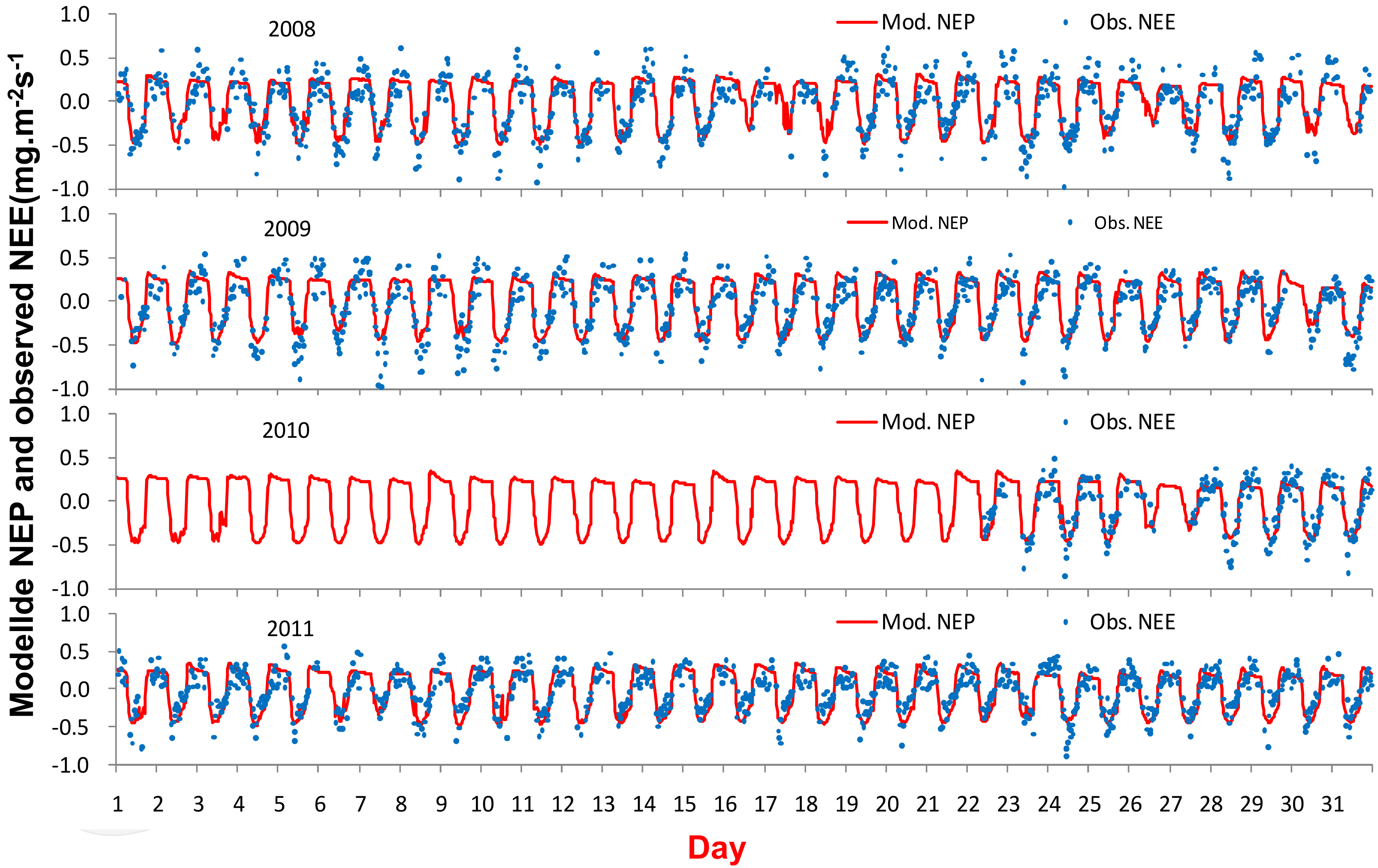
Half H Observations vs. Simulations (June)



Half H Observations vs. Simulations (July)

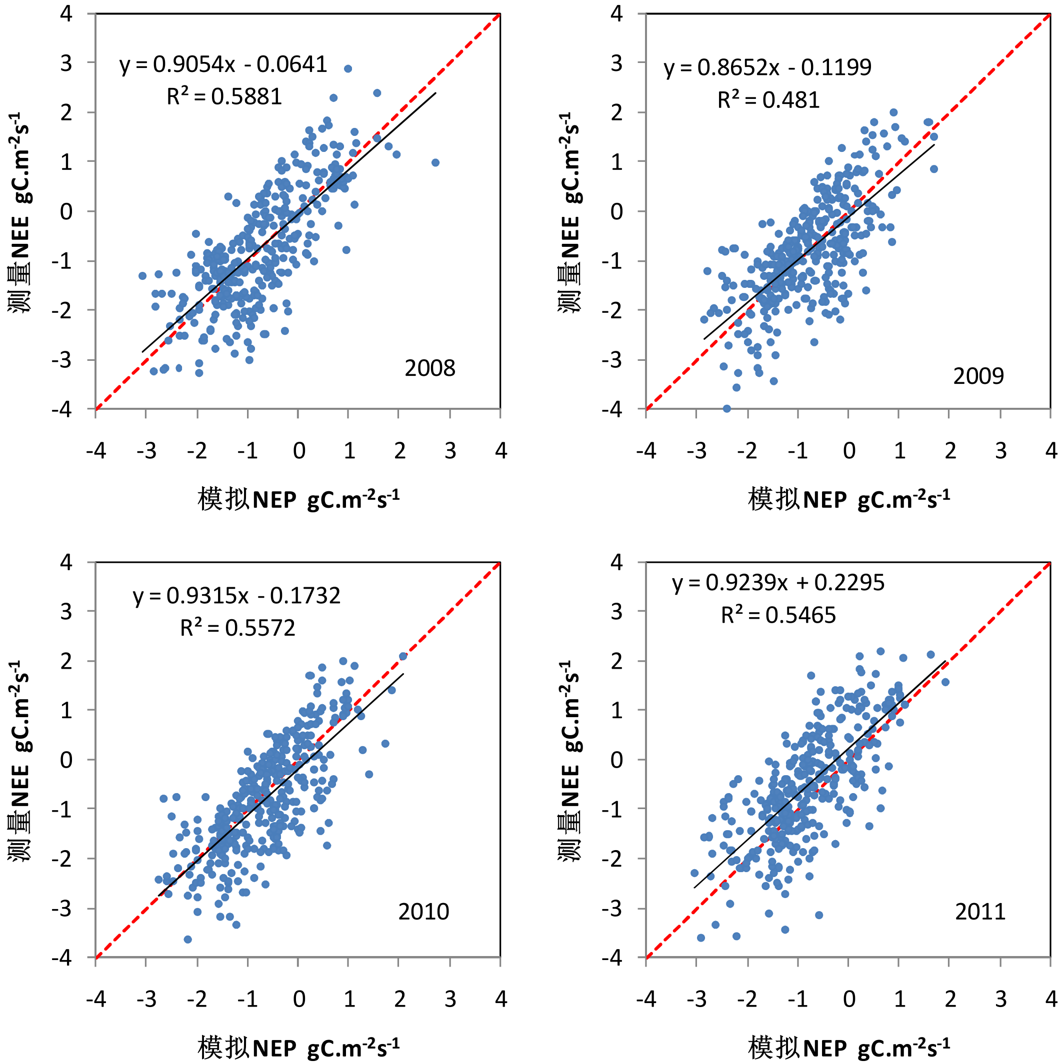


Half H Observations vs. Simulations (August)



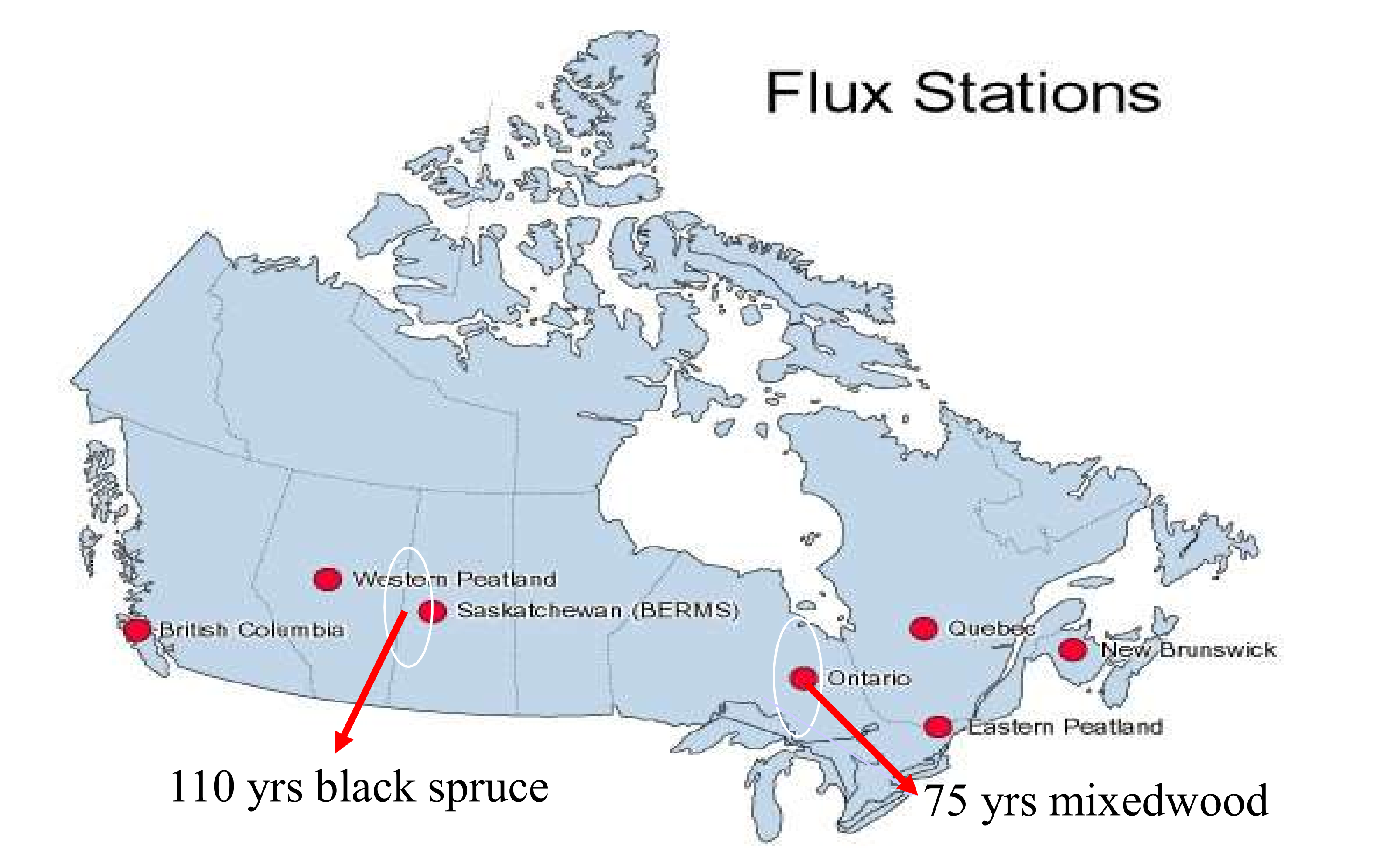
Daily Observations vs. Simulations (2008-2011)

Observations



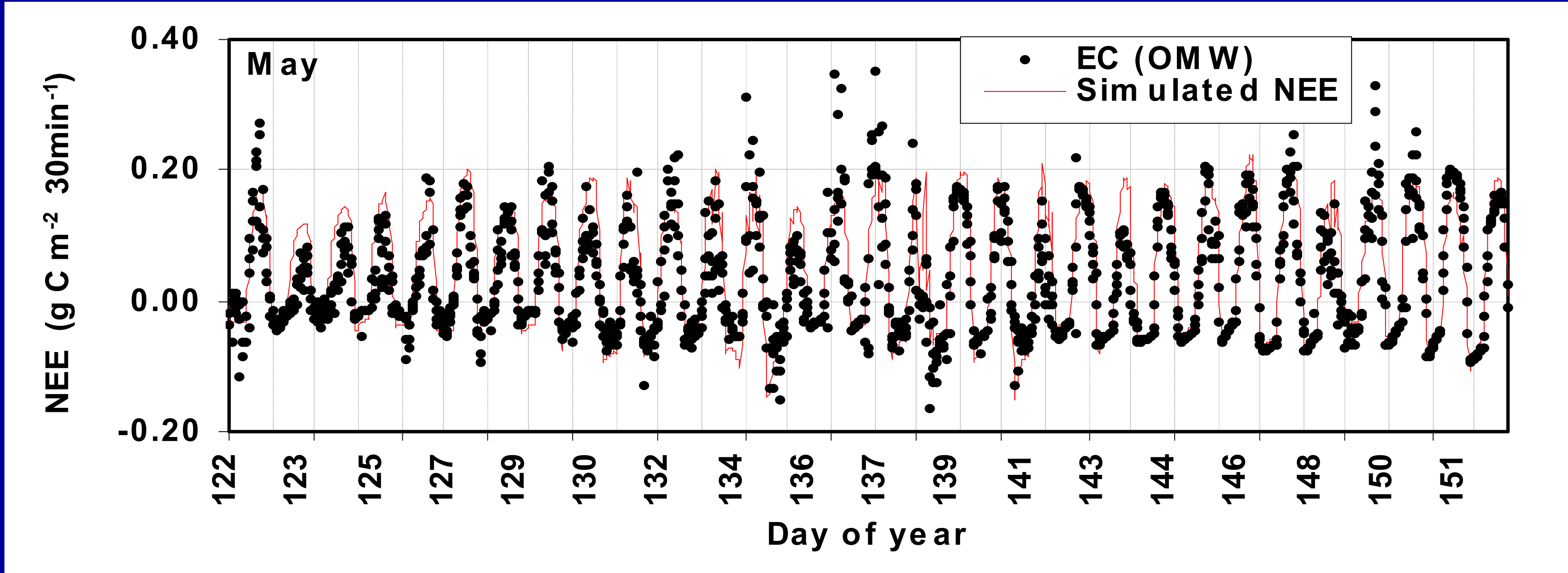
TRIPLEX-FLUX Simulations

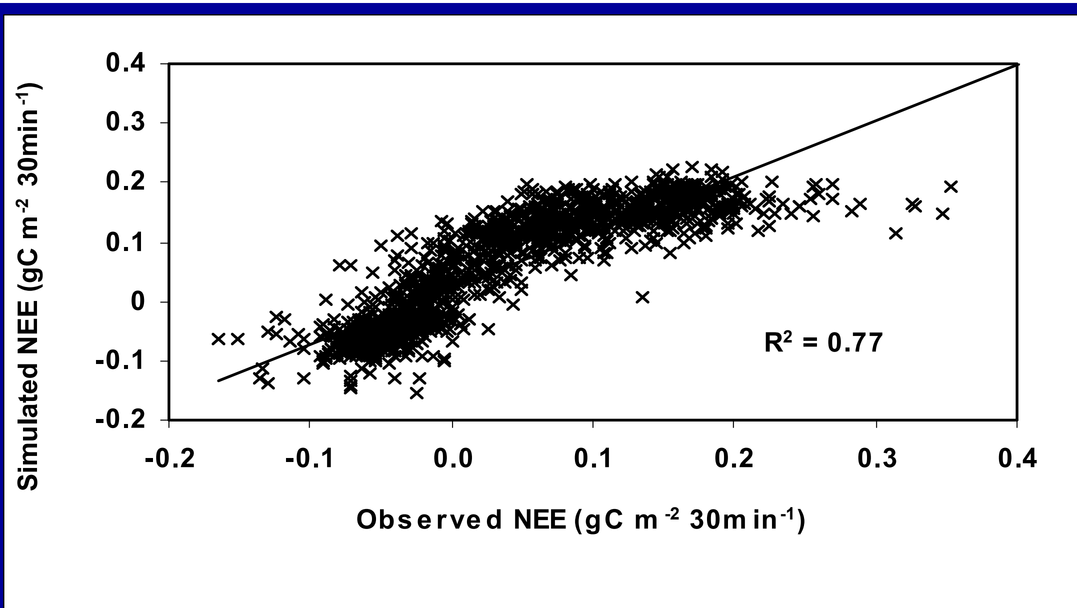
Model Testing for 2 Flux tower sites in Canada



(Fluxnet-Canada)

Boreal Mixedwood Site (Ontario)

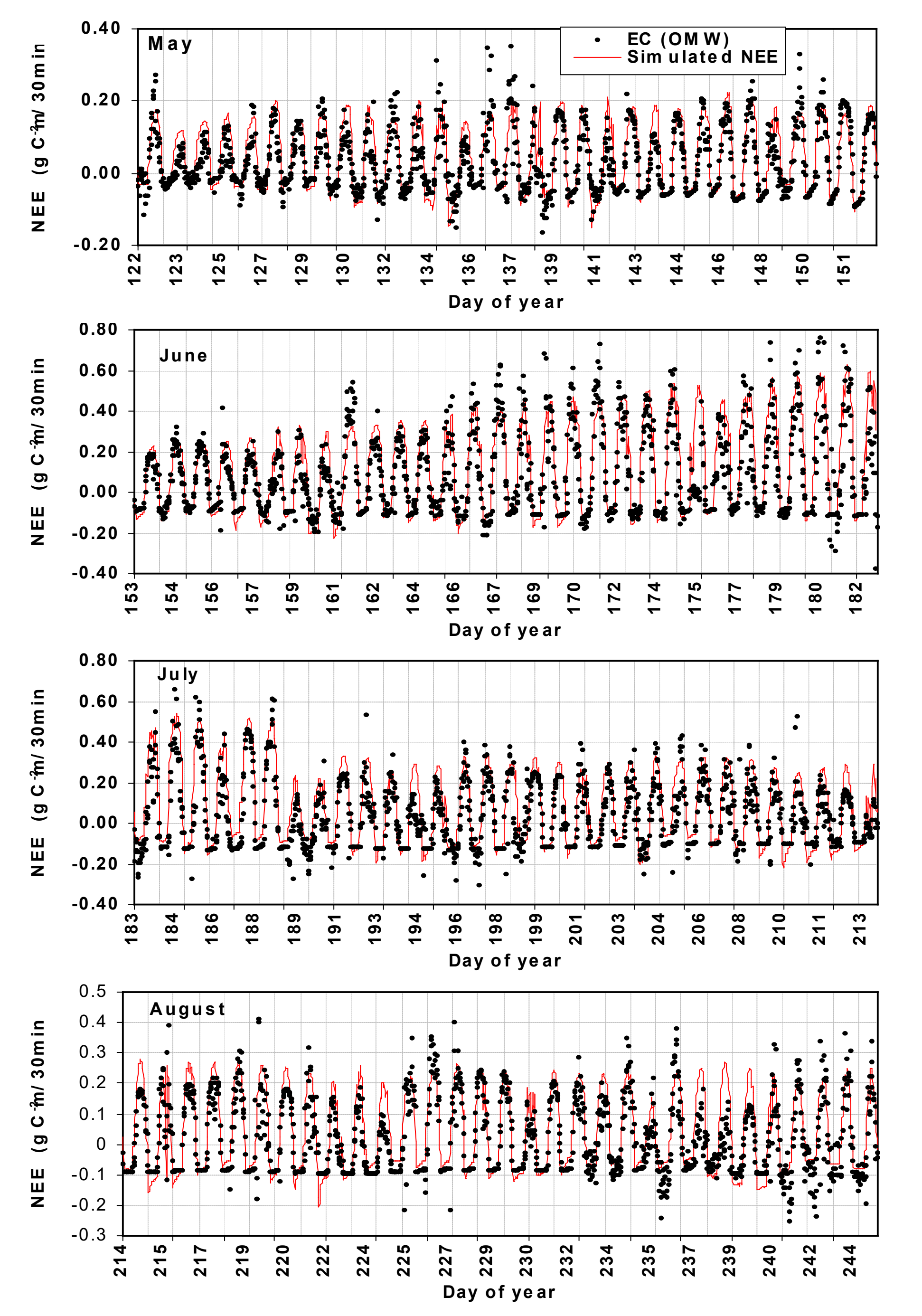




(Sun et al., 2008)

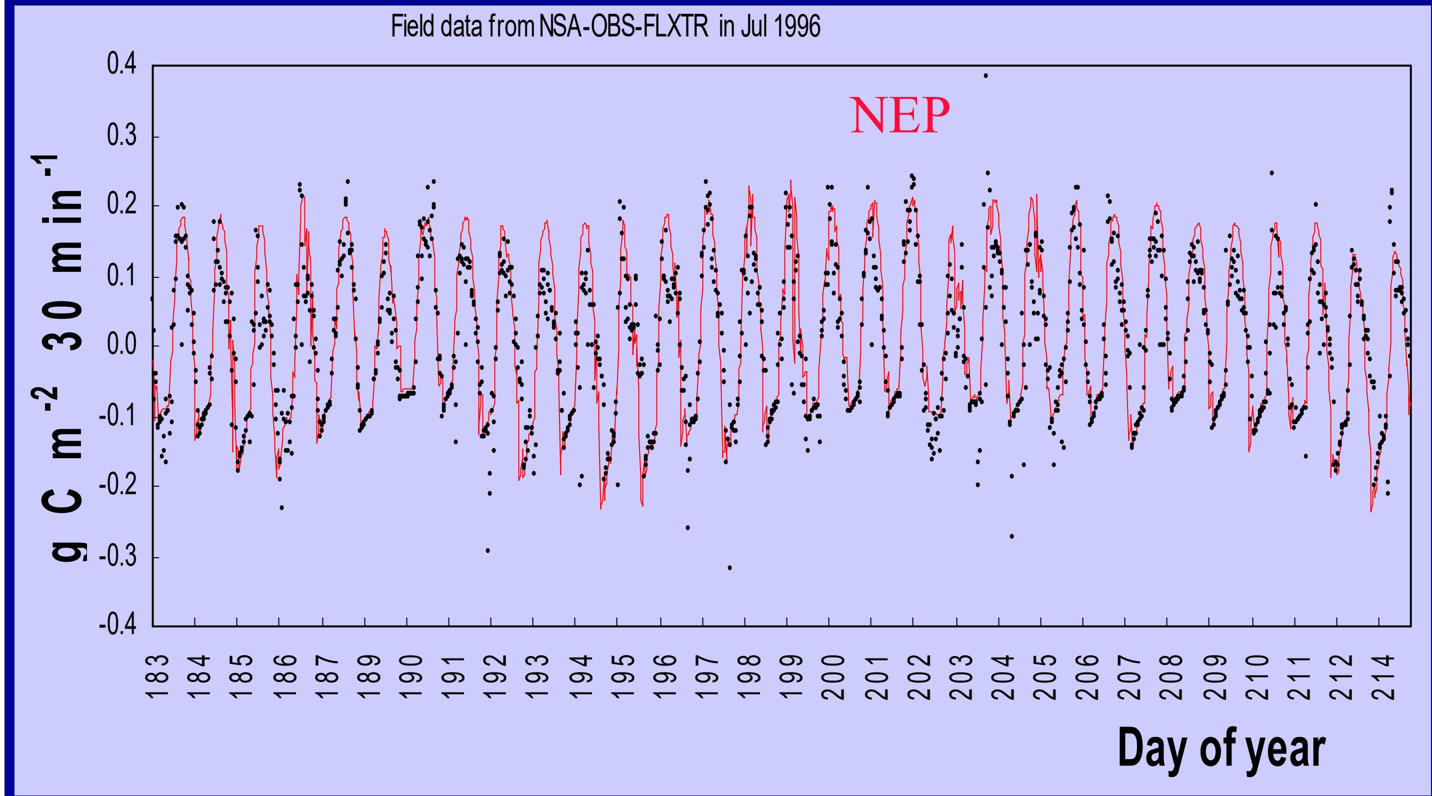
OMW

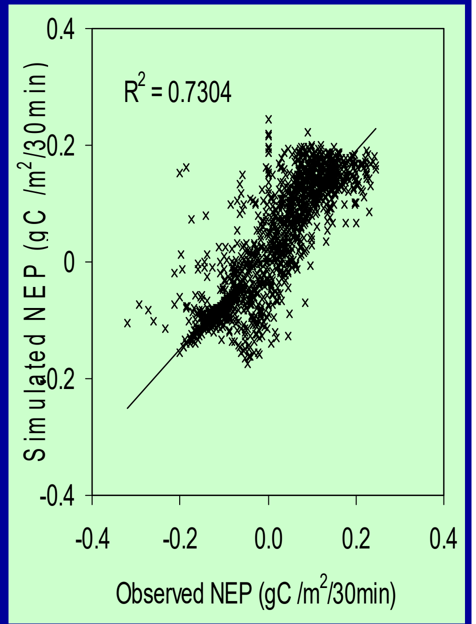
Diurnal dynamics of measured and simulated NEE during the growing season of 2004



* old boreal mixedwood (OMW)

Old Black Spruce (OBS) Flux Tower



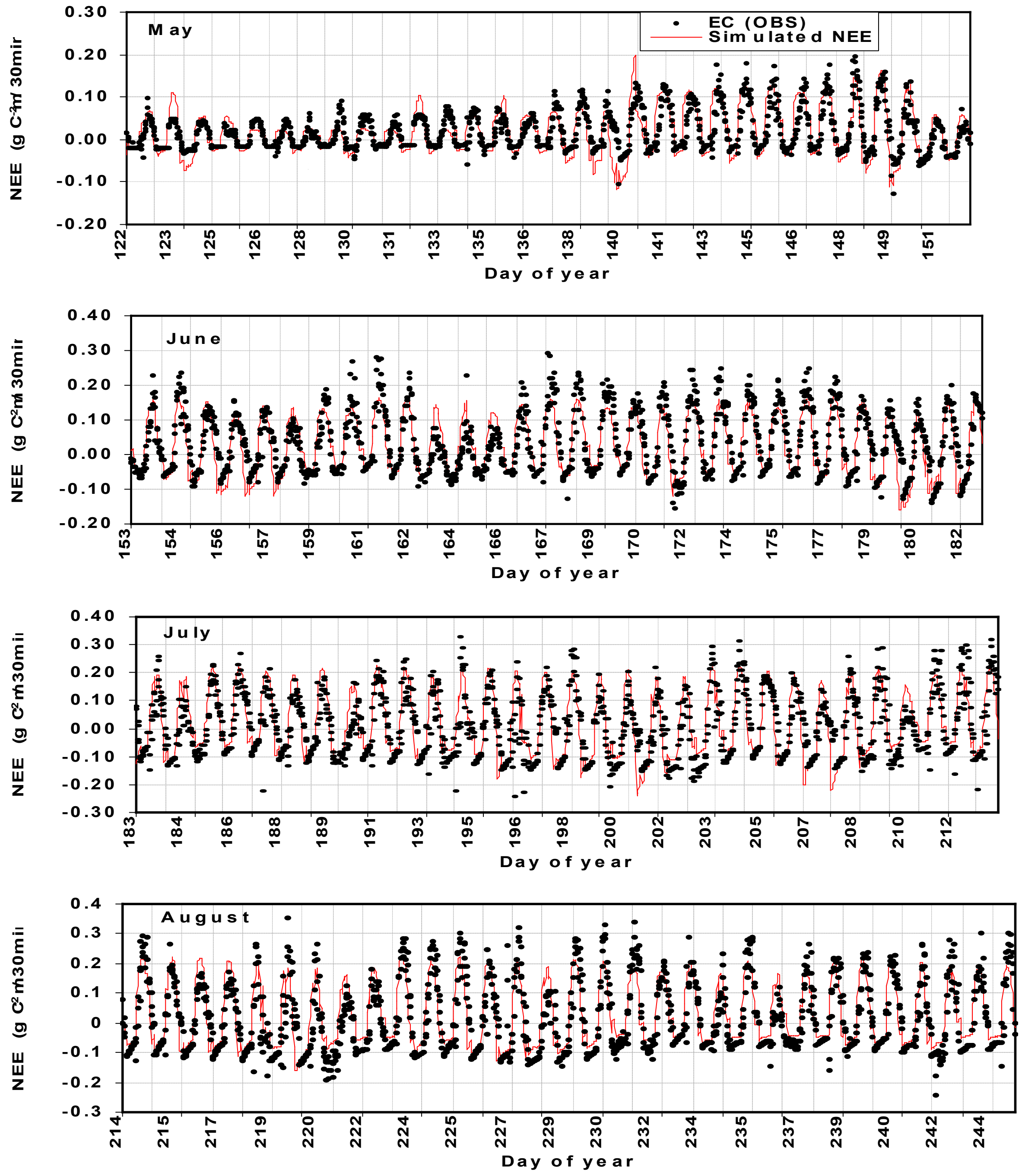


Daily Simulation using TRIPLEX-FLUX

(Zhou et al, 2008)

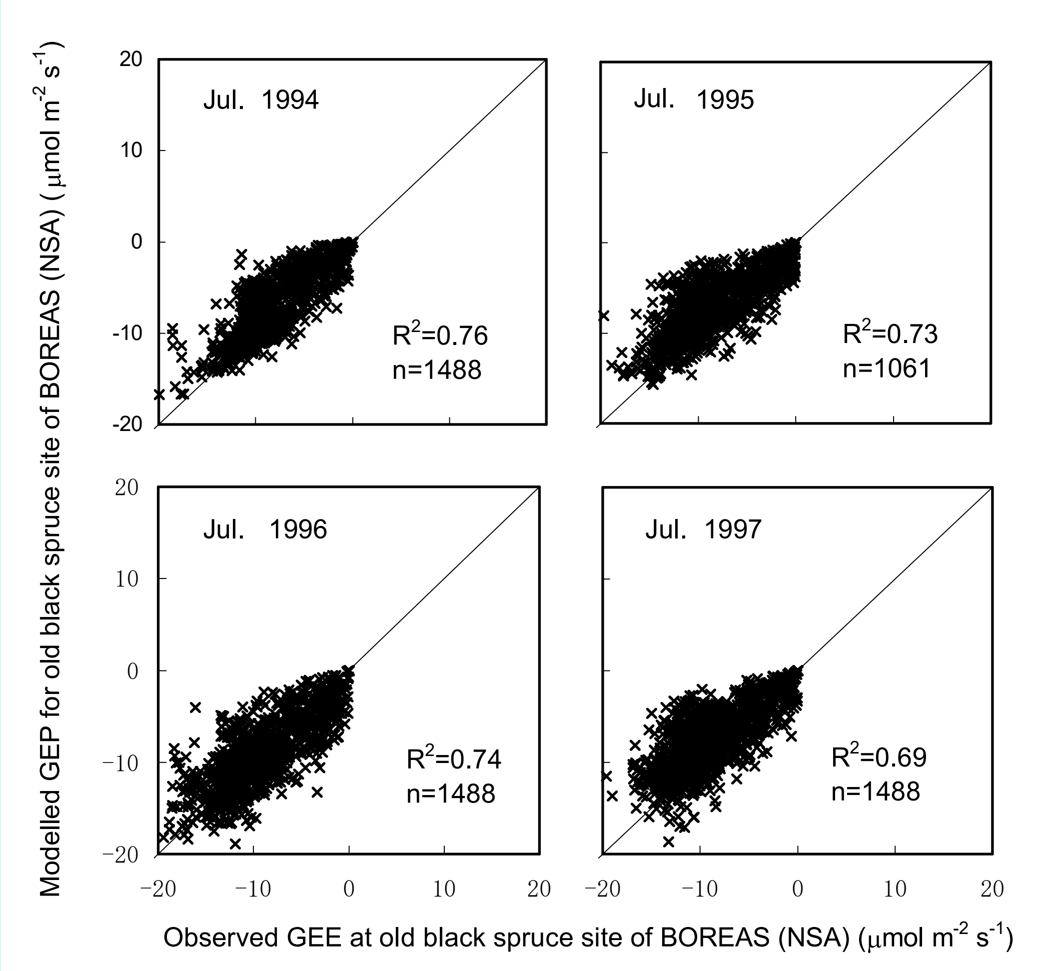
OBS

Diurnal dynamics of measured and simulated NEE during the growing season of 2004



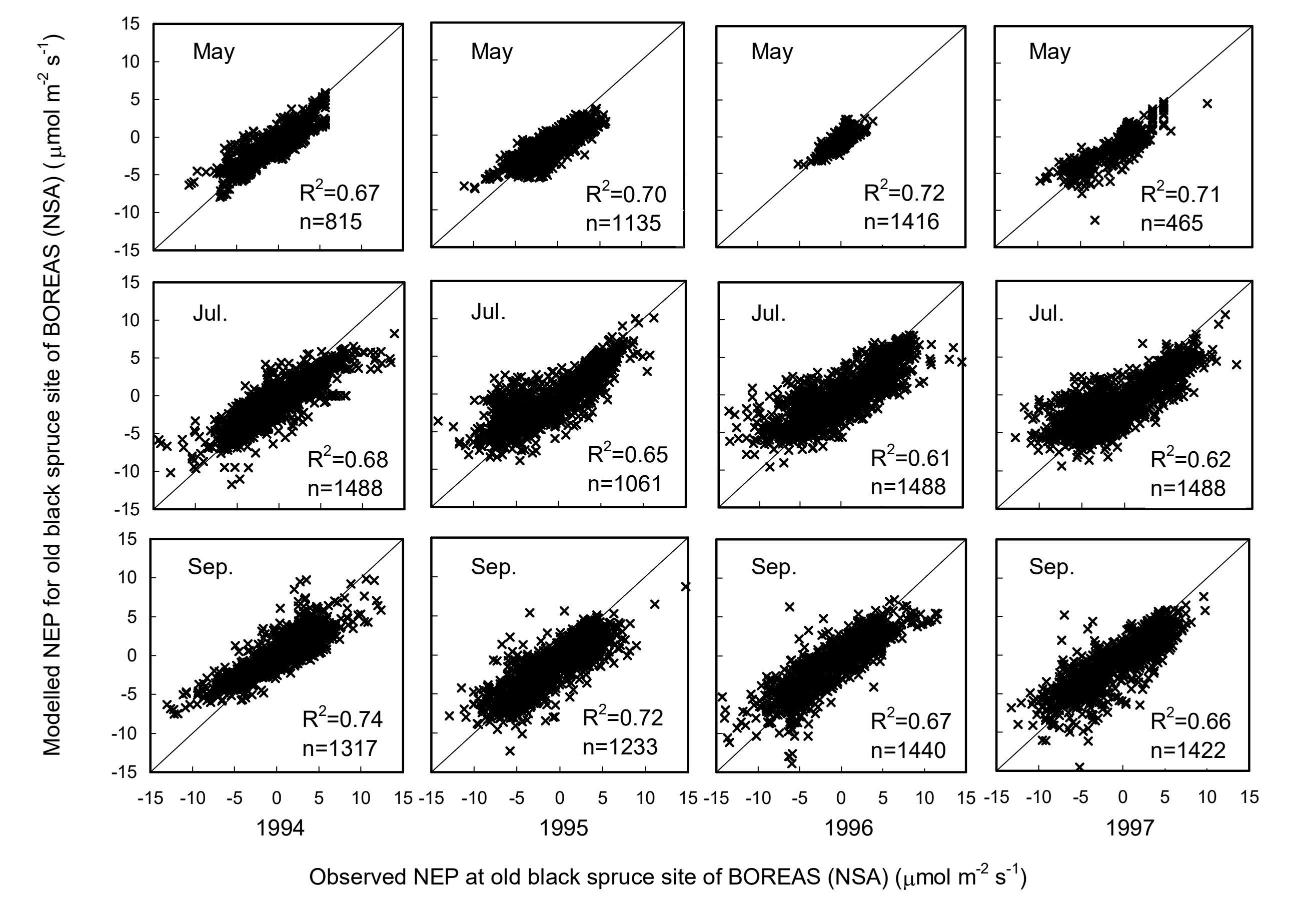
* old black spruce (OBS)

Comparison with measured GPP



Comparisons of hourly simulated GPP vs hourly observed GPP for July in 1994, 1995, 1996, and 1997.

Comparison with measured NEP



Comparisons (with 1:1 line) of hourly simulated NEP vs hourly observed NEP for May, July, and September in 1994, 1995, 1996, and 1997.

Summary:

1)、simple model with few inputs, but，able to capture key processes

2)、A acceptable agreement between model simulations and observations- a good job!

Limitations：

1)、Some uncertainty with peak values。

2)、Model simulations are not sensitive for changes in Vc_{max} , J_{max}, M, R_{10}, RH etc and need to improve。

3. Ongoing Challenges: Model-Data Fusion

esa ECOSPHERE

SPECIAL FEATURE: DATA ASSIMILATION

Application of the ecosystem model and Markov Chain Monte Carlo for parameter estimation and productivity prediction

WEIZHONG LI,[1] CHANGHUI PENG,[1,2,]† XIAOLU ZHOU,[2] JIANFENG SUN,[2] QIUAN ZHU,[1] HAIBIN WU,[2,3] AND BENOIT ST-ONGE[4]

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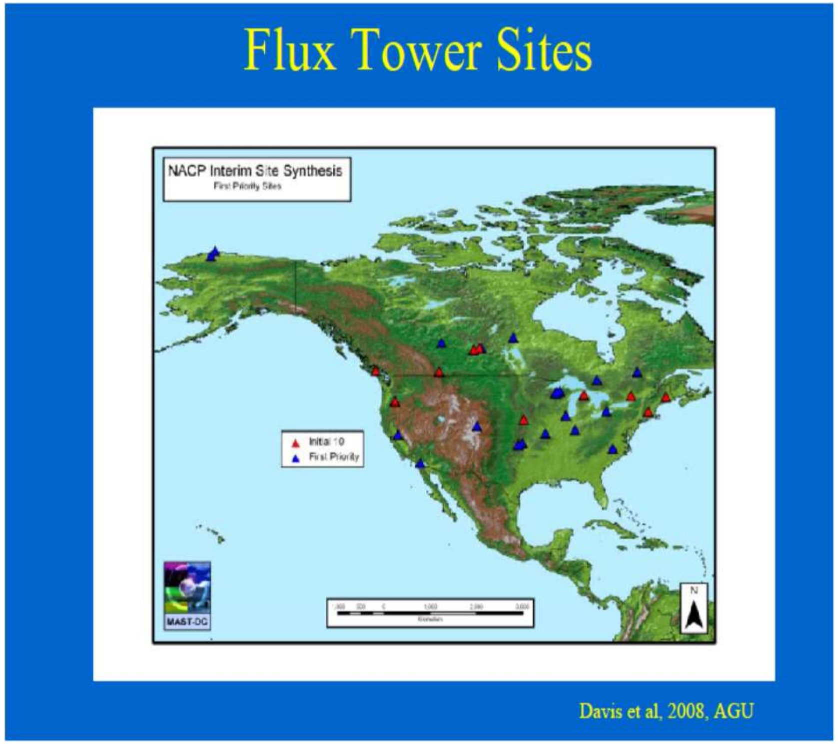
Citation: Li, W., C. Peng, X. Zhou, J. Sun, Q. Zhu, H. Wu, and B. St-Onge. 2015. Application of the ecosystem model and Markov Chain Monte Carlo for parameter estimation and productivity prediction. Ecosphere 6(12):270. http://dx.doi.org/10.1890/ES15-00034.1

Location:

7 North America Carbon Program flux sites

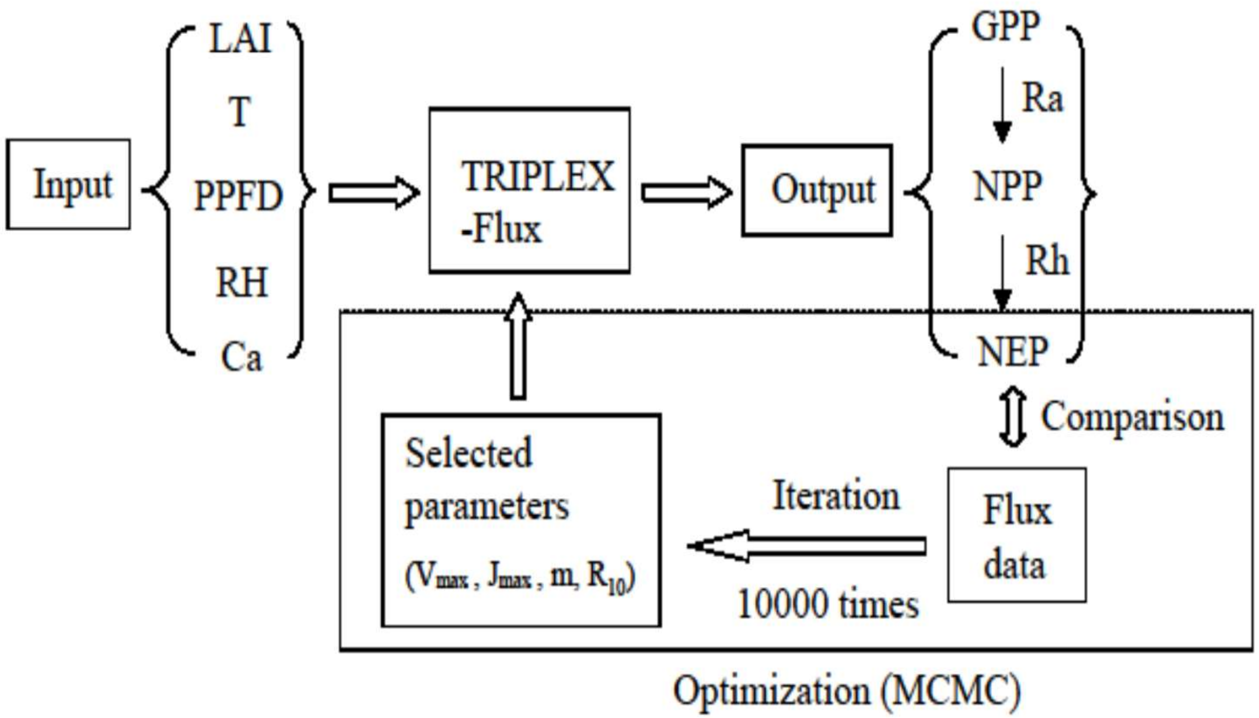


4 sites in USA

3 sites in Canada

Site Code	Full Name	State/ Province	Latitude(° N) / Longitude(° W)	Forests	Age	AMT (°C)	AMP (mm)
CA-Ca1	Campbell River – Mature Douglas-fir	BC (Canada)	49.87 / 125.33	ENT	60	8.3	1461
CA-Oas	BERMS – Old Aspen	SK (Canada)	53.63 / 106.20	DB	83	0.4	467.2
CA-Obs	BERMS – Old Black Spruce	SK (Canada)	53.99 / 105.12	ENB	111	0.4	467.2
US-Ha1	Harvard Forest – EMS Tower	MA (USA)	42.54 / 72.17	DB	81	8.3	1120
US-Ho1	Howland Forest – Main Tower	ME (USA)	45.20 / 68.74	ENT	109	6.65	778
US-Me2	Metolius – Intermediate-aged Ponderosa Pine	OR (USA)	44.45 / 121.56	ENT	90	4.5-8.3	447
US-UMB	University of Michigan Biological Station (UMBS)	MI (USA)	45.56 / 84.71	DB	90	6.2	750

model-data assimilation



MCMC: Markov chain Monte Carlo

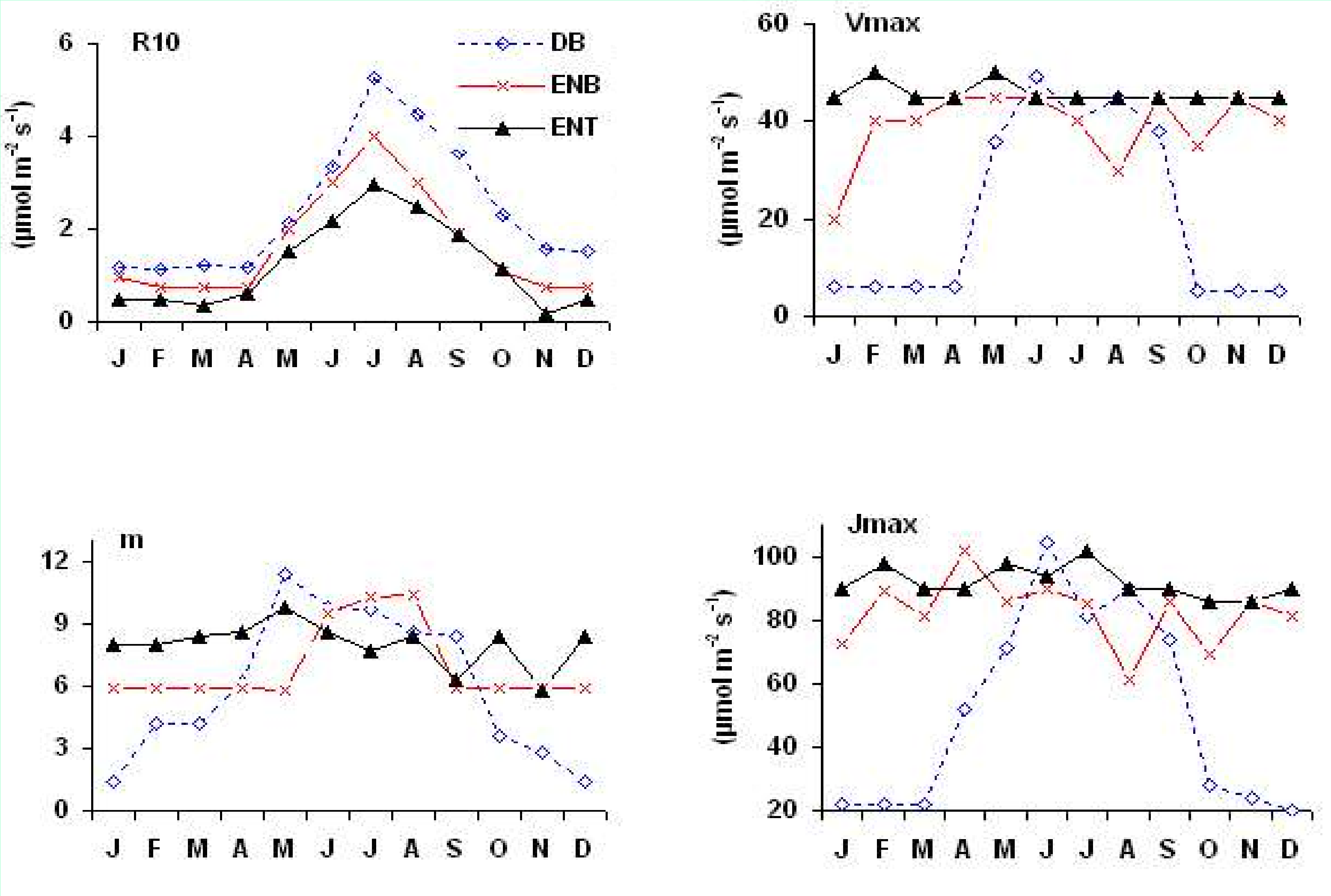
Li et al., (2015)

PPFD: photosynthetic photon flux density

4 Selected Key Parameters

- V_{max} : maximum carboxylation rate at 25° C in the photosynthetic carbon cycle in leaf
- J_{max} : light-saturated rate of electron transport in the photosynthetic carbon cycle in leaf
- m : coefficient of stomatal conductance
- R_{10} : the reference respiration rate at 10 ºC

Seasonal variation of parameters at different forest ecosystems

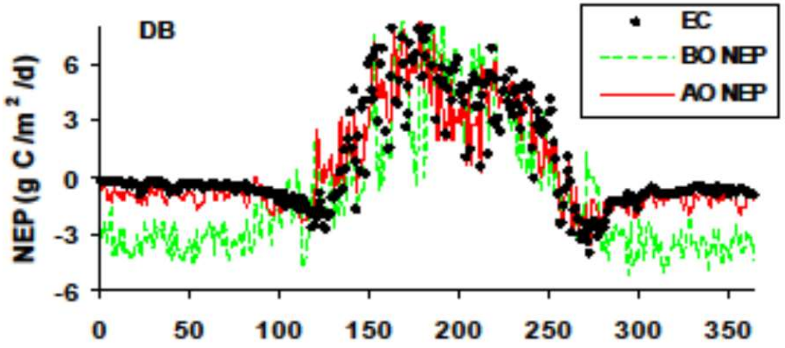


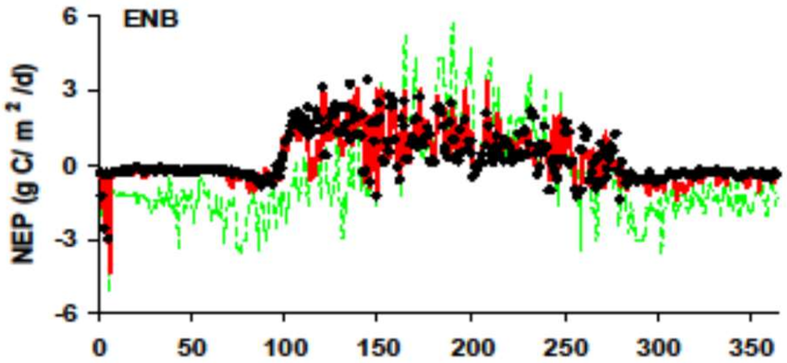
Note:
DB = deciduous broad-leaf forest
ENB = evergreen needle-leaf boreal forest
ENT = evergreen needle-leaf temperate forest

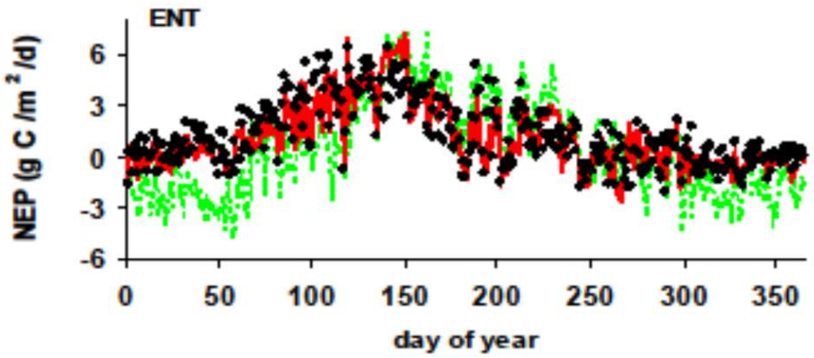
NEP simulation

MCMC optimization

(Li et al. 2015)



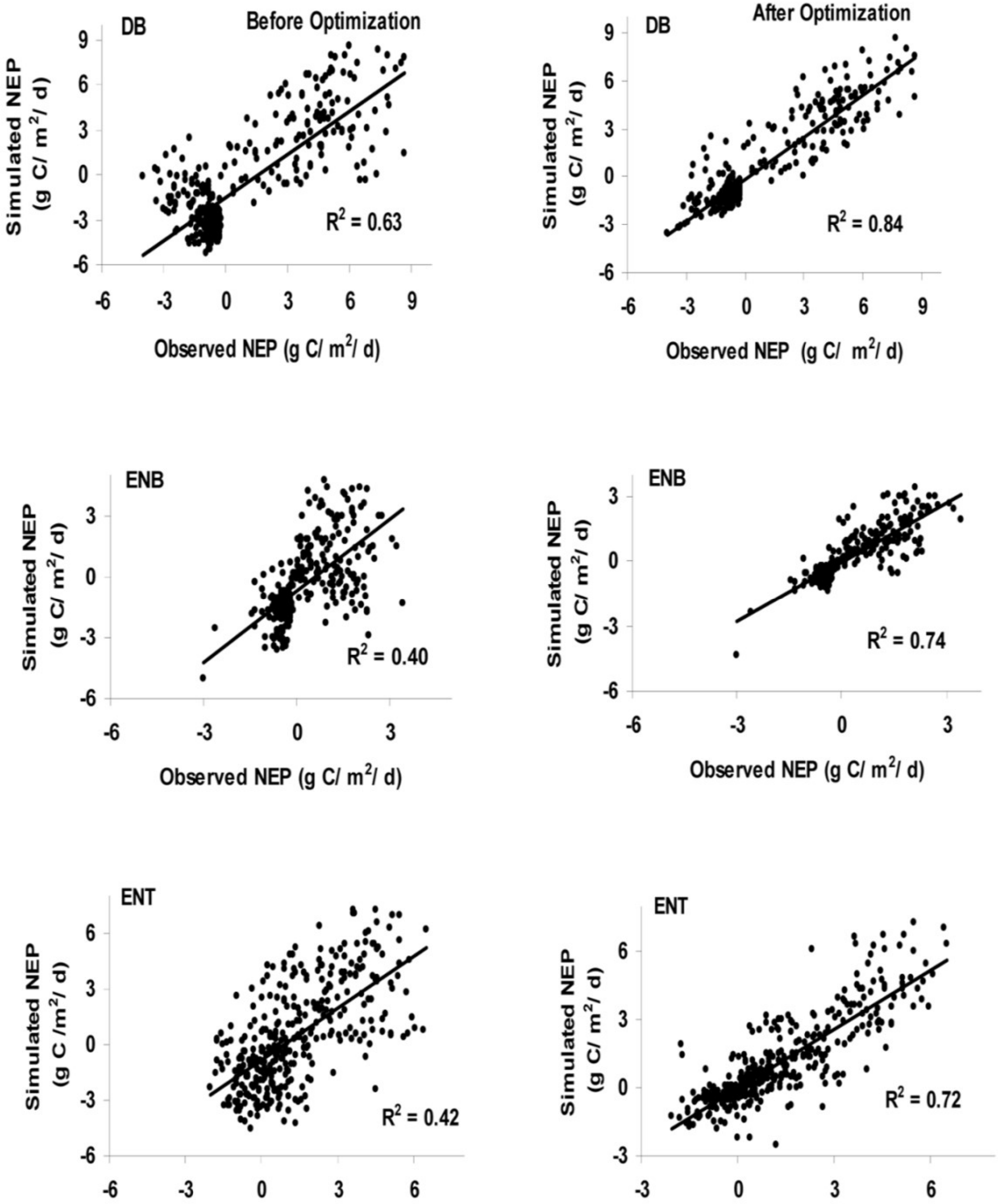




EC: eddy covariance, BO: before optimization, AO: after optimization
ENB = Evergreen needle-leaf boreal forest, ENT = evergreen needle-leaf temperate forest,
DB = deciduous broad-leaf forest

for 2006

Before OptimizationO **After Optimization**

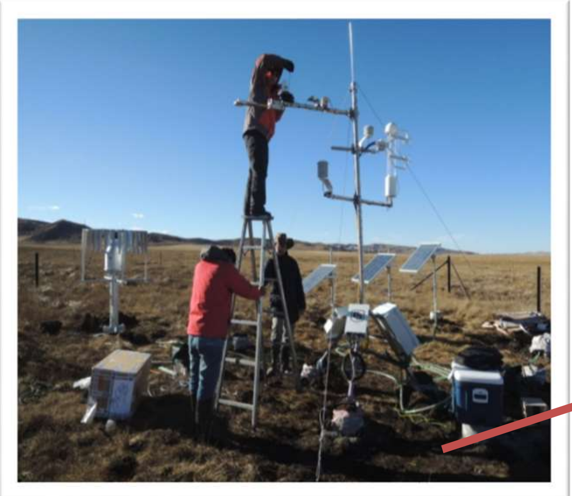


Research Needs and Ongoing Challenges:

- An improved network of observations CH_4, both ground-based and remotely sensed, is needed to quantify global CH_4 budget

- Very few wetland CH_4 flux measurements and data sets limit our ability to test and validate large-scale modelled CH_4 emissions. The further extension of the CO_2 FLUXNET measurements and database

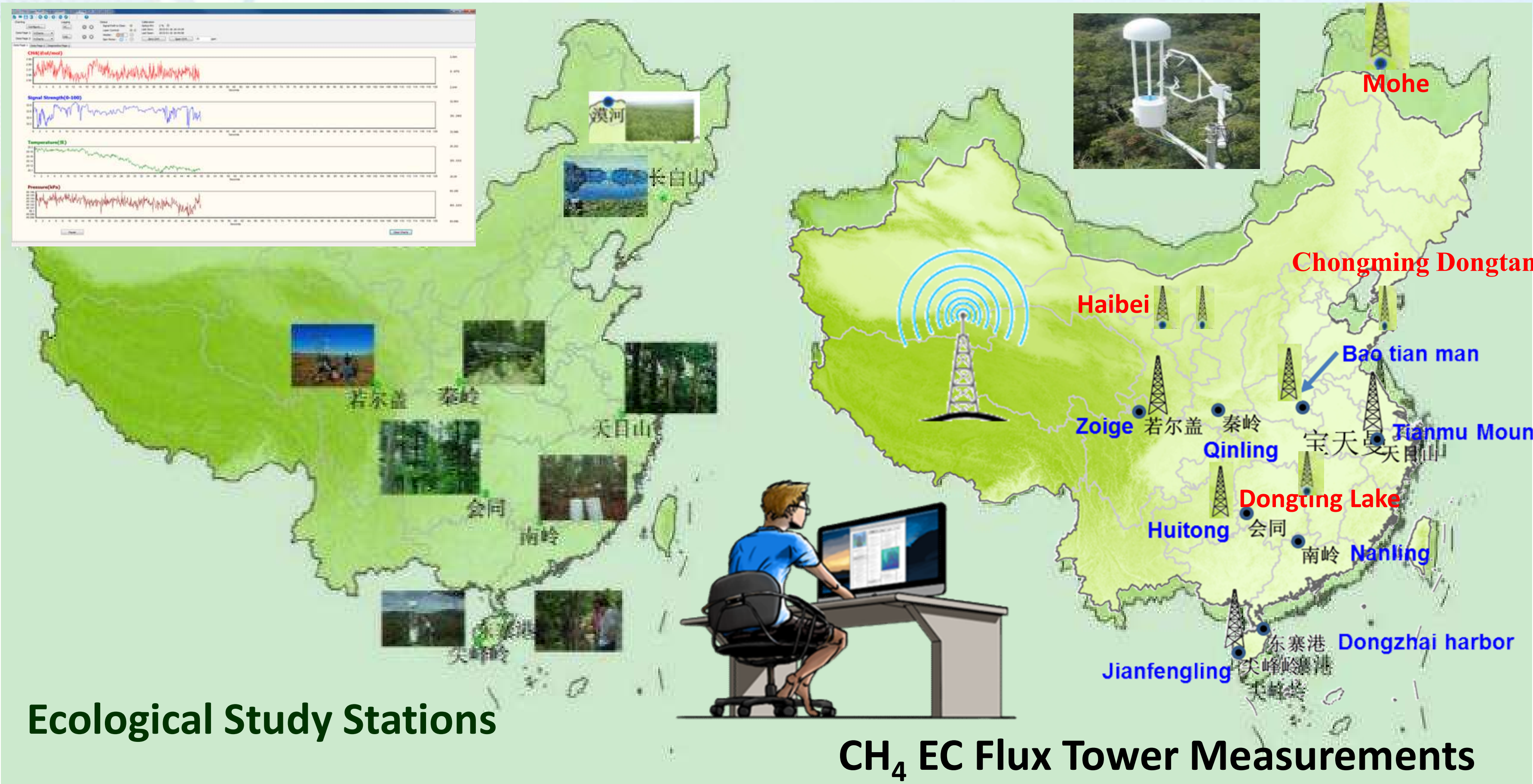
EC Flux Tower with Li-Co 7700 (CH_4)



Wetland in Tibet Plateau (2013)

Tropical Rain Forests (2012)

China Methane (CH_4) Fluxnet Initiative (CMFI)



Take –Home Messages:

-To keep the model as simple as possible,
as complex as necessary

- Integrating the observations with the state of the art models has great potential to improve model prediction and advance science

Acknowledgments: **Funding for this study was provided by QianRen Plan and National Natural Science Foundation of China, the NSERC Discovery Grant (Canada), etc…**

Collaborators: **Xiaolu Zhou, Wenhua Xiang, Xianwen Deng, Zhonghui Zhao,** etc…

Thanks (谢谢）！

Open for Questions and Collaboration (www.crc.uqam.ca)