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A Discussion on Two-layer Models of Ecosystem Evapotranspiration

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Outline :

- The introduction to the S-W model.
- Its short-term performance.

（refer to Evaporation from sparse crops-an energy combination theory ）

- Its long-term performance.

（refer to Partitioning of evapotranspiration and its controls in four grassland ecosystems: Application of a two-source model）

The introduction to the S-W model

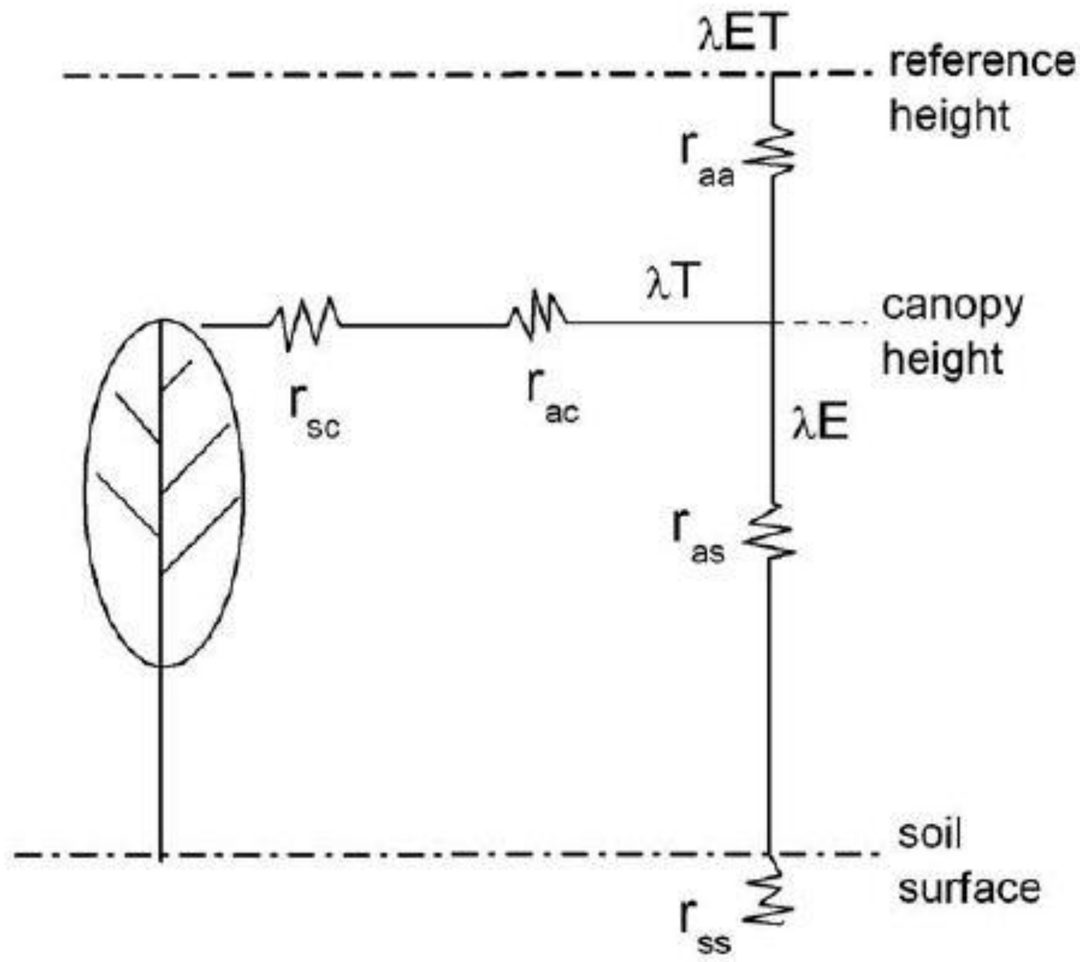

Fig. 1. Schematic description of the energy partitioning for a canopy with the S–W model. λET is the latent heat flux (i.e. evapotranspiration) from the vegetation (λT) and soil surface (λE).

The equation combination

$$\lambda \mathrm{ET} = \lambda T + \lambda E = C_c PM_c + C_s PM_s \quad (1)$$

$$PM_c = \frac{\Delta R + (\rho c_p D - \Delta r_{ac} R_s)/(r_{aa} + r_{ac})}{\Delta + \gamma(1 + (r_{sc}/(r_{aa} + r_{ac})))} \quad (2)$$

$$PM_s = \frac{\Delta R + (\rho c_p D - \Delta r_{as}(R - R_s))/(r_{aa} + r_{as})}{\Delta + \gamma(1 + (r_{ss}/(r_{aa} + r_{as})))} \quad (3)$$

$$R = R_n - G \quad (4)$$

$$R_s = R_{ns} - G \quad (5)$$

$$R_{ns} = R_n \exp(-0.6\mathrm{LAI}) \quad (6)$$

In Eq.(6), 0.6 is the extinction coefficient of the canopy for net radiation, chosen arbitrarily as 0.6 or 0.7.

The equation combination

$$C_c = \frac{1}{1 + (\rho_c \rho_a / (\rho_s(\rho_c + \rho_a)))} \tag{7}$$

$$C_s = \frac{1}{1 + (\rho_s \rho_a / (\rho_c(\rho_s + \rho_a)))} \tag{8}$$

$$\rho_a = (\Delta + \gamma) r_{aa} \tag{9}$$

$$\rho_c = (\Delta + \gamma) r_{ac} + \gamma r_{sc} \tag{10}$$

$$\rho_s = (\Delta + \gamma) r_{as} + \gamma r_{ss} \tag{11}$$

The equation combination

$$r_{ss} = b_1 \left(\frac{\theta_s}{\theta}\right)^{b_2} + b_3 \quad (12)$$

$$r_{sc} = \frac{1}{g_0 + a_1 f(\theta) P_n h_s / C_S} \quad (13)$$

$$f(\theta) = \frac{\theta - \theta_w}{\theta_f - \theta_w} \quad (14)$$

Its short-term performance:

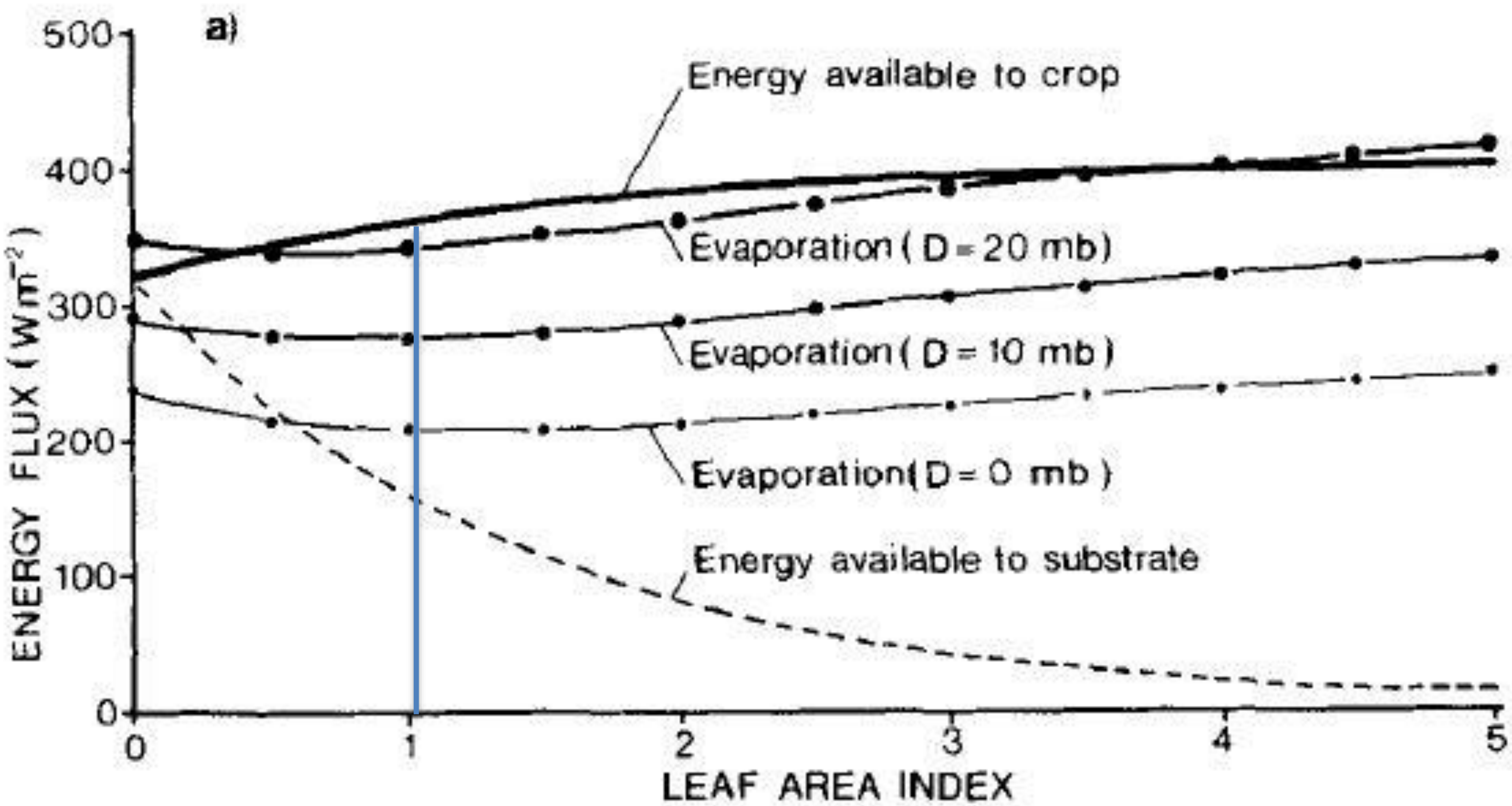

Fig 2a. Energy available to the crops and their free water substrates varies with changes of vapor pressure deficit D .

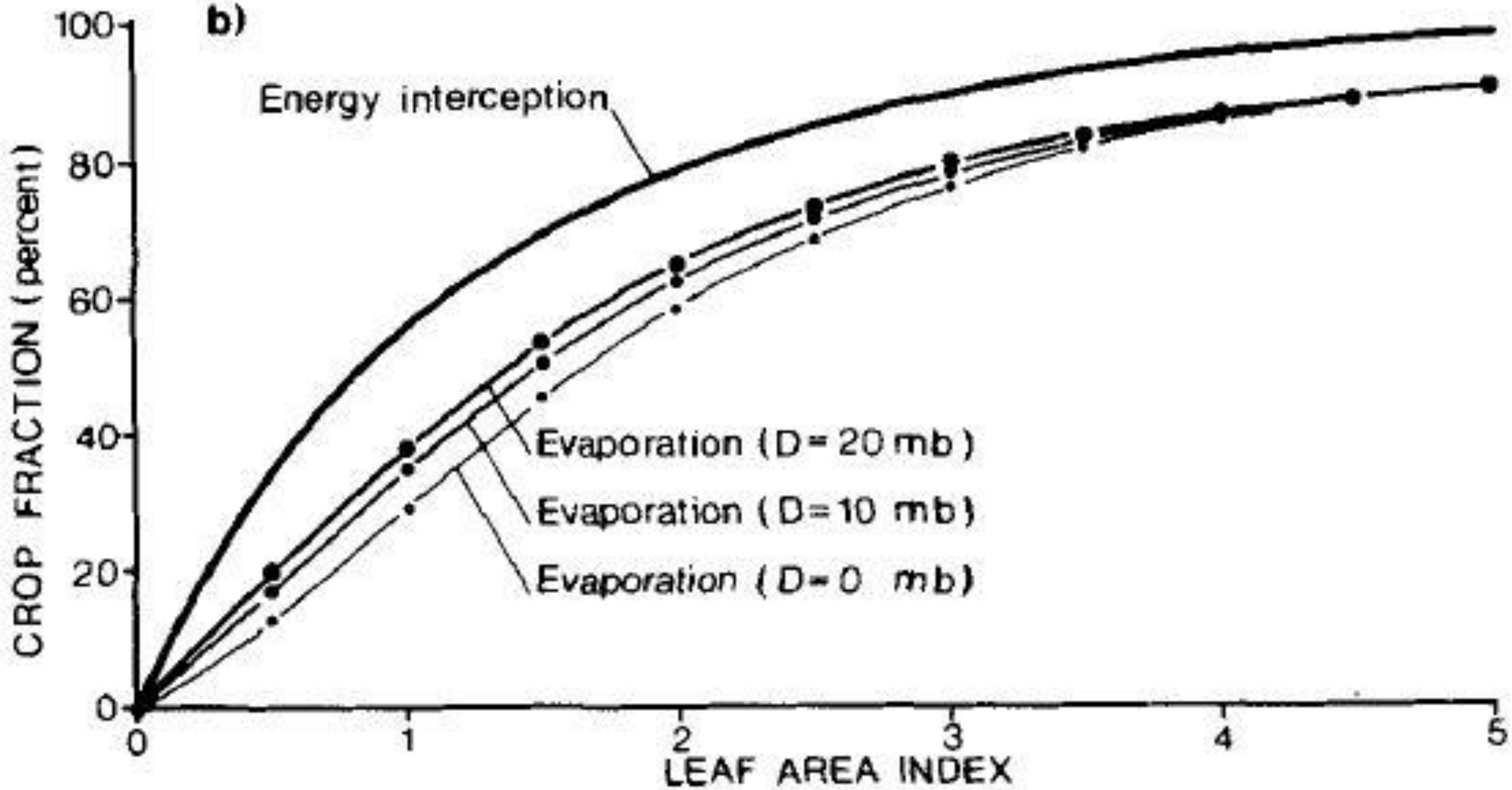

Fig 2b. Fraction of total evaporation originating from the plants varies with changes of vapor pressure deficit D.

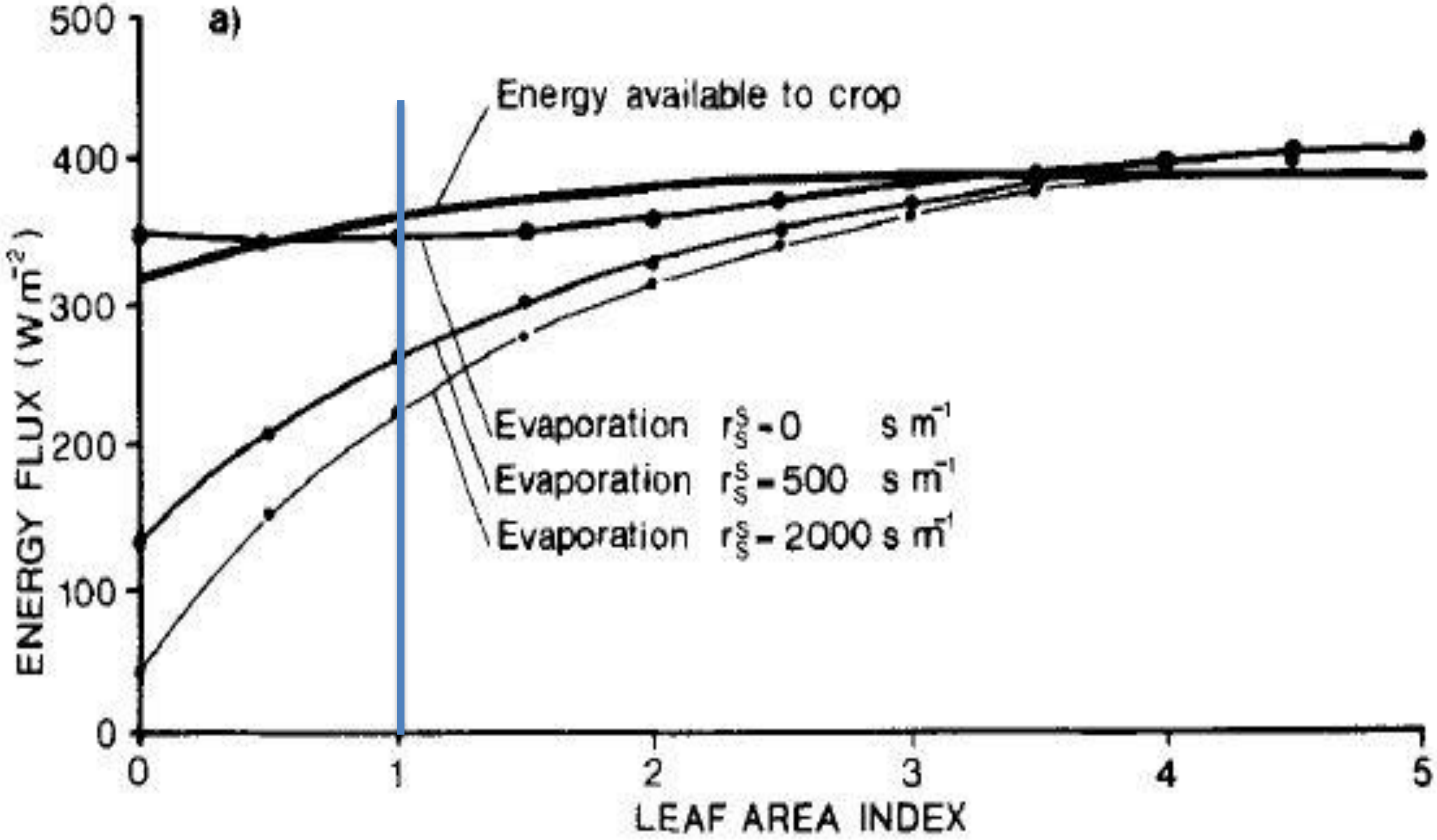

Fig 3a. Computed total crop evaporation rates for the model varies with changes of soil surface resistance.

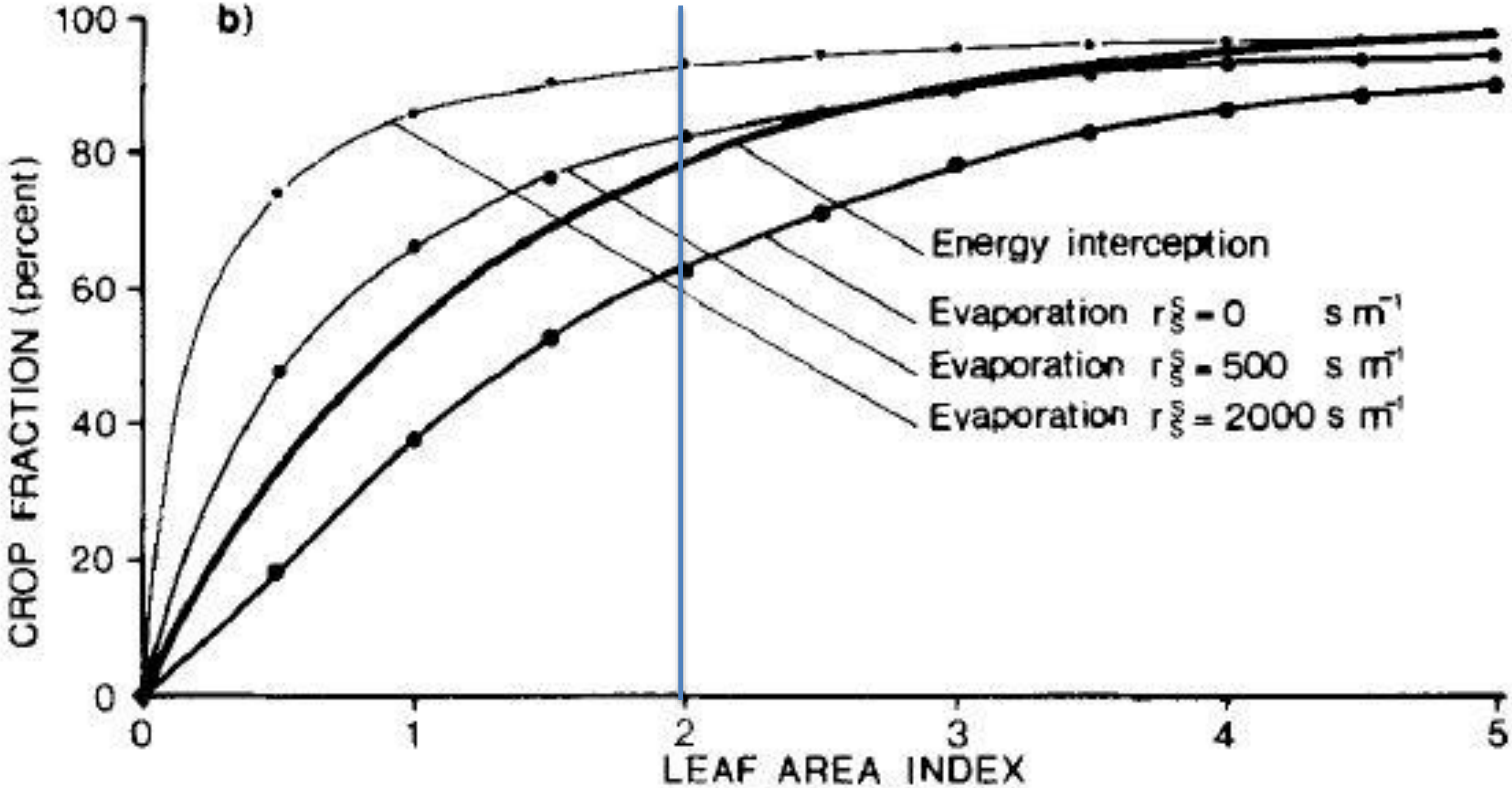

Fig 3b. Fraction of total evaporation originating from the plants varies with changes of soil surface resistance.

Tab 1. Calculated total crop evaporation rates with changes in the parameterization of aerodynamic resistance.

Model change	Leaf area index 0	0·5	1·0	1·5	2·0	3·0	4·0
(a) $r_b = 12{\cdot}5\ \mathrm{s\,m^{-1}}$	135	210	263	302	331	370	394
No change	135	209	261	300	329	368	392
$r_b = 50\ \mathrm{s\,m^{-1}}$	135	207	259	297	325	364	387
	(0)	(1·4)	(1·5)	(1·7)	(1·8)	(1·6)	(1·8)
(b) $n = 1{\cdot}25$	135	207	259	299	329	370	396
No change	135	209	261	300	329	368	392
$n = 5{\cdot}0$	135	223	270	303	328	362	382
	(0)	(7·7)	(4·2)	(1·3)	(0·3)	(2·2)	(3·6)
(c) Cover	164	221	265	299	326	365	392
No change	135	209	261	300	329	368	392
Bare	135	206	259	300	332	378	409
	(21·5)	(7·2)	(2·3)	(0·3)	(1·8)	(3·5)	(4·3)

The table illustrate the effect of halving and doubling the assumed value of mean boundary layer resistance, the exponential decay in eddy diffusivity through a fully developed crop and extreme changes in the parameterization of r_{aa} and r_{as}.

Tab 2 Fraction of total evaporation originating from the plants with changes in the parameterization of aerodynamic resistance.

Model change	Leaf area index						
	0	0·5	1·0	1·5	2·0	3·0	4·0
(a) $r_b = 12{\cdot}5\,\mathrm{s\,m^{-1}}$	0	48·2	66·7	76·6	82·8	89·7	93·3
No change	0	47·9	66·5	76·4	82·5	89·5	93·2
$r_b = 50\,\mathrm{s\,m^{-1}}$	0	47·4	66·0	75·9	82·1	89·2	92·9
	(0)	(1·7)	(1·0)	(0·9)	(0·8)	(0·6)	(0·4)
(b) $n = 1{\cdot}25$	0	48·7	67·3	76·9	82·6	88·8	92·0
No change	0	47·9	66·5	76·4	82·5	89·5	93·2
$n = 5{\cdot}0$	0	43·3	62·5	74·4	82·3	91·2	95·4
	(0)	(11·3)	(7·2)	(3·3)	(0·4)	(2·7)	(3·6)
(c) Cover	0	44·4	64·6	75·7	82·4	89·7	93·2
No change	0	47·9	66·5	76·4	82·5	89·5	93·2
Bare	0	48·7	67·3	76·9	82·6	88·8	91·9
	(0)	(9·0)	(4·1)	(1·6)	(0·2)	(1·0)	(1·4)

Tab 3. Total crop evaporation rate and fraction of total evaporation originating from the plants , for changes in the net radiation extinction coefficient C=0.5,0.7,0.9.

Calculated parameter	Leaf area index						
	0	0·5	1·0	1·5	2·0	3·0	4·0
(a) Evaporation							
$C = 0{\cdot}5$	135	208	260	298	327	366	390
$C = 0{\cdot}7$	135	209	261	300	329	368	392
$C = 0{\cdot}9$	135	209	262	301	330	369	392
	(0)	(0·5)	(0·8)	(1·0)	(0·9)	(0·8)	(0·5)
(b) Plant fraction							
$C = 0{\cdot}5$	0·0	45·5	63·2	72·9	79·1	86·7	91·0
$C = 0{\cdot}7$	0·0	47·9	66·5	76·4	82·5	89·5	93·2
$C = 0{\cdot}9$	0·0	50·1	69·1	78·9	84·8	91·1	94·1
	(0)	(9·6)	(8·9)	(7·9)	(6·9)	(4·9)	(3·3)

Numbers in brackets are the full range difference in the two perturbed values expressed as a percentage of those given with C=0.7.

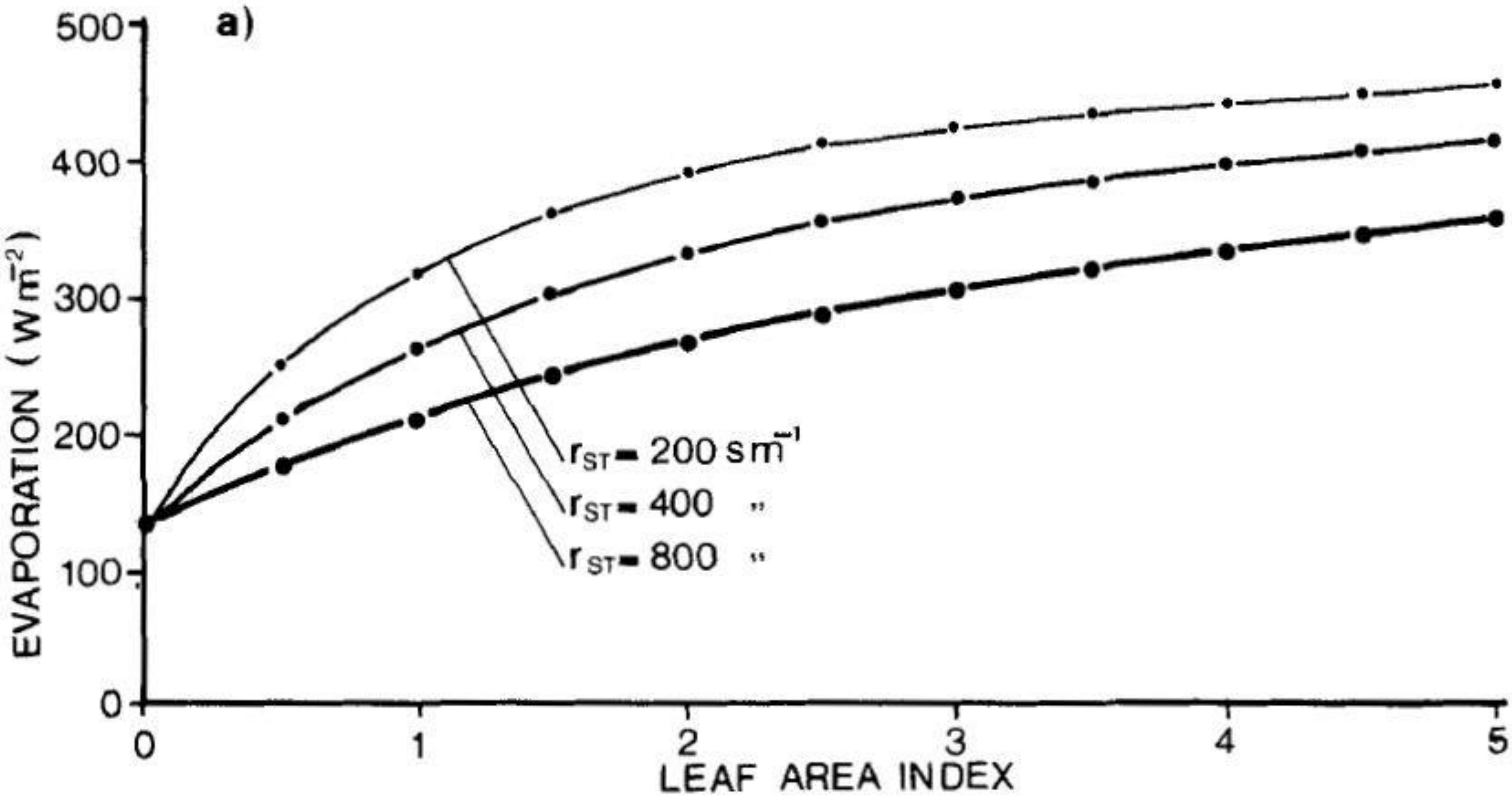

Fig 4a. Computed total crop evaporation rates vary with changes of mean stomatal resistance.

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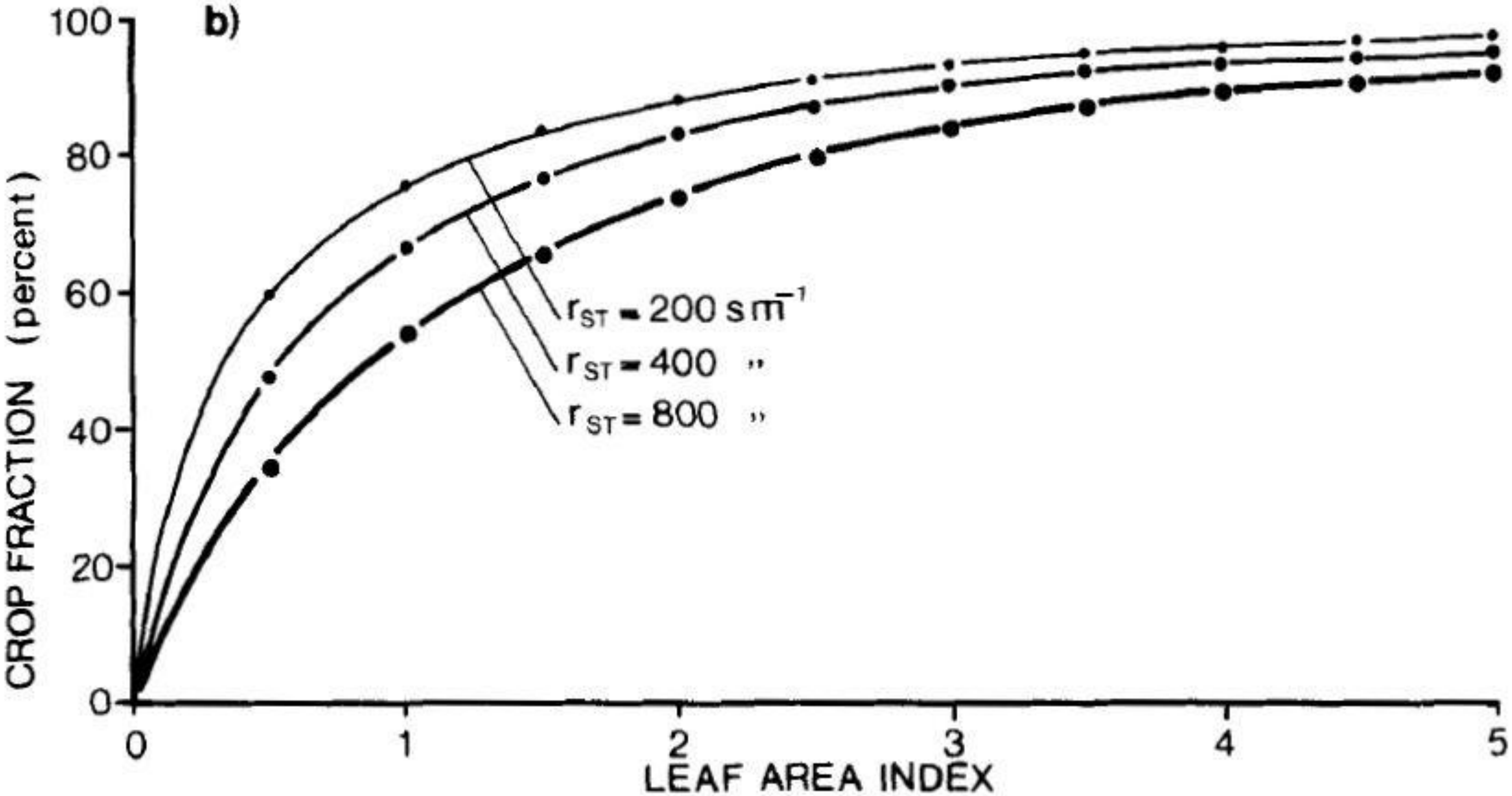

Fig 4b. Fraction of total evaporation originating from the plants varies with changes of mean stomatal resistance.

Its long-term performance:

Study sites

Study sites	Location	A.Mean. Ta	A.Mean Precipitation	Max Height	Max LAI
SD	$37^{o}37'$N,$101^{o}20'$E; 3160m a.s.l	-1.7℃	580 mm	45cm	4
GCT	$37^{o}40'$N,$101^{o}20'$E; 3293m a.s.l	-1.7℃	580 mm	60cm	2.8
DX	$30^{o}51'$N,$91^{o}05'$E; 4333m a.s.l	1.3℃	477mm	5-10cm	1.1
NM	$43^{o}33'$N,$116^{o}40'$E; 1252m a.s.l	-0.4℃	350mm	50-60cm	1.5

The equation combination

$$r_{ss} = b_1 \left(\frac{\theta_s}{\theta} \right)^{b_2} + b_3 \qquad (12)$$

$$r_{sc} = \frac{1}{g_0 + a_1 f(\theta) P_n h_s / C_S} \qquad (13)$$

$$f(\theta) = \frac{\theta - \theta_w}{\theta_f - \theta_w} \qquad (14)$$

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Table 1
Feasible ranges of parameters for each site applied to the Monte Carlo simulations.

Parameter	Range			
	SD[a]	GCT	DX	NM
b_1	–	1–5	2–5	1–5
b_2	–	1–4	3–5	1–3
b_3	40–90	150–200	1–50	450–500
a_1	20–50	20–50	35–65	20–50

[a] b_1 and b_2 were not estimated for SD since there was standing water under the canopy and the soil surface resistance could be regarded as a constant (i.e. b_3).

Table 2
Range and mean (sd) of each parameter and of the ratio of total estimated E to total estimated ET($\sum E/\sum ET$) based on the simulations with the selected 20 most successful parameter sets.

Parameter and value		SD ($R^2 > 0.8427$)	GCT ($R^2 > 0.8936$)	DX ($R^2 > 0.79963$)	NM ($R^2 > 0.83146$)
b_1	Range	–	1.04–4.98	2.02–3.07	1.16–4.18
	Mean (sd)	–	3.04 (1.39)	2.32 (0.28)	2.63 (0.94)
b_2	Range	–	2.45–3.39	4.09–4.65	1.03–1.93
	Mean (sd)	–	2.84 (0.28)	4.36 (0.14)	1.32 (0.22)
b_3	Range	84.85–89.93	180.82–199.61	1.26–9.73	471.34–497.72
	Mean (sd)	86.91 (1.73)	193.33 (5.49)	5.35 (2.29)	486.60 (8.66)
a_1	Range	37.83–39.80	25.49–28.20	43.11–64.31	34.38–37.50
	Mean (sd)	38.66 (0.66)	26.55 (0.71)	54.41 (6.06)	35.85 (0.93)
$\sum E/\sum ET(\%)$	Range	59.71–60.89	56.49–60.69	55.53–65.10	63.43–66.43
	Mean (sd)	60.41 (0.40)	58.92 (1.02)	60.02 (2.69)	64.91 (0.84)

R^2 in the parenthesis illustrates the criterion for selecting the 20 most successful parameter sets at each site.

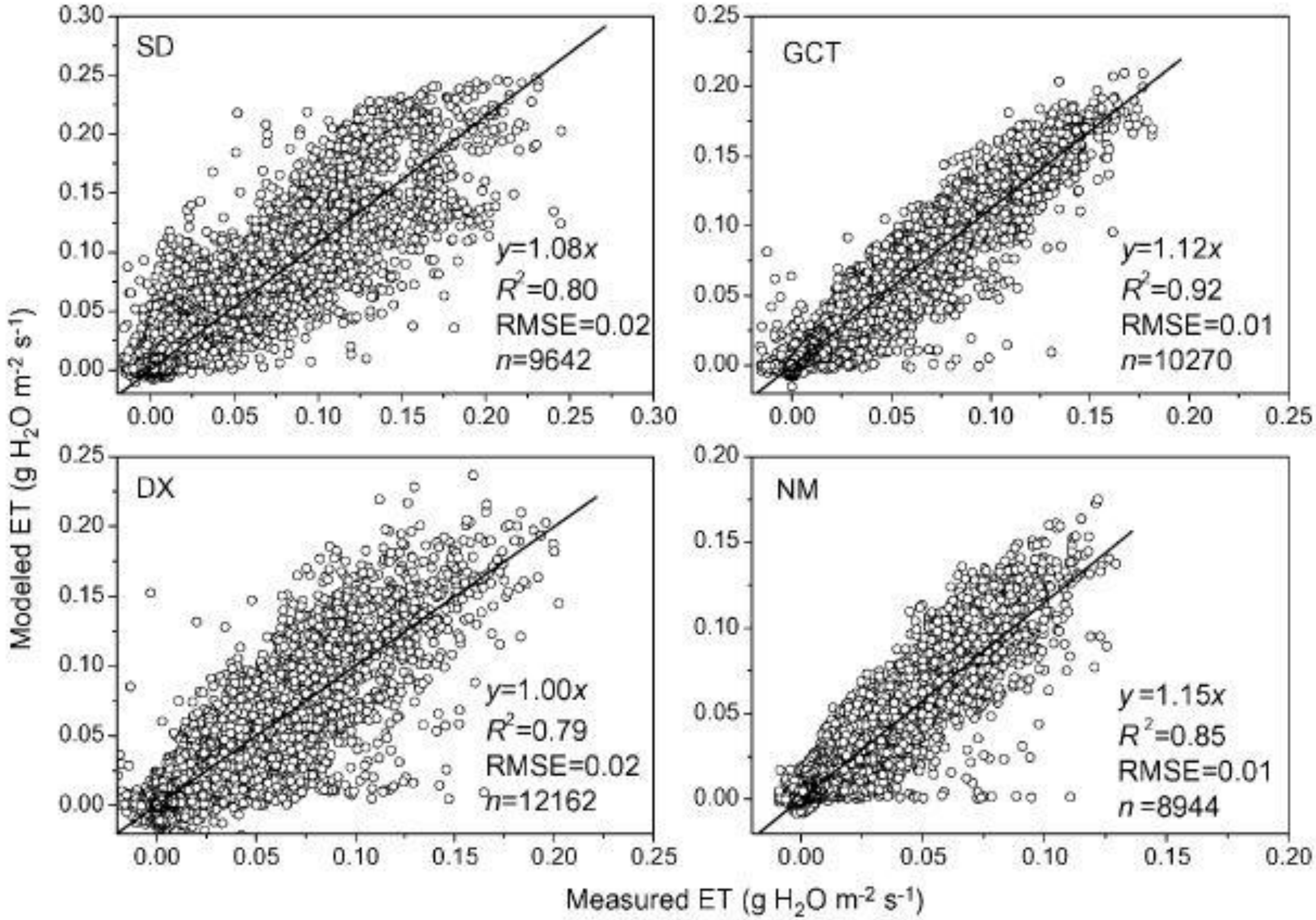

Fig 2. comparisons between the modeled and measured evapotranspiration(ET) at half-hourly time scale. The years of data used are 2005 in SD, GCT and DX and 2004 in NM.

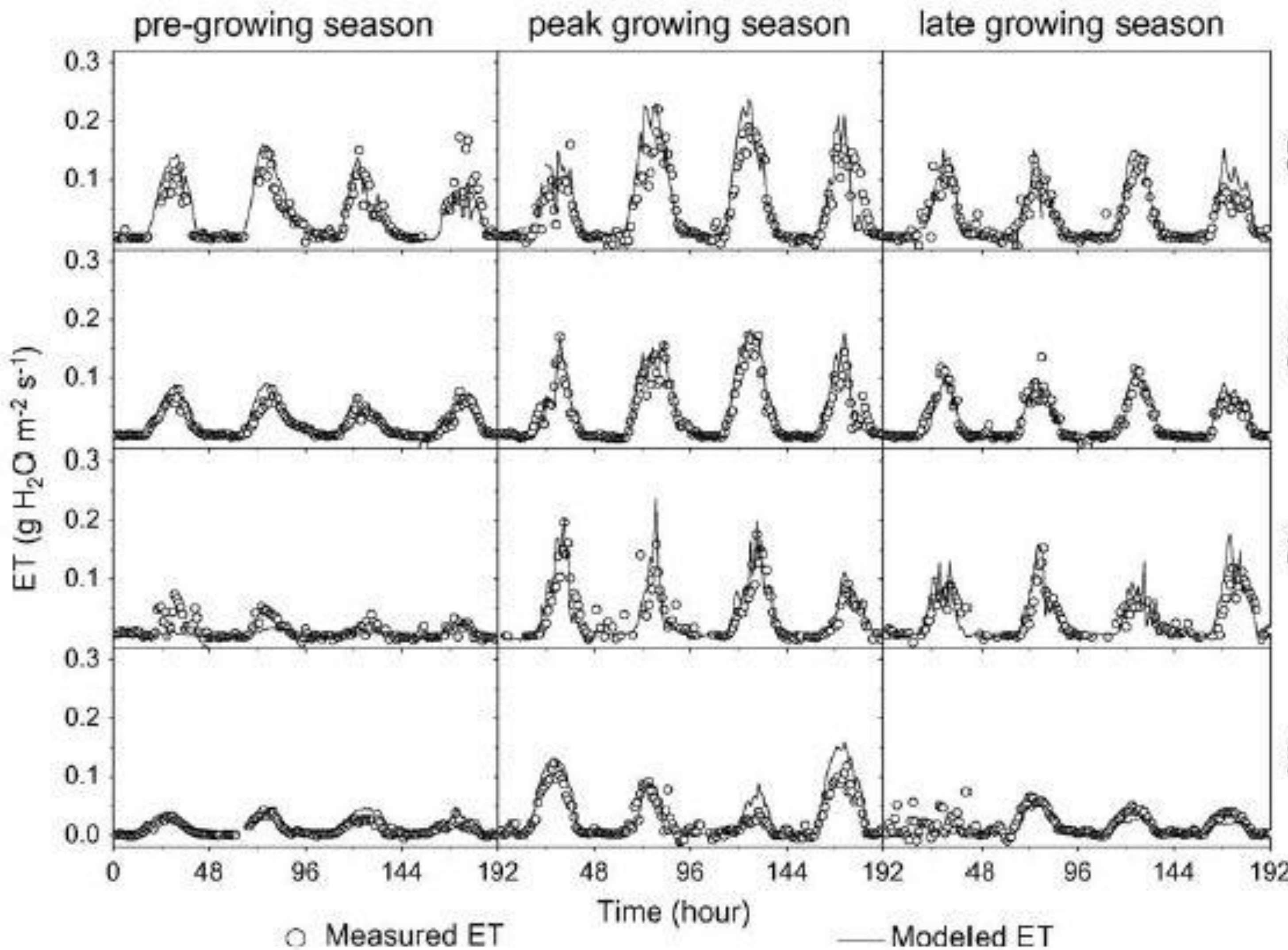

Fig 3. diurnal variations of the modeled and measured ET during pre-growing season, peak growing season and late growing season. For the sites SD, GCT and DX, the days Selected to represent each period were April 20-23, August 1-4 and September 15-18, 2005 respectively. For NM, the days selected were May 5-8, August 1-4 and September 15-18, 2004, respectively.

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Table 3
Model performance in growing season and non-growing season.

Site	Growing season (May–September)				Non-growing season (October-April)			
	k	R^2	RMSE	*n*	*k*	R^2	RMSE	*n*
SD	1.10	0.82	0.03	3788	0.97	0.53	0.05	5854
GCT	1.15	0.93	0.02	4665	0.86	0.73	0.01	5605
DX	1.01	0.79	0.02	5806	0.84	0.57	0.01	6356
NM	1.15	0.84	0.01	5644	0.96	0.47	0.01	3300

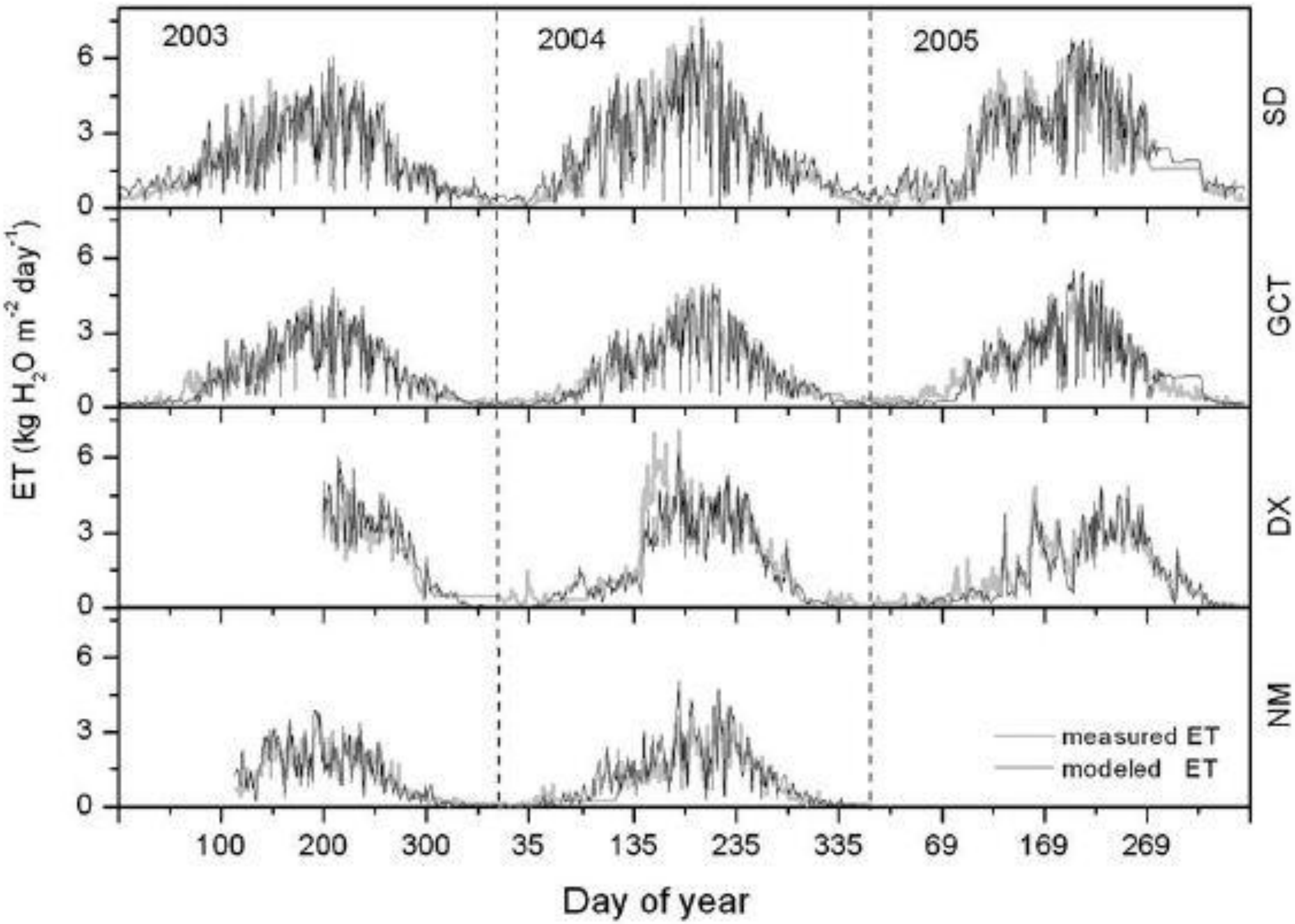

Fig 4. comparisons of the seasonal dynamics between modeled and measured ET in 2003-2005.

Table 5
Magnitudes of mean daily LAI in growing seasons (LAI_{mean}), total modeled ET (ET_{mod}), total modeled E (E_{mod}), total modeled T (T_{mod}), and the ratio of E_{mod} to ET_{mod} (E/ET_{mod}) in entire years and in growing seasons.

Site	Year	LAI_{mean}	All year around (January–December)				Growing season (May–September)			
			ET_{mod}	E_{mod}	T_{mod}	E/ET_{mod}	ET_{mod}	E_{mod}	T_{mod}	E/ET_{mod}
SD	2003	1.7	725	452	273	0.62	471	202	269	0.43
	2004	1.8	817	490	327	0.60	537	214	323	0.40
	2005	1.9	878	506	372	0.58	590	239	351	0.41
	Mean	1.8	807	483	324	0.60	533	218	314	0.41
GCT	2003	1.2	483	282	201	0.58	358	162	196	0.45
	2004	1.3	500	288	212	0.58	373	163	210	0.44
	2005	1.4	543	278	265	0.51	409	148	261	0.36
	Mean	1.3	509	283	226	0.56	380	158	222	0.42
DX	2004	0.5	539	333	206	0.62	453	252	201	0.56
	2005	0.5	453	303	150	0.67	361	217	144	0.60
	Mean	0.5	496	318	178	0.64	407	235	173	0.58
NM	2003	0.8	–	–	–	–	283	174	109	0.61
	2004	0.9	391	254	137	0.65	313	177	136	0.57
	Mean	0.9	–	–	–	–	298	176	123	0.59

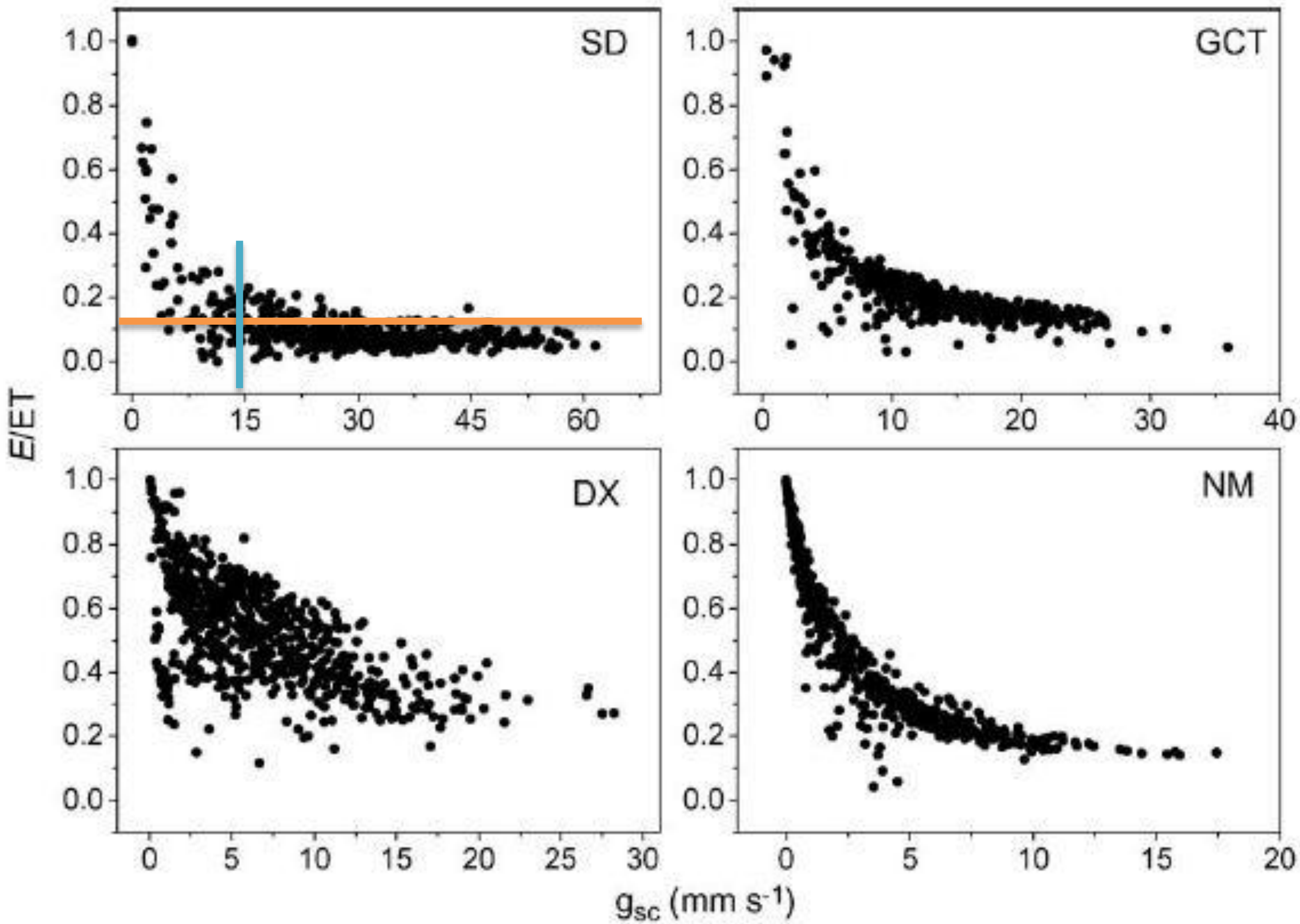

Fig 5. Effect of canopy stomatal conductance (g_{sc}) on E/ET at the half-hourly Time scale. Data were selected in the peak growing season(July 15-August 15) In 2005(SD, GCT and DX) and in 2004 (NM).

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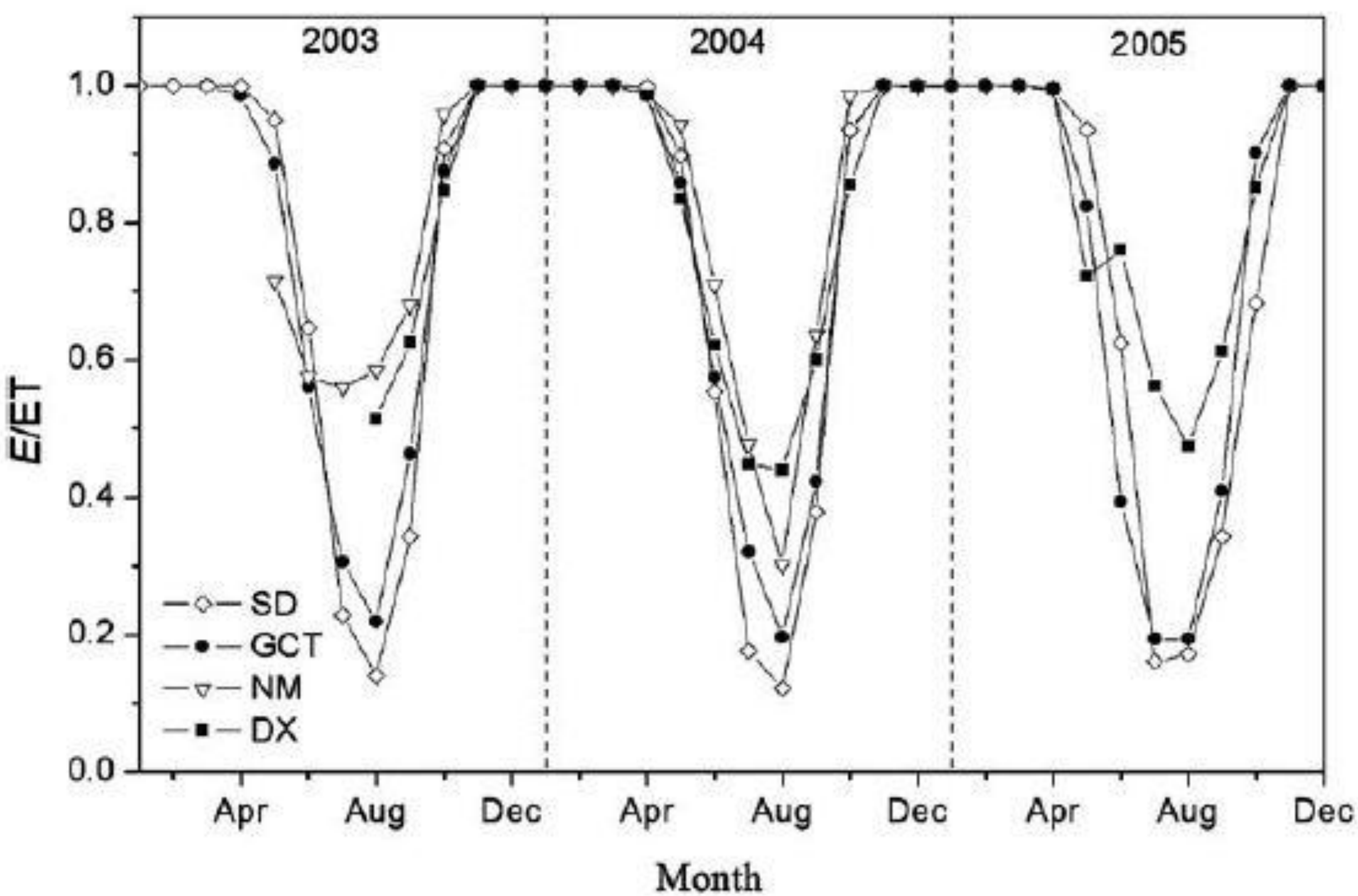

Fig. 6. Seasonal dynamics of the ratio of modeled monthly soil water evaporation to modeled monthly evapotranspiration (E/ET).

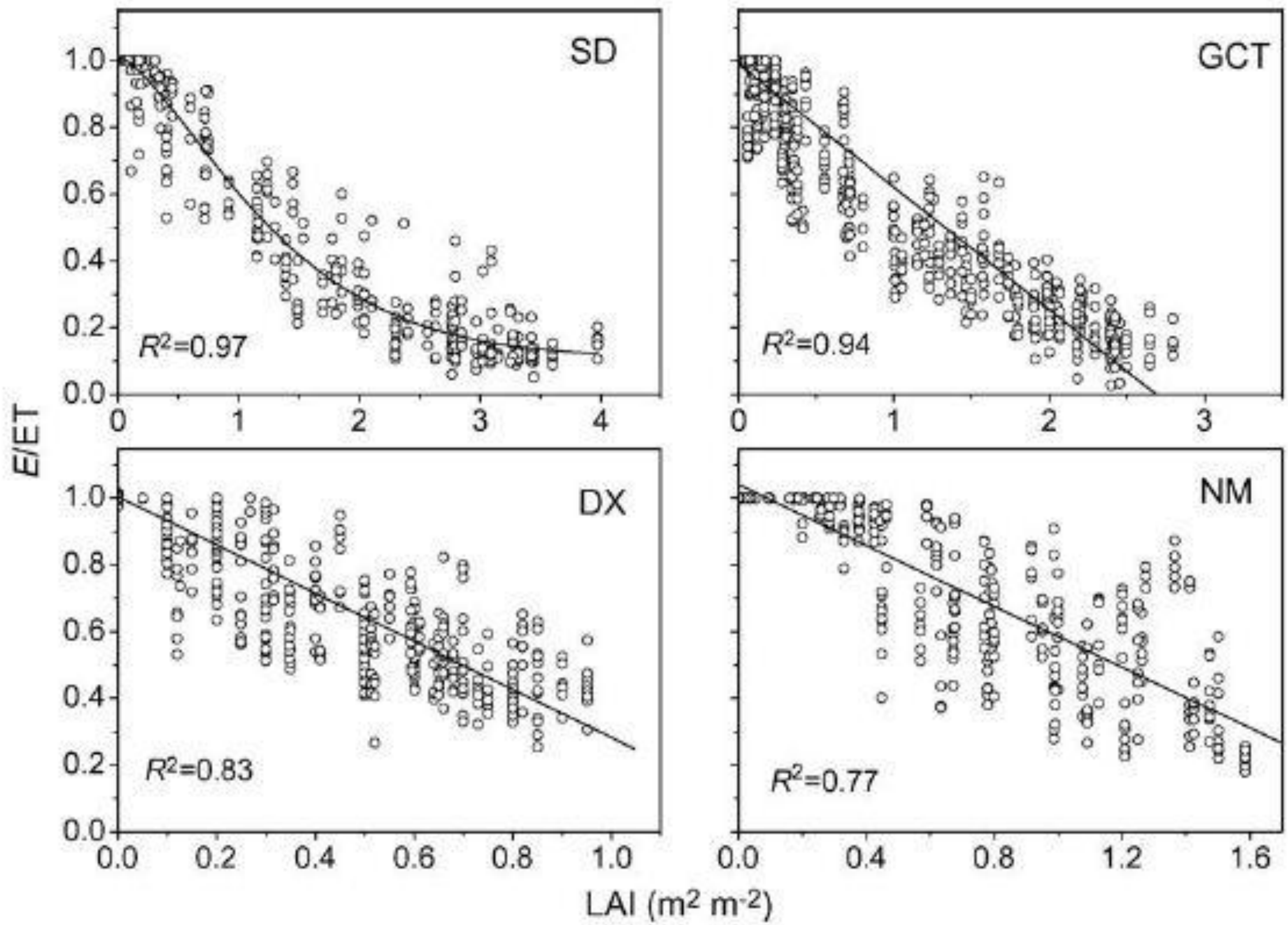

Fig 7. Effect of leaf area index (LAI) on daily E/ET was calculated as the ratio of modeled daily E to modeled daily ET.

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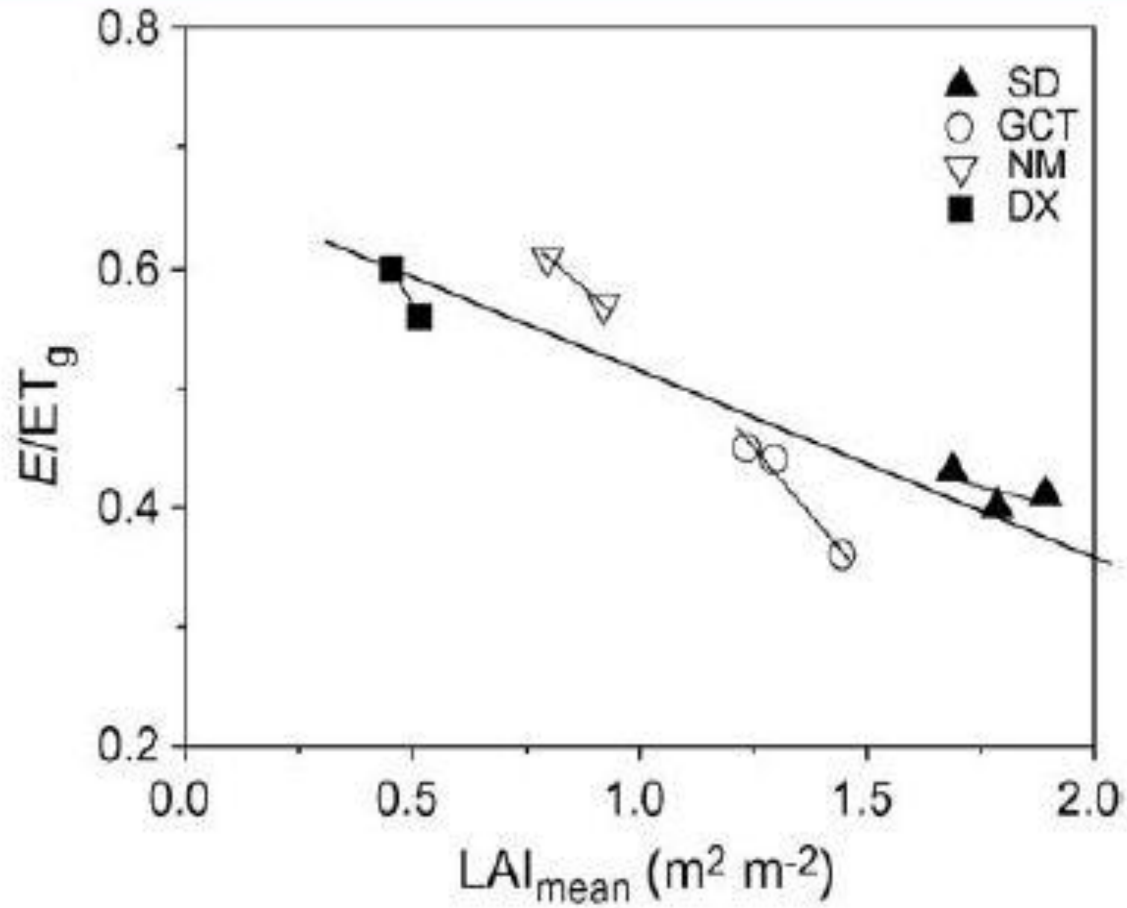

Fig. 8. Effect of LAI on annual *E*/ET at each site. *E*/ET_g was the ratio of modeled total *E* to modeled total ET in growing season, and LAI_{mean} was the mean daily LAI of each growing season.

$$\frac{E}{\mathrm{ET_g}} = -0.16\mathrm{LAI}_{\mathrm{mean}} + 0.67 (P < 0.001,\ R^2 = 0.79) \tag{15}$$

$$\frac{E}{\mathrm{ET_g}} = -0.07\mathrm{LAI}_{\mathrm{max}} + 0.65 (P < 0.001,\ R^2 = 0.75) \tag{16}$$

where $E/\mathrm{ET_g}$ was the ratio of total E to total ET in growing season (May–September), $\mathrm{LAI}_{\mathrm{mean}}$ and $\mathrm{LAI}_{\mathrm{max}}$ were the mean daily LAI and the maximum daily LAI in the growing seasons.

Conclusion

This study confirmed the good long-term performance of the S-W model at the four grassland ecosystems in China.

The possible reasons:

(1)Key parameters were estimated from Monte Carlo simulations.

(2)The effect of soil water condition on canopy stomatal conductance was added to the S-W model.

(3)Robust EC data were used for the model-measurement comparison.

Thanks for your attention and advice!