Response of a Deciduous Forest to the Mount Pinatubo Eruption: Enhanced Photosynthesis

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Lianhong Gu, *et al.*

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Reporter: Yue Kun

Outline

- Background and Objectives
- Materials and Methods
- Results and Discussions
- Conclusion

Background and Objectives

The growth rate of atmospheric CO_2 concentration experienced a sharp decline in the early 1990s, an observation that was unprecedented since CO_2 monitoring began in the late 1950s.

This aerosol envelope led to a decrease in global (diffuse plus direct) solar radiation *an increase in diffuse solar radiation, warming in winter, cooling* in summer.

Measurements have indicated that an enhanced terrestrial carbon sink explains this decline.

Materials and Methods

01

summer periods (roughly from day 160 to 260)

02

Harvard Forest (a northern hardwood forest , 42.5° N, 72.2° W)

03

The diffuse and direct beam radiation measurements at Albany.

04

two sky conditions: (i) the perturbed cloudless solar radiation regime with volcanic aerosols present, (ii) the normal cloudless solar radiation regime after the aerosols had been deposited from the atmosphere

Materials and Methods

The first method

couples eddy covariance flux tower measurements and an empirical model to detect and quantify the eruption signal.

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The second method

resorts to long-term averages from statistical analyses, uses flux measurements only and provides an independent check on the first method.

the First Method

rectangular hyperbola model

$F = R_e - P$

$$P = \frac{(\alpha_f I_f + \alpha_r I_r)(\beta_f I_f + \beta_r I_r)}{(\beta_f I_f + \beta_r I_r) + (\alpha_f I_f + \alpha_r I_r) I_t}$$

$$R_e = c_1 e^{c_2 [c_3 T_a + (1 - c_3) T_s]} + d_1 e^{d_2 T_s}$$

- where α_f *is the initial diffuse radiation use efficiency (RUE),* β_f *diffuse closeness to linear* response (CLR) *direct beam RUE,* β_r *direct beam CLR coefficient,* and I_t *is global solar radiation (=* $I_f + I_r$*).*
- where c_1, c_2, c_3, d_1 *and* d_2 *are regression coefficients,* T_s *is soil surface temperature at 5* cm, and T_a *is air temperature at 27.9 m.*

the First Method

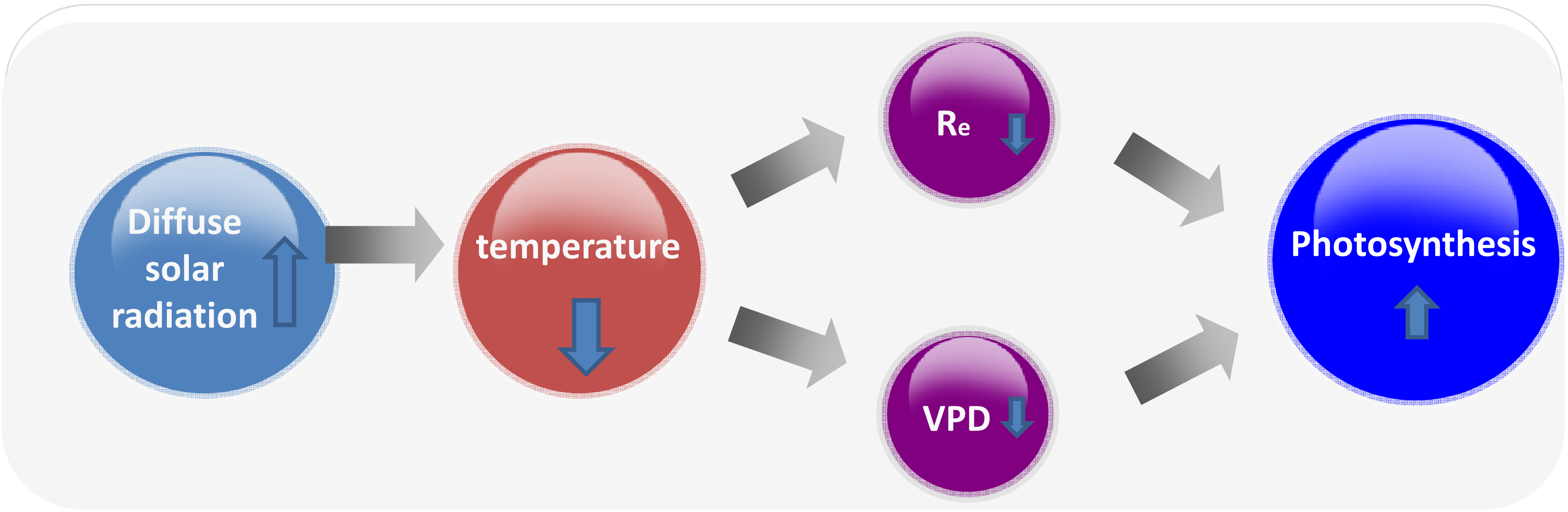
Table 1. Inferred canopy parameters in 1992, 1993, and 1994 from hourly NEE measurements under cloudless conditions. Parameters associated with diffuse radiation are larger than those associated with direct beam radiation, indicating advantages of diffuse radiation over direct beam radiation for canopy photosynthesis (*33*, *34*, *36*).

	1992	1993	1994
Initial diffuse RUE (µmol/J) × 100	11.82	7.39	10.18
Initial direct RUE (µmol/J) × 100	3.94	6.17	3.78
Diffuse CLR (µmol m^{-2} s^{-1})	139.60	169.07	146.93
Direct CLR (µmol $m^{-2}s^{-1}$)	19.33	18.95	28.66

- Examination of robustness of the first method focused on two aspects:
- The first aspect was the criteria used to identify cloudless conditions.
- The second aspect was the year-to-year variations in α_f, β_f, α_r, and β_r

the Second Method

- Major uncertainties of the second method are caused by variations in temperature and VPD.



the Second Method

a temperature sensitivity test

$$\Delta R_e = \frac{dR_e}{dT}\Delta T$$

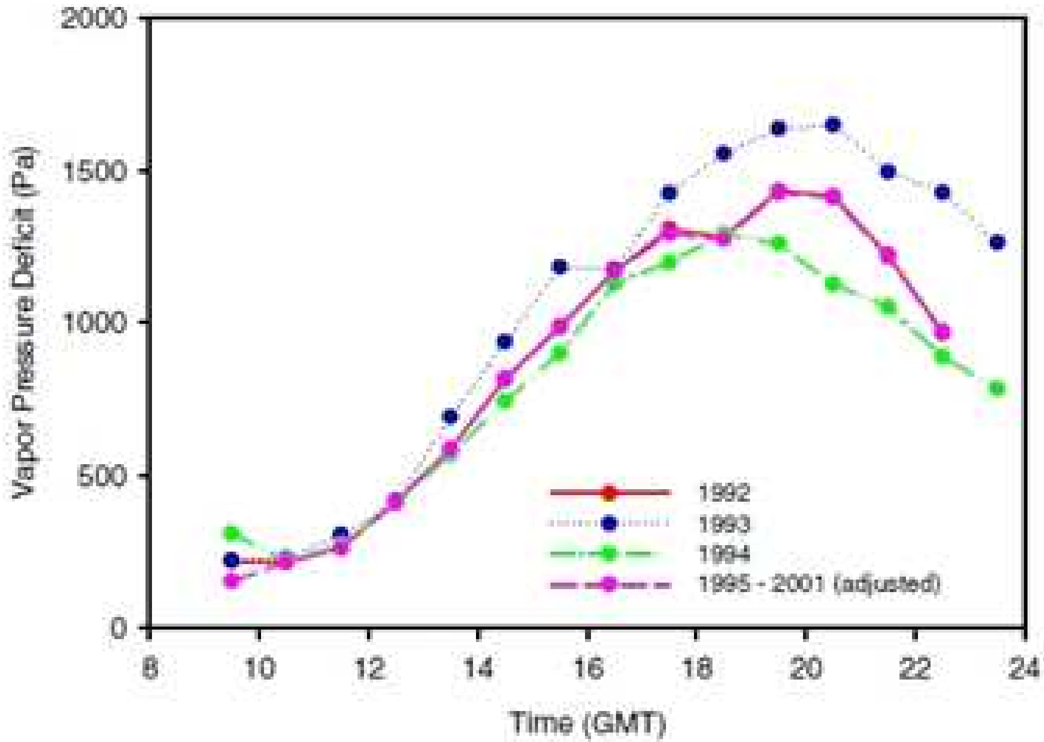
hypothetically warmed the soil surface temperature by 2 ℃ in both 1992 and 1993. *ΔT = 2* ℃

$$R_e = \exp(0.129 + 0.073T)$$

After the adjustment, the estimated enhancement of NEE was reduced from 18% to 14% and from 15% to 10% in 1992 and 1993

	1992 $\Delta T = 2$°C	1993 $\Delta T = 2$°C	1994	1995 – 2001
Mean (95%)	1.12 (0.05)	1.08 (0.07)	0.97 (0.08)	0.98 (0.03)
% difference	14.3	10.2	-1.0	
		t test against 1995-2001		
t stat	4.72	2.64	-0.32	
$t_{0.05}$	1.97	1.98	1.98	
P value	0.00	0.01	0.75	

the Second Method



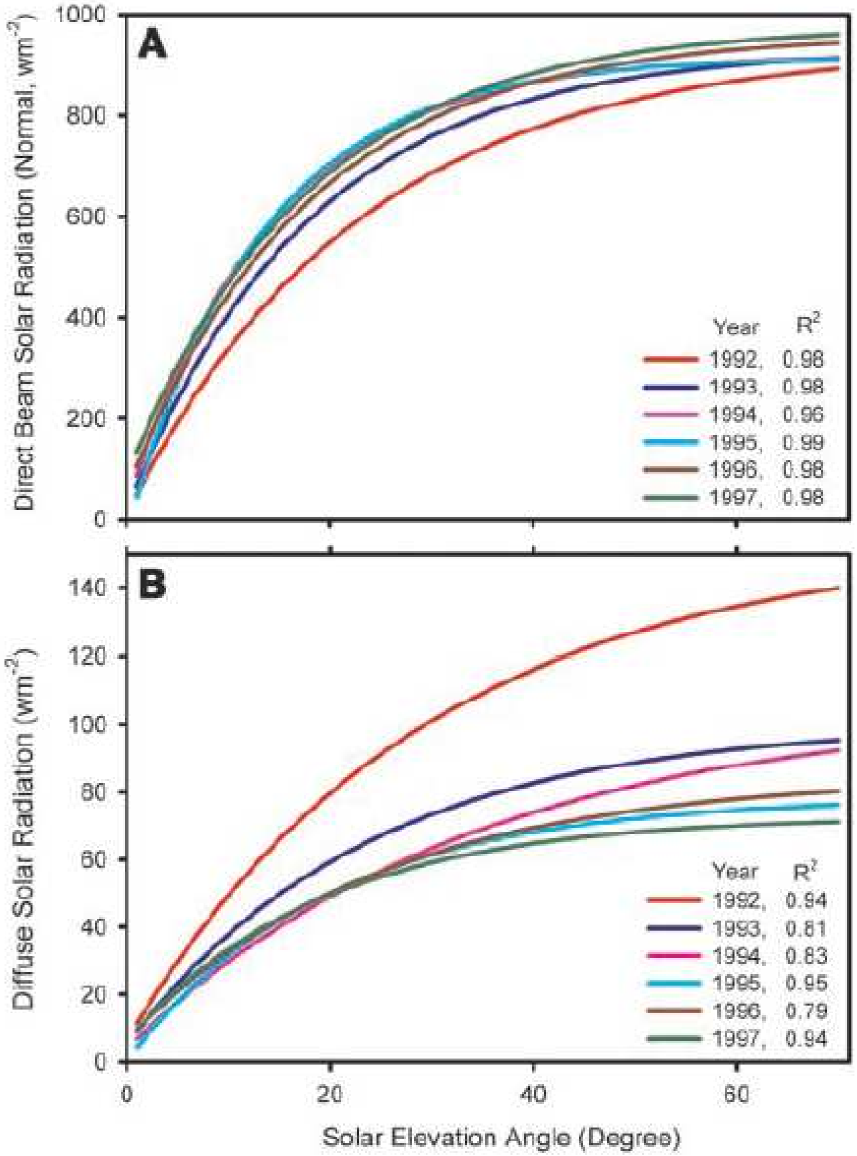
	1992	1993	1994	1995 – 2001 (VPD adjusted)
Mean (95%)	1.12 (0.04)	1.08 (0.06)	0.93 (0.07)	0.97 (0.03)
% difference	14.7	10.4	-4.9	
	t test against 1995-2001 (VPD adjusted)			
t stat	5.25	2.87	-1.23	
$t_{0.05}$	1.97	1.97	1.98	
P value	0.00	0.00	0.22	

a VPD sensitivity test

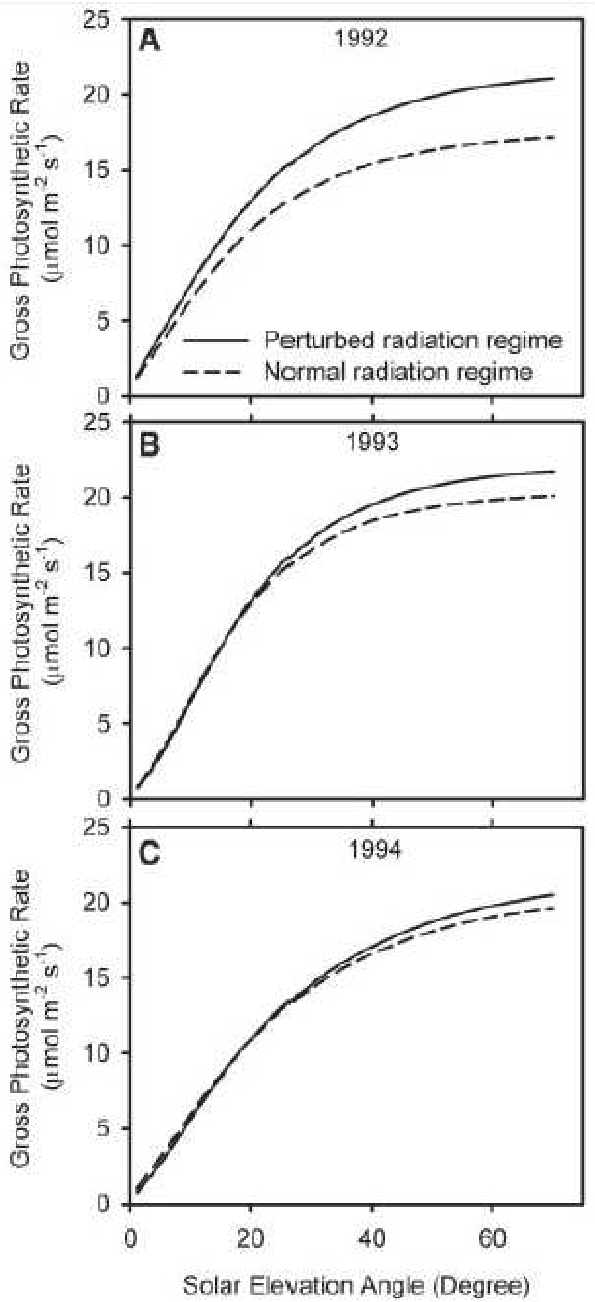
removed the highest VPD points in each one-hour interval in the 1995 -2001 dataset and conducted a reanalysis using the second method.

The obtained enhancement for net carbon uptake from this VPD test was slightly reduced as expected (from 18% to 15% for 1992 and from 15% to 10% for 1993)

Results and Discussions



- In 1992,diffuse radiation was almost twice as high as in 1995, 1996, and 1997 for the same solar elevation angle.



Results and Discussions

- Around noontime (solar elevation angle 70°) in the midgrowing season(day 200), the gross photosynthetic rate under the perturbed cloudless solar radiation regime was 23, 8, and 4% higher than that under the normal cloudless solar radiation regime in 1992, 1993, and 1994, respectively. Integrated over a day, the enhancement for canopy gross photosynthesis by the volcanic aerosols was 21% in 1992, 6% in 1993, and 3% in 1994.

Results and Discussions

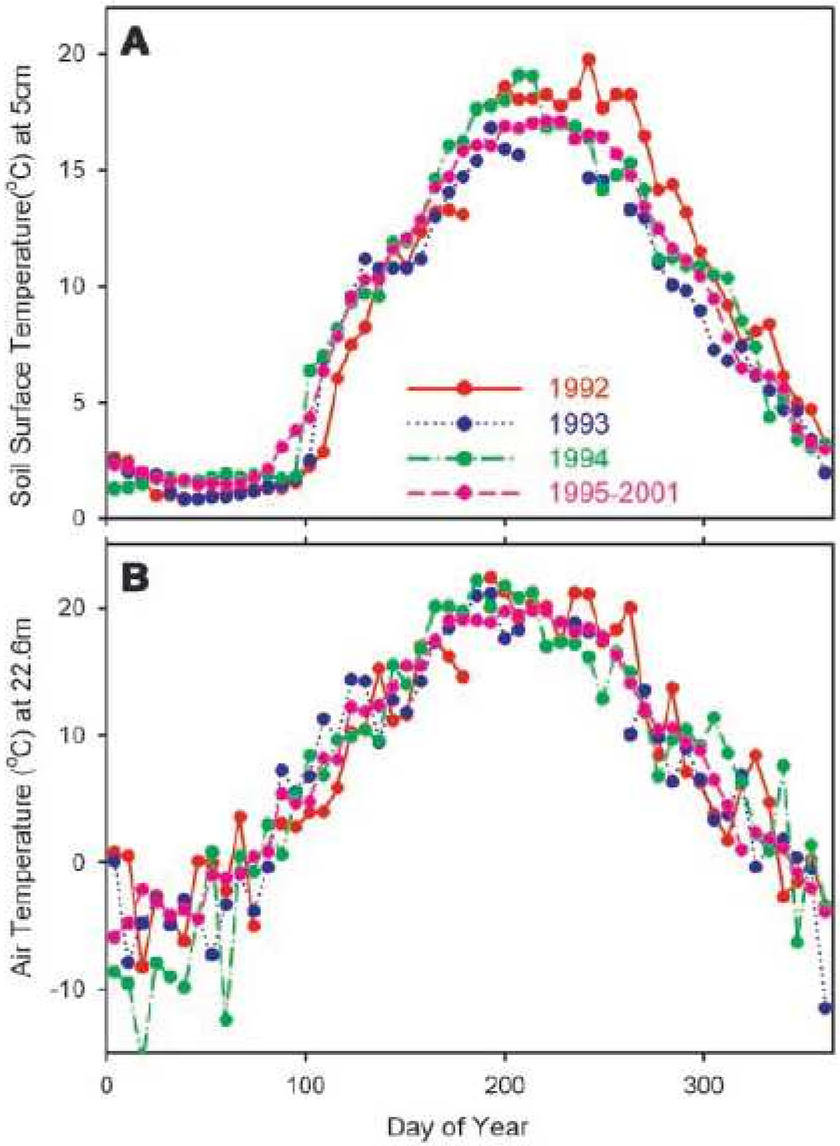
	1992	1993	1994	1995–2001
Mean (95%)	1.15 (0.05)	1.12 (0.07)	0.96 (0.08)	0.97 (0.03)
% difference	18.3	14.6	−1.3	
t test against 1995–2001				
t stat	6.33	3.77	−0.32	
$t_{0.05}$	1.97	1.98	1.98	
P value	0.00	0.00	0.75	

	the First Method	the Second Method
1992	21%	18%
1993	6%	15%

- The means of the normalized cloudless NEE in 1992 and 1993 were significantly larger than that of the reference sample, with *P values less than 0.01 .*

- The relatively large difference between the two approaches in the estimated effects of the eruption in 1993 can be explained partly by changes in temperature and, therefore, ecosystem respiration.

Results and Discussions



- In 1993, the soil surface temperature was consistently lower than the average soil surface temperature from 1995 to 2001. A cooler soil may have reduced soil respiration and contributed to the increase in net absorption of CO2 under cloudless conditions.
- the soil surface in the second half-year of 1992 was actually warmer than the average of 1995 to 2001 at Harvard Forest. The warmer soil could have led to higher soil respiration.

Conclusion

The increase in diffuse radiation caused by volcanic aerosols enhanced Harvard Forest photosynthesis under cloudless conditions for the two years after the Mount Pinatubo eruption.

This study suggests that long-term trends and interannual variability in cloudiness and aerosol concentrations *may play important roles in* the dynamics of the global carbon cycle.