

Impacts of Environmental Variation on Photosynthetic Enhancement in a Forest Exposed to Atmospheric CO₂ Enrichment

Carla A. Gunderson¹, Johnna D. Sholtis²,
Richard J. Norby¹

¹Oak Ridge National Laboratory

²Texas Tech University

The Oak Ridge Experiment on CO₂ Enrichment of Sweetgum

Oak Ridge Experiment on the CO₂ Enrichment of Sweetgum (FACE)

ORNL and guest collaborators:

- R. J. Norby, P. J. Hanson, S. D. Wullschleger, C. A. Gunderson, D. Todd, T.J. Tschaplinski, E. G. O'Neill, N.T. Edwards, A.W. King, W.M. Post
- J. Sholtis, C. Benner, S. Schweitzer, E. Duke, D. Tissue, R. Sobiecki, D. Yee, E. Greer, S. Hileman, C. Pendley, K. Voiles, M. Scannell, P. Allen, K. Smith

Research supported by the U.S. Department of Energy, Office of Science, Biological and Environmental Research (PER and TCP)

Expectations in CO₂ research:

- CO₂ enrichment increases photosynthesis
 - means: +45 to +65%
- CO₂ enrichment decreases stomatal conductance
 - means: ns to ! 30% (a note of uncertainty!)

Continuing uncertainties:

- Will large trees respond the same as seedlings?
- Will responses be sustained?
- What are the sources of variability?
 - **Environmental variation / stress**

Oak Ridge Experiment on CO₂ Enrichment of Sweetgum

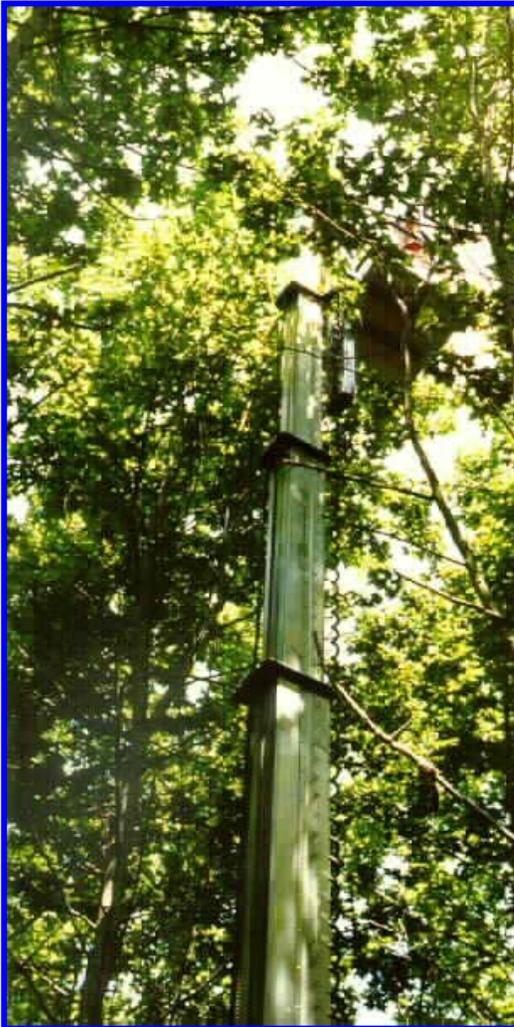


Experimental design:

- ***Liquidambar styraciflua***
 - Planted in 1988
 - Plots 25 m diameter
 - Trees now 15 m tall
 - Exposure began in 1998
- **2 elevated CO₂ plots -**
 - 560 ppm CO₂
- **3 control plots-**
 - ~360 ppm CO₂

Oak Ridge Experiment: CO₂ Enrichment of Sweetgum

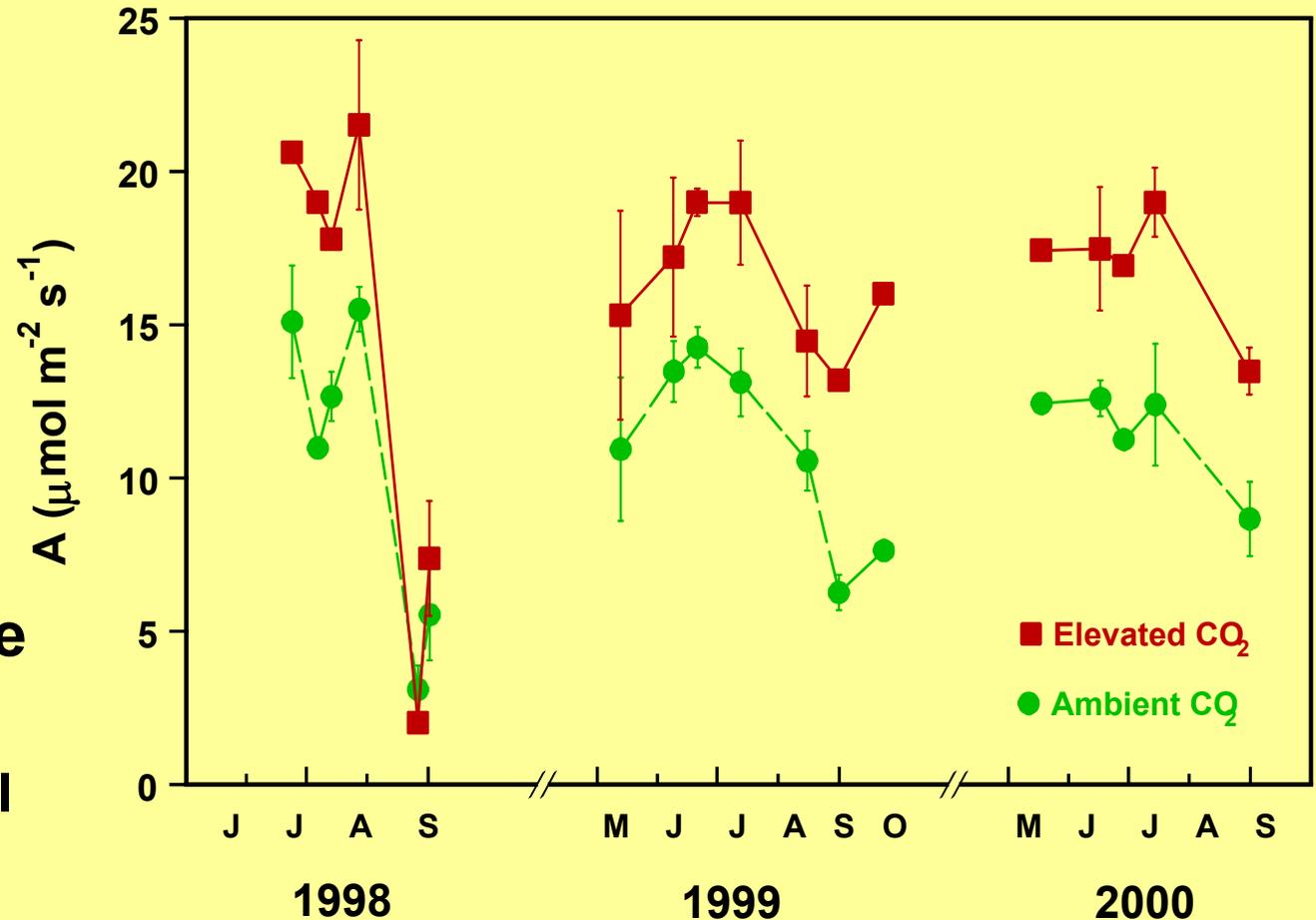
- Gas exchange:**
- Light-saturated
 - 360 or 560 ppm CO₂
 - LI-COR LI-6400
 - Red-Blue LED



- Upper canopy for 3 years; mid-canopy added in year 3
- Prevailing atmospheric and soil conditions
 - VPD, temperatures, natural rainfall
 - (soil moisture monitored by TDR)

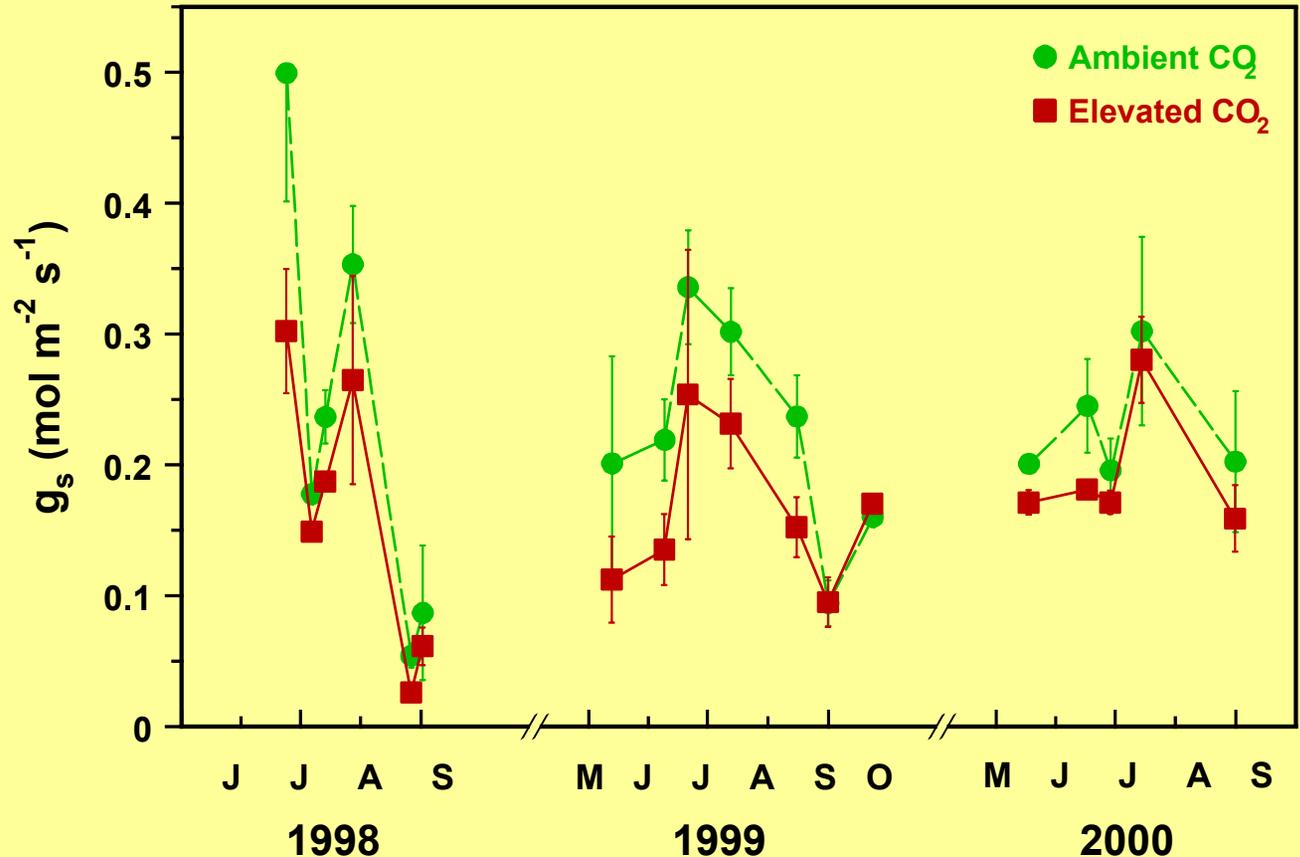
Photosynthesis remained higher in elevated CO₂

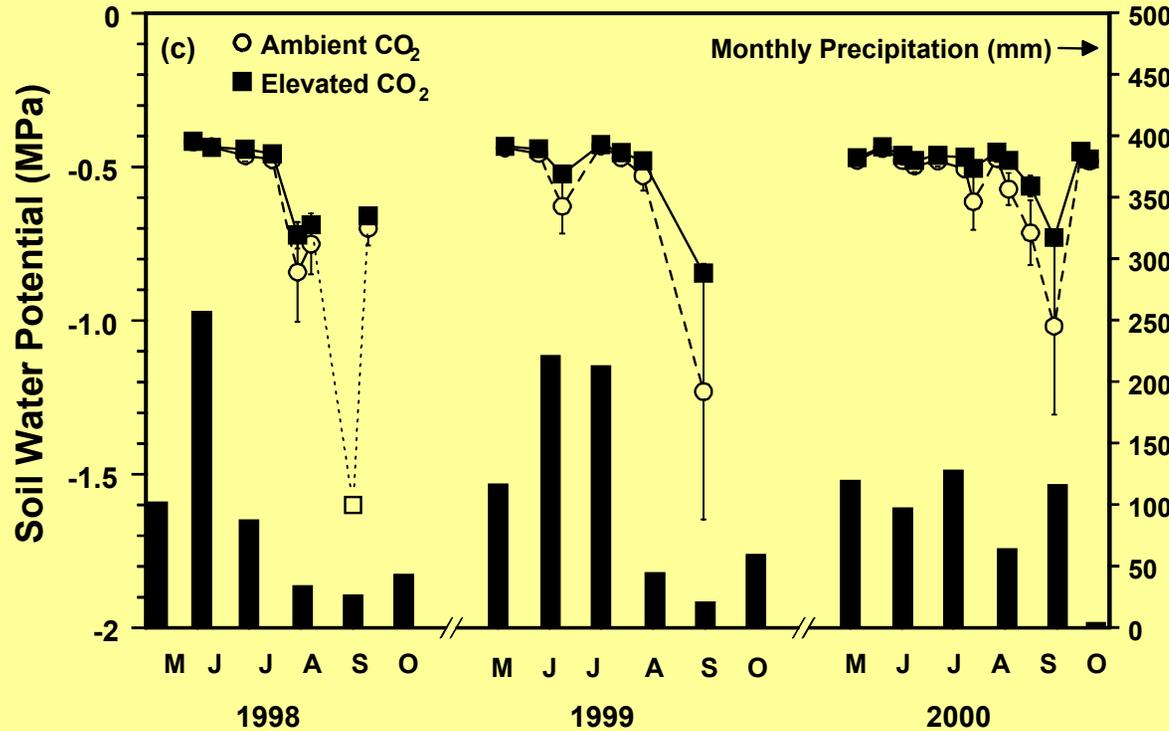
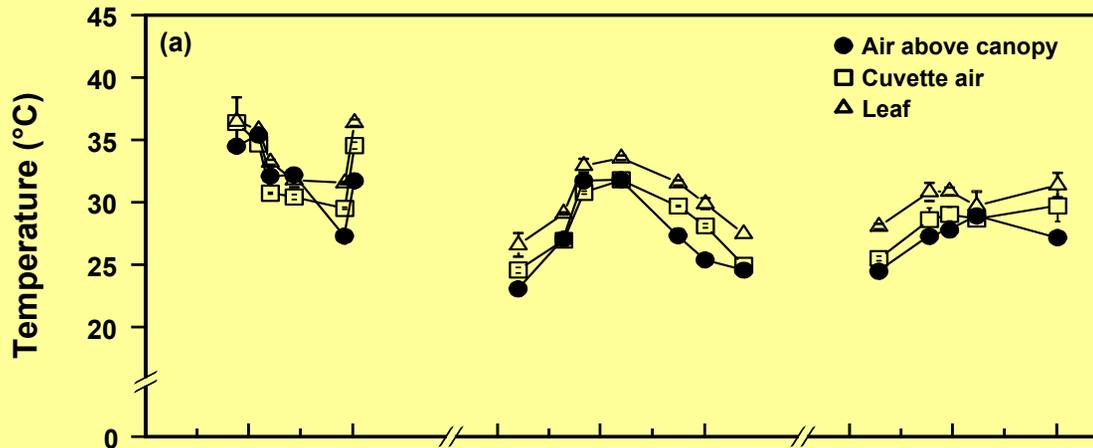
- Averaged 46% higher
- Effect persisted—no decline over time
- More variation late in season
 - Low rainfall
 - Dry air
 - High T?



Differences in stomatal conductance with CO₂ were smaller, and more variable

- Averaged 24% lower
 - often ns
- No decline over time
- Responses often muted (variable) late in season



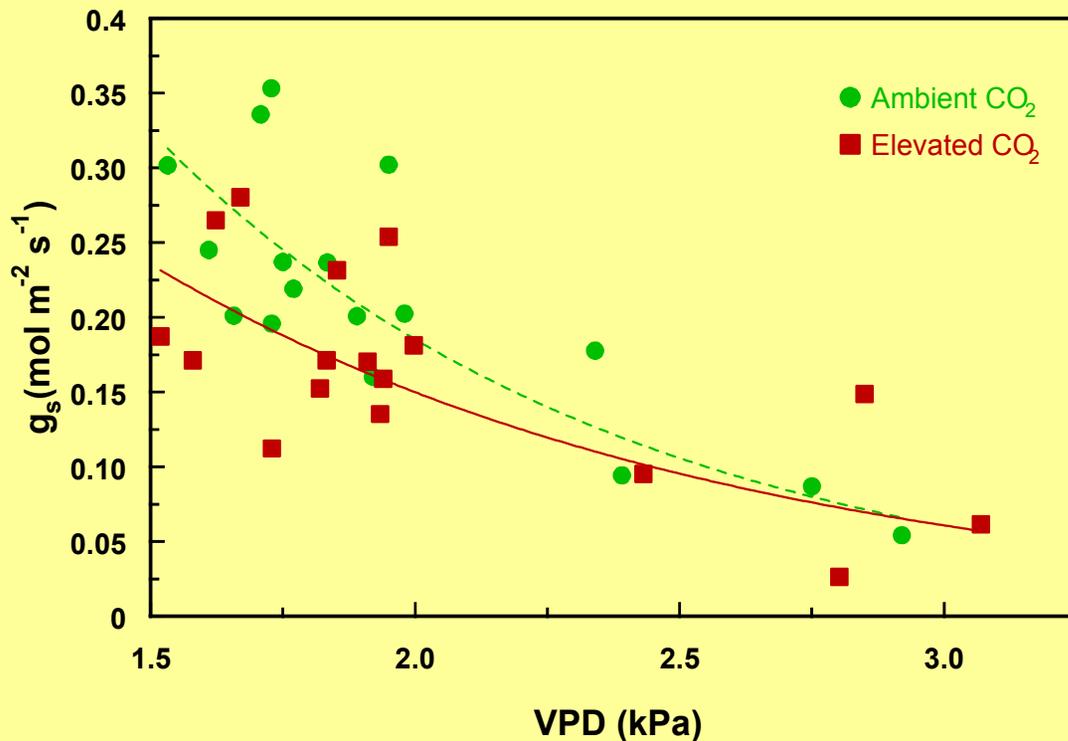
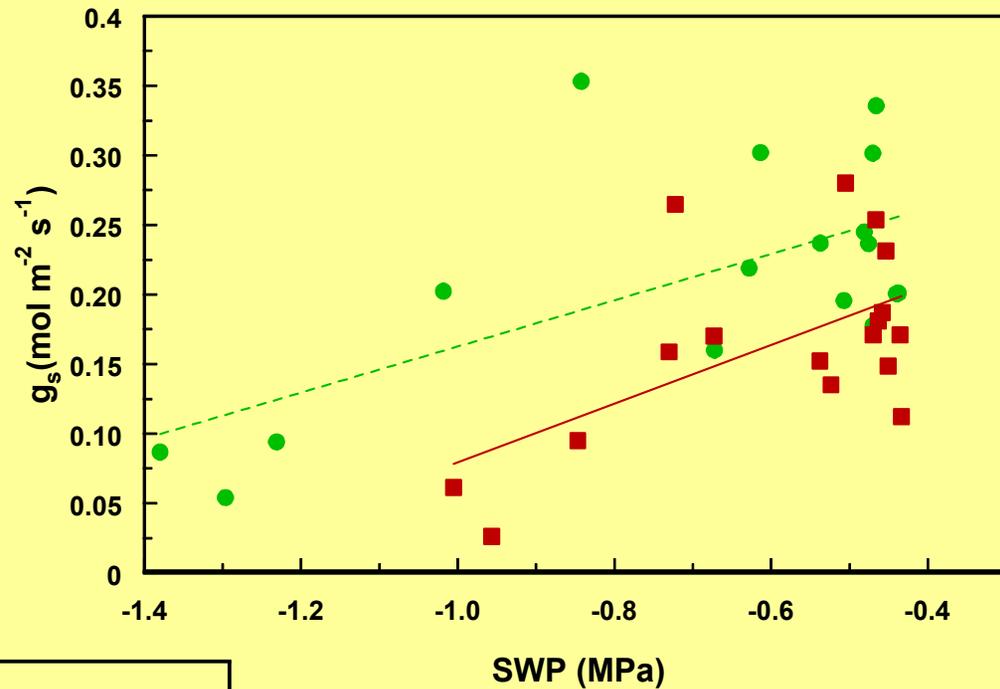


- Atmospheric conditions (temperature, VPD) varied seasonally

- Late season droughts developed in 1998 & 1999

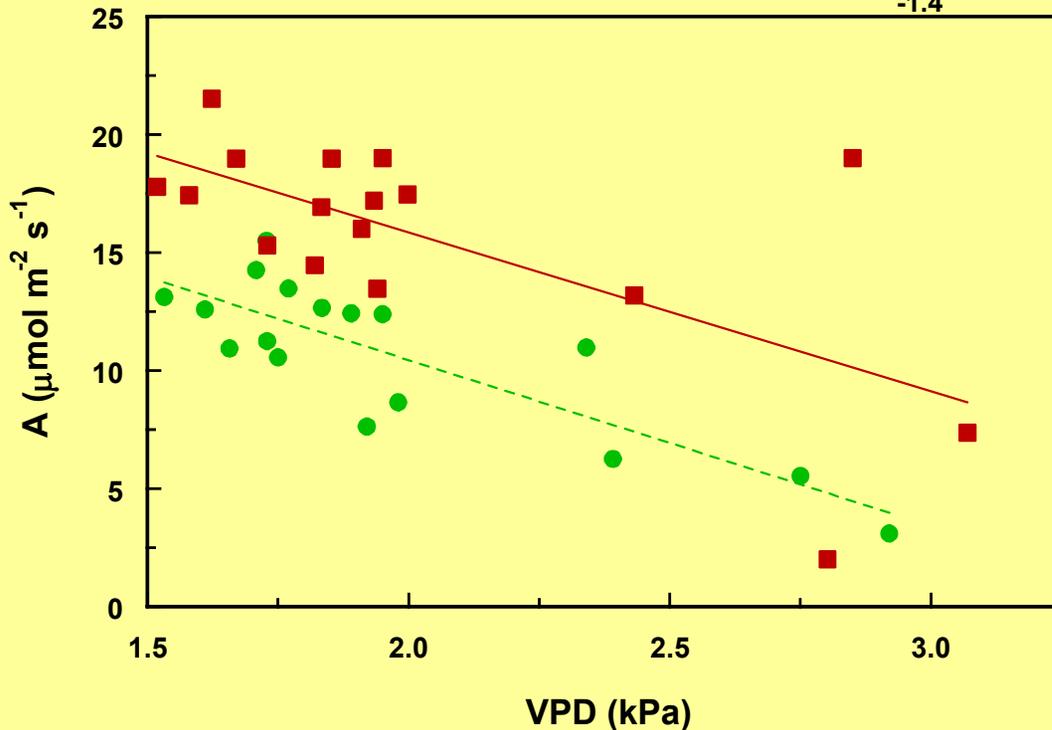
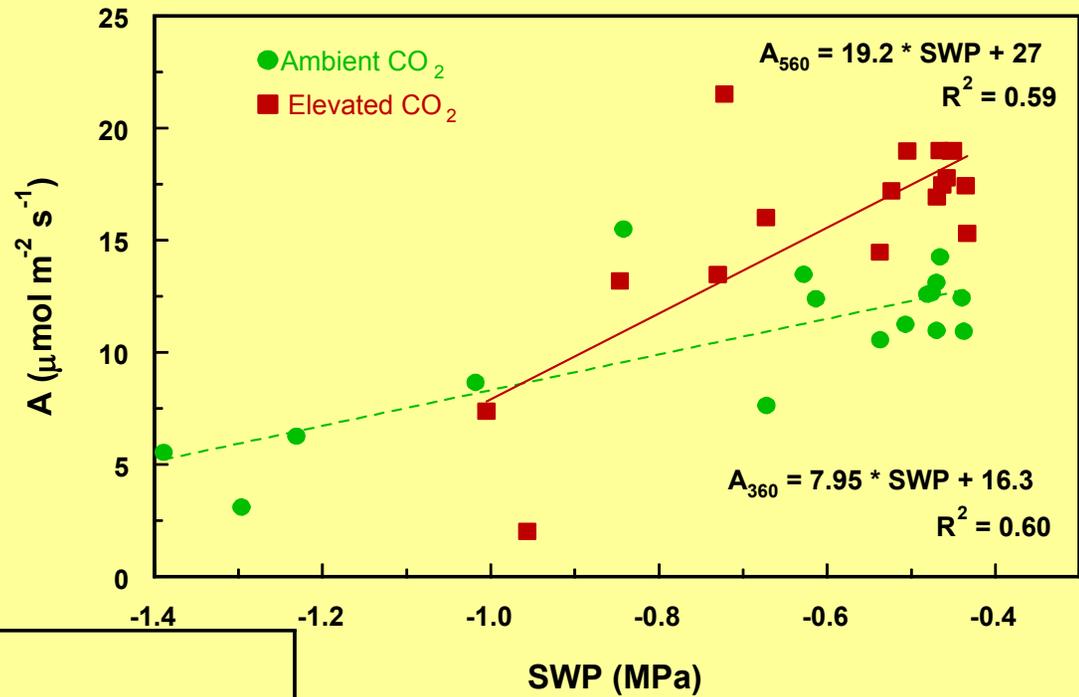
- How did environmental variation impact CO₂ effects?

In both CO₂ treatments, g_s decreased in response to drought and high VPD



The absolute effect of CO₂ on g_s was larger at low VPD
–disappeared at high VPD

In both CO₂ treatments, A decreased in response to drought and high VPD



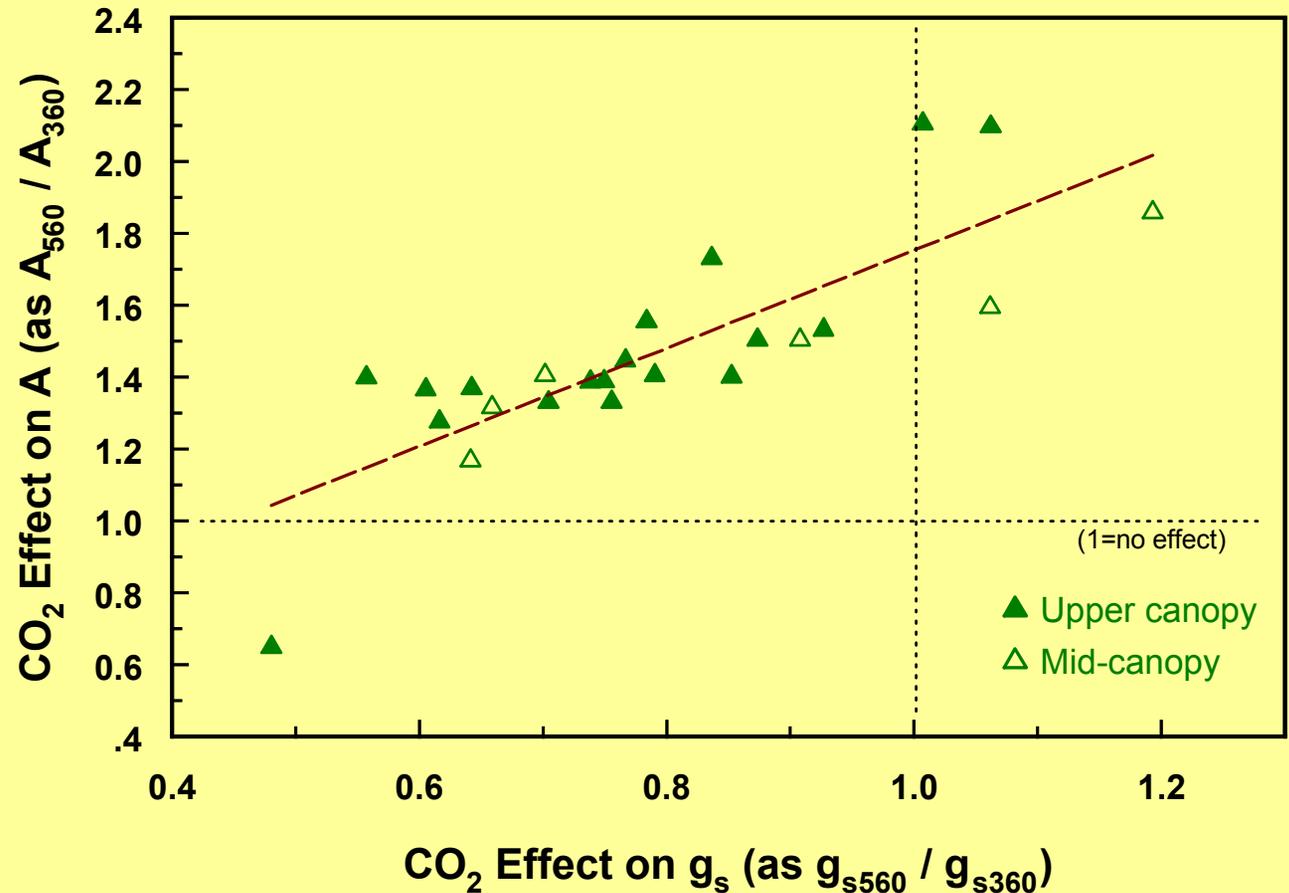
The effect of CO₂ on A was more variable under stress. In very dry soil there was a difference in the *absolute effect* (treatment *difference*)

Which environmental factors were *most* important? (Multiple regression)

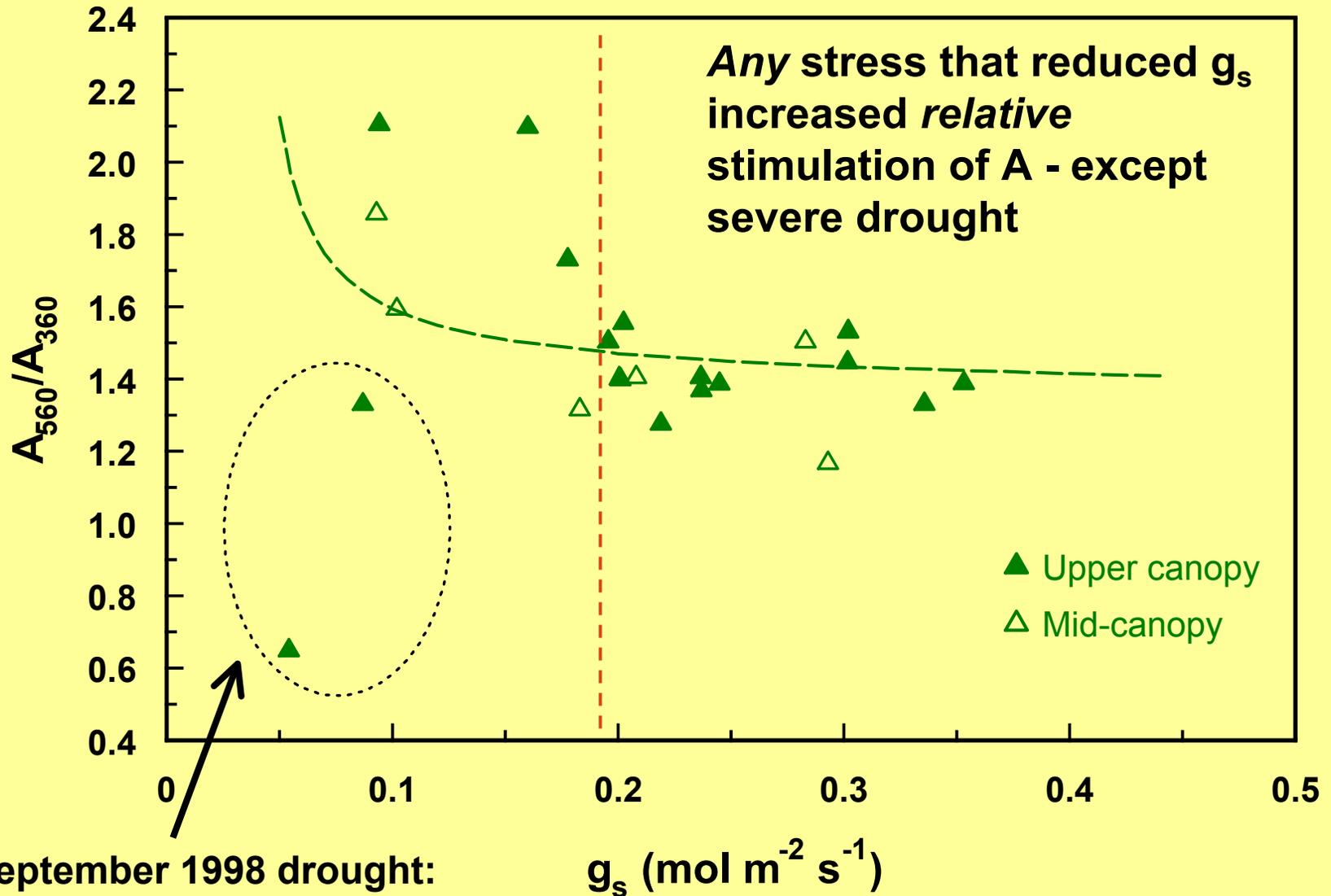
- Variation in VPD most significant
 - g_s & A_{Amb} (within treatment; negative relationships)
 - Absolute CO₂ effects: Elevated - Ambient -- negative relationship with g_s
- SWP - significant for A_{EL} and $A_{Elevated}$ $A_{Ambient}$ (positive)
- Leaf Temperature
 - Increased A_{Amb} , g_s (within trt) after accounting for VPD
 - No relationship with CO₂ effects
- **No** factors significant for *relative* CO₂ effects
 - (Elevated / Ambient)--- **Highly variable under stress**

When CO₂ reduced stomatal conductance the most, photosynthetic enhancement was limited

- Inverse relationship between CO₂ effects on g_s and A (as EI/Amb)
- Similar throughout the canopy



What influenced *relative* CO₂ effects on A?



September 1998 drought:
non-stomatal limitations

Summary--

- **CO₂ effects on A and g_s were sustained for 3 years in a closed canopy deciduous stand**
- **Moisture stresses (high leaf:air VPD, drought) limited stomatal effects of CO₂**
 - (Because stomata were already closed)
- **All stresses that closed stomata (below a threshold) tended to increase the *relative* stimulation of A, unless drought induced biochemical limitations**

Broader Implications--

- In mesophytic ecosystems, seasonal environmental stresses may have transitory impacts on CO₂ effects, limiting carbon gain during the stress event, but will not impact long-term photosynthetic stimulation.
- *Absolute* CO₂ effects may be more pertinent than *relative* effects when scaling up to issues of stand level carbon gain or water losses