

# Process Based Belowground Carbon Dioxide Modeling in a Desert Ecosystem

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## Research Question

- Do biological processes affect belowground CO<sub>2</sub> concentrations during small summer rain pulses?

## Introduction

- Belowground CO<sub>2</sub> concentrations were measured every 15 minutes at a desert grassland site at the southern edge of Canyonlands National Park in Utah using Vaisala GMT220 series solid-state NDIR sensors (Helsinki, Finland).
- Measurements were collected at 5 and 15 cm depth within the rooting zones of two dominant grass species, *Stipa hymenoides* and *Hilaria jamesii*, as well as the interspaces between the two.
- Rain events caused belowground carbon dioxide levels at all measurement sites to rise from 500 ppm to 1500 ppm with a response time of 8 hours to a gradual return to quasi-steady state levels in subsequent days.
- We developed and simulated a one-dimensional diffusion model with a production term to determine if the rise in CO<sub>2</sub> concentrations following a rain event was due to physical or biological processes.
- The model was simulated from April-November 2003.

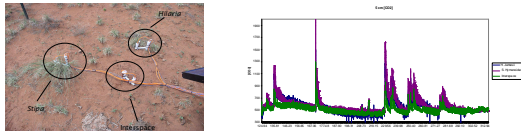


Figure 1: Physical arrangement of CO<sub>2</sub> sensors (left) and output data from sensors (right)

## Mathematical Formulation

- CO<sub>2</sub> is transported through the soil according to the classical diffusion equation with a production term:

$$\frac{\partial c}{\partial t} = D_s \frac{\partial^2 c}{\partial z^2} + S(z, t)$$

$D_s$  = effective diffusion coefficient

$S(z, t)$  = CO<sub>2</sub> production due to microbial respiration, rooting density, and soil respiration

- We numerically calculated CO<sub>2</sub> using finite differences with volumetric soil water content, bulk density, and soil temperature as inputs.

## Diffusion Coefficient

- The diffusion coefficient was modeled using the formulation of Tang, et al (2003). Running sensitivity analyses on the coefficient showed it was extremely sensitive to changes in soil water content, but not temperature.

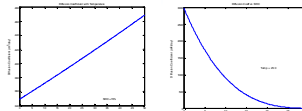


Figure 2: Sensitivity of diffusion coefficient to temperature (left) and soil water content (right). Note the difference in axes.

## Formulation of Source Term

- The production term was formulated as a temperature, space, volumetric water content dependent term of the following form:

$$S(z, t) = \gamma_0 f(z) f(\theta_v) f(T)$$

- $\gamma_0$  = production under optimal conditions (25 C under no water stress).
- $f(z)$  = functional response due to plant respiration dependent on plant type (*S. hymenoides* or *H. jamesii*). This was formulated using rooting distributions from data in Nobel (1989) and Distel & Fernandez (1988).
- $f(\theta_v)$  = functional response of soil microbes dependent on soil water content (Pumpanen et al 2003).
- $f(T)$  = functional response of soil respiration due to temperature. (Simunek & Suarez 1993).

$$f(\theta_v) = \min(a\theta_v^d, b(E_0 - \theta_v), 1)$$

- $E_0$  is the porosity,  $a, b, d$  are fitted data dependent on soil type (Skopp 1990).

$$f(T) = \exp\left[\frac{T - 23.85}{23.85}\right]$$

## Simulation with a Constant Source

- Using a constant production term (non-biological), our simulations indicated that during rain pulses CO<sub>2</sub> levels rise due to physical processes. The soil becomes saturated with water, effectively preventing CO<sub>2</sub> molecules from diffusing out of the soil.

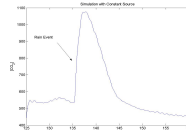


Figure 3: Model simulation with a constant source. Note the sharp rise in CO<sub>2</sub> concentrations following the onset of a rain pulse

## Simulation with a Process Based Source

- Incorporating a process-based biological term helps reduce CO<sub>2</sub> levels after rain events. The rain acts as a biological switch to activate soil microbes until the soil dries out.

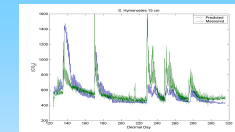


Figure 4: Model simulation (blue) compared to observed CO<sub>2</sub> concentrations (green) for *S. hymenoides* at 15 cm.

- Comparing model predictions to observed measurements shows that the model captures the essential biological and physical processes.

	Fit Values	r <sup>2</sup>	m
<i>H. jamesii</i>	5 cm	.5969	.4168
	15 cm	.7794	.5662
<i>S. hymenoides</i>	5 cm	.5201	.5478
	15 cm	.6896	1.126
Interspace	5 cm	.4749	.9153
	15 cm	.7088	.8449

Table 1: Correlation coefficients (r<sup>2</sup>) and best-fit slope (m) between model predictions and observed concentrations for days 125-316 of 2003.

- During summer rain pulses physical processes dominate in determining belowground CO<sub>2</sub> concentrations. As the soil dries following pulses, biological responses dominate more.
- Future research includes a better characterization of model inputs (rooting distributions, soil microbial activity, and soil respiration).

## References

- Distel, R. A., O. A. Fernandez. 1988 Dynamics of root growth and decay in two grasses native to semi-arid Argentina. *Australian Journal of Ecology*. 13:327-336.
- Lloyd, J. and J. A. Taylor. 1994. On the temperature dependence of soil respiration. *Functional Ecology*. 8:315-323.
- Nobel, P. S. 1989. Temperature, Water Availability, and Nutrient Levels, at various Soil Depths—Consequences for Shallow Rooted Desert Succulents, Including Nurse Plant Effects. *American Journal of Botany*. 76:10. 1486-1492.
- Pumpanen, J., H. Ilvesniemi, P. Hari. 2003. A Process Based Model for Predicting Soil Carbon Dioxide Efflux and Concentration. *Soil Science Society of America Journal*. 67:402-413.
- Simunek, J., D. L. Suarez. 1993. Modeling of Carbon Dioxide Transport and Production in Soil 1. Model Development. *Water Resources Research*. 29(2):487-497.
- Skopp, J., M. D. Dawson, J. W. Doran. 1990. Steady-state microbial activity as a function of soil water content. *Soil Sci. Soc. Am. J.* 67:402-413.
- Tang, J., D. D. Baldocchi, Y. Qi, L. Xu. 2003. Assessing soil CO<sub>2</sub> efflux using continuous measurements of CO<sub>2</sub> profiles in soils with small soil-state sensors. *Agricultural and Forest Meteorology*. 118:207-220.

## Acknowledgments

Many thanks to S. Bethers, C. K. Lunch, T. E. Cerling, F. R. Adler, and J. P. Keener. This work was supported under NSF Grant # DGE-0217424