Comparing Three Respiration Models for the ISBA SVAT

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Abstract

We investigate the CO2 flux calculated by the ISBA soil-vegetation-atmosphere transfer model (Noilhan and Planton, 1989)by comparing three different formulations for the plant (dark) respiration scheme applied to a soybean culture. The model includes CO2 flux/photosynthesis based on Jacobs (1994) in a manner similar to Calvet et al. (1998) (ISBA-A-gs). The first respiration scheme (M0) computed the autotrophic respiration Rd similarly to Jacobs (1994) but with an ad-hoc temperature correction calibrated by statistical parameter fitting using measured data. For the second model (M1), we implemented the respiration proposed by Joetzjer et al. (2015). Finally we implemented a third respiration scheme (M2) as in Wang (1996). The three models were calibrated and CO2 fluxes were compared with measurements made over a soybean culture using eddy covariance method between December, 2008 and March, 2009, at a farm near Buenos Aires, Argentina. The total CO2 maximum, minimum and mean measured flux values were respectively 0.9890, -0.2479 and 0.3087 mg m-2 s-1. For the sake of comparison, statistics were computed for the full daily cycle flux (total) and also for nighttime flux, as a means to avoid masking of the results due to the much larger daytime photosynthetic flux. We here present the Nash-Sutcliffe efficiency (NSE) coefficient for each model. M0 gave the best overall performance with 0.7568 for the total daily CO2 flux and 0.0795 for the dark flux. M1 gave similar predictions for the daily CO2 flux with 0.7582, butthe worst result for the nighttime period with -0.4965. M2 gave 0.7424 for the full daily flux and 0.0119 for the night CO2 flux. The results show a seemingly better performance of the models in predicting the total CO2 flux compared to the dark CO2 flux. This is due to several facts such as: respiration is less understood and harder to predict than photosynthesis; measurements are more difficult at nighttime due to the limitations of the eddy-covariance technique in low turbulent activity; in the measured data, it is difficult to identify and separate the portions of CO2 fluxes as soil respiration, autotrophic respiration and photosynthetic flux, without many auxiliary measurements. We also conclude that there is a clear influence of the temperature on the respiration, which can be suitably incorporated in the models.

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Greenhouse effect

- An important scientific issue today is the intensification of the greenhouse effect.
- A significant effort has been made to quantify the CO_2 flux between the surface and the atmosphere.
- Main research fronts are in measurement techniques and mathematical modeling.

Figure: Laboratory for Environmental Monitoring and Modeling Studies (LEMMA).

Modeling

- Low cost to obtain results, ease spatialization, possibility of forecasting and future prognostics scenarios.
- Used in conjunction with surface, ecological, meteorological, climatic and hydrological models.
- Our model was built around an existing SVAT known as ISBA [Noilhan and Planton, 1989] with some modifications.
- We included a physiological approach [Jacobs, 1994] for the CO_2 flux calculation[Calvet et al., 1998].

Figure: Laboratory for Environmental Monitoring and Modeling Studies (LEMMA).

Stomatal conductance

- The stomata opening is influenced by environmental conditions and plant properties: light, atmospheric CO_2, air temperature, air humidity, leaf age and soil moisture.

- The diffusion of water vapor and CO_2 flux occurs along the same leaf path, so the g_s is define as:

$$g_s = \frac{1.6A_n}{C_{out} - C_{in}}, \qquad (1)$$

where A_n is the net photosynthetic assimilation and C is the CO_2 concentration inside and outside the leaf.

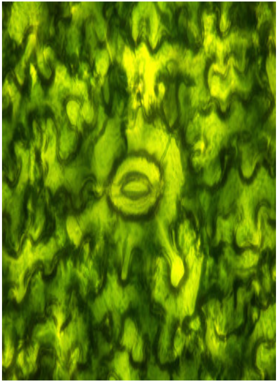


Figure: vector created by barbol (stock.adobe.com/302237422).

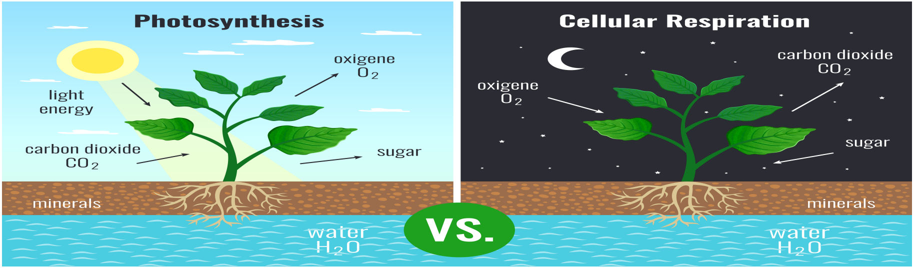


Figure: vector created by macrovector (br.freepik.com/vetores/seta).

- Essential photosynthesis responses for C3 and C4 plants [Goudriaan et al., 1985]:

$$A_n = (A_m + R_d)\left[1 - \exp\left(\frac{-\varepsilon PAR}{A_m + R_d}\right)\right] - R_d, \tag{2}$$

where A_m is the photosynthetic rate at saturating light, ε is the initial light use efficiency and R_d is the leaf respiration.

Soil Respiration

- Soil respiration R_{soil} is implemented as a $Q_{10} = 2.0$ temperature function [Calvet et al., 1998].

$$R_{soil} = R_{soil,25} Q_{10}^{\frac{Ta-25}{10}}, \tag{3}$$

where T_a is the air temperature.

- Soil respiration at 25°C is estimated by,

$$R_{soil,25} = (0.594 + 0.2376 LAI) w_g, \tag{4}$$

where w_g is the superficial soil moisture.

Figure: Laboratory for Environmental Monitoring and Modeling Studies (LEMMA).

Autotrophic Respiration: concepts

- The total respiration of a plant is the sum of growth and maintenance components.
- Growth respiration is necessary for new tissues synthesis.
- Maintenance respiration provides energy to keep healthy existing tissues.
- Proportion to the total respiration varies during plant development stages and between species.

Figure: Laboratory for Environmental Monitoring and Modeling Studies (LEMMA).

Autotrophic Respiration: concepts

- Respiration process tends to increase with temperature due to a gain of speed on enzymatic reactions.
- Many environmental physiologists uses exponential formulations for predicting the respiration response to temperatures changes.
- We proposed here a correlation between R_d and T_a as:

$$R_d = R_{d,ref} \, Q_{10}^{\frac{T_a - T_{ref}}{10}}, \tag{5}$$

  where T_{ref} is a reference temperature and $R_{d,ref}$ is the R_d value at T_{ref}.

- Although the widely usage of Q_{10}, researchers argue that itself is a function of the temperature.

Autotrophic Respiration: local correlation ($R_{d,ref}$ estimating)

- We mask out measured CO_2 flux data with positive *PAR*, just leaving the dark CO_2 flux.
- To extract only R_d in the absence of soil flux measurements, we used a soil respiration series calculated with the original ISBA-A-gs SVAT (with $R_d = A_m/9$) and subtract it from the total dark CO_2 measured flux.
- The mean R_d at $25°\mathrm{C}$ was $R_{d,ref} = 0.0682\,\mathrm{mg\,m^{-2}\,s^{-1}}$.
- For $T_{ref} = 25°\mathrm{C}$, when $T_a \approx 25°\mathrm{C}$ the Q_{10} exponent is ≈ 0 taking it to ≈ 1.
- So it's possible to use temperatures around $25°\mathrm{C}$ to adjust $R_{d,ref}$, but it isn't feasible to adjust Q_{10}.

Autotrophic Respiration: local correlation ($R_{d,ref}$ and Q_{10} estimating)

- Still leaving $T_{ref} = 25^\circ\mathrm{C}$ but adjusting T_a and R_d by the least square method.
- Q_{10} and $R_{d,ref}$ can be estimated:

$$10 \ln R_d = \ln Q_{10} \, (T_a - T_{ref}) + 10 \ln R_{d,ref} \,. \tag{6}$$

- $Q_{10} = 1.0053$ and $R_{d,ref} = 0.0933\,\mathrm{mg\,m^{-2}\,s^{-1}}$.
- Pairs of T_a and R_d were used for all temperatures, thus besides also being able to estimate Q_{10} the $R_{d,ref}$ estimation quality is improved too.
- These were the coefficients used in model-M0.

Autotrophic Respiration: model-M1

- For comparison, we used an evolution in the R_d calculation of the original ISBA-A-gs [Joetzjer et al., 2015]:

$$R_d = \frac{A_m}{9} \exp(-k_n\, LAI) \frac{1}{LAI}, \tag{7}$$

where $k_n = 0.2$ is the within-canopy profile of photosynthetic capacity.

Autotrophic Respiration: model-M2

- Another methodology for R_d calculation tested here has the temperature dependence during nighttime with the same response pattern with the respiration rate in light, with a correction coefficient of 1.45 [Wang, 1996]. For daytime:

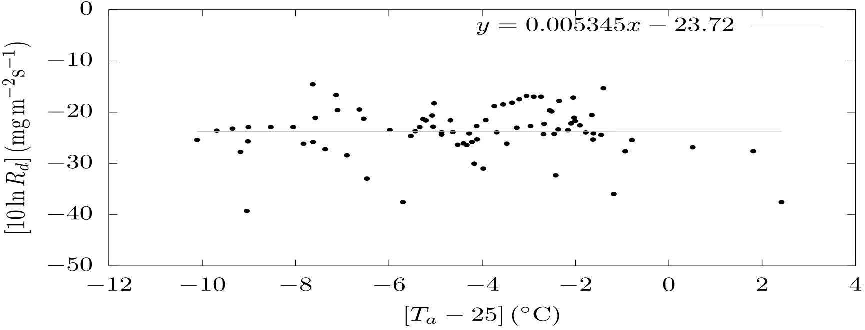
$$R_d = \exp\left[\frac{C_R - \Delta H_{a,R}}{R(T_a + 273.2)}\right], \tag{8}$$

and for dark period

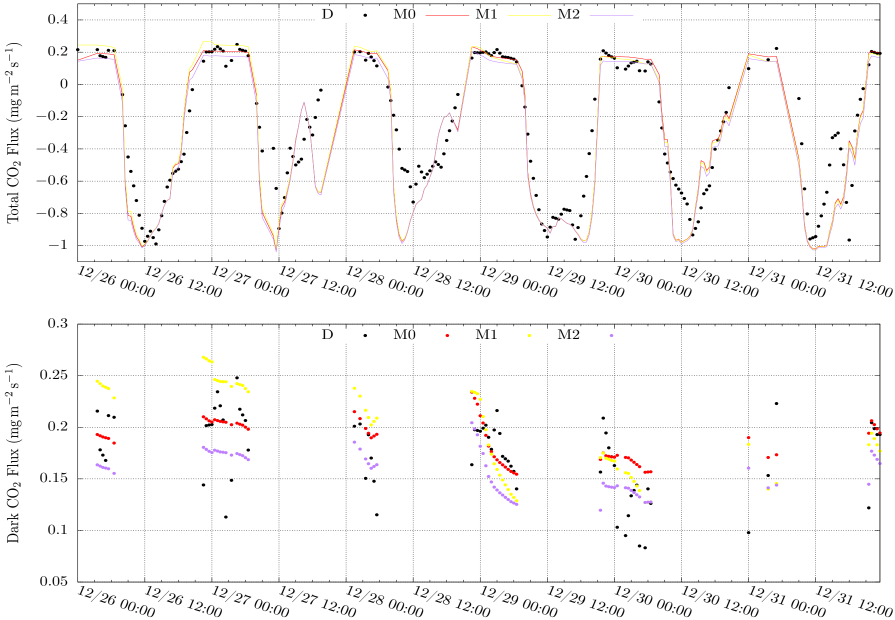
$$R_d = 1.45 \exp\left[\frac{C_R - \Delta H_{a,R}}{R(T_a + 273.2)}\right], \tag{9}$$

where $\Delta H_{a,R} = 33.87\,\mathrm{J\,mol^{-1}}$ is the activation energy, $C_R = 13.68$ is a constant and $R = 8.314\,\mathrm{J\,K^{-1}mol^{-1}}$ is the gas constant.

R_d **Calculation Equations**	
M0	$R_d = R_{d,ref}\, Q_{10}^{\frac{T_a - T_{ref}}{10}}$
M1	$R_d = \frac{A_m}{9}\ \exp(-k_n\, LAI)\frac{1}{LAI}$
M2	$R_{d,day} = \exp\left[\frac{C_R - \Delta H_{a,R}}{R(T_a + 273.2)}\right]$ and $R_{d,night} = 1.45 R_{d,day}$



Results: total and only dark CO_2 fluxes (timeline)

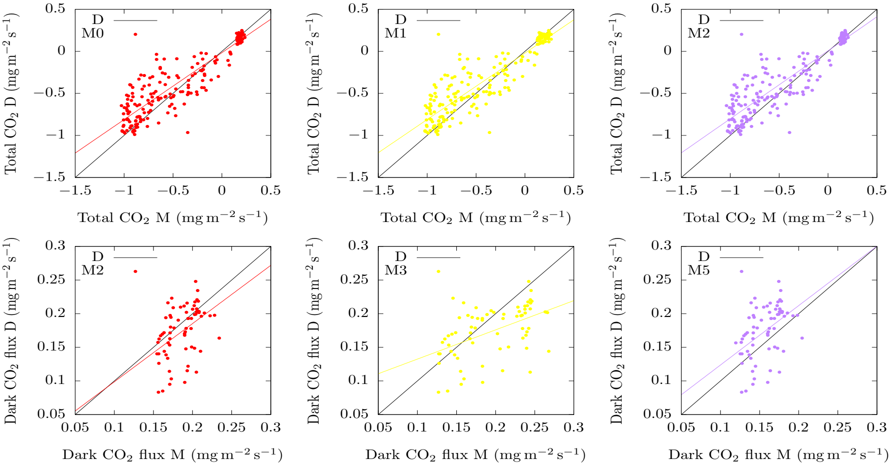


Results: total and only dark CO_2 fluxes (statistics)

	Total CO_2 fluxes			Dark CO_2 fluxes		
	M0	*M1*	*M2*	*M0*	*M1*	*M2*
ME	-0.0592	-0.0565	-0.0813	0.013	0.0217	0.0170
MSE	0.0387	0.0385	0.0410	0.0013	0.0022	0.0014
RMSE	0.1967	0.1962	0.2025	0.0364	0.0464	0.0377
NSE	0.7568	0.7582	0.7424	0.0795	-0.4965	0.0119

- M0 gave the best overall performance with $NSE = 0.7568$ for the total daily CO_2 flux and $NSE = 0.0795$ for the dark flux.
- M1 gave similar predictions for the daily CO_2 flux with $NSE = 0.7582$, but the worst result for the nighttime period with $NSE = -0.4965$.
- M2 gave $NSE = 0.7424$ for the full daily flux and $NSE = 0.0119$ for the night CO_2 flux.

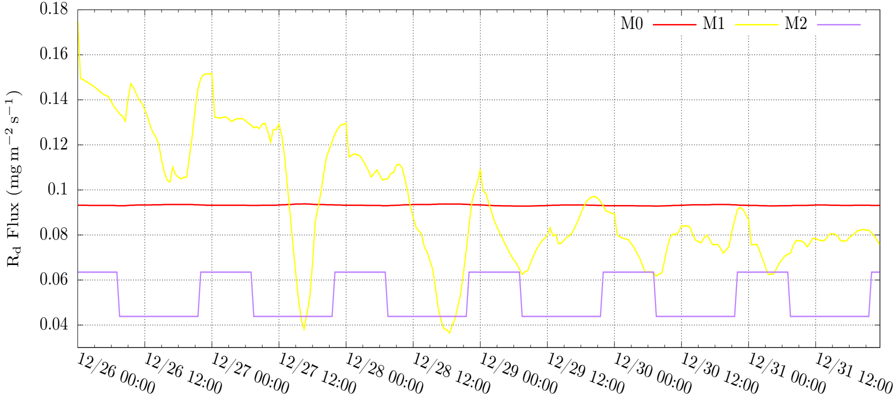
Results: total and only dark CO_2 fluxes (linear regression)



Total CO_2 fluxes			
	M0	*M1*	*M2*
Slope	0.7958	0.7906	0.8090

Dark CO_2 fluxes		
M0	*M1*	*M2*
0.8659	0.4346	0.8835

Results: R_d



- It's necessary to compare the calculated results with measured data.
- It's difficult to identify and separate portions of CO_2 fluxes from photosynthesis, autotrophic and heterotrophic respiration, without auxiliary measurements.

Conclusions

- The results show a seemingly better performance of the models in predicting the total CO_2 flux compared to the dark CO_2 flux.
- This is due to several facts such as:
  - respiration is less understood and harder to predict than photosynthesis,
  - measurements are more difficult at nighttime due to the limitations of the eddy-covariance technique in low turbulent activity,
  - in the measured data, it is difficult to identify and separate the portions of CO_2 fluxes as photosynthetic, heterotrophic and autotrophic, without many auxiliary measurements.
- We also conclude that there is a clear influence of the temperature on the respiration, which can be suitably incorporated in the models.

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