AGU FALL MEETING 2020

Comparing Three Respiration Models for the ISBA SVAT

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AGU FALL MEETING

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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:

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

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

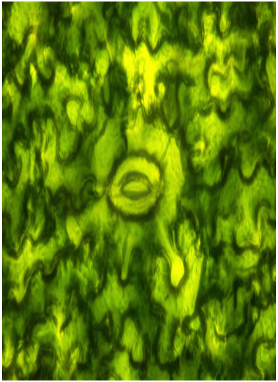


Figure: vector created by barbol (stock.adobe.com/302237422).

Photosynthetic module

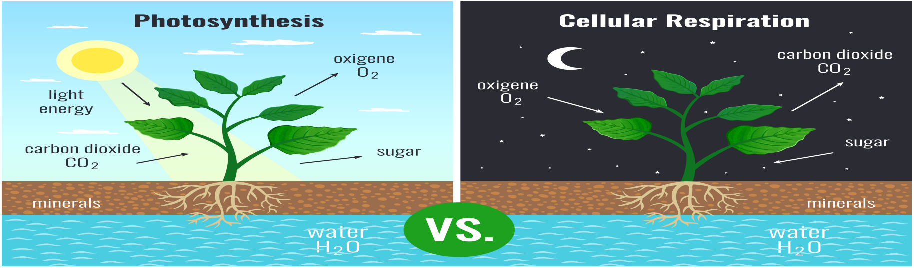


Figure: vector created by macrovector (br.freepik.com/vetores/seta).

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

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

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 $25^{\circ}\mathrm{C}$ is estimated by,

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

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:

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

- $Q_{10} = 1.0053$ 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:

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

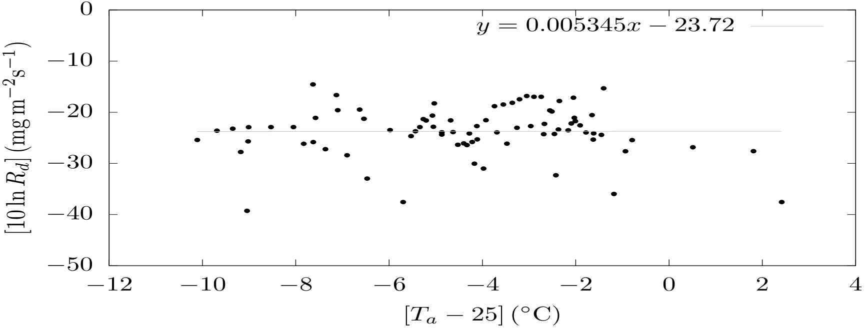
and for dark period

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

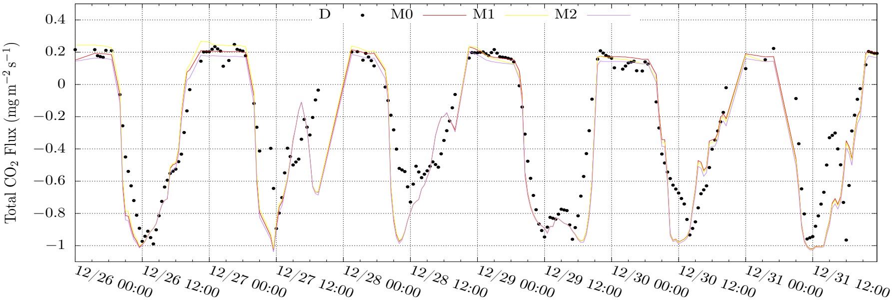
where $\Delta H_{a,R} = 33.87\,\mathrm{J\,mol^{-1}}$ is the activation energy, $C_R = 13.68$ is a constant and $R = 8.314\,\mathrm{J\,K^{-1}mol^{-1}}$ is the gas constant.

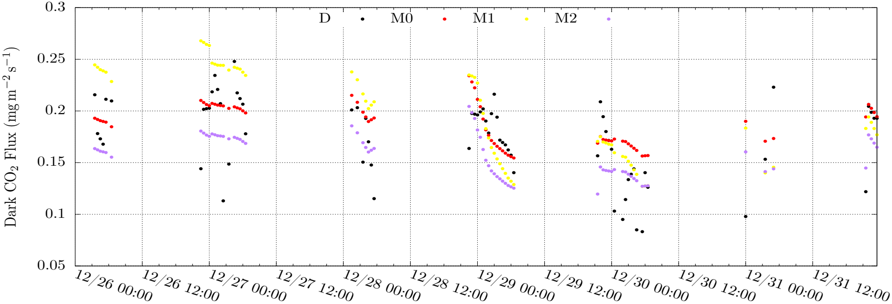
Autotrophic Respiration: summary of equations

	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)



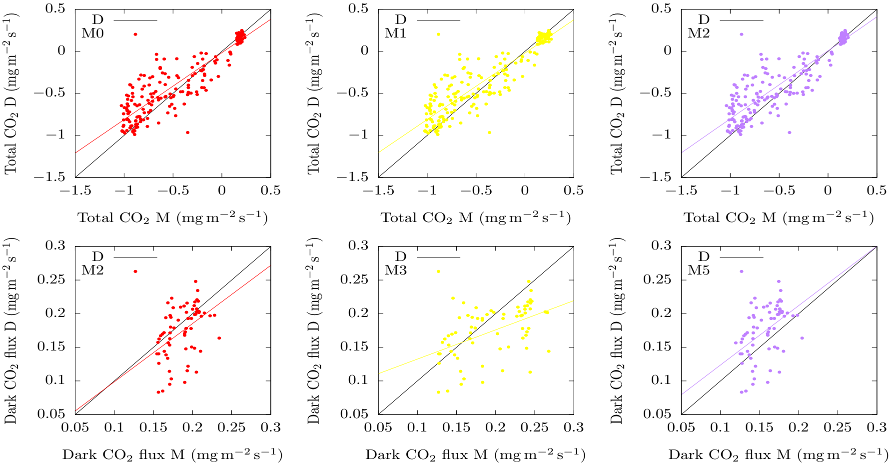


Results: total and only dark CO_2 fluxes (statistics)

	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

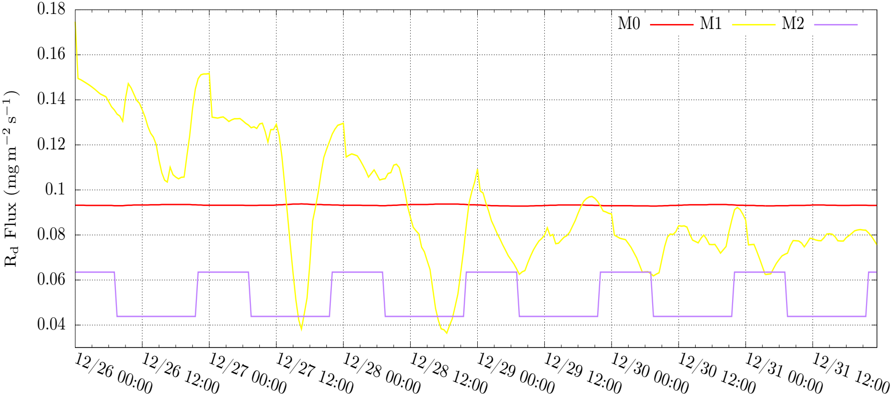
- M0 gave the best overall performance with $NSE = 0.7568$ for the total daily CO_2 flux and $NSE = 0.0795$ for the dark flux.
- M1 gave similar predictions for the daily CO_2 flux with $NSE = 0.7582$, but the worst result for the nighttime period with $NSE = -0.4965$.
- M2 gave $NSE = 0.7424$ for the 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			Dark CO_2 fluxes		
	M0	*M1*	*M2*	*M0*	*M1*	*M2*
Slope	0.7958	0.7906	0.8090	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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THANK YOU

FOR YOUR ATTENTION!!!

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