Brigham Young University
BYU ScholarsArchive

International Congress on Environmental Modelling and Software

7th International Congress on Environmental Modelling and Software - San Diego, California, USA - June 2014

Jun 16th, 2:00 PM - 3:20 PM

A model component for simulating the seasonal cycle of heterotrophic respiration

G. A. Alexandrov
A.Mm Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, g.alexandrov@ifaran.ru

Follow this and additional works at: https://scholarsarchive.byu.edu/iemssconference

Part of the Civil Engineering Commons, Data Storage Systems Commons, Environmental Engineering Commons, Hydraulic Engineering Commons, and the Other Civil and Environmental Engineering Commons

Alexandrov, G. A., "A model component for simulating the seasonal cycle of heterotrophic respiration" (2014). *International Congress on Environmental Modelling and Software*. 2.
https://scholarsarchive.byu.edu/iemssconference/2014/Stream-G/2

This Event is brought to you for free and open access by the Civil and Environmental Engineering at BYU ScholarsArchive. It has been accepted for inclusion in International Congress on Environmental Modelling and Software by an authorized administrator of BYU ScholarsArchive. For more information, please contact scholarsarchive@byu.edu, ellen_amatangelo@byu.edu.

International Environmental Modelling and Software Society (iEMSs)
7th Intl. Congress on Env. Modelling and Software, San Diego, CA, USA,
Daniel P. Ames, Nigel W.T. Quinn and Andrea E. Rizzoli (Eds.)
http://www.iemss.org/society/index.php/iemss-2014-proceedings

A model component for simulating the seasonal cycle of heterotrophic respiration

G.A. Alexandrov

A.M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Pyzhevsky 3 Moscow, Russia (g.alexandrov@ifaran.ru)

Abstract: Heterotrophic respiration, an important item in ecosystem carbon balance, is the process which is addressed in the global carbon cycle models and Earth system models. The seasonal cycle of the heterotrophic respiration is determined by seasonal changes in climatic conditions and in the storage of litter (i.e., in the amount of organic substrate available as a food source for organisms composing the heterotrophic community). The model component presented in this paper is focussing at effects produced by seasonal depletion in litter storage. The seasonal changes in litter storage are modelled by ordinary differential equations, which are solved analytically to make model spin-up runs unnecessary. The steady seasonal cycle is calculated by using solutions of the differential equations expressed in functional form.

Keywords: heterotrophic respiration; steady seasonal cycle; modelling

1 Introduction

There are several ”processes that have the potential to accelerate the rate of warming beyond that attributed to human emissions of greenhouse gases”, which are called ”sleeping giants” of the carbon cycle (Steffen, 2006). Heterotrophic respiration is one of them. Despite the debate of its sensitivity to increasing temperature there is a general consensus that it will increase dramatically, and due to this reason, a large amount of carbon stored in the soil will be released to the atmosphere.

The ability of Earth system models (ESMs) to predict the extent of this positive climate feedback is evaluated using model estimates of global soil carbon (Todd-Brown et al., 2013). Since they vary in a wide range, there is certain demand for improving the simulation of driving variables and modifying model structures.

The study reported here concentrates on the problem of simulating the seasonal cycle of the heterotrophic respiration. In many northern hemisphere ecosystems, a significant fraction of leaf litterfall occurs in the end of growing season. This pool of leaf litter formed by such fractions is depleted with warm temperatures in spring, and heterotrophic respiration in this pool become substrate-limited (Randerson et al., 1996).

2 Methods

Heterotrophic respiration from a litter pool or a pool of soil organic matter depends on the decay rate, $r(t)$, and the amount of the organic matter stored in the pool, s. The changes in the amount of the organic matter stored in the pool are usually described by a difference equation or by an ordinary differential equation of the following form:

$$\frac{ds}{dt} = p(t) - r(t)s; s(0) = s_0 \quad (1)$$

where p(t) is the rate of organic matter input.

The analytic solution of this equation has the form:

$$s(t) = \exp(-F(t))(s_0 + \int_0^t p(t)\exp(F(t))dt; F(t) = \int_0^t r(t)dt \tag{2}$$

Let t is measured in months. Since in the case of a steady seasonal cycle $s(12) = s(0)$,

$$s_0 = \exp(-F(12))(s_0 + \int_0^{12} p(t)\exp(F(t))dt \tag{3}$$

and hence

$$s_0 = \frac{\exp(-F(12))\int_0^{12} p(t)\exp(F(t))dt}{1 - \exp(-F(12))} \tag{4}$$

If r_m is the average decay rate in the month m (i.e., $r_m = \int_{m-1}^{m} r(t)dt; m = 1, 2, ..., 12$), then

$$F(m) = \sum_{n=1}^{m} r_n \tag{5}$$

And if p_m is the average input rate during the period from $m - 1/2$ to $m + 1/2$ (i.e., $p_m = \int_{m-1/2}^{m+1/2} p(t)dt; m = 1, 2, ..., 12$), then applying trapezium rule we obtain

$$\int_{m-1}^{m} p(t)\exp(F(t))dt \approx \frac{p_{m-1}\exp(F(m-1)) + p_m\exp(F(m))}{2} \tag{6}$$

Therefore

$$\int_0^m p(t)\exp(F(t))dt \approx \sum_{n=1}^{m} \frac{p_{m-1}\exp(F(m-1)) + p_m\exp(F(m))}{2} \tag{7}$$

and thus

$$s(m) \approx \exp(-F(m))(s_0 + \sum_{n=1}^{m} \frac{p_{m-1}\exp(F(m-1)) + p_m\exp(F(m))}{2}) \tag{8}$$

Consequently, the monthly heterotrophic respiration, $R_{h,m}$ is estimated as follows

$$R_{h,m} \approx r_m \frac{s(m-1) + s(m)}{2} \tag{9}$$

3 Results

The model component for simulating heterotrophic respiration from a litter pool or a pool of soil organic matter implements the algorithm which is based on the method explained above. This algorithm can be expressed in standard mathematical notation as follows.

Step 1:

$$F_0 = 0; F_m = F_{m-1} + r_m; (m = 1, 2, ..., 12) \quad (10)$$

Step 2:

$$G_0 = 0; G_m = G_{m-1} + \frac{p_{m-1}\exp(F_{m-1}) + p_m \exp(F_m)}{2}; (m = 1, 2, ..., 12) \quad (11)$$

Step 3:

$$s_0 = \frac{\exp(-F_{12})}{1 - \exp(-F_{12})} G_{12} \quad (12)$$

Step 4:

$$s_m = exp(-F_m)(s_0 + G_m); (m = 1, 2, ..., 12) \quad (13)$$

Step 5:

$$R_{h,m} = r_m \frac{s_{m-1} + s_m}{2}; (m = 1, 2, ..., 12) \quad (14)$$

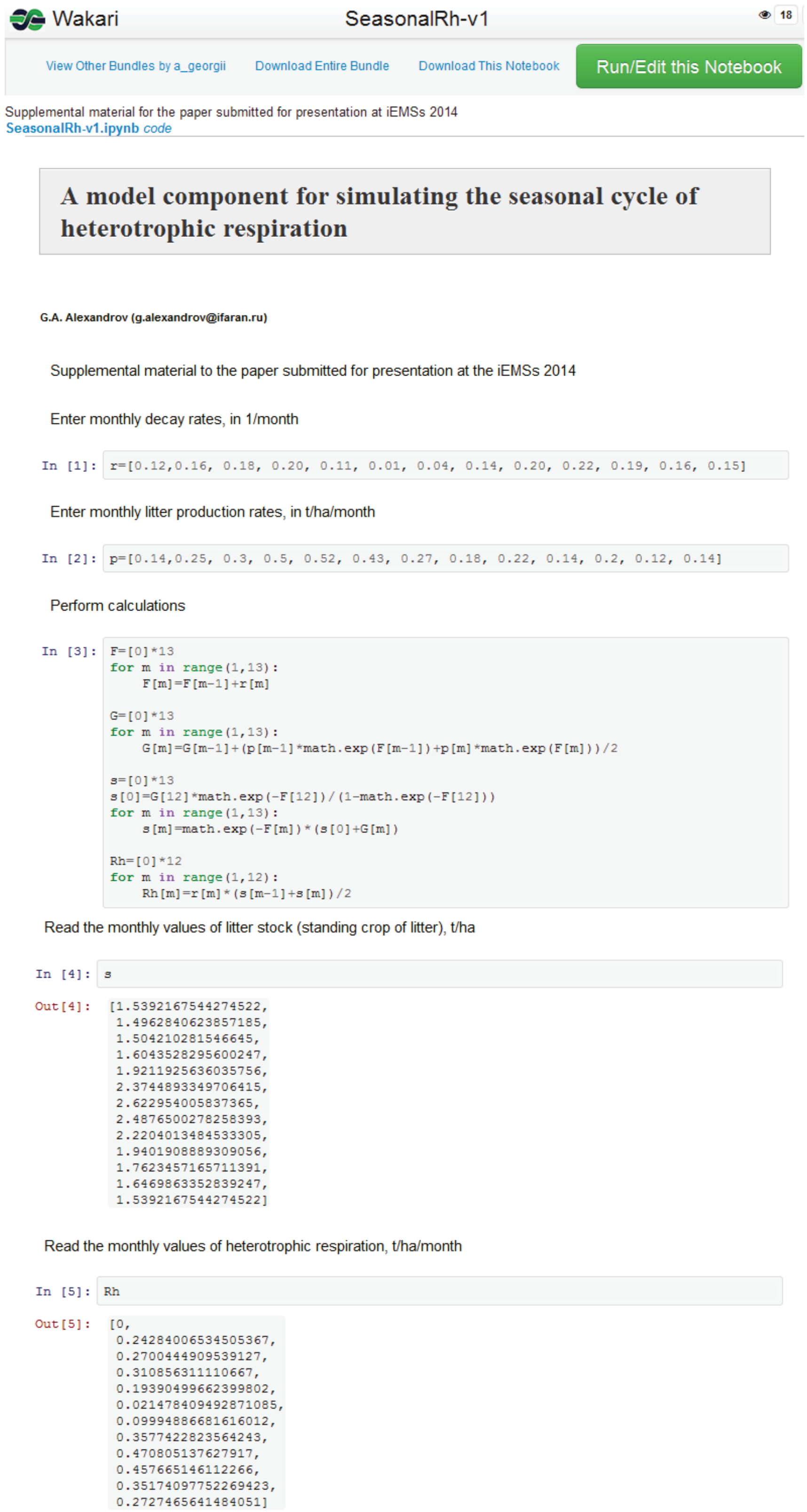
It also can be expressed in the notation of the Python language (Perez et al., 2011):

```
F=[0]*13
for m in range(1,13):
       F[m]=F[m-1]+r[m]

G=[0]*13
for m in range(1,13):
    G[m]=G[m-1]+(p[m-1]*math.exp(F[m-1])+p[m]*math.exp(F[m]))/2

s=[0]*13
s[0]=G[12]*math.exp(-F[12])/(1-math.exp(-F[12]))
for m in range(1,13):
    s[m]=math.exp(-F[m])*(s[0]+G[m])

Rh=[0]*12
for m in range(1,12):
    Rh[m]=r[m]*(s[m-1]+s[m])/2
```

And it can be used immediately for simulating monthly R_h and s through web-browser by employing the cloud computing service provided by Wakari (`www.wakari.io/sharing/bundle/a_georgii/SeasonalRh-v1`).

4 Discussion

Applying the model component to the data on litter production, decomposition and storage one should be certain that the data are collected using proper sampling procedures. In the ideal case, the litterfall should be measured in the middle of each month, whereas litter stock (or standing crop of litter) should be measured in the beginning of each month. The litter bags used for measuring the rate of weight loss should be also



Wakari SeasonalRh-v1 18

View Other Bundles by a_georgii   Download Entire Bundle   Download This Notebook   Run/Edit this Notebook

Supplemental material for the paper submitted for presentation at iEMSs 2014
SeasonalRh-v1.ipynb *code*

A model component for simulating the seasonal cycle of heterotrophic respiration

G.A. Alexandrov (g.alexandrov@ifaran.ru)

Supplemental material to the paper submitted for presentation at the iEMSs 2014

Enter monthly decay rates, in 1/month

In [1]:
```
r=[0.12,0.16, 0.18, 0.20, 0.11, 0.01, 0.04, 0.14, 0.20, 0.22, 0.19, 0.16, 0.15]
```

Enter monthly litter production rates, in t/ha/month

In [2]:
```
p=[0.14,0.25, 0.3, 0.5, 0.52, 0.43, 0.27, 0.18, 0.22, 0.14, 0.2, 0.12, 0.14]
```

Perform calculations

In [3]:
```
F=[0]*13
for m in range(1,13):
    F[m]=F[m-1]+r[m]

G=[0]*13
for m in range(1,13):
    G[m]=G[m-1]+(p[m-1]*math.exp(F[m-1])+p[m]*math.exp(F[m]))/2

s=[0]*13
s[0]=G[12]*math.exp(-F[12])/(1-math.exp(-F[12]))
for m in range(1,13):
    s[m]=math.exp(-F[m])*(s[0]+G[m])

Rh=[0]*12
for m in range(1,12):
    Rh[m]=r[m]*(s[m-1]+s[m])/2
```

Read the monthly values of litter stock (standing crop of litter), t/ha

In [4]:
```
s
```

Out[4]:
```
[1.5392167544274522,
 1.4962840623857185,
 1.504210281546645,
 1.6043528295600247,
 1.9211925636035756,
 2.3744893349706415,
 2.622954005837365,
 2.4876500278258393,
 2.2204013484533305,
 1.9401908889309056,
 1.7623457165711391,
 1.6469863352839247,
 1.5392167544274522]
```

Read the monthly values of heterotrophic respiration, t/ha/month

In [5]:
```
Rh
```

Out[5]:
```
[0,
 0.24284006534505367,
 0.2700444909539127,
 0.310856311110667,
 0.19390499662399802,
 0.021478409492871085,
 0.09994886681616012,
 0.3577422823564243,
 0.470805137627917,
 0.457665146112266,
 0.35174097752269423,
 0.2727465641484051]
```

Figure 1. A snapshot of the iPython notebook that can be run in the browser by employing the cloud computing service provided by Wakari. The data correspond to the case study of litter production, decomposition and storage in cocoa plantations reported by Muoghalu and Odiwe (2011).

weighted in the beginning of each month. If litterfall is measured in the beginning of each month, then p_m should be set at the average value of litterfall measured in the beginning of month m and that measured in the beginning of the month $m + 1$.

The case study of data on litter production, decomposition and storage in cocoa plantations reported by Muoghalu and Odiwe (2011) has shown that this model component could be essential to understanding what the data say. The attempt to simulate the reported data on leaf litter with the model component presented above was not successful, because the reported increase in the stock of leaf litter from December to January was 2-3 times higher than the amount of leaf litter fall in December. Such increase is not possible under assumption that the increase in the stock of litter is equal to the amount of litterfall minus heterotrophic respiration. It seems that a large amount of litterfall may avoid the literfall traps under some climatic conditions.

5 Conclusions and Recommendations

The fact that models need empirical validation is widely recognized. However, this is not always possible due to the lack of suitable observations. Most observations are not planned to validate a model. And some observations are not interpreted using a model, or any theoretical framework. There is a general consensus that a good science should include both modelling and observations. In practice, there are many obstacles to using models for planning observations and for interpreting theoretical validity of observations with a model. The model component presented in this paper provides quite a simple tool for planning and interpreting monthly observations of litter production, decomposition and storage which are essential to understanding the seasonal cycle of heterotrophic respiration.

Acknowledgments

This research is connected to the project ”Seasonal changes in atmospheric CO2 caused by the terrestrial carbon sink ” that received financial support from the Russian Foundation for Basic Research, grant No 13-05-00781.

References

Muoghalu, J. and Odiwe, A. (2011). Litter production and decomposition in cacao (theobroma cacao) and kolanut (cola nitida) plantations. *ECOTROPICA*, 17:79–90.

Perez, F., Granger, B. E., and Hunter, J. D. (2011). Python: An ecosystem for scientific computing. *Computing in Science and Engineering*, 13(2):13–21.

Randerson, J. T., Thompson, M. V., Malmstrom, C. M., Field, C. B., and Fung, I. Y. (1996). Substrate limitations for heterotrophs: Implications for models that estimate the seasonal cycle of atmospheric co2. *Global Biogeochemical Cycles*, 10:275–308.

Steffen, W. (2006). The anthropocene, global change and sleeping giants: where on earth are we going? *Carbon Balance and Management*, 1(1):3.

Todd-Brown, K. E. O., Randerson, J. T., Post, W. M., Hoffman, F. M., Tarnocai, C., Schuur, E. A. G., and Allison, S. D. (2013). Causes of variation in soil carbon simulations from cmip5 earth system models and comparison with observations. *Biogeosciences*, 10(3):1717–1736.