Parameterization of Soil Respiration in GEMTM

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AT 730

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Outline

- Equation
- Components of the Parameterization
- Parameter Values
- Original Equation
- Parameter a’
- Parameter $T_{s,\text{ref}}$
- Parameter c’
- Temperature Sensitivity
- Soil Water Content Sensitivity
- Look up Table
- Summary
Equation

- Of the form:

\[ F_{css} = a'(\Theta_{20} - 12)/(40-12)e^{c'(T_{s,10} - T_{s,ref})} \]

- \( F_{css} \) is the soil respiration rate in \( \mu \text{mol m}^{-2}\text{s}^{-1} \)
- Function of available carbon, soil moisture, and soil temperature
Equation

\[ F_{css} = \frac{a'(\Theta_{20} - 12)}{(40-12)e^{c'(T_{s,10} - T_{s,ref})}} \]

- \( a' \) is the soil CO\(_2\) flux at field capacity
- Describes how much carbon is available for decomposition
Equation

\[ F_{css} = a'(\Theta_{20} - 12)/(40-12)e^{c'(T_{s,10} - T_{s,ref})} \]

- \( \Theta_{20} \) is the soil-water content in percent at 20 cm depth
- Describes the part of the function dependent upon soil moisture
Equation

\[ F_{css} = a'(\Theta_{20} - 12)/(40-12)e^{c'(T_{s,10} - T_{s,ref})} \]

- \( c' \) is the temperature coefficient and determines the soil respiration’s dependence on temperature.
- Describes the function’s dependence upon temperature.
Equation

\[ F_{css} = a'(\Theta_{20} - 12)/(40-12)e^{c'(T_{s,10} - T_{s,ref})} \]

- \( T_{s,10} \) is the soil temperature in °C at 10cm depth
- \( T_{s,ref} \) is the reference soil temperature at 10cm depth
Equation

\[ F_{css} = a'(\Theta_{20} - 12)/(40-12)e^{c'(T_{s,10} - T_{s,ref})} \]

- 12% is the soil water content when soil CO\textsubscript{2} fluxes go to zero - this is just drier than the permanent wilting stage
- 40% is near field capacity - when the prescribed CO\textsubscript{2} fluxes occur
Components of the parameterization

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Theta_{20}$</td>
<td>$F_{css}$</td>
<td>$a'$</td>
</tr>
<tr>
<td>$T_{s,10}$</td>
<td></td>
<td>$c'$</td>
</tr>
<tr>
<td>$T_{s,\text{ref}}$</td>
<td></td>
<td>$T_{s,\text{ref}}$</td>
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<tr>
<td></td>
<td></td>
<td>12</td>
</tr>
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<td></td>
<td></td>
<td>40</td>
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</tbody>
</table>
Parameter Values

- Based off of 1000 observations of soil surface CO$_2$ fluxes in the FIFE area (central Kansas), Norman et al., 1992 set
  - $a' = 12.1$
  - $c' = 0.0365$
  - $T_{s,ref} = 26.0$
Parameter Values

- However, for these observations, $T_{s,10}$ varied only between 20°C and 30°C
- Another study by Grammerer, 1989 made observations between 3°C and 30°C which gave different values for $c'$ and $T_{s,\text{ref}}$
- Changes $c' = 0.069$, $T_{s,\text{ref}} = 25$, and $a' = 11$ to best fit the 1000 observations with the new $c'$ and $T_{s,\text{ref}}$ based on Grammerer’s study
Forms the equation

$$F_{css} = 11(\Theta_20 - 12)/(40-12)e^{0.069(T_{s,10} - 25)}$$

This form of the equation was used in GEM when it was first built

However, the value of a’ was based only on one vegetation type (tall grass) in central Kansas
Parameter a’

- The parameter a’ is the product of the heterotrophic respiration rate $K_d$ at 0°C and $C_s$, the carbon in the soil and detritus (dead or decaying organic matter).
- At present in GEMTM, a’ is based off of 28 different vegetation types with values ranging from 0.4161 to 6.
Parameter a’

- The blue represents the range of values of a’ used in GEMTM.
- The red is if the values of $K_d$ and $C_s$ are each increased by 10%.
- The yellow is if the values of $K_d$ and $C_s$ are each decreased by 10%.
Parameter $a'$

1. evergreen needleleaf tree
2. deciduous needleleaf tree
3. deciduous broadleaf tree
4. evergreen broadleaf tree
5. short grass
6. tall grass
7. desert
8. semi-desert
9. tundra
10. evergreen shrub
11. deciduous shrub
12. mixed woodland
13. crop/mixed farming
14. irrigated crop
15. bog or marsh
16. evergreen needleleaf forest
17. evergreen broadleaf forest
18. deciduous needleleaf forest
19. deciduous broadleaf forest
20. mixed cover
21. woodland
22. wooded grassland
23. closed shrubland
24. open shrubland
25. grassland
26. cropland (corn)
27. bare ground
28. urban and built up

Variations in parameter $K_dC_s$

$K_dC_s - 10\%$

$K_dC_s + 10\%$
Parameter a’

- The default in GEMTM uses vegetation types 1 - 15, 22, 27, and 28
- Many of the different vegetation types use the same value for a’

1. evergreen needleleaf tree
2. deciduous needleleaf tree
3. deciduous broadleaf tree
4. evergreen broadleaf tree
5. short grass
6. tall grass
7. desert
8. semi-desert
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Parameter a’

- a’ is very uncertain and varies according to soil type and vegetation
- Another set of values comes from Raich and Schlesinger, 1992
  - Uses more values from North America, Europe, and Asia
Parameter a’

Vegetation type
1 tundra
2 boreal forests and woodlands
3 temperate grasslands
4 temperate coniferous forests
5 temperate deciduous forests
6 mediterranean woodlands and heath
7 croplands, fields, etc.
8 desert scrub
9 tropical savannas and grasslands
10 tropical dry forests
11 tropical moist forests
12 northern bogs and mires
13 marshes

Variations of a’ from Raich and Schlesinger

- Mean Rh in umol CO2 m^-2 s^-1
- Bottom range of Rh
- Top range of Rh
Parameter a’
Parameter $T_{s,\text{ref}}$

- Depends on the observations and the soil temperatures of the observations
- Initially taken to be 26°C based on soil temperatures between 20°C and 30°C
- Changed to 25°C based on temperatures between 3°C and 30°C
Parameter $T_{s,\text{ref}}$

- As temperature increases, the dependence on $T_{s,\text{ref}}$ increases.
- A 10% decrease in $T_{s,\text{ref}}$ can lead to a 20% increase in respiration due to the exponential
Parameter $c'$

- The value of $c'$ also depends on the observations and the soil temperatures of the observations.
- Initially, $c' = 0.0365$ based on temperatures between 20°C and 30°C from Norman et al., 1992.
- Changed to 0.069 based on observations between 3°C and 30°C by Grammerer, 1989.
Parameter $c'$

- Red colors are air temperatures greater than 30°C on 21 April 2006 at 19:00 UTC
- For these regions the temperature range for which $c'$ was calculated may not apply depending on how these warm temperatures transfer through the soil
Parameter $c'$

- Similar issue appears in Africa
- Is $c'$ valid for these warm regions?
Parameter c’

- For soil temperatures very near the reference temperature, variations in c’ are unimportant.
- At temperatures away from the reference temperature, variations in c’ can make a large difference since c’ is in an exponential.
Temperature Sensitivity

- The temperature sensitivity of soil respiration can be affected by:
  1. Physical protection
  2. Chemical protection
  3. Drought
  4. Flooding
  5. Freezing
Temperature Sensitivity

- Physical protection
  - Organic matter physically protected in the interior of soil aggregates; microorganisms and enzymes have limited access
  - Climate can affect aggregate formation through the action of raindrops and the growth of fungal hyphae
Temperature Sensitivity

- Chemical Protection
  - Organic matter adsorbed onto mineral surfaces through bonds
  - This process also affected by temperature
Temperature Sensitivity

- **Drought**
  - Reduces the thickness of soil water films, inhibiting diffusion of extracellular enzymes and soluble organic-C substrates
  - Determined by climate-driven hydrologic balance
Temperature Sensitivity

- Flooding
  - Slows oxygen diffusion, allowing only anaerobic decomposition which is generally slower
  - Flooding determined by precipitation and evapotranspiration
Temperature Sensitivity

- Freezing
  - Diffusion of substrates and extracellular enzymes is slow when the soil water is frozen
  - Melting of permafrost will expose additional organic matter
Soil Water Content Sensitivity

- Relationship of soil water content to respiration is linear in GEMTM
Soil Water Content Sensitivity

- In other models, relationship is different
- In dry regions, drought prevents much microbial activity in the soil
- When too much soil water content, microbes drown and cannot decompose soil organic matter and so produces a reduction in soil respiration
Soil Water Content Sensitivity

- In GEMTM, soil respiration continues to increase as soil water content increases.
- Neglects the affect of flooding and limitation to anaerobic respiration only.
Much of the parameterization is already in the form of a look up table due to the dependence of a’ on biome type.

The model knows what the simulated vegetation type is and goes to an array of values and picks out the a’ that corresponds to that type.
Look up Table

- Could have a look up table for the exponential function
- The rest of the parameterization is linear and not much would be gained by a look up table
- The computer would not need to recompute exponentials every time it runs the program for each temperature
- Accuracy of this method depends very much on temperature and becomes less accurate as temperature increases
Look up Table

<table>
<thead>
<tr>
<th>Temperature</th>
<th>$\exp(0.069\times(T-25))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.178173052</td>
</tr>
<tr>
<td>1</td>
<td>0.190901059</td>
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<td>2</td>
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<td>3</td>
<td>0.219149748</td>
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<td>6</td>
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<td>15</td>
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</table>

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<tr>
<th>Temperature</th>
<th>$\exp(0.069\times(T-25))$</th>
</tr>
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<tbody>
<tr>
<td>16</td>
<td>0.537406762</td>
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<tr>
<td>17</td>
<td>0.575797064</td>
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<td>19</td>
<td>0.661000951</td>
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<td>0.708220353</td>
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<td>0.758812931</td>
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<td>0.871098692</td>
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<tr>
<td>25</td>
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<td>1.317847864</td>
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<tr>
<td>30</td>
<td>1.41198992</td>
</tr>
</tbody>
</table>
Summary

- Soil respiration in GEMTM based on 5 parameters
- Format of current parameterization based on observations in central Kansas with limited soil temperature, soil type, and vegetation type
- Parameters are highly variable depending on temperature, soil type, and vegetation type
- Need different values for different geographical locations
- Soil respiration is much more complex than what is accounted for in parameterizations
Image of soil CO$_2$ emissions
References


A BIG thanks to Adriana Beltran!!