Parameterization of Soil Respiration in GEMTM

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Outline

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- Parameter c'
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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 µmol $m^{-2}s^{-1}$
- Function of available carbon, soil moisture, and soil temperature

Equation

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

- a' is the soil CO_2 flux at field capacity
- Describes how much carbon is available for decomposition

Equation

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

- Θ_{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 ºC 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_2 fluxes go to zero - this is just drier than the permanent wilting stage
- 40% is near field capacity - when the prescribed CO_2 fluxes occur

Components of the parameterization

Input	Output	Parameters
Θ_{20}	F_{css}	a’
$T_{s,10}$		c’
		$T_{s,ref}$
		12
		40

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 $T_{s,ref}$
- Changes c’ = 0.069, $T_{s,ref}$ = 25, and a’ = 11 to best fit the 1000 observations with the new c’ and $T_{s,ref}$ based on Grammerer’s study

Original Equation

- Forms the equation

$$F_{css} = 11(\Theta_{20} - 12)/(40-12)e^{0.069(T_{s,10} - 25)}$$

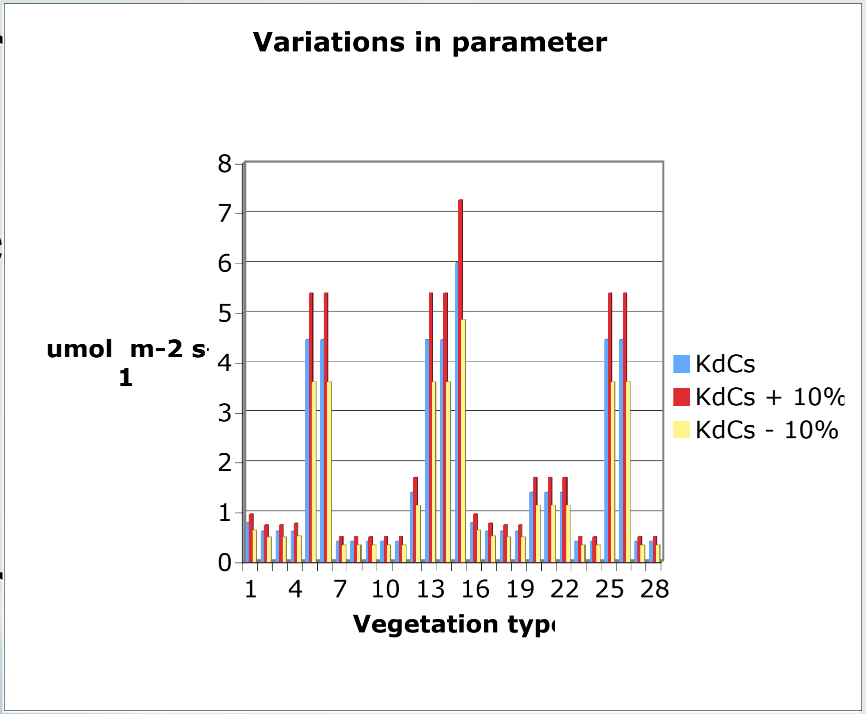
- This form of the equation was used in GEMTM when it was first built
- However, the value of a’ was based only on one vegetation type (tall grass) in central Kansas

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

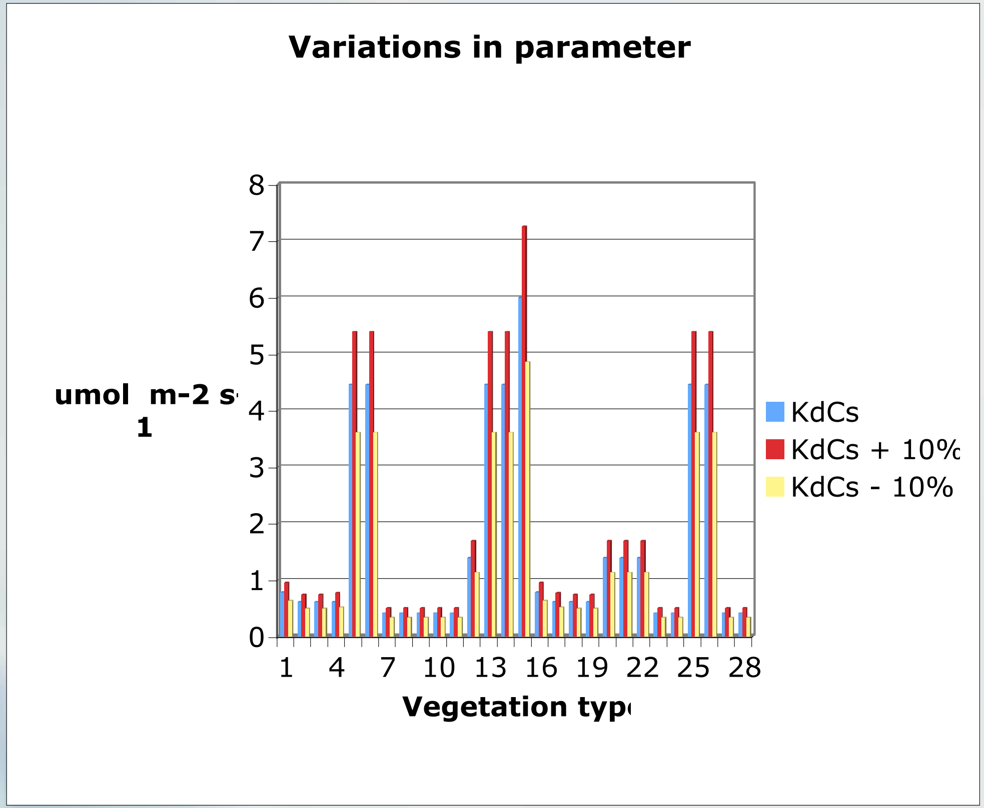
Parameter a’

- The blue represents the range of values of a’ used in GEMTM
- The red is if the value 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



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
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4 evergreen broadleaf tree
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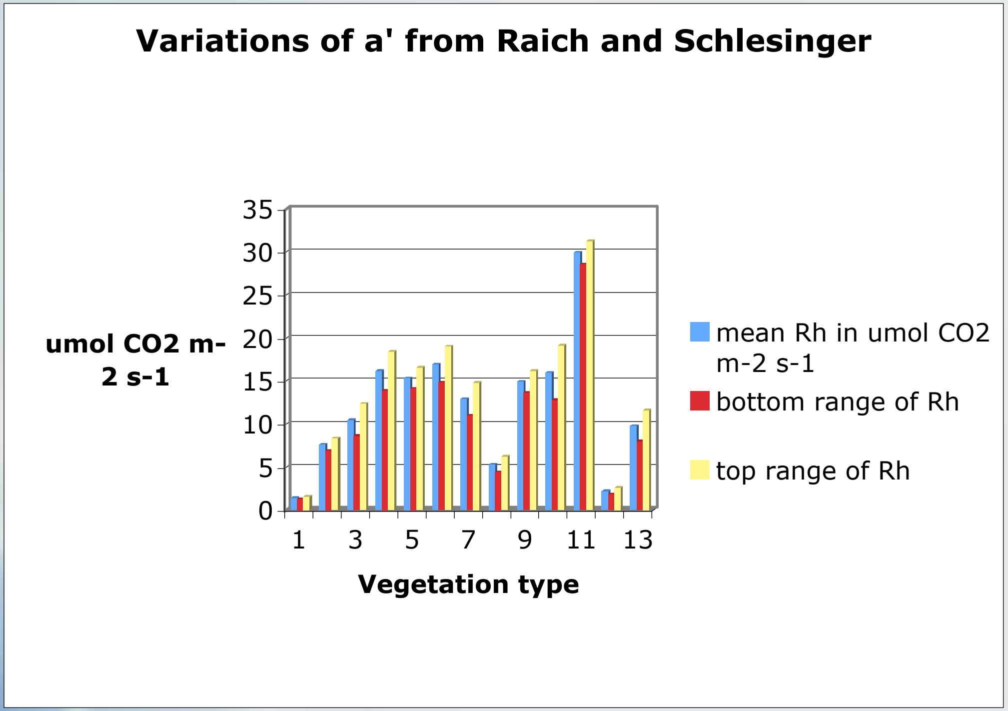
27 bare ground
28 urban and built up

Parameter a’

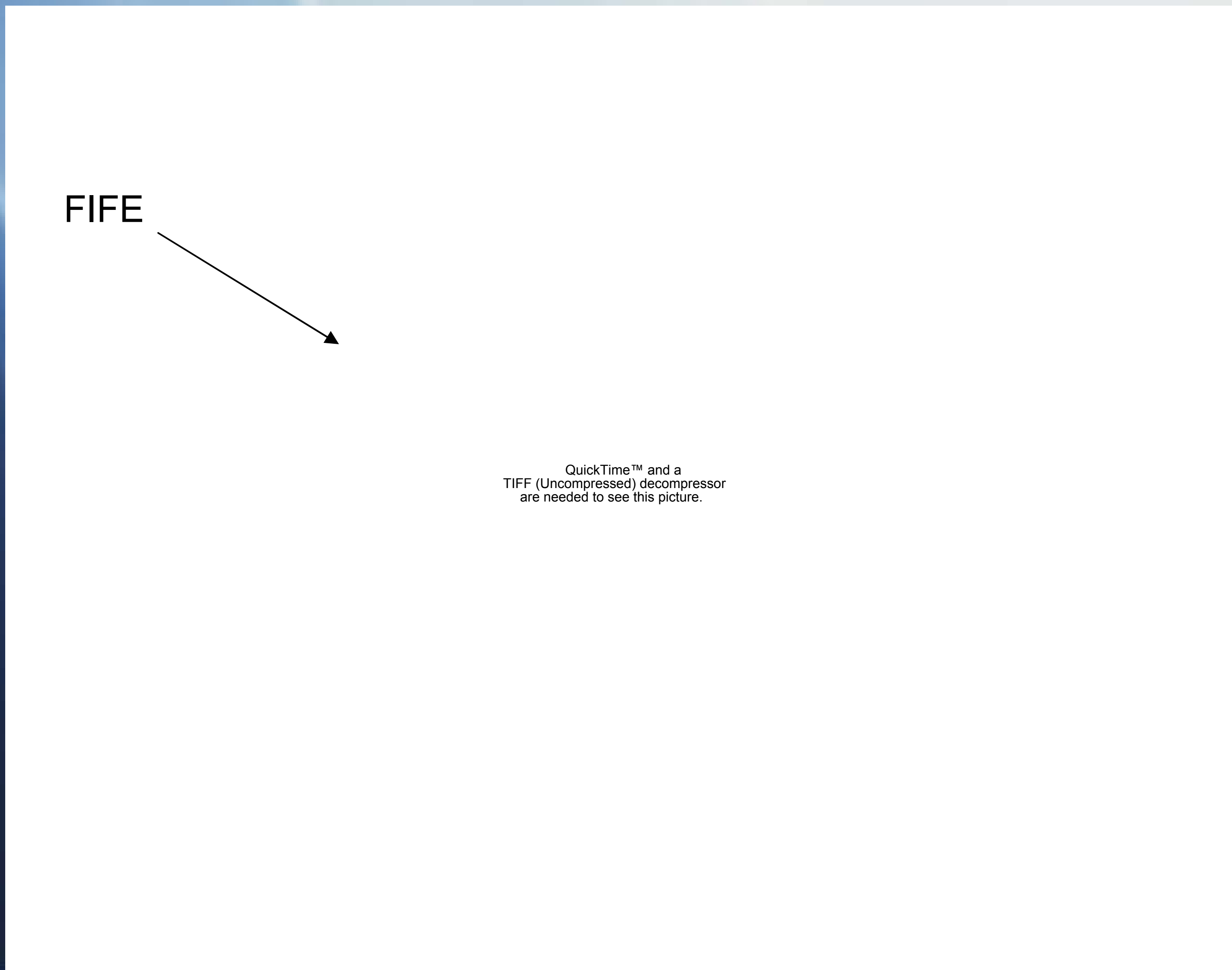
- a’ is very uncertain and varies according to soil type and vegetation
- Another set of values comes from Raich and Schlesinger, 1992
  - Uses more values from North America, Europe, and Asia

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



Parameter a'

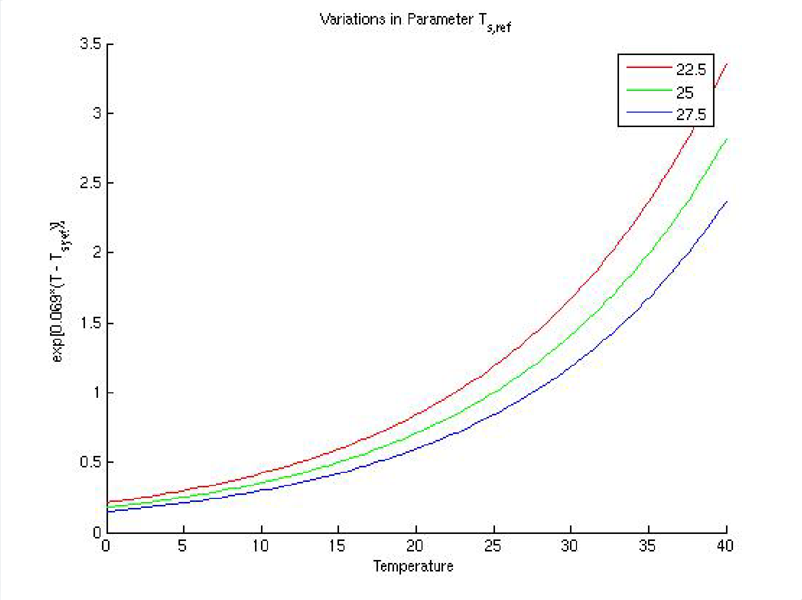

FIFE
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Parameter $T_{s,ref}$

- Depends on the observations and the soil temperatures of the observations
- Initially taken to be 26ºC based on soil temperatures between 20ºC and 30ºC
- Changed to 25ºC based on temperatures between 3ºC and 30ºC

Parameter $T_{s,ref}$

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

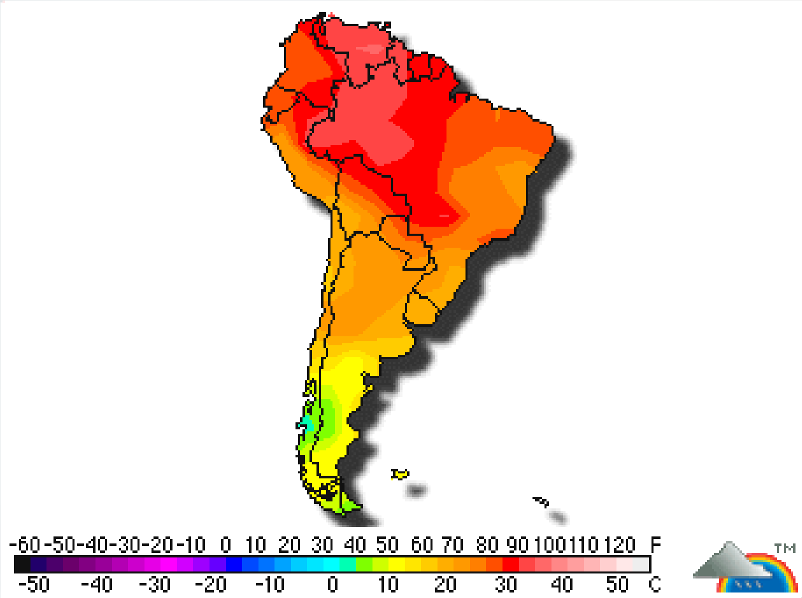


Parameter c’

- 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

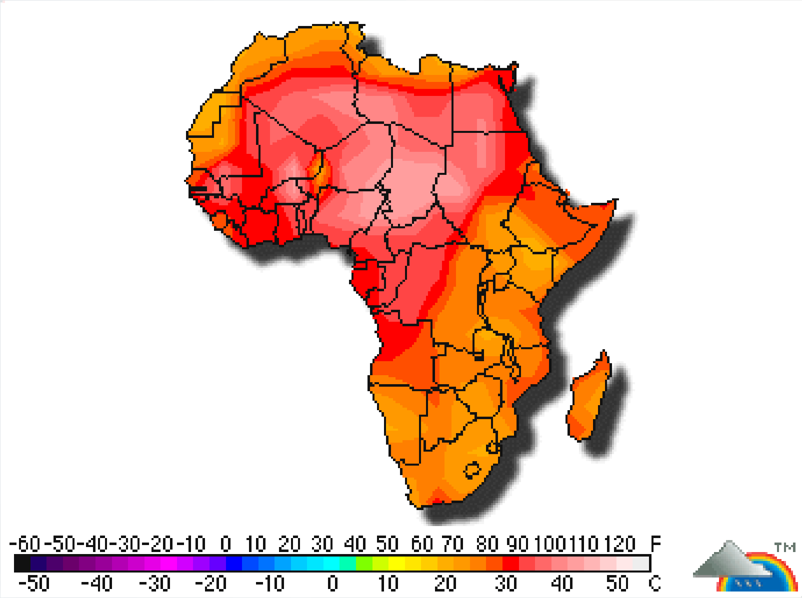
Parameter c’

- 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 my not apply depending on how these warm temperatures transfer through the soil



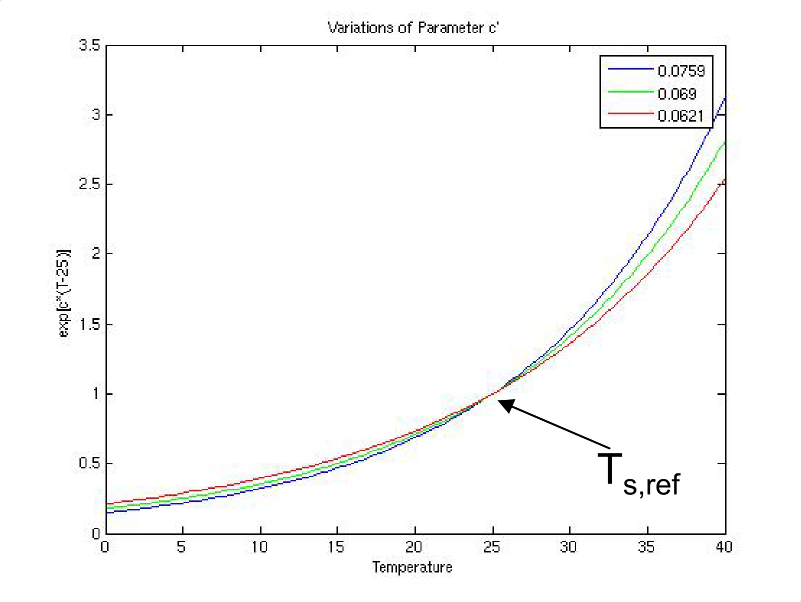
Parameter c’

- 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

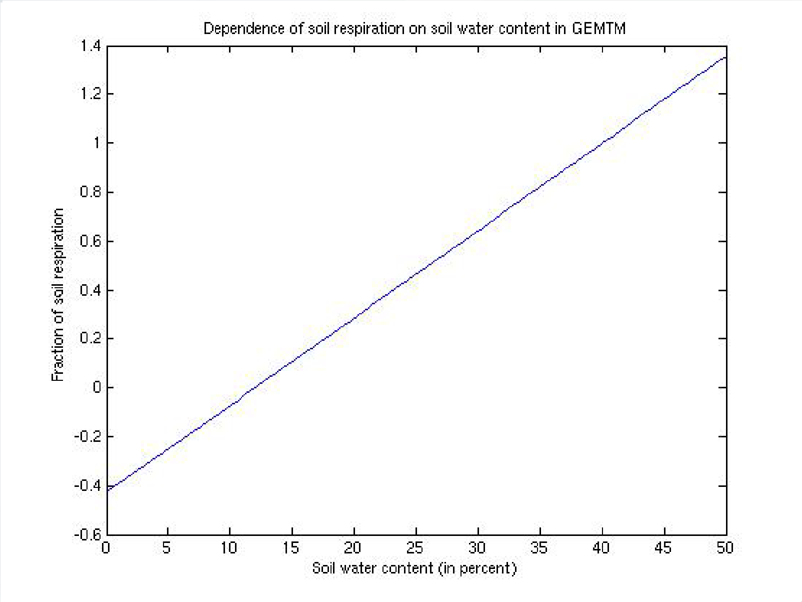
- Flooding
  - Slows oxygen diffusion, allowing only anaerobic decomposition which is generally slower
  - Flooding determined by precipitation and evapotranspiration

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

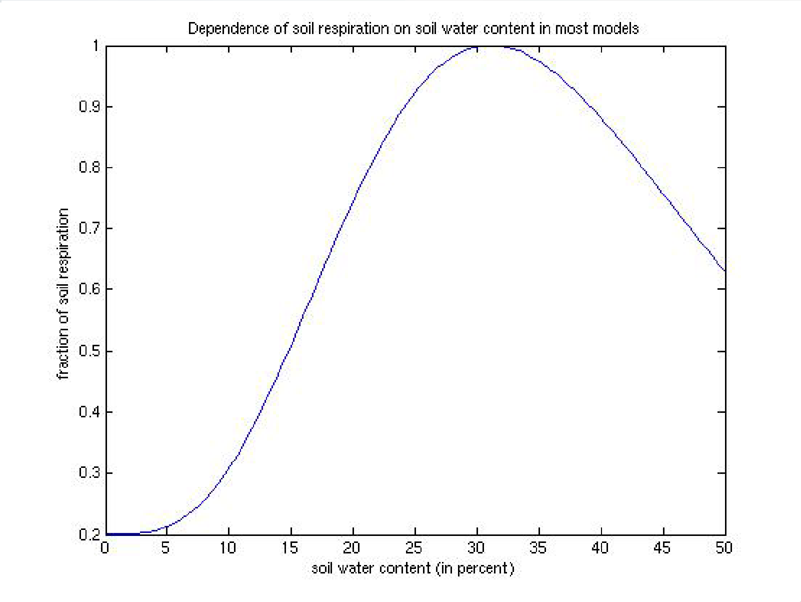
Soil Water Content Sensitivity

- Relationship of soil water content to respiration is linear in GEMTM



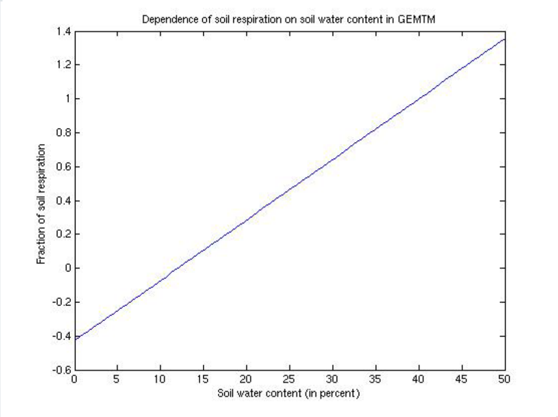
Soil Water Content Sensitivity

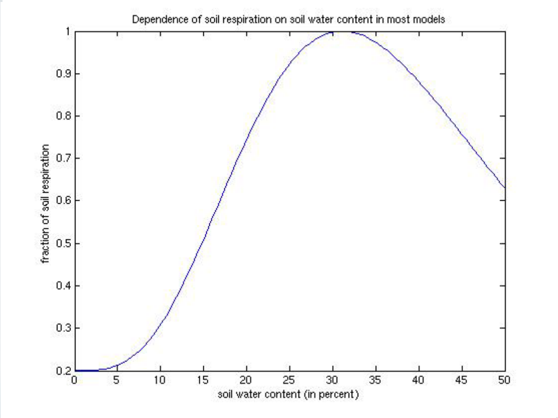
- In other models, relationship is different
- In dry regions, drought prevents much microbial activity in the soil
- When too much soil water content, microbes drown and cannot decompose soil organic matter and so produces a reduction in soil respiration



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





Look up Table

- 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

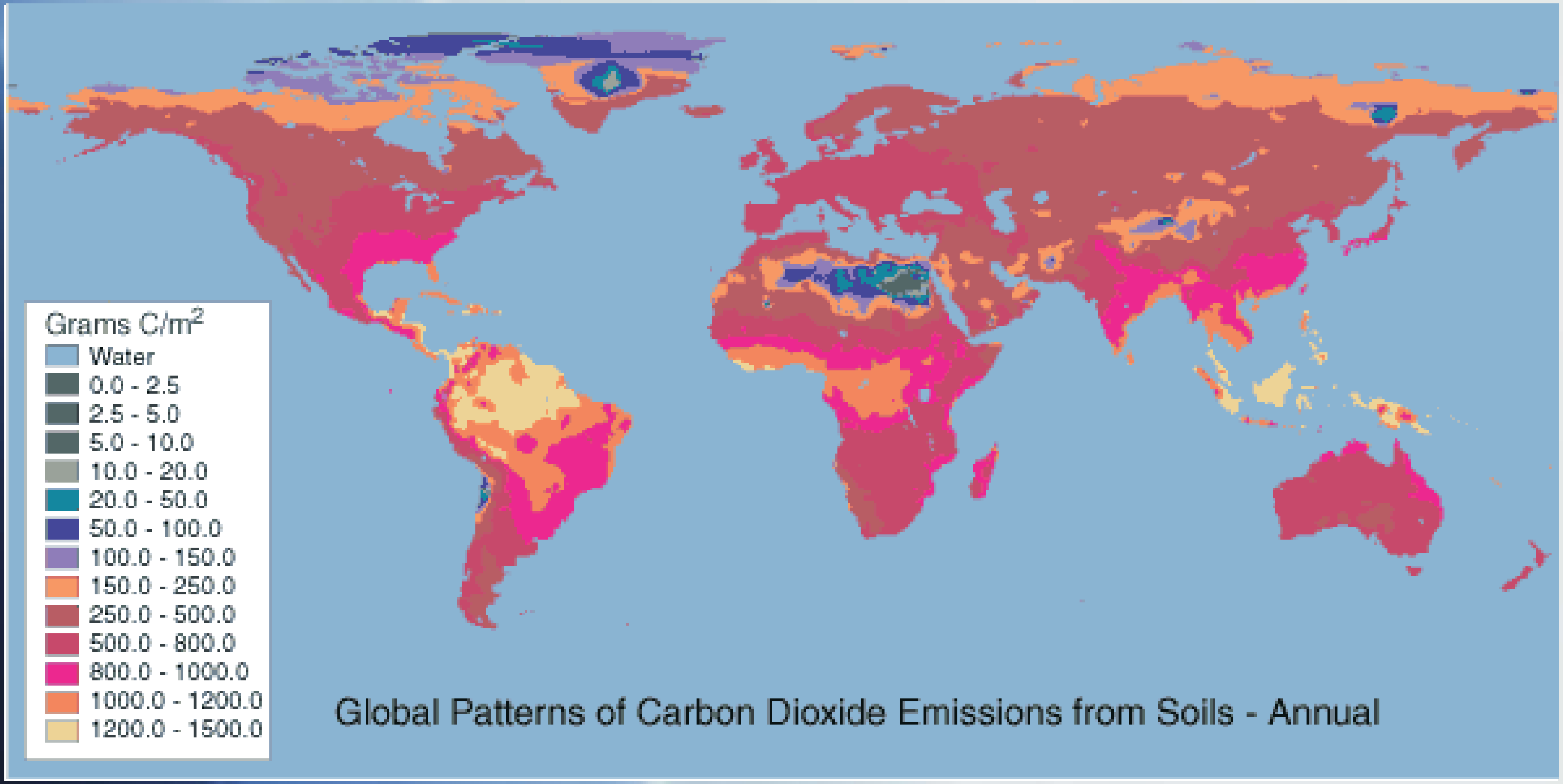
Temperature	exp(0.069*(T-25))
0	0.178173052
1	0.190901059
2	0.204538307
3	0.219149748
4	0.234804976
5	0.251578553
6	0.269550371
7	0.288806028
8	0.309437236
9	0.331542259
10	0.355226381
11	0.380602407
12	0.4077912
13	0.436922258
14	0.468134327
15	0.501576069

Temperature	exp(0.069*(T-25))
16	0.537406762
17	0.575797064
18	0.616929823
19	0.661000951
20	0.708220353
21	0.758812931
22	0.81301965
23	0.871098692
24	0.93332668
25	1
26	1.071436209
27	1.14797555
28	1.229982572
29	1.317847864
30	1.41198992

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



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