Development, Evaluation, and Application of a BGC Transport and Reaction Capability for CLM4.5 (CLM4-BeTR)

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ACKNOWLEDGEMENT: DOE REGIONAL AND GLOBAL CLIMATE MODELING PROGRAM AND NGEE-ARCTIC

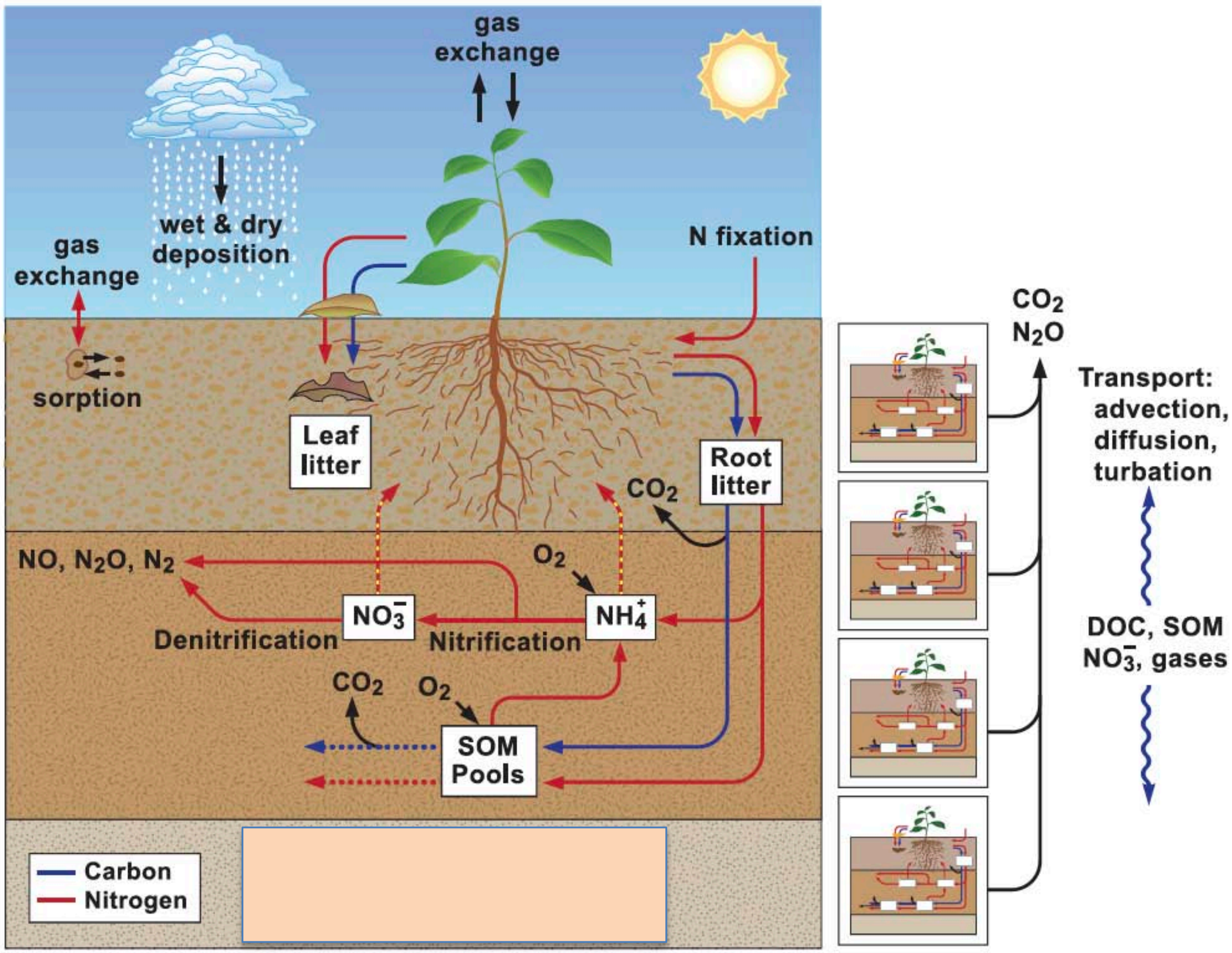
Outline

- MOTIVATION
- MODEL DESCRIPTION
  - Structure
  - Numerical implementation
  - Testing
- APPLICATION TO INTERPRETING SOIL-GAS CO_2 CONCENTRATIONS, ^{14}C MEASUREMENTS, AND FLUX PARTITIONING

Motivation

- **CURRENT ESM LAND MODEL FORMULATIONS ARE INSUFFICIENT TO RESOLVE DEPTH-DEPENDENT BGC CRITICAL TO ECOSYSTEM CLIMATE RESPONSES**
  - Aerobic/anaerobic fractions (e.g., CH_4 oxidation and production)
  - Vertical gradients in SOM content
  - Permafrost
  - Root access to nutrients and water
- **CLM CANNOT BE COMPARED DIRECTLY TO DEPTH-DEPENDENT BGC OBSERVATIONS**
- **OUR GOAL WAS TO BUILD A GENERIC REACTIVE TRANSPORT SOLVER IN CLM**
  - Tang et al. 2013, Geoscientific Model Development

Model Structure and Implementation



Model Structure and Implementation

- **SOLVES TRANSIENT MASS BALANCE FOR MULTI-PHASE REACTIVE FLOW**

$$\frac{\partial}{\partial t}\left(C_s + \theta C_w + \varepsilon C_g\right) =$$

Accumulation in multiple phases

Model Structure and Implementation

- **SOLVES TRANSIENT MASS BALANCE FOR MULTI-PHASE REACTIVE FLOW**

$$\frac{\partial}{\partial t}\left(C_s + \theta C_w + \varepsilon C_g\right) =$$ Accumulation in three phases

$$\frac{\partial}{\partial z}\left(D_s \frac{\partial C_s}{\partial z}\right) + \frac{\partial}{\partial z}\left(\theta D_w \frac{\partial C_w}{\partial z}\right) + \frac{\partial}{\partial z}\left(\varepsilon D_g \frac{\partial C_g}{\partial z}\right) -$$ Diffusion

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$$\frac{\partial\left(u_w C_w\right)}{\partial z} - \frac{\partial\left(u_g C_g\right)}{\partial z} +$$ Advection

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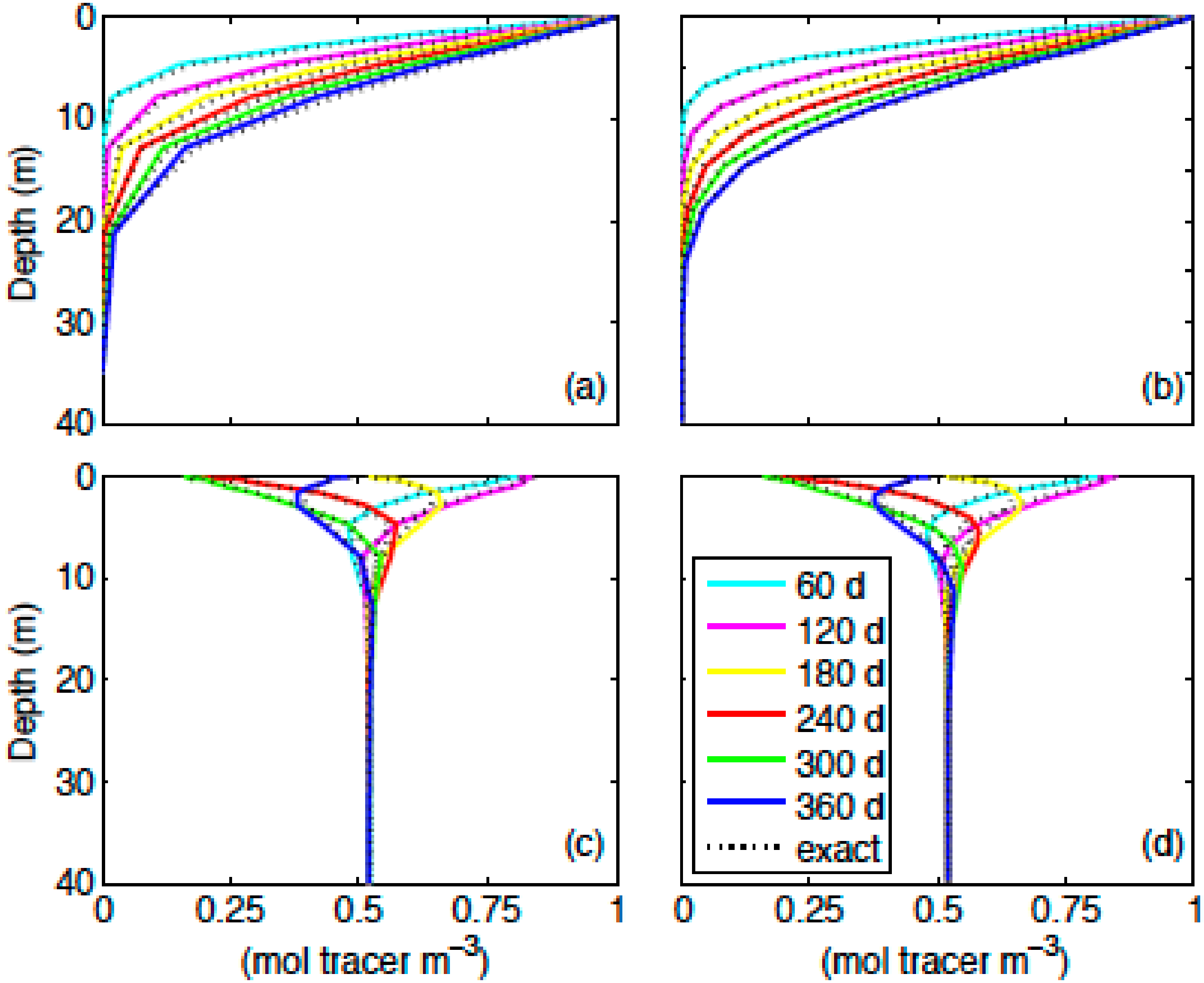
$$R$$ Chemical and biogeochemical reactions

Model Structure and Implementation

- **OPERATOR SPLITTING APPROACH (STRANG, 1968)**
  - **Diffusion: Crank Nicholson**
  - **Advection:**
    - Upstream discretization (Tremback et al. 1987)
    - Transpiration fluxes
    - Horizontal fluxes with surface runoff: assume in equilibrium with top 2 soil layers
  - **Snow:**
    - Comparable to aerosols for accumulation and melt (Oleson et al. 2010)
    - Allows tracer movement through advection and diffusion; fast equilibration
  - **Reaction example: CO_2 production currently calculated in CLM4.5 BGC module**
- **FINITE VOLUME METHOD**
- **SURFACE BC FROM TANG AND RILEY (2013); DESCRIBED YESTERDAY FOR VAPOR, BUT GENERICALLY APPLICABLE**
- **SOIL PHYSICAL VARIABLES (T, LIQUID & ICE CONTENT, WATER TABLE, VERTICAL AND HORIZONTAL FLUXES) FROM CLM PHYSICS**
- **CODE IS STRUCTURED TO ALLOW DIFFERENT BIOGEOCHEMICAL REACTION NETWORKS**

Model Testing

- **SUCCESSFUL COMPARISON TO ANALYTICAL SOLUTIONS**

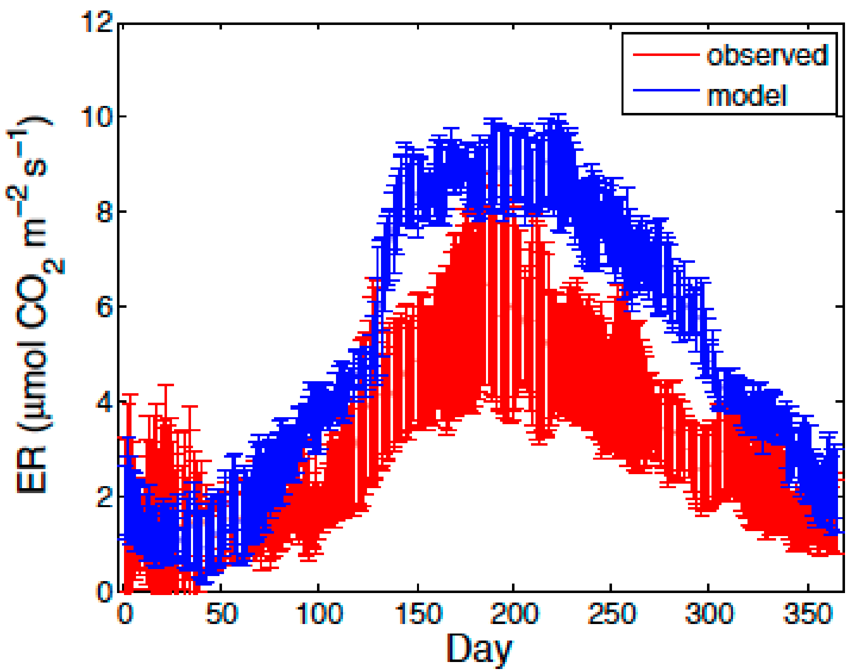


Harvard Forest Simulations

- **APPLIED CLM4-BETR AT HARVARD FOREST**
- **MULTI-YEAR OBSERVATIONAL RECORD**
  - Atmospheric forcing: repeating 57-yr (1948–2004) cycle (Qian et al., 2006)
  - Partitioned GPP into Ecosystem Respiration from AmeriFlux dataset (level 4), from 1992 to 2006
  - Soil-gas CO_2 from June 1995 to December 2004 (Davidson et al., 2006)
- 1000 YEAR SPINUP FOLLOWED BY A 40 YEAR SIMULATION, FROM WHICH THE LAST 10 YEARS OF OUTPUT WERE USED
- TRACERS SIMULATED: N_2, O_2, AR, CO_2, N_2O, NO

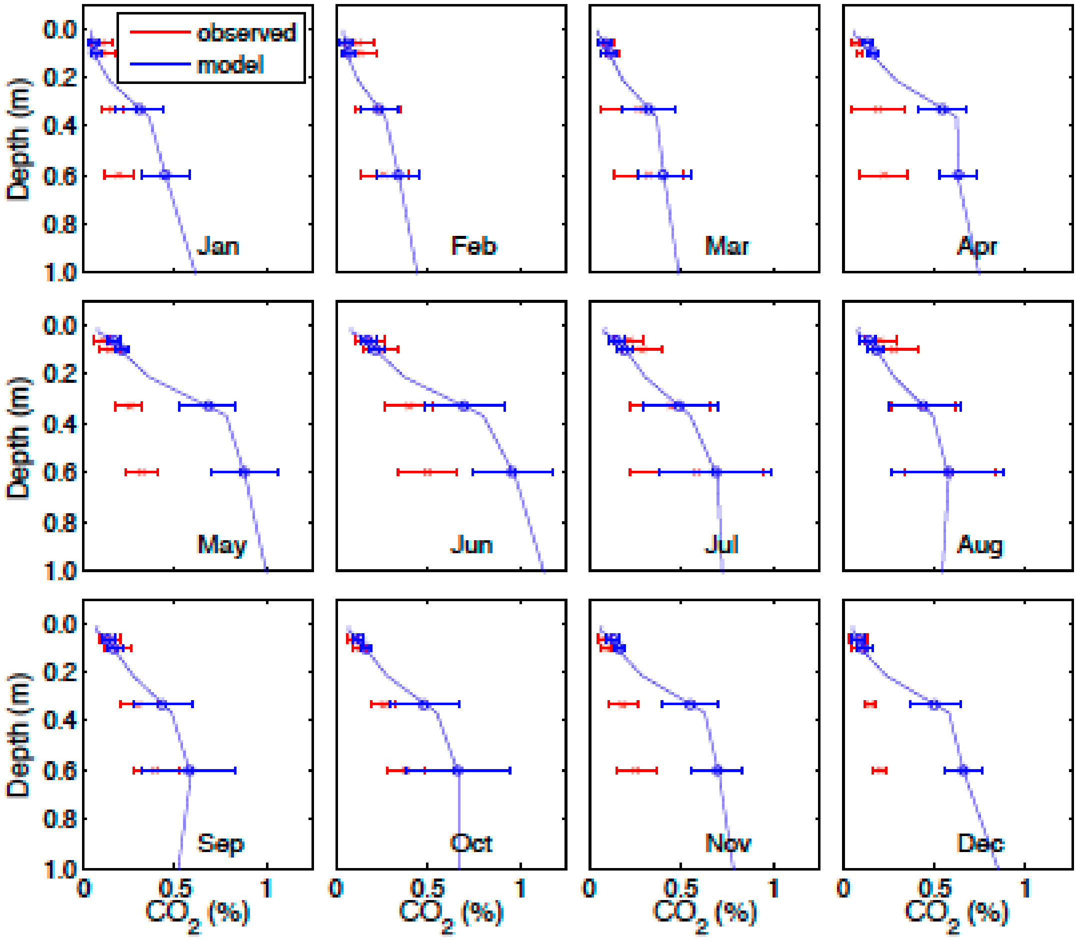
Harvard Forest Simulations

- **TOTAL ECOSYSTEM RESPIRATION OVERESTIMATED IN CLM4**
  - Observations do not allow a check on BG/AG split
  - Often substantial error in flux partitioning of ECOR data



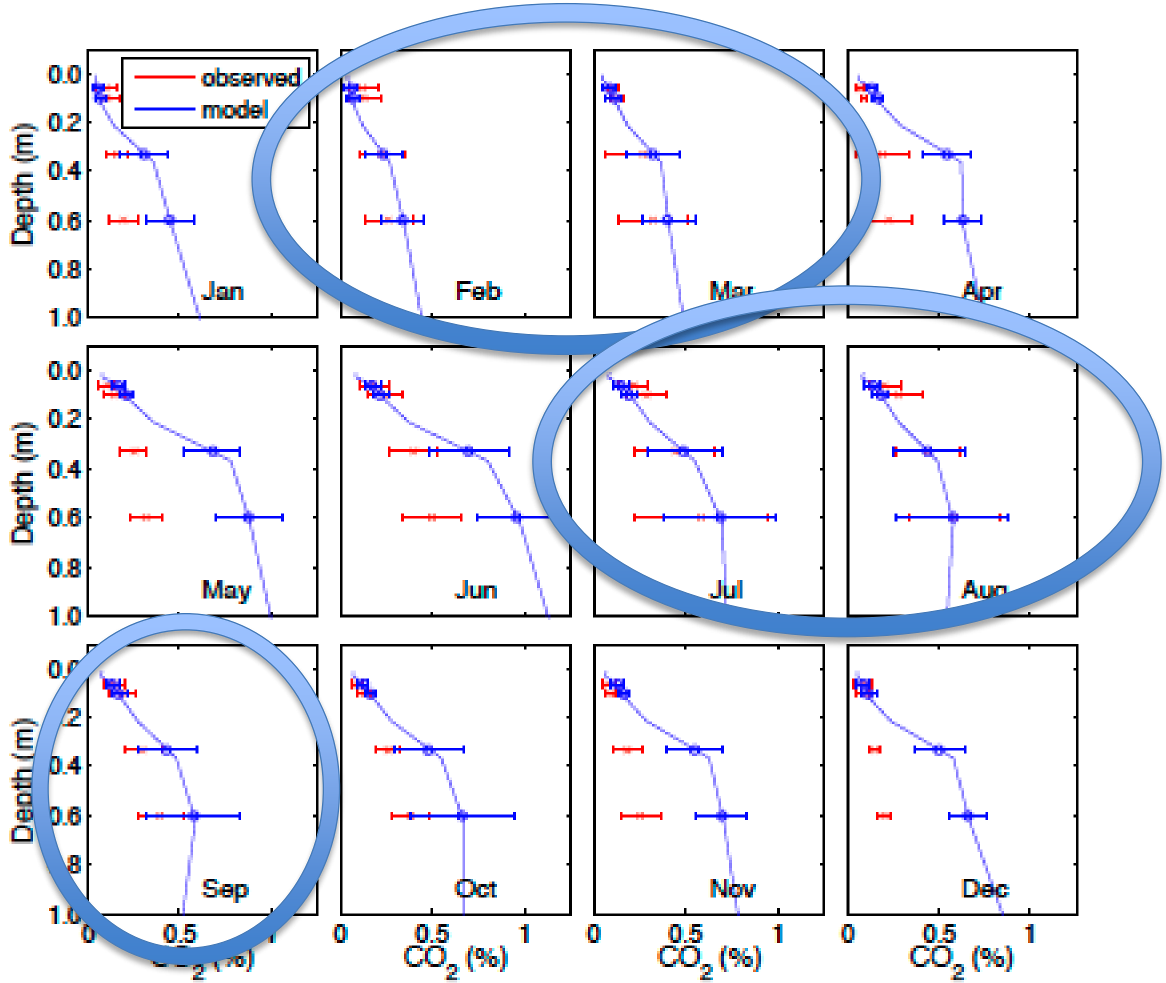
- **SIMULATED SOIL TEMPERATURE WAS IN GOOD AGREEMENT WITH MEASUREMENTS**
- **SIMULATED SOIL MOISTURE WAS HIGHER THAN OBSERVED THROUGHOUT MOST OF THE YEAR**

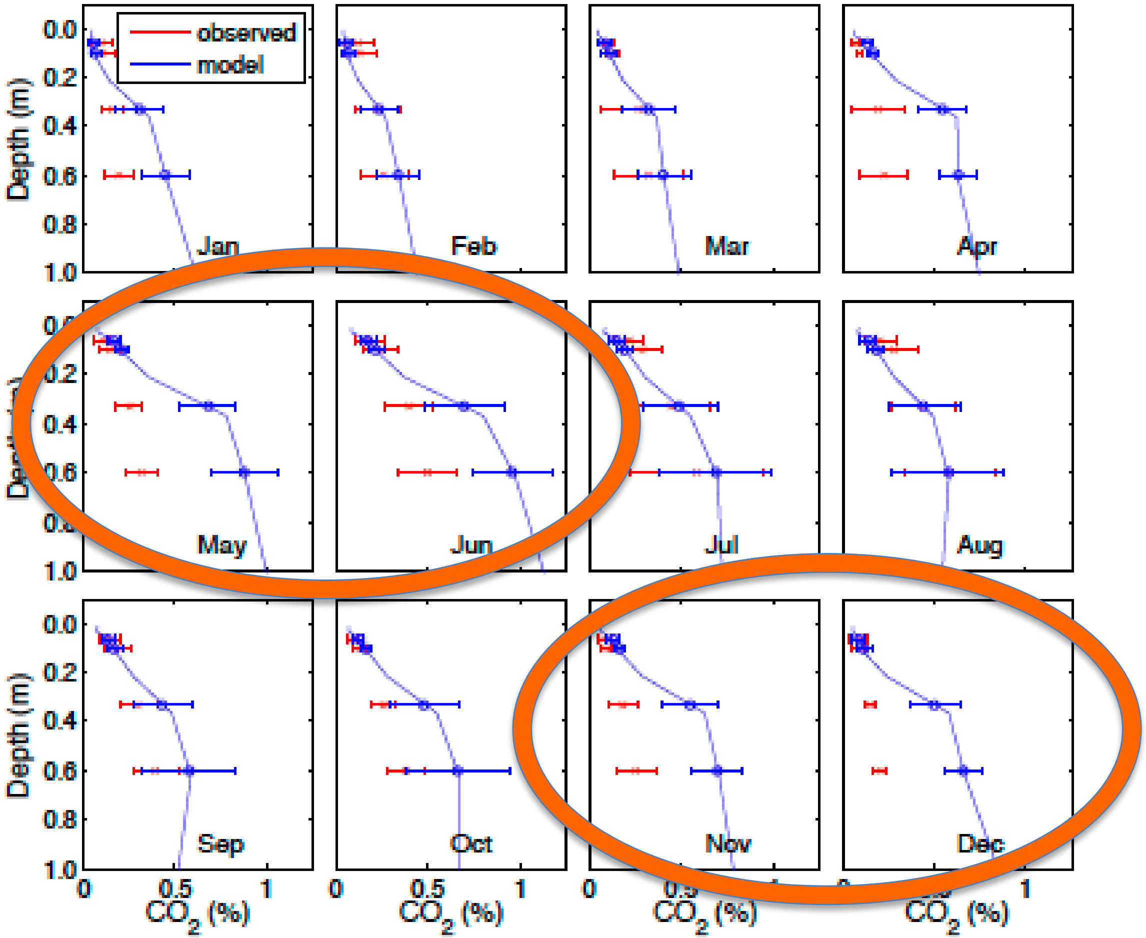
Soil-Gas CO_2



observed
model
Depth (m)
0.0
0.2
0.4
0.6
0.8
1.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
0.5
1
CO2 (%)

- **PREDICTED SOIL CO_2 PROFILES BIASES INCONSISTENT WITH PREDICTED ER BIASES**

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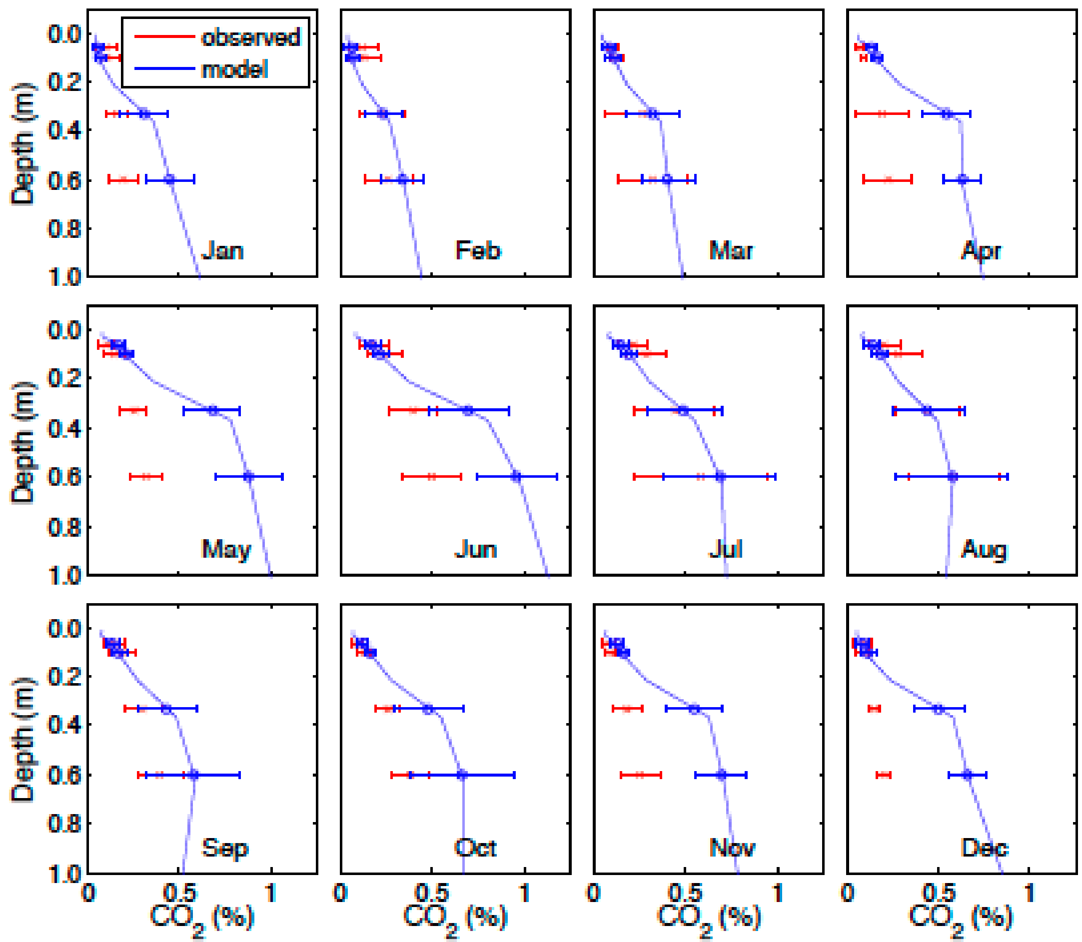
CO2 (%)

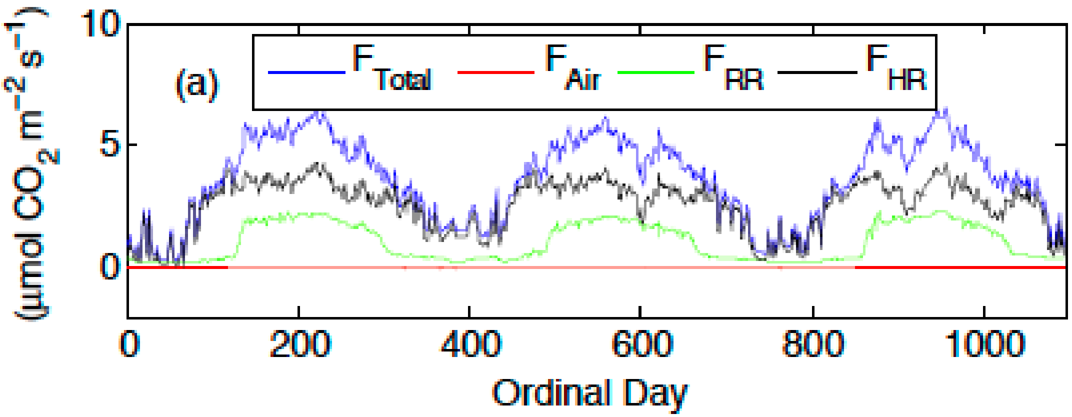
- **SOIL CO_2 PROFILES BIASES OFTEN INCONSISTENT WITH RESPIRATION BIASES**



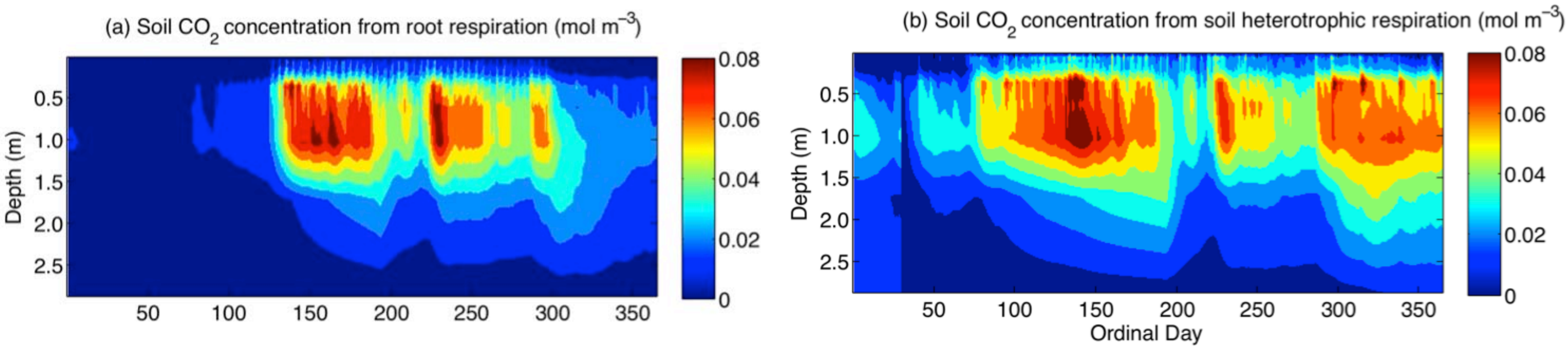
- **INCORRECT SOIL WATER DYNAMICS AFFECTED BOTH TRANSPORT AND DECOMPOSITION RATE**

Belowground Flux Partitioning

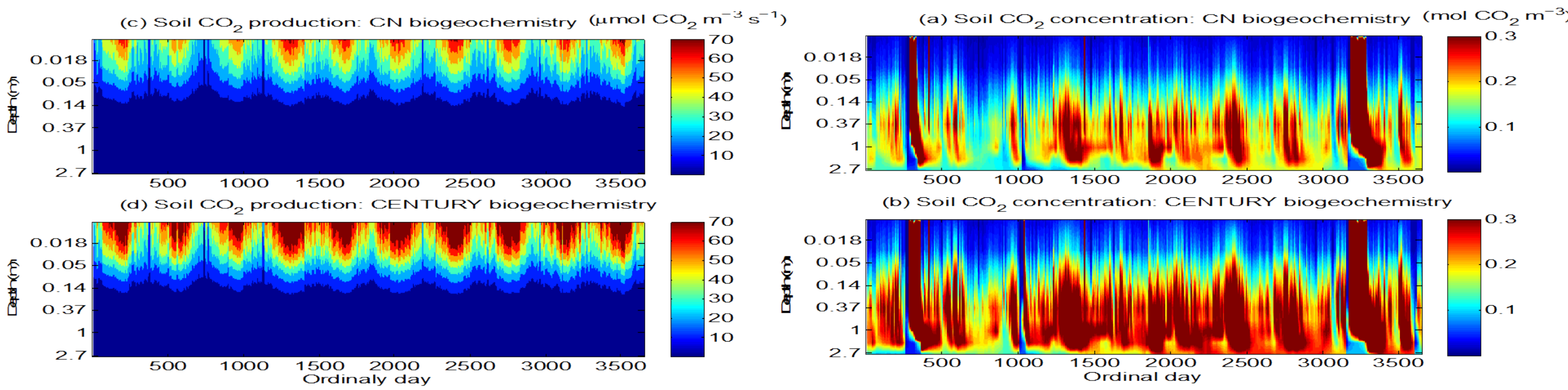
- **DIFFERENT TEMPORAL PATTERNS OF ROOT AND HETEROTROPHIC RESPIRATION**



- **MANIFESTED AS DIFFERENT SOIL-GAS CO_2 PROFILES**



Using ^{14}C to Characterize CO_2 Sources



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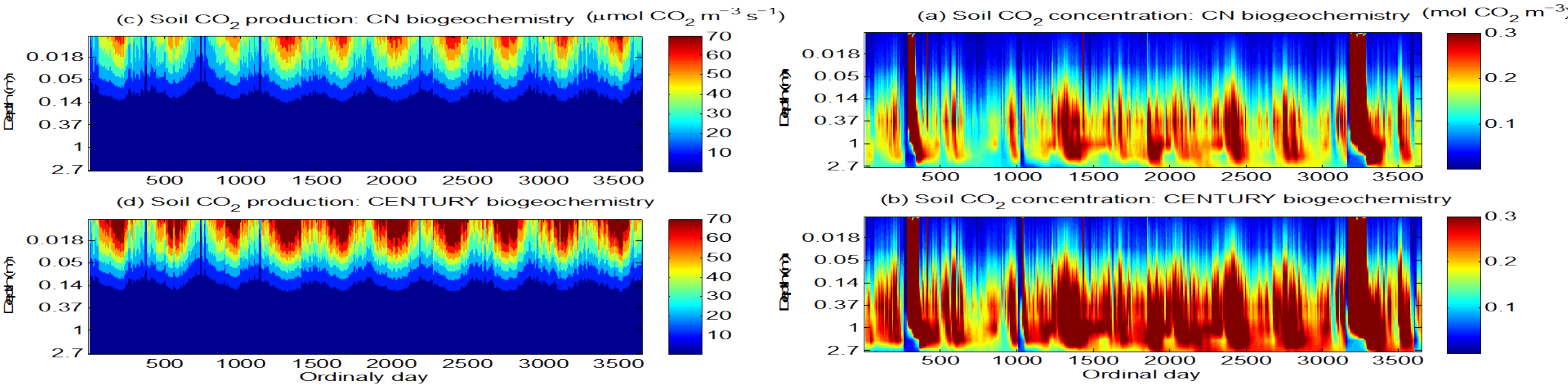
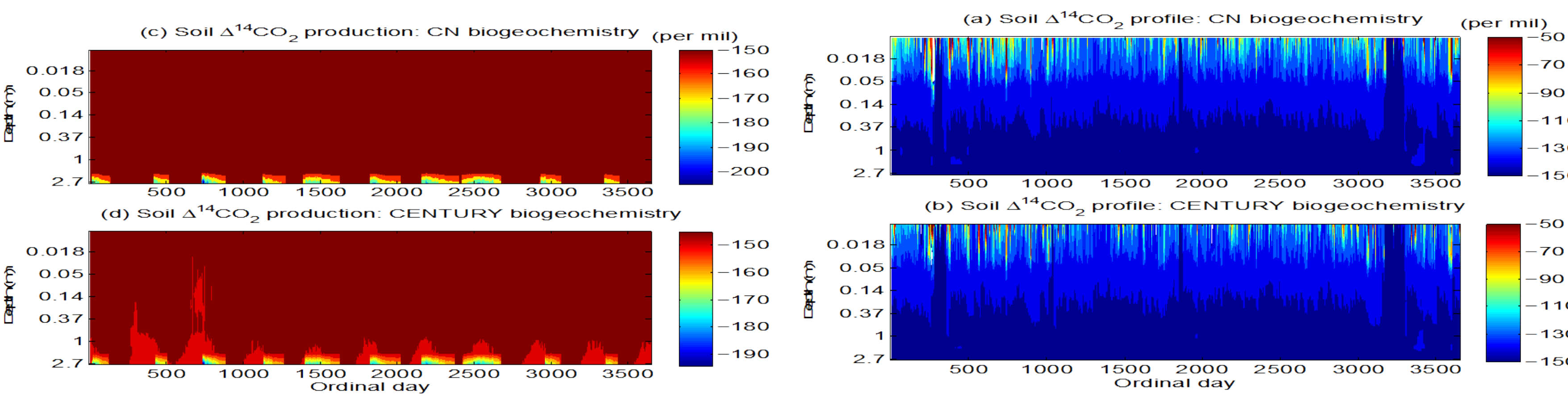
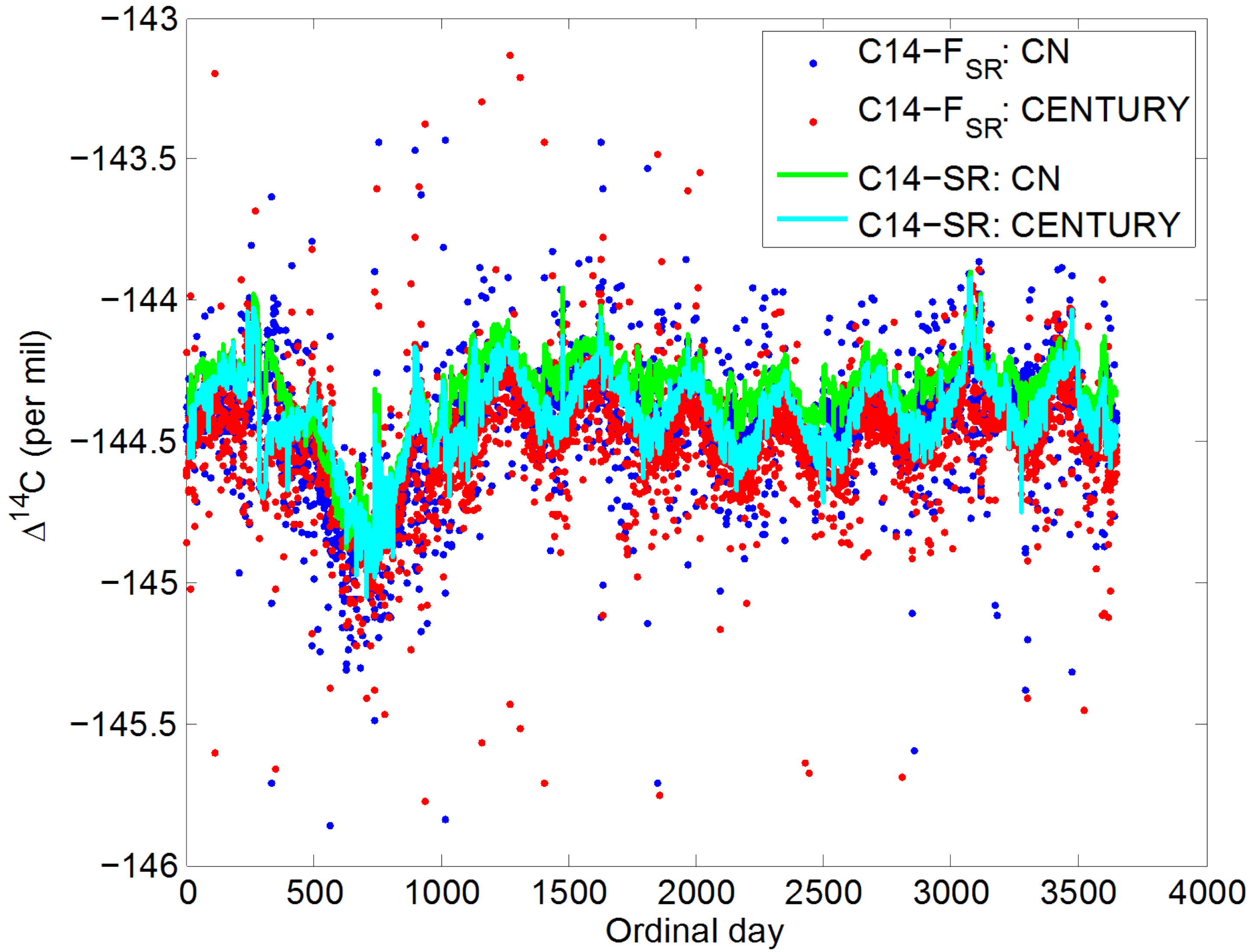




Summary, Etc.

- GENERIC REACTIVE TRANSPORT CAPABILITY INTEGRATED WITH CLM4.5 (NOT IN RELEASE VERSION, THOUGH)
- EVALUATION OF BENEFITS OF ADDITIONAL MODEL COMPLEXITY UNDERWAY ☺
- OTHER ONGOING ANALYSES:
  - Belowground N BGC and interactions with plants
  - ^{14}C in SOM and CO_2
  - SOM dynamics and deep C stability



F_{SR} = Surface CO_2 Flux

SR = Subsurface CO_2 Production

Radio-carbon simulation in CLM4-BeTR