Matrix-based diagnosis of plant biomass response to environmental change—an example of warming response in permafrost ecosystem

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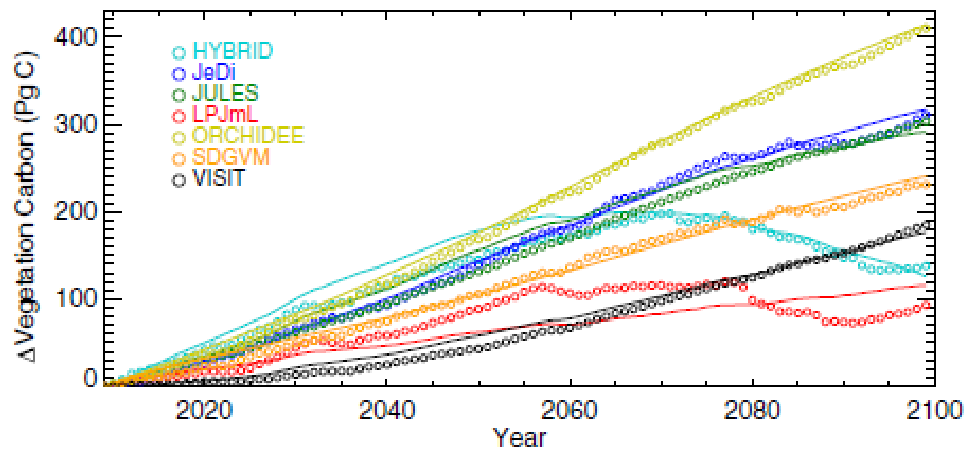
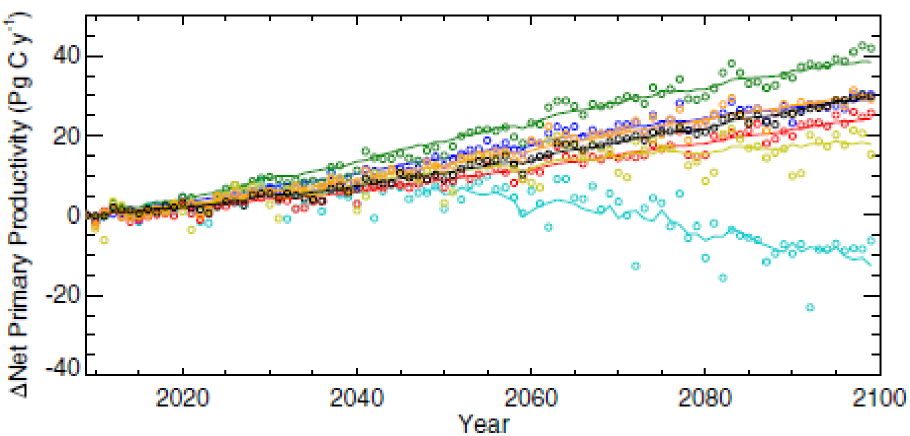
Outline

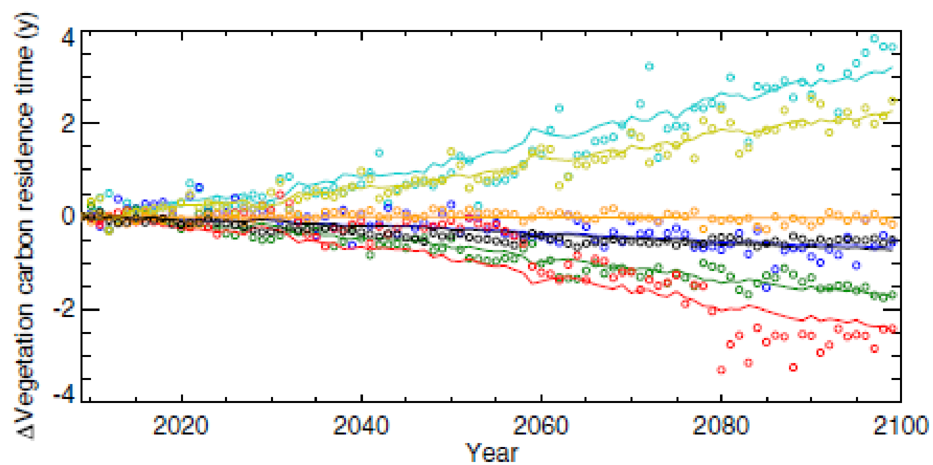
- Motivation
- Matrix-based CLM vegetation model
- An application example

Model uncertainties in vegetation C response

- Modeling growth in global vegetation carbon are in great uncertain among global vegetation models.







Friend et al., 2015 (PNAS)

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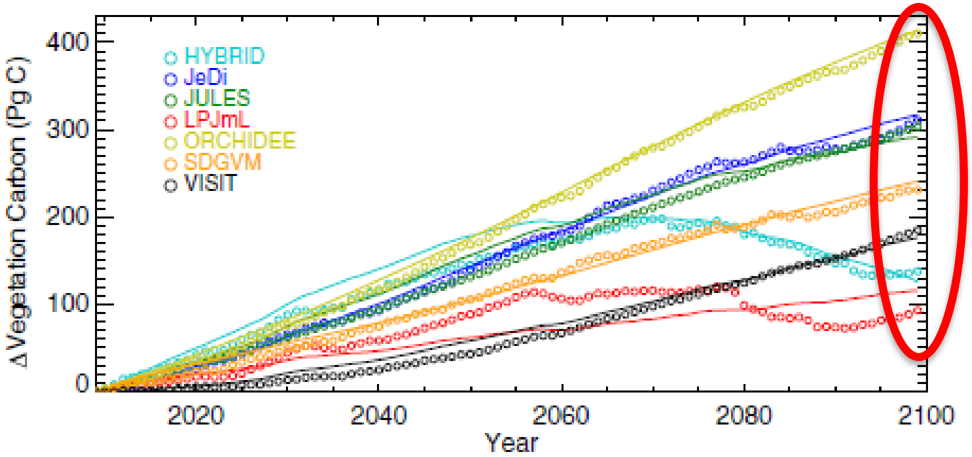
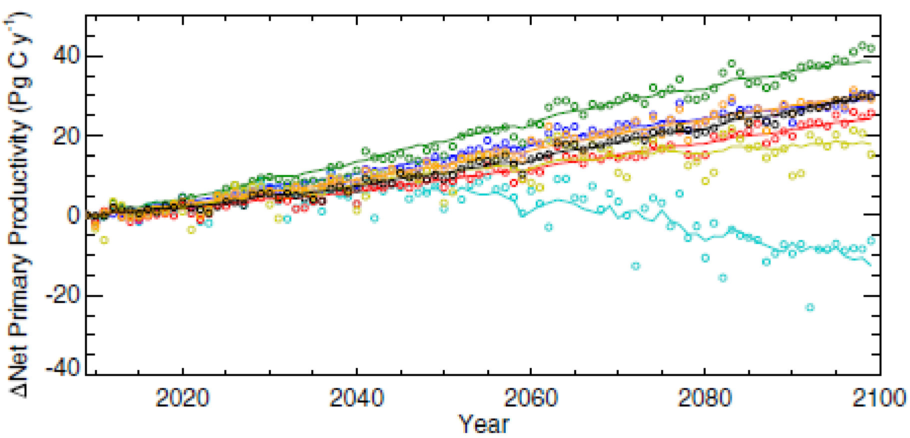
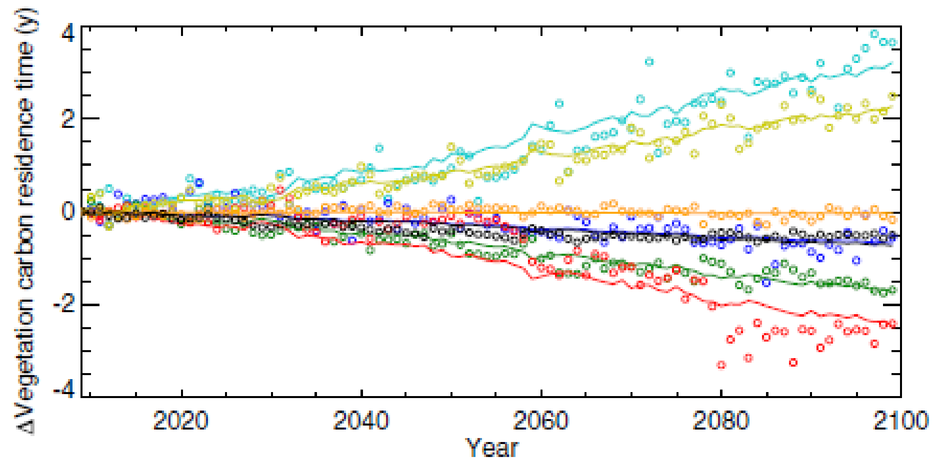
Model uncertainties in vegetation C response

- Modeling growth in global vegetation carbon are in great uncertain among global vegetation models.

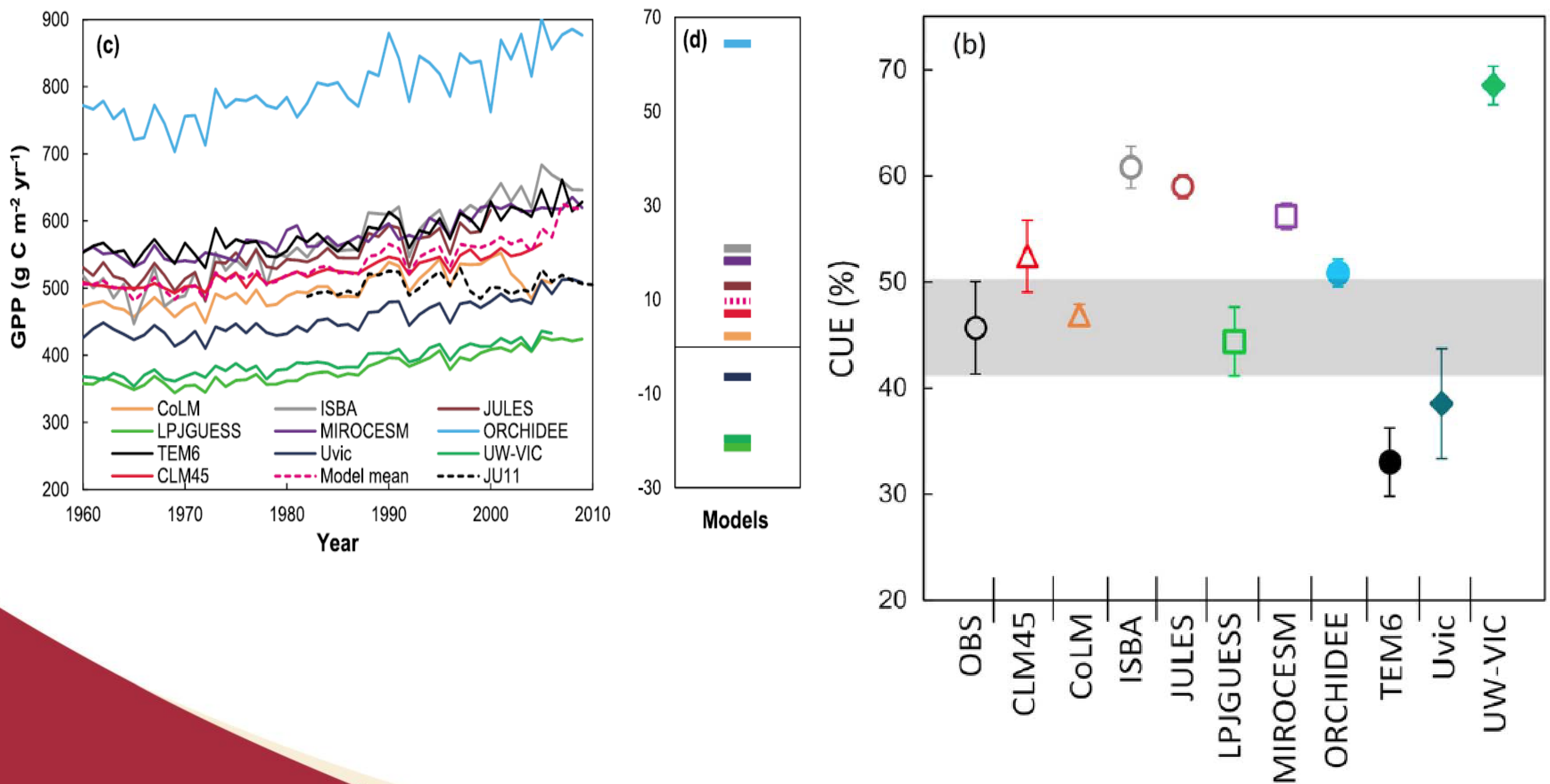






Friend et al., 2015 (PNAS)

Uncertainties in permafrost modeling



Xia et al., 2017 (JGR-biogeoscience)

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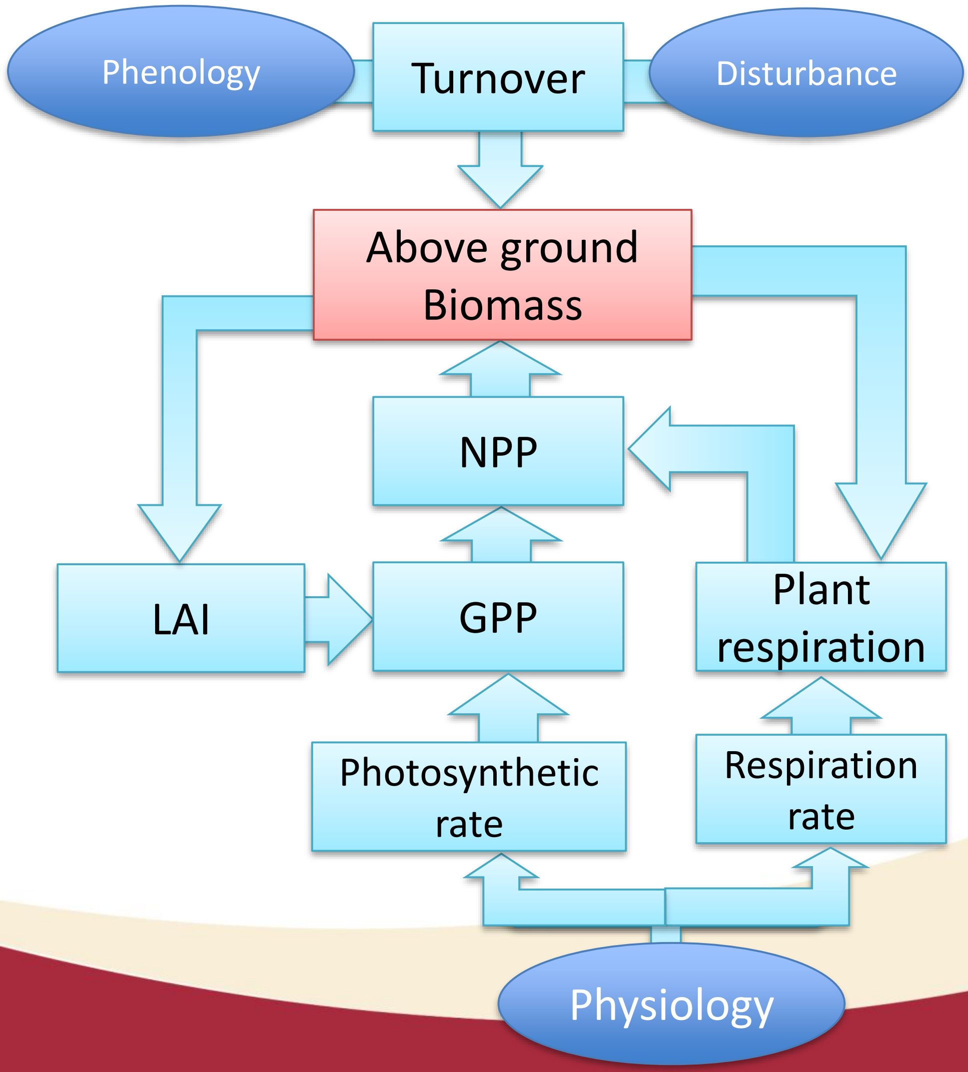
Joint controls in vegetation C diagnosis

Difficulties in diagnosing modeled vegetation C cycle:

- Variables in vegetation C cycle are interacted with each other.
- Effects from different processes are hard to be isolated

CLM vegetation C cycle



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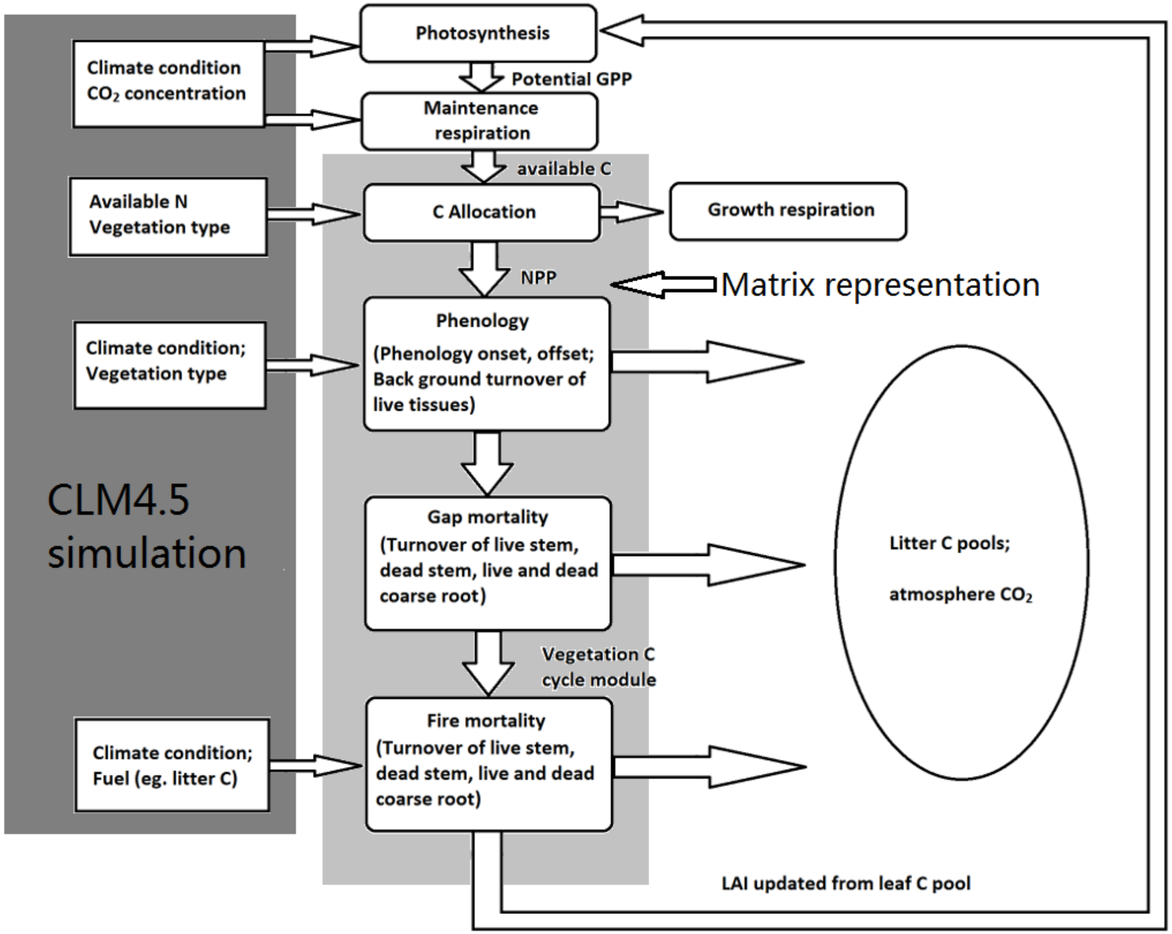
A simple vegetation C model isolated from CLM4.5

- Aims to segregated effects from different processes
- Environmental drivers from CLM4.5 includes: canopy temperature, soil moisture, soil mineral N, snow depth and so on.



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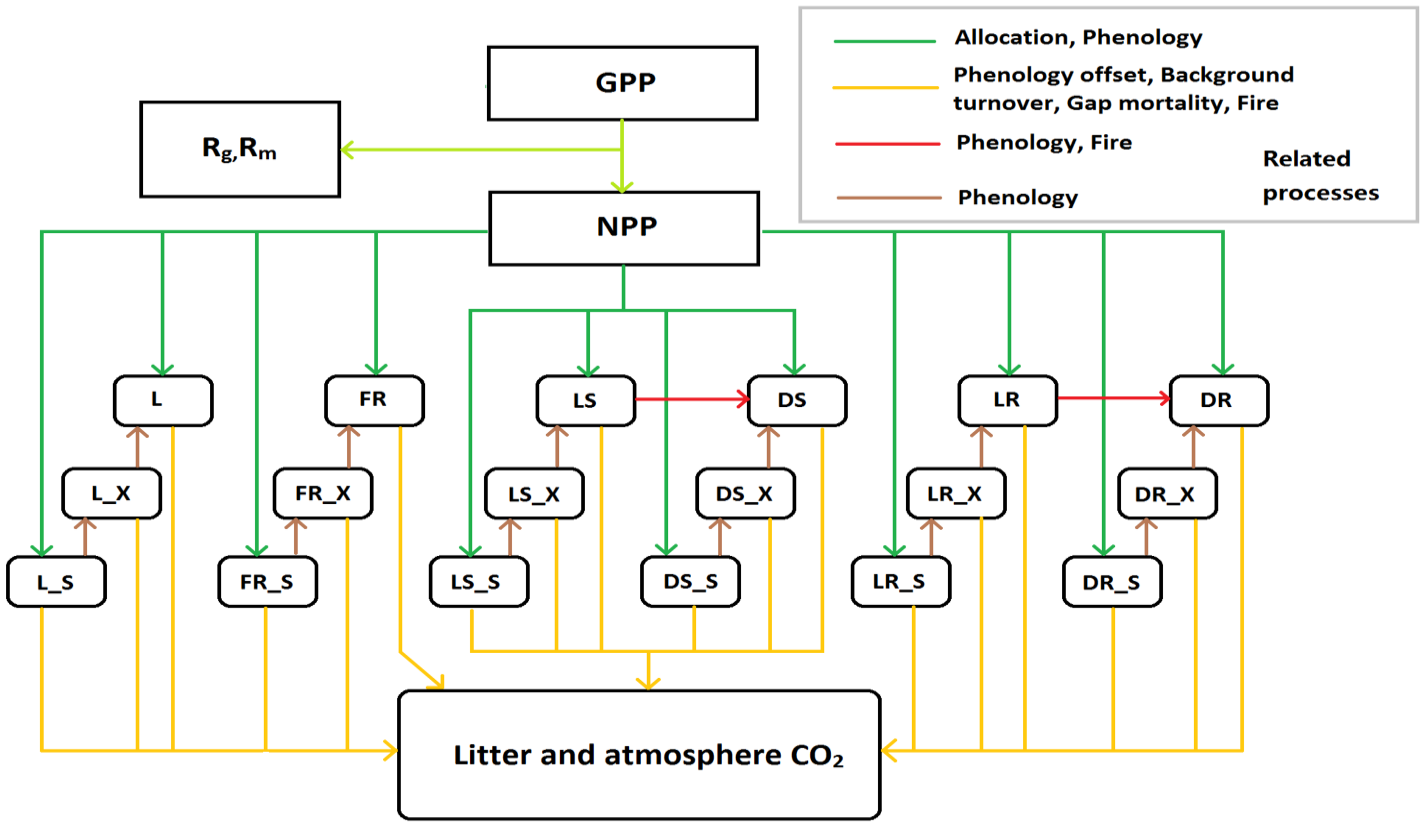
CLM vegetation C transfers among 18 pools



L: leaf;
FR: fine root;
LS: live stem;
DS: dead stem;
LR: live coarse root;
DR: dead coarse root;

L_X: leaf transfer;
FR_X: fine root transfer;
LS_X: live stem transfer;
DS_X: dead stem transfer;
LR_X: live coarse root transfer;
DR_X: dead coarse root transfer;

L_S: leaf storage
FR_S: fine root storage
LS_S: live stem storage
DS_S: dead stem storage
LR_S: live coarse root storage
DR_X: dead coarse root storage

Matrix representation

- Vegetation C dynamics:

$$\frac{dX(t)}{dt} = Bu(t) - (A_p(t)K_p(t) + A_mK_m + A_fK_f(t))X(\mathrm{t})$$

X (vector): C pool sizes;

B (vector): allocation;

u (scalar): NPP;

A (matrix): transfer ratio among pools;

K (diagonal matrix): turnover rate.

Subscripts ***p***, ***m*** and ***f*** indicates: phenology, gap mortality and fire processes.

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How does the matrix look like?

For examples: Phenology transfer matrix

Display pools | Transfer pools | Storage pools

$$
A_p = \begin{array}{c} \\ \end{array}
\overset{\begin{array}{cccccccccccccccccc} l & fr & ls & ds & lcr & dcr & l_{xfer} & fr_{xfer} & ls_{xfer} & ds_{xfer} & lcr_{xfer} & dcr_{xfer} & l_{st} & fr_{st} & ls_{st} & ds_{st} & lcr_{st} & dcr_{st} \end{array}}{
\begin{pmatrix}
-1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1
\end{pmatrix}}
$$

Rows 1–6: Display pools

Rows 7–12: Transfer pools

Rows 13–18: Storage pools

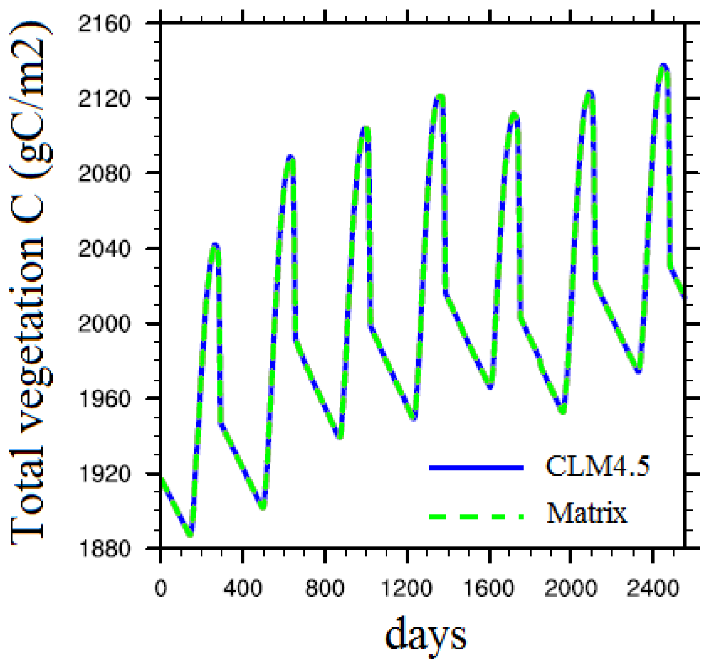
How does the matrix look like?

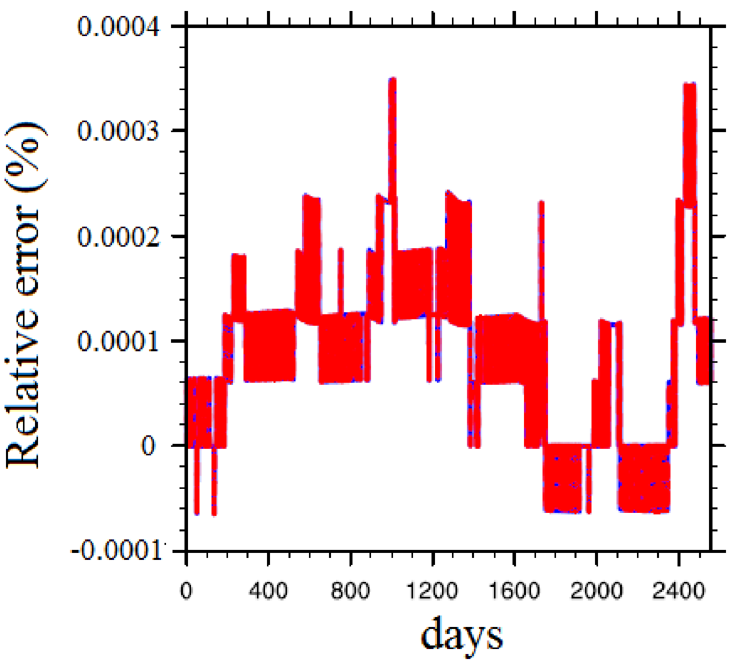
- $K_p = \begin{pmatrix} -k_{leaf} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & -k_{dcr\_st} \end{pmatrix}$

- k_i = turnover C / original C pool size

- $B = \begin{pmatrix} a_{leaf} \\ \vdots \\ a_{dcr\_st} \end{pmatrix}$

Matrix model validation





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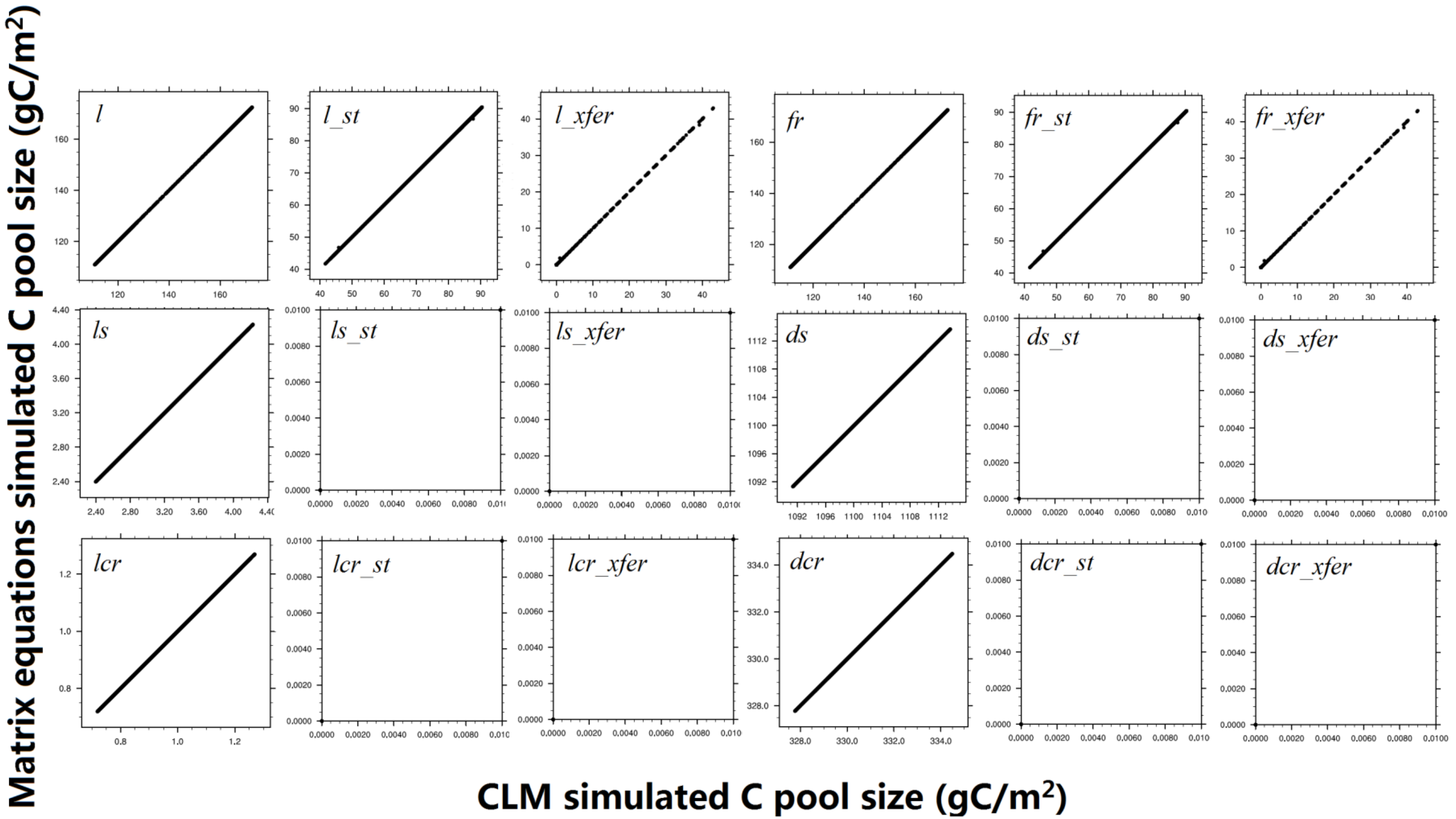
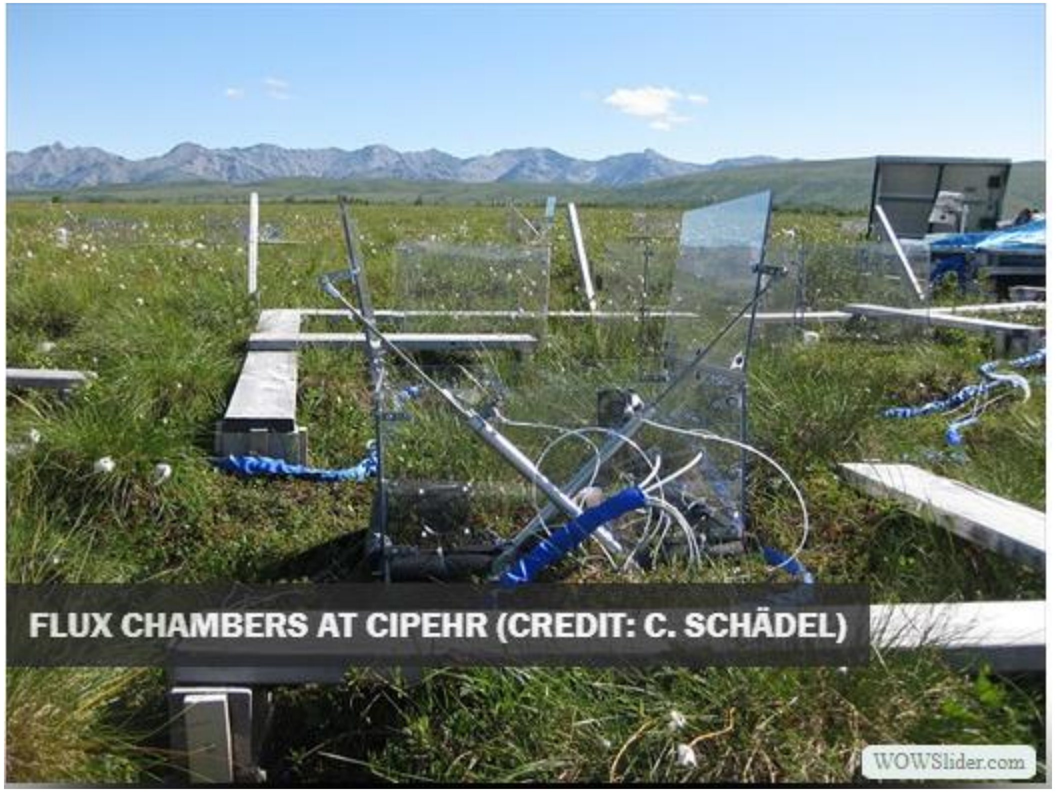
Matrix model validation (individual pool)



Simulations on an air warming experiment

- The Carbon in Permafrost Experimental Heating Research (CiPEHR) in Alaska established in 2008

- Air warming experiments use open top chamber (OTC) to increase air temperature by 2°C during summer season.



https://www2.nau.edu/schuurlab-p/CiPEHR.html

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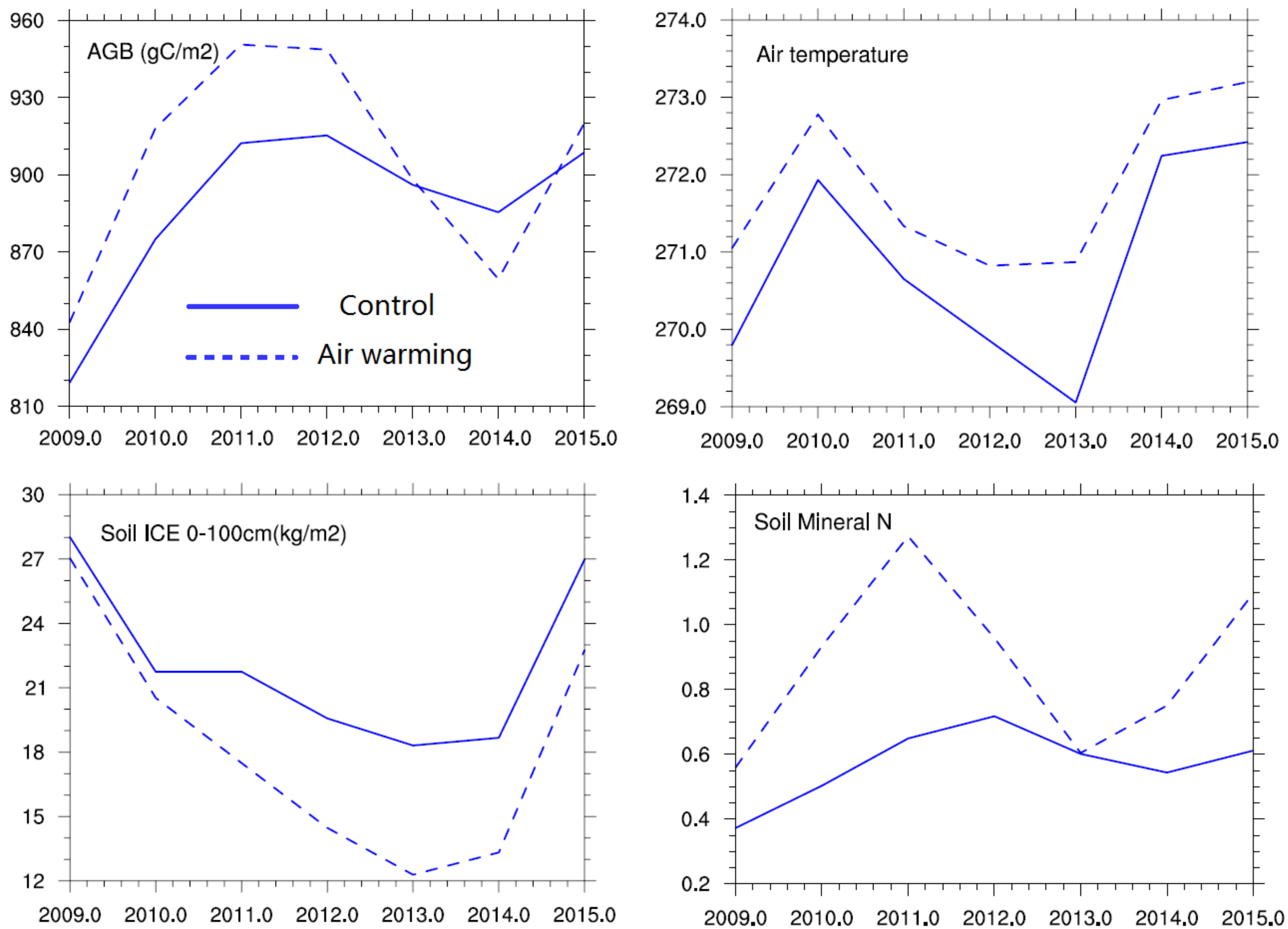
CLM simulation setup

- CLM4.5 simulation is initialized in 1901 using span up vegetation and soil C pool sizes.
- Spin up is driven by using cycled 1901-1910 CRUNCEP forcing (QIAN, Version7)
- Historical simulation is from 1901 to 2008 to enable vegetation and soil steadily increase in a transient state.
- Two runs (air warming vs. control) use adjusted temperature and precipitation based on site-level annual observation data.

Warming response from CLM4.5



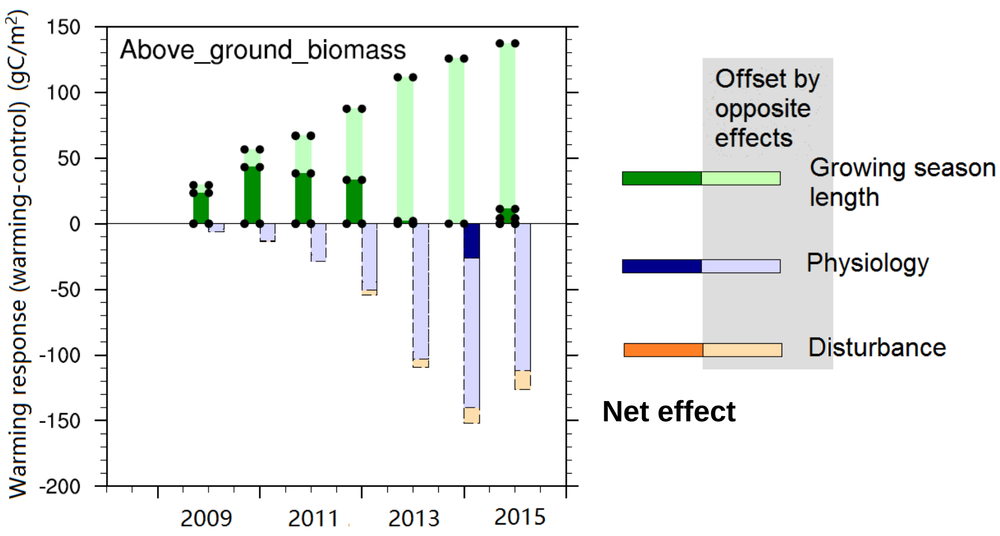
Matrix-based diagnosis

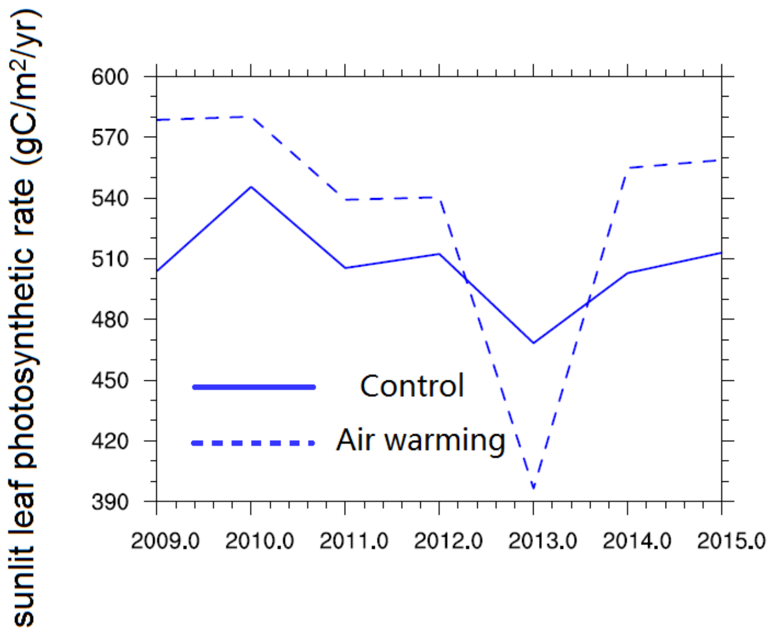
$$\frac{dX(t)}{dt} = Bu(t) - (A_p(t)K_p(t) + A_mK_m + A_fK_f(t))X(\mathrm{t})$$

$$\mathrm{u(t)} = f(psn, r_m(T), LAI(psn, r_m, A_p, K_p, A_m, K_m, A_f, K_f))$$

Simulation abbreviation	Physiology component	Phenology matrix	Disturbance matrix
S_pgd	psn_c, r_m_c	A_p_c, K_p_c	A_m_c, K_m_c, A_f_c, K_f_c
S_Pgd	psn_w, r_m_w	A_p_c, K_p_c	A_m_c, K_m_c, A_f_c, K_f_c
S_PGd	psn_w, r_m_w	A_p_w, K_p_w	A_m_c, K_m_c, A_f_c, K_f_c
S_PGD	psn_w, r_m_w	A_p_w, K_p_w	A_m_w, K_m_w, A_f_w, K_f_w

Response in above ground biomass





Future application

- Data assimilation

  30 times faster than original CLM.

- Spin up:

$$X_C = (A_p(t)K_p(t) + A_mK_m + A_fK_f(t))^{-1}B(t)$$

Summary

- Matrix representation is a useful tool to segregate effects from vegetation C cycle processes with strong interaction.

- Simulated warming response in plant biomass and productivity in permafrost ecosystem is mainly controlled by two processes--phenology (positive) and physiology (negative).

Thanks for your attention