Tentative schedule for

4th Training course (virtual) on

New Advances in Land Carbon Cycle Modeling

(17-28 May 2021 with weekend on 22 and 23 off)

Note: All time in this schedule refers to the time in **Phoenix, Arizona, US** (UTC-7)

Overview: This virtual training course will have 10 units. Units 1-5 are on the matrix approach to land carbon cycle modeling. Attendee will learn how to convert land carbon cycle models to matrix equations (units 1 and 2), add diagnostic variables in the models (unit 3), implement semi-analytic spin-up (SASU) to accelerate model initialization (unit 4), and conduct traceability analysis (unit 5). In addition, attendees will learn about general theory and some essential concepts behind the matrix approach in units 1-5. Units 6-10 are on data assimilation, ecological forecasting, and machine learning. Attendees will learn essential concepts and seven-step procedure of data assimilation (unit 6), make an application to SPRUCE project (unit 7), evaluate value of different data sets (unit 8), conduct ecological forecasting (unit 9), and combine machine learning with data assimilation to improve predictions (unit 10).

Design of training units: We strive to design lectures to be understandable and practices to be doable by attendees with minimal background in modeling. Meanwhile, we offer options for attendees with advanced modeling skills to work on specific projects. We are particularly ready to help you apply the matrix approach to your own models or conduct data assimilation with your own data. Meanwhile, nine invited talks will present you the latest results on relevant research subjects.

Materials available for training: In support to this training course, we have prepared pre-recorded lectures (videos) and a book (manuscripts for this year), *Land Carbon Cycle Modeling: Matrix Approach, Data Assimilation, and Ecological Forecasting*. The book also has 10 units. Each unit has three chapters and one practice. Each chapter is corresponding to one pre-recorded lecture and one pre-recorded instruction is for one practice. (There are two chapters in the book but three pre-recorded lectures for units 9 and 10.) We have also prepared three additional chapters and corresponding pre-recorded preparatory lectures on linear algebra, Python programming, and training package CarboTrain. The latter is designed to help you do practices.

Methods: The training will be mostly conducted in asynchrony in combination with synchronized (i.e., live virtual) meetings via Zoom. For each unit, attendees will attend one synchronized virtual meeting, read three book chapters (but two for units 9 and 10), listen to three pre-recorded lectures, take quizzes for each lecture, and do one practice according to pre-recorded instruction (most of the practices will be done through a training package, CarboTrain). Our instructors will go over your answers to quizzes and practices to ensure that you understand the concepts and master the skills. In each synchronized virtual meeting, we will have one invited talk (starting from unit 2), assess your learning in the previous unit, give an overview on the current unit, and answer your questions.

Attendees who do not have much background in linear algebra and/or Python programming need to study the **preparatory lectures before 17 May**.
L0.1 Ye Chen: Matrix algebra in land carbon cycle modeling
L0.2 Xin Huang: Brief introduction on programming in Python

Before the training course starts, all the attendees need to install CarboTrain according to L0.3 Yuan Gao: CarboTrain user guide for Carbon cycle modeling Training course.

All the attendees need to attend the opening meeting at the very beginning of the training course and the virtual meeting for each unit via Zoom unless the time is not good for you (the Zoom meeting will be recorded and shared with attendees). In addition, we offer a virtual mixing via Zoom each day (attending this virtual mixing is optional).

Times: Attendees go through 10 units at your locations, one unit per day from 17-28 May 2021 (with weekend on 22 and 23 off). Attendees may need to spend about 4 hours to finish one unit.

The opening meeting via Zoom (7:00am on 17 May)
Introduction by attendees and instructors by groups
Yiqi Luo: Overview and objectives of the virtual training course
Yiqi Luo: Overview of training in unit 1

Unit 1: Carbon flow diagrams and balance equations

Pre-recorded lectures (* indicates the lecture is essential for attendees to do practices)
L1.1 Ben Smith: Introduction to modeling
L1.2 *Yiqi Luo: Theoretical foundation of carbon cycle in terrestrial ecosystems
L1.3 *Yuanyuan Huang: Carbon flow diagrams and balance equations of TECO, CLM, and ORCHIDEE

Pre-recorded instruction for practice
P1 Yuanyuan Huang: Carbon flow diagrams and balance equation practice

Synchronized mixing via Zoom (5:00pm on 17 May)

Unit 2: **Matrix representation of carbon balance equations and coding**

Synchronized virtual meeting (7:00am on 18 May)
- Invited talk by Will Wieder, National Center for Atmospheric Research, USA
- General assessment of learning for the last unit and overview on this unit
- Q&A

Pre-recorded lectures
L2.1 *Yuanyuan Huang: Development of matrix models for TECO, CLM and/or ORCHIDEE
L2.2 Zheng Shi and Xingjie (Chris) Lu: Coupled carbon-nitrogen Matrix models

L2.3 Carlos Sierra: Compartmental systems

Pre-recorded instruction for practice
P2 Yuanyuan Huang: Matrix representation of carbon balance equations and coding

Synchronized mixing via Zoom (5:00pm on 18 May)

Unit 3: **Diagnostics of carbon cycle with matrix models for uncertainty analysis**

Synchronized virtual meeting (7:00am on 19 May)
- Invited talk by Susan Trumbore, Max Planck Institute for Biogeochemistry, Germany
- General assessment of learning for the last unit and overview on this unit
- Q&A

Pre-recorded lectures
L3.1 *Yiqi Luo: Unified diagnostic system for uncertainty analysis
L3.2 Yuanyuan Huang: Sensitivity analysis with matrix equations of ORCHIDEE
L3.3 Enqing Hou: Matrix phosphorus model and data assimilation

Pre-recorded instruction for practice
P3 Xingjie (Chris) Lu: Diagnostic variables in matrix models

Synchronized mixing via Zoom (5:00pm on 19 May)

Unit 4: **Semi-analytic spin-up (SASU)**

Synchronized virtual meeting (7:00am on 20 May)
- Invited talk by Chris Jones, Meteorological Office, UK
- General assessment of learning for the last unit and overview on this unit
- Q&A

Pre-recorded lectures
L4.1 Ying Wang: An introduction to ordinary differential equation system solver and stability analysis of the terrestrial carbon dynamics
L4.2 *Xingjie (Chris) Lu: Semi-Analytic Spin-Up (SASU) of coupled carbon-nitrogen cycle model
L4.3 Carlos Sierra: Time characteristics of land carbon cycle

Pre-recorded instruction for practice
P4 Xingjie (Chris) Lu: Efficiency and convergence of semi-analytic spin-up (SASU) in TECO

Synchronized mixing via Zoom (5:00pm on 20 May)

Unit 5: **Traceability and benchmark analysis**

Synchronized virtual meeting (7:00am on 21 May)

- Invited talk by Sönke_Zaehle, Max Planck Institute for Biogeochemistry, Germany_
- General assessment of learning for the last unit and overview on this unit
- Q&A

Pre-recorded lectures
L5.1 *Jianyang Xia: Overview of traceability analysis
L5.2 Lifen Jiang: Applications of traceability analysis
L5.3 Forrest Hoffman: Benchmark analysis

Pre-recorded instruction for practice
P5 Jianyang Xia and Jian Zhou: Traceability analysis for evaluating terrestrial carbon cycle model

Synchronized mixing via Zoom (5:00pm on 21 May)

Unit 6: **Introduction to data assimilation**

Synchronized virtual meeting (7:00am on 24 May)
- Invited talk by Alexandra Konings, Stanford University, USA
- General assessment of learning for the last unit and overview on this unit
- Q&A

Pre-recorded lectures
L6.1 *Yiqi Luo: Data assimilation: Introduction, procedure, and applications
L6.2 *Feng Tao: Bayesian statistics and Markov chain Monte Carlo method in data assimilation
L6.3 Junyi Liang: Application of data assimilation to soil incubation data

Pre-recorded instruction for practice
P6 Xin Huang: The seven-step procedure for data assimilation

Synchronized mixing via Zoom (5:00pm on 24 May)

Unit 7: **Data assimilation at the SPRUCE experiment and with satellite data**

Synchronized virtual meeting (7:00am on 25 May)
- Invited talk by Wenjuan Huang, Iowa State University, USA
- General assessment of learning for the last unit and overview on this unit
- Q&A

Pre-recorded lectures
L7.1 Daniel Ricciuto: A brief introduction to the SPRUCE experiment
L7.2 *Shuang Ma: Application of data assimilation to a peatland methane study
L7.3 Matthew Williams: Global Data Assimilation Using Earth Observation – the CARDAMOM approach

Pre-recorded instruction for practice

P7 Shuang Ma: Assimilation at the SPRUCE site using CarboTrain

Synchronized mixing via Zoom (5:00pm on 25 May)

Unit 8: **Values of data to constrain model and prediction**

Synchronized virtual meeting (7:00am on 26 May)

- Invited talk by Trevor Keenan, University of California, Berkeley, USA
- General assessment of learning for the last unit and overview on this unit
- Q&A

Pre-recorded lectures

L8.1 *Enqing Hou: Information contents of different types of data sets to constrain parameters and predictions

L8.2 Sasha Hararuk: Using data assimilation to identify mechanisms controlling lake carbon dynamics

L8.3 Zheng Shi: Data-constrained uncertainty analysis in global soil carbon models

Pre-recorded instruction for practice

P8.1 Enqing Hou: Information contents of land carbon pool and flux measurements to constrain land carbon model

Synchronized mixing via Zoom (5:00pm on 26 May)

Unit 9: **Ecological forecasting with EcoPAD**

Synchronized virtual meeting (7:00am on 27 May)

- Invited talk by Anna Trugman, University of California, Santa Barbara, USA
- General assessment of learning for the last unit and overview on this unit
- Q&A

Pre-recorded lectures

L9.1 Yiqi Luo: Introduction to ecological forecasting

L9.2 *Shuang Ma: Ecological Platform for Assimilating Data into model (EcoPAD) for ecological forecasting

L9.3 Xin Huang: Cyberinfrastructure to facilitate ecological forecasting (no book chapter)

Pre-recorded instruction for practice

P9 Jiang Jiang: Ecological forecasting at SPRUCE site

Synchronized mixing via Zoom (5:00pm on 27 May)

Unit 10: **Process-based machine learning and data-driven modeling (PRODA)**

Synchronized virtual meeting (7:00am on 28 May)

- Invited talk by Shilong Piao, Peking University, China.

- General assessment of learning for the last unit and overview on this unit
- Q&A

Pre-recorded lectures
L10.1 Toby Hocking: Introduction to machine learning and neural networks
L10.2 *Feng Tao: PROcess-guided deep learning and Data-driven modeling (PRODA)
L10.3 Umakant Mishra: Applications of machine learning to soil carbon research (no book chapter)

Pre-recorded instruction for practice
P10 Feng Tao: Deep learning for optimizing parameters estimated from data assimilation with CLM5 matrix model

Synchronized mixing and closing via Zoom (5:00pm on 28 May)