

Schedule for

6th Training course (primarily online with an option of in-person) on

New Advances in Land Carbon Cycle Modeling

(5-16 June 2023 with weekend on 10 and 11 off)

Note: All time in this schedule refers to the time in **Eastern Daylight Time (EDT), USA.**

Overview: This 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 theories and essential concepts behind the matrix approach in units 1-5. Units 6-10 are on data assimilation, ecological forecasting, machine learning and deep learning. Attendees will learn essential concepts and the seven-step procedure of data assimilation (unit 6), conduct data assimilation with data from field studies and remote sensing (unit 7), perform ecological forecasting (unit 8), apply machine learning in carbon cycle research (unit 9), and integrate deep 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 and machine learning 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, *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. We have prepared a pre-recorded lecture and a pre-recorded instruction for each chapter and each practice, respectively. Note that the content of unit 8 in the book is no longer used and the content of unit 9 in the book is now unit 8. We have added machine learning in carbon cycle research as unit 9 since 2022. There are pre-recorded preparatory lectures with three corresponding book chapters, respectively, on linear algebra, Python programming, and the software, *CarboTrain*. The latter was developed for the practice sessions of the training course.

Methods: The 6th training course will primarily be held online. We also offer an option for in-person interactions if attendees plan to travel to Ithaca, New York, USA for two weeks. Both online and in-person attendees will take the course mostly 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 (or supplementary materials if any), listen to three pre-recorded lectures, take a quiz for each lecture, and do one practice according to pre-recorded instruction (most of the practices will be done with *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.

We offer in-person interactions with attendees who travel to Ithaca, New York, USA. Specifically, we will have in-person discussion session with those in-person attendees in each afternoon during the training course. Note that in-person attendees will study the materials in the same way as the online attendees.

Attendees who do not have much background in linear algebra and/or Python programming need to study the preparatory lectures as described in the two appendix chapters in the book before 5 June, 2023.

Appendix 1 Ye Chen: Matrix algebra in land carbon cycle modeling

Appendix 2 Xin Huang: Brief introduction on programming in Python

****Important****: All attendees need to install *CarboTrain* following Appendix 3 before the training course starts as:

Appendix 3 Jian Zhou & Yuan Gao: *CarboTrain* user guide for Carbon cycle modeling Training course. Please use Appendix 3 in the link, <https://ecolab.cals.cornell.edu/?workshop>, instead of Appendix 3 in the book for the installation.

All attendees need to attend the opening meeting on the first day and the virtual meeting for each unit via Zoom unless the time is not good for you (the Zoom meetings 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 5-16 June 2023 (with weekend on 10 and 11 off). Attendees may need about 4 hours to finish one unit.

The opening meeting via Zoom (10:00-11:00am on 5 June)

Introduction by attendees and instructors by groups

Yiqi Luo: Overview and objectives of the training course

Yiqi Luo: Overview of unit 1

Unit 1: Fundamentals of carbon cycle modeling

Pre-recorded lectures (* indicates the lecture is essential for attendees to do practices)

L1.1 *Yiqi Luo: Theoretical foundation of the land carbon cycle and matrix approach

L1.2 Ben Smith: Introduction to carbon cycle modeling

L1.3 *Yuanyuan Huang: Flow diagrams and balance equations of land carbon cycle models

Pre-recorded instruction for practice

P1 Yuanyuan Huang: Developing carbon flow diagrams and balance equation

Synchronized mixing via Zoom (8:00pm on 5 June)

Unit 2: Matrix representation of carbon balance

Synchronized virtual meeting (10:00-11:00am on 6 June)

- Invited talk by Chris Field on carbon dioxide removal and nature-based solutions
- General assessment of learning for the last unit and overview on the current unit
- Q&A

Pre-recorded lectures

L2.1 *Yuanyuan Huang: Developing matrix representation of land carbon models

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 (8:00pm on 6 June)

Unit 3: Carbon cycle diagnostics for uncertainty analysis

Synchronized virtual meeting (10:00-11:00am on 7 June)

- Invited talk by Pierre Gentine
- General assessment of learning for the last unit and overview on the current 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: A case study with 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 (8:00pm on 7 June)

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

Synchronized virtual meeting (10:00-11:00am on 8 June)

- Invited talk by Stafeno Manzoni
- General assessment of learning for the last unit and overview on the current unit
- Q&A

Pre-recorded lectures

L4.1 Ying Wang: Non-autonomous ODE system solver and stability analysis

L4.2 *Xingjie (Chris) Lu: Semi-Analytic Spin-Up (SASU) of coupled carbon-nitrogen cycle models

L4.3 Carlos Sierra: Time characteristics of compartmental systems

Pre-recorded instruction for practice

P4 Xingjie (Chris) Lu: Efficiency and convergence of semi-analytic spin-up (SASU) in TECO

Synchronized mixing via Zoom (8:00pm on 8 June)

Unit 5: Traceability and benchmark analysis

Synchronized virtual meeting (10:00-11:00am on 9 June)

- Invited talk by Ying Sun
- General assessment of learning for the last unit and overview on the current unit
- Q&A

Pre-recorded lectures

L5.1 *Jianyang Xia: Overview of traceability analysis

L5.2 *Lifen Jiang: Applications of the transient traceability framework

L5.3 Forrest Hoffman: Benchmark analysis

Pre-recorded instruction for practice

P5 Jianyang Xia & Jian Zhou: Traceability analysis for evaluating terrestrial carbon cycle models

Synchronized mixing via Zoom (8:00pm on 9 June)

Unit 6: Introduction to data assimilation

Synchronized virtual meeting (10:00-11:00am on 12 June)

- Invited talk by Paul Levine
- General assessment of learning for the last unit and overview on the current 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 (8:00pm on 12 June)

Unit 7: Data assimilation with field measurements and satellite data

Synchronized virtual meeting (10:00-11:00am on 13 June)

- Invited talk by Song Wang
- General assessment of learning for the last unit and overview on the current unit
- Q&A

Pre-recorded lectures

L7.1 Daniel Ricciuto: Model-data integration at 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: Data assimilation at the SPRUCE site.

Synchronized mixing via Zoom (8:00pm on 13 June)

Unit 8: Ecological forecasting with EcoPAD

Synchronized virtual meeting (10:00-11:00am on 14 June)

- Invited talk by Paul Hanson
- General assessment of learning for the last unit and overview on the current unit
- Q&A

Pre-recorded lectures

L8.1 Yiqi Luo: Introduction to ecological forecasting

L8.2 *Shuang Ma: Ecological Platform for Assimilating Data (EcoPAD) for ecological forecasting

L8.3 Xin Huang: Cyberinfrastructure to facilitate ecological forecasting (no book chapter)

Pre-recorded instruction for practice

P8 Jiang Jiang: Ecological forecasting at the SPRUCE site

Synchronized mixing via Zoom (8:00pm on 14 June)

Unit 9: Applications of machine learning to carbon cycle research

Synchronized virtual meeting (10:00-11:00am on 15 June)

- Invited talk by Julia Green
- General assessment of learning for the last unit and overview on the current unit
- Q&A

Pre-recorded lectures

L9.1 *Yuanyuan Huang: Machine learning in carbon cycle research (scripts)

L9.2 Yao Zhang: Long-short term memory network for Earth science (scripts)

L9.3 Yu Jiang: Sensing, AI, and Robotics for Sustainable and Resilient Specialty Crops Production (no scripts)

Pre-recorded instruction for practice

P9 Feng Tao & Kostiantyn Viatkin: Applications of random forest for global soil carbon mapping (scripts)

Synchronized mixing via Zoom (8:00pm on 15 June)

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

Synchronized virtual meeting (10:00-11:00am on 16 June)

- Invited talk by Forrest Hoffman
- General assessment of learning for the last unit and overview on the current unit
- Q&A

Pre-recorded lectures

L10.1 Toby Hocking: Introduction to machine learning and neural networks

L10.2 *Feng Tao and Yiqi Luo: 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 to optimize parameterization of CLM5.

Synchronized mixing and closing via Zoom (8:00pm on 16 June)