From EddyPro to Tovi: Advanced Analysis of Flux Results

Dave Johnson
Senior Product Manager

LI-COR

Introduction

- LI-COR is in the business of innovation.

  We work closely with our research partners to understand their needs, applying our scientific and engineering talents to develop innovative solutions to address those needs.

- LI-COR mission: “Impacting Lives through Science.”

  Together we will move toward a deeper understanding of our fields of interest and make an impact on the world.

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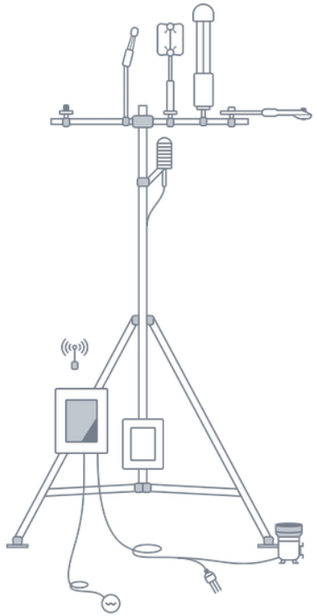
Eddy Covariance Data/Workflow Pipeline

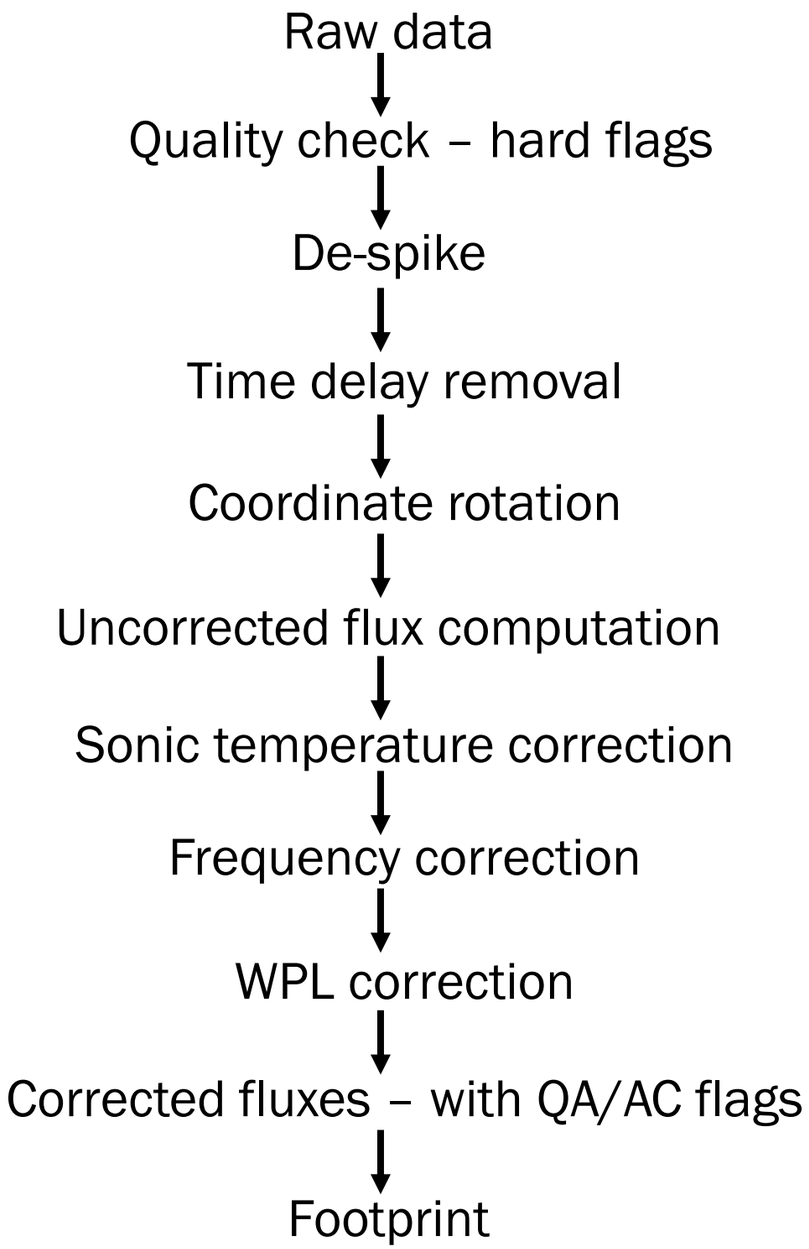
Raw Data Collection → Data Processing → Post-Processing and Analysis → Publication



10 or 20 samples/sec ≈
36,000 records/hour
(.ghg files)

Data Processing

- Computing Fluxes



Option	Settings	
Crosswind correction:	Not applied in EddyPro; assuming the correction was applied by the sonic anemometer.	
Processing Options		
Axis rotation for tilt correction:	Double rotation	
Turbulent fluctuations:	Block averaging	
Time lag compensation:	Covariance maximization	
Statistical Tests		
Spike count/removal:	Maximum number of consecutive outliers: 3 Accepted spikes: 1.0% Replace spikes with linear interpolation: Yes Plausibility ranges: • W: 5.0 [σ] • CO_2: 3.5 [σ] • H_2O: 3.5 [σ] • CH_4: 8.0 [σ] • 4^{th} Gas: 8.0 [σ] • All other variables: 3.5 [σ]	
Amplitude resolution:	Range of variation: 7.0 [σ] Number of bins: 100 Accepted empty bins: 70%	
Drop-outs:	Percentile defining extreme bins: 10 Accepted central drop-outs: 10.0 [σ] Accepted extreme drop-outs: 6.0%	
Absolute limits:	Minimum • U: -30.0 [m/s] • W: -5.0 [m/s] • T_s: -20.0 [°C] • CO_2: 200 [µmol/mol] • H_2O: 0.0 [mmol/mol] • CH_4: 0.170 [µmol/mol] • 4^{th} Gas: 0.03 [µmol/mol]	Maximum • U: 30.0 [m/s] • W: 5.0 [m/s] • T_s: 50.0 [°C] • CO_2: 600 [µmol/mol] • H_2O: 40.0 [mmol/mol] • CH_4: 1000 [µmol/mol] • 4^{th} Gas: 1000 [µmol/mol]
Skewness and kurtosis:	Hard-flag threshold • Skewness lower limit: -2.0 • Skewness upper limit: 2.0 • Kurtosis lower limit: 1.0 • Kurtosis upper limit: 8.0	Soft-flag threshold • Skewness lower limit: -1.0 • Skewness upper limit: 1.0 • Kurtosis lower limit: 2.0 • Kurtosis upper limit: 5.0

Data Processing: EddyPro Software

- A collaboration with the community:

  LI-COR collaborated with the IMECC consortium, the ECO$_2$S team, the Univ. of Tuscia (Italy), and scientists around the world.

- EddyPro data processing software:

  Open-source software developed, maintained, and supported by LI-COR Biosciences.

  Computes high-quality gas (CO_2, H_2O, CH_4,…) and energy fluxes with the Eddy Covariance method.

Data Processing: EddyPro

- Performs 24 to 58 processing steps to compute accurate flux data and avoid/correct potential errors and under- or over-estimation of the fluxes.

- Implementations based on 60+ peer-reviewed publications.

References

Note: References are linked to the original publication when possible.

Arya, S. P. 1998. Introduction to Micrometeorology. San Diego, Academic Press.

Aubinet, M., B. Chermanne, M. Vandenhaute, B. Longdoz, M. Yernaux and E. Laitat. 2001. Long term carbon dioxide exchange above a mixed forest in the Belgian Ardennes. Agricultural and Forest Meteorology, 108: 293-315.

Billesbach, D. 2011. Estimating uncertainties in individual eddy covariance flux measurements: A comparison of methods and a proposed new method. Agricultural and Forest Meteorology, 151: 394-405.

Burba, G. G., D. Mc Dermitt, A. Grelle, D. J. Anderson, and L. Xu. 2008. Addressing the influence of instrument surface heat exchange on the measurements of CO2 flux from open-path gas analyzers. Global Change Biology, 14:1854–1876.

Burba, G., A. Schmidt, R. L. Scott, T. Nakai, J. Kathilankal, G. Fratini, C. Hanson, B. Law, D. K. McDermitt, R. Eckles, M. Furtaw, and M. Velgersdyk. 2012. Calculating CO_2 and H_2O eddy covariance fluxes from an enclosed gas analyzer using an instantaneous mixing ratio. Global Change Biology, 18: 385-399.

Campbell, G. S. and J. M. Norman. 1998. Introduction to Environmental Biophysics. New York, Springer Science.

De Ligne, A. B. Heinesch, and M. Aubinet. 2010. New Transfer Functions for Correcting Turbulent Water Vapour Fluxes. Boundary-Layer Meteorology, 137: 205-221.

Fan, S. M., Wofsy, S. C., Bakwin, P. S., Jacob, D. J. and Fitzjarrald, D. R. 1990. Atmosphere-biosphere exchange of CO_2 and O_3 in the Central Amazon Forest. Journal of Geophysical Research, 95: 16851-16864.

Finkelstein, P. L., and P. F. Sims. 2001. Sampling error in eddy correlation flux measurements. Journal of Geophysical Research, 106: 3503-3509.

Finnigan, J.J., R. Clement, Y. Mahli, R. Leuning, H.A. Cleugh. 2003. A re-evaluation of long-term flux measurement techniques. Part I: averaging and coordinate rotation, Boundary-Layer Meteorology 107: 1–48.

Foken, T. and B. Wichura. 1996. Tools for quality assessment of surface-based flux measurements. Agricultural and Forest Meteorology, 78: 83-105.

Foken, T., M. Gockede, M. Mauder, L. Mahrt, B. D. Amiro, and J. W. Munger. 2004. Edited by X. Lee, et al. Post-field quality control, in Handbook of micrometeorology: A guide for surface flux measurements, Dordrecht: Kluwer Academic, 81-108.

Fratini, F., A. Ibrom, N. Arriga, G. Burba, D. Papale. 2012. Relative humidity effects of water vapour fluxes measured with closed-path eddy-covariance systems with short sampling lines. Agriculture and Forest Meteorology, 165: 53-63.

Gash, J. H. C. 1986. A note on estimating the effect of a limited fetch on micrometeorological evaporation measurements. Boundary-Layer Meteorology, 35: 409-413.

Gash, J. H. C. and A. D. Culf. 1996. Applying linear de-trend to eddy correlation data in real time. Boundary-Layer Meteorology, 79: 301-306.

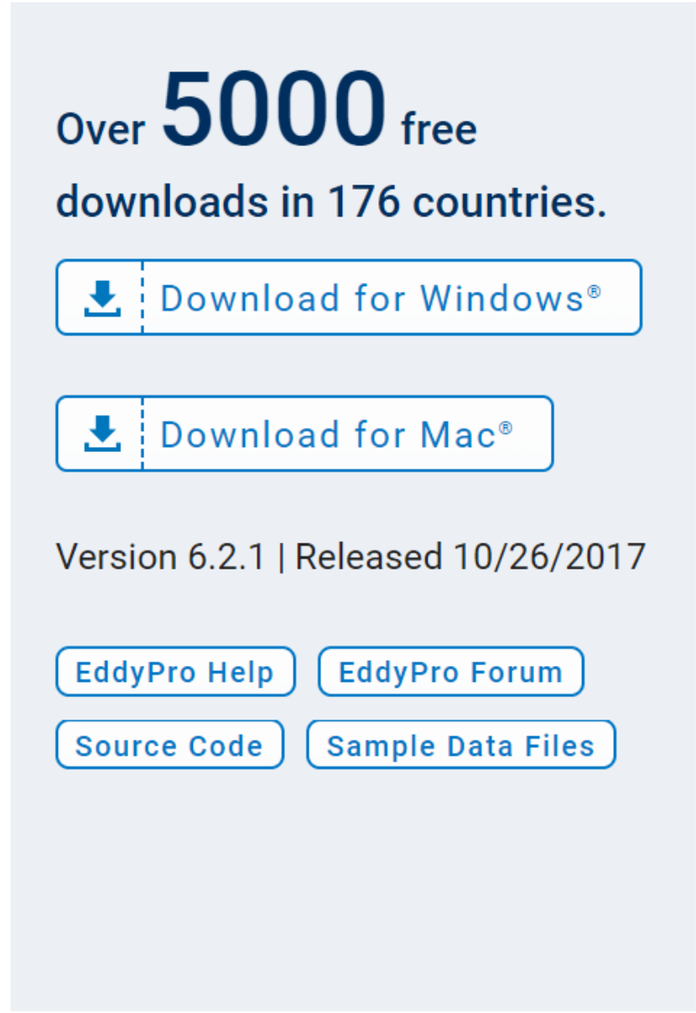
Data Processing: EddyPro Software

- A community standard:

  Widely adopted by researchers with over **5,000** individual downloads in 176 Countries and **400+** citations in peer-reviewed Journals.

  Adopted as the **standard software for data processing** by Flux networks including ICOS, AmeriFlux, the Chinese Ecosystem Research Network (CERN), and others.

- Available for free: download from LI-COR at www.licor.com/eddypro



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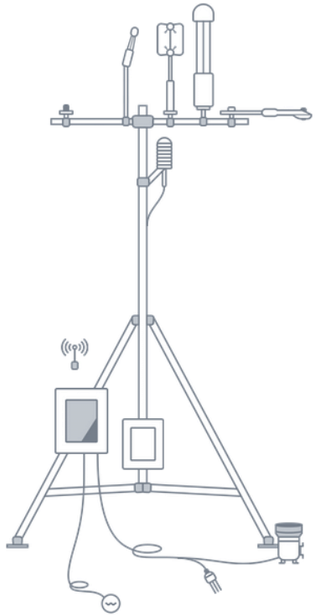

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30 minute files ≈
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(“full output” file)

Data Analysis: Common Post-Processing steps

- Quality Control
- Meteorological Gap Filling
- Averaging Replicates and/or Redundant Variables
- Friction Velocity (u*) Threshold Detection
- Flux Gap Filling
- Flux Partitioning
- Energy Balance Closure/Analysis
- Footprint Analysis
- …

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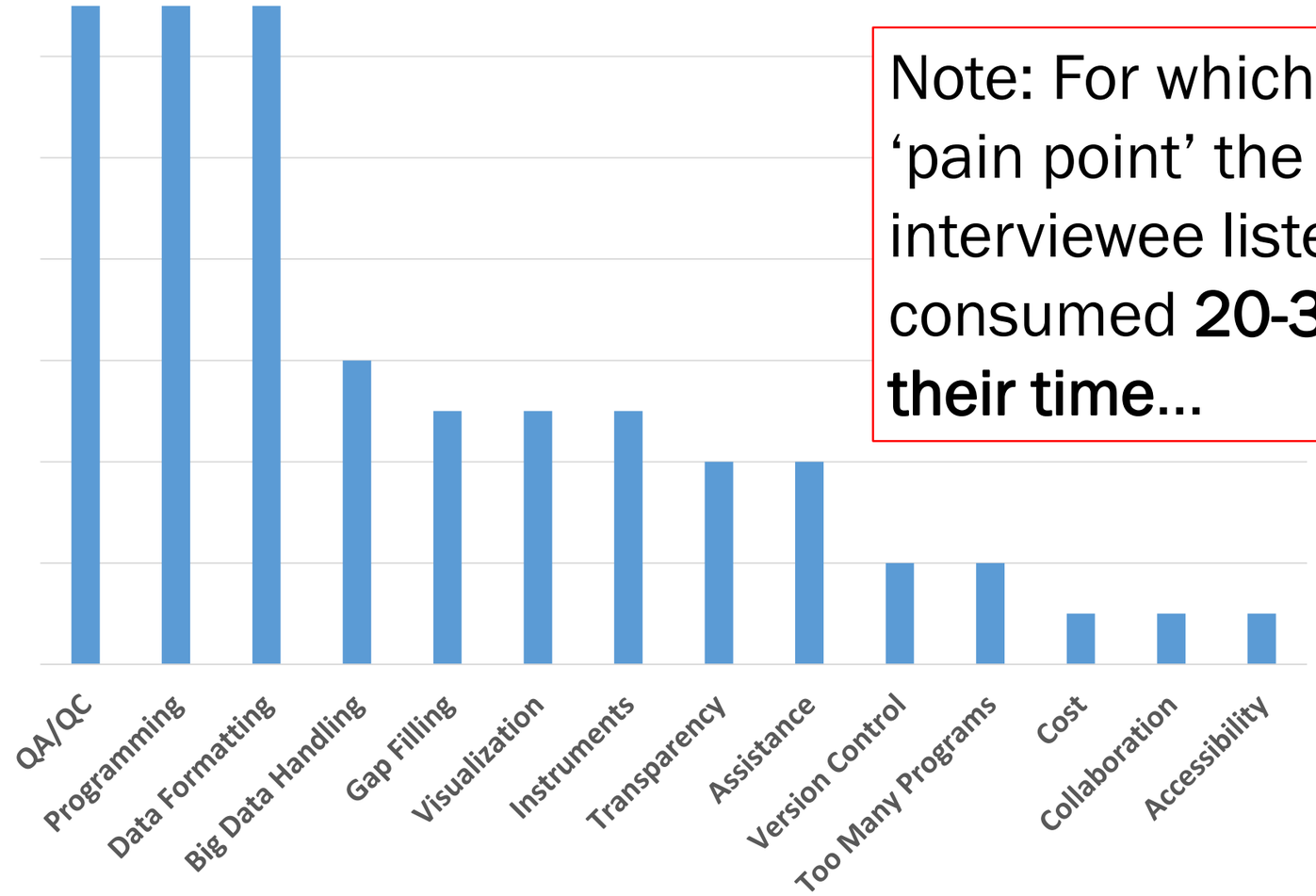
Is there a Market? (Data Analysis Pain Points)



Note: For whichever ‘pain point’ the interviewee listed, it consumed **20-30% of their time…**

In summary:

- save me time
- save me money
- make it easier
- make it reproducible

Post-Processing: Community Collaboration

- Post-processing software goals, in line with EddyPro strategy and our mission statement:
  - Collaborate with the community.
  - Assist in the furthering of scientific discovery.
  - Help scientists expand the reach of their new developments to a larger community (wider usage) and citing their work

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Post-Processing: Community Collaboration

- Post-processing software goals, in line with EddyPro strategy and our mission statement:
  - Pull everything together in a single platform.
  - Design an easy-to-use UI, a highly-visual experience.
  - Build a robust software.
  - Provide support through scientific staff and documentation.
  - Reproducibility, Transparency (open-source), Citable Documentation.
  - Continual additions, improvements, innovations…

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Introducing: Tovi Software

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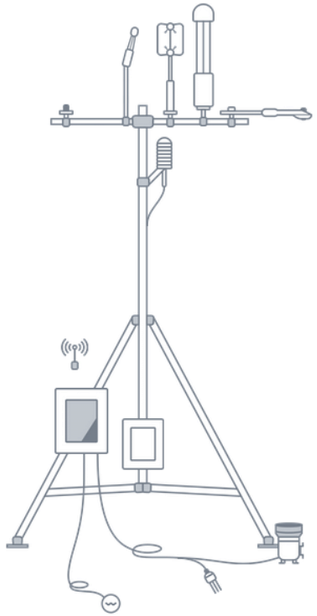

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Tovi Software Collaboration Efforts

- Began design and development two years ago.
- Collaboration with **OzFlux**
  - QC Screening
  - Meteorological Gap Filling
  - Averaging
    - *Isaac, P. et al., 2017*
- Collaboration with **ICOS, AmeriFlux, Euroflux**
  - U* Threshold Detection and Flux Gap Filling
    - *Reichstein, M. et al., 2005*
- Collaboration with world-class individual scientists
  - Footprint Analysis
    - *Kljun, N. et al., 2015.*

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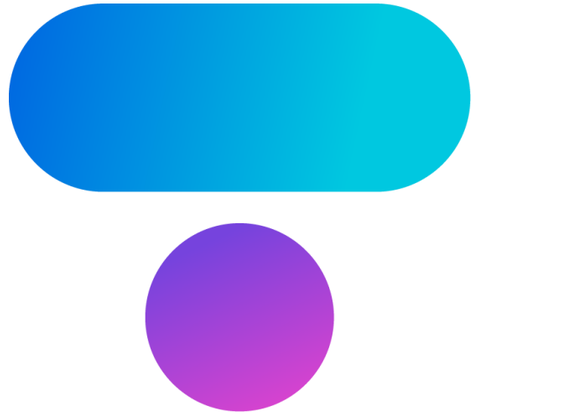
Tovi Software: Live Demonstration



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Tovi Software: Coming Soon

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ICOS Quality Check

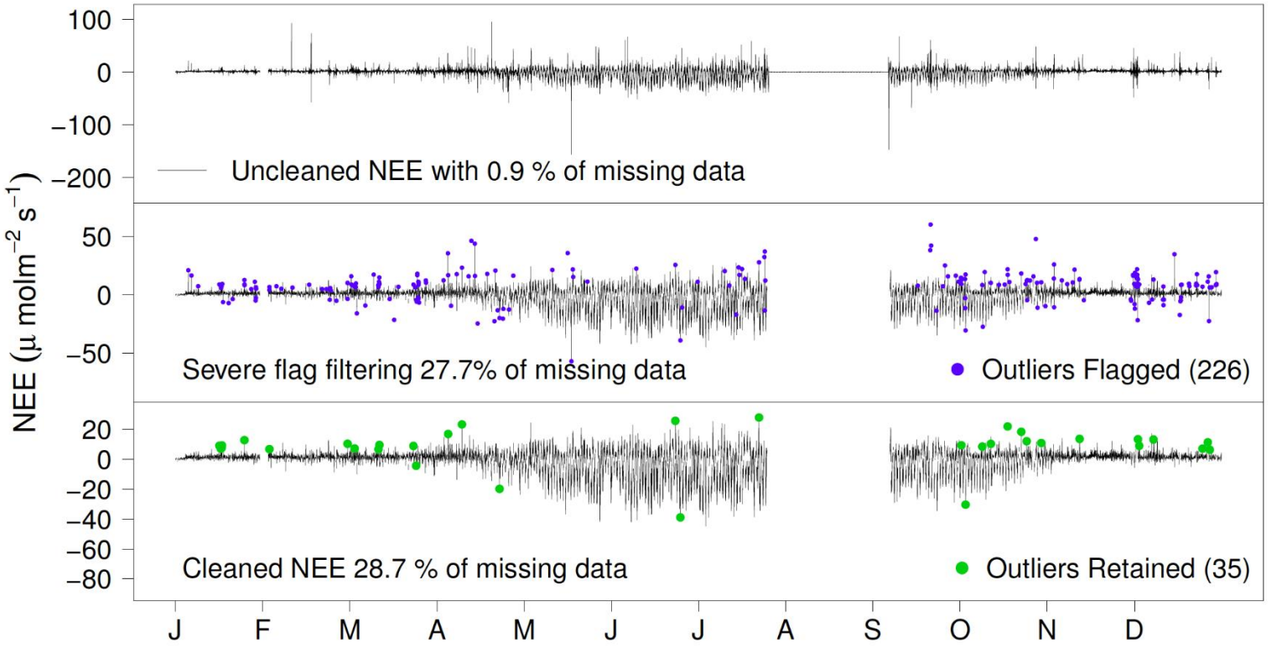
In Development

- ✓ **Unsupervised, scalable, reproducible QC scheme.**
- ✓ Generates a **binary** quality assessment to **reject** or **retain** data.
- ✓ Developed and engineered at Univ. of Tuscia, Viterbo, Italy.
- ✓ Publication is in preparation by **D. Vitale et al.**

Collaborating with:

ICOS | INTEGRATED CARBON OBSERVATION SYSTEM

ICOS ETC, Univ. of Viterbo, Italy



source:

Vitale et al., 2017, EGU

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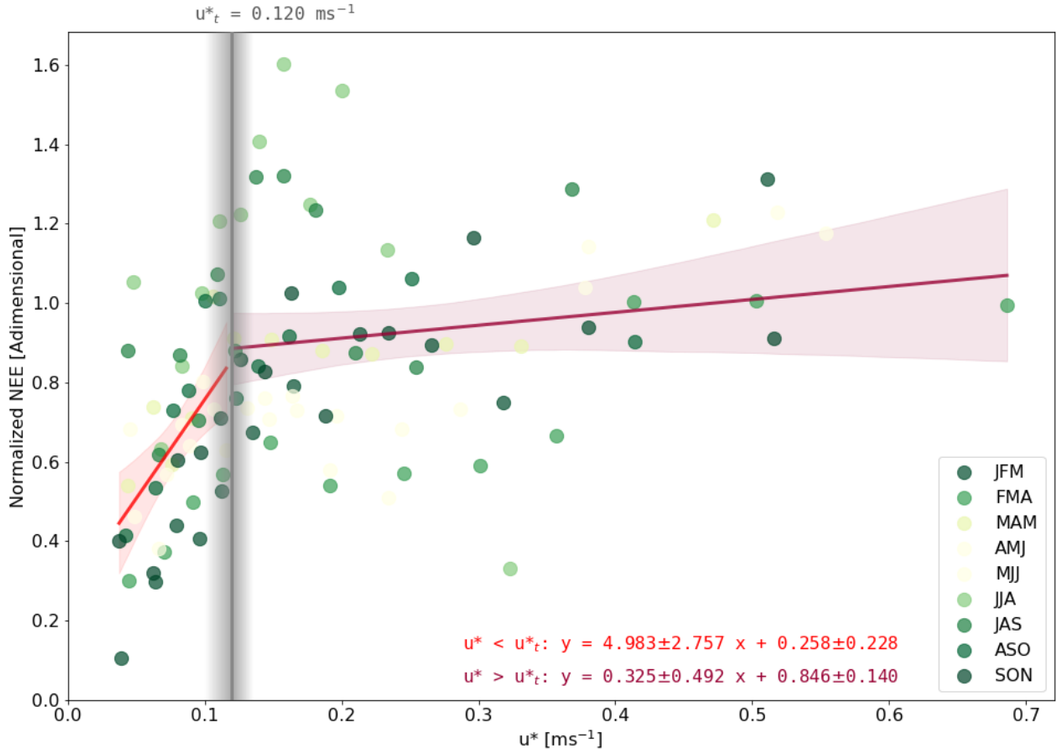
u* Threshold – CPD Method

In Development

- ✓ **Change Point Detection** algorithm after **Barr et al., 2013(*).**
- ✓ Developed in collaboration with AmeriFlux and ICOS networks.



Collaborating with:

INTEGRATED CARBON OBSERVATION SYSTEM

ICOS ETC, Viterbo, Italy

AmeriFlux Data Team, LNBL, CA, USA

(*) Barr A. et al., 2013, Agr For Met, doi: http://dx.doi.org/10.1016/j.agrformet.2012.11.023

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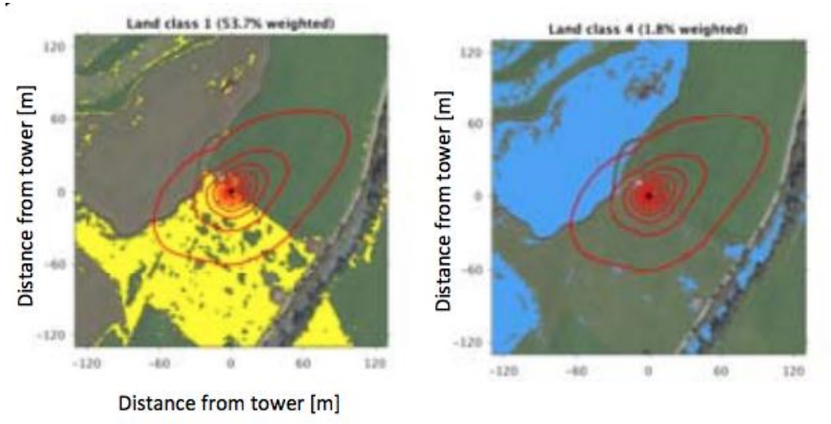
Footprint-Based Flux Allocation

In Development

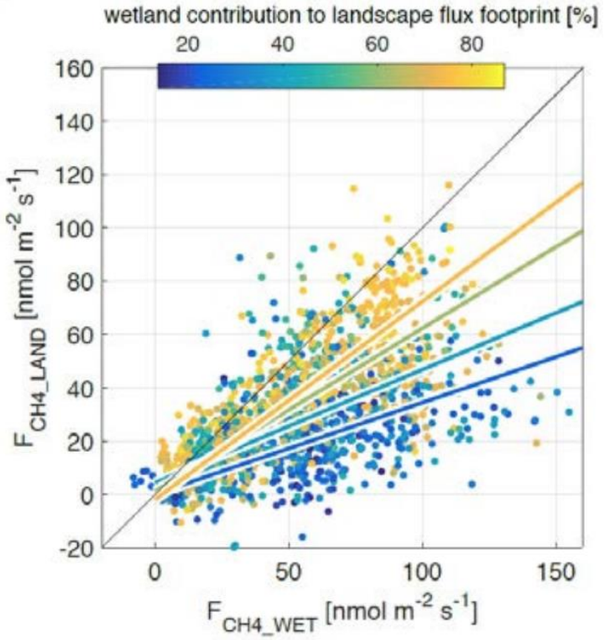
- ✓ **Footprint fractions** from a **given land cover type** can be used to interpret the data.
- ✓ **Fluxes** can be **allocated** to a given land cover type, based on footprint fraction.

Collaborating with:

Prof. Natascha Kljun Lund Univ.



source: Kljun et al. 2018, OPTIMISE Final Conference



source: Helbig et al. 2017, GCB 23, 2413-2427

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ICOS/AmeriFlux NEE Partitioning

In Development

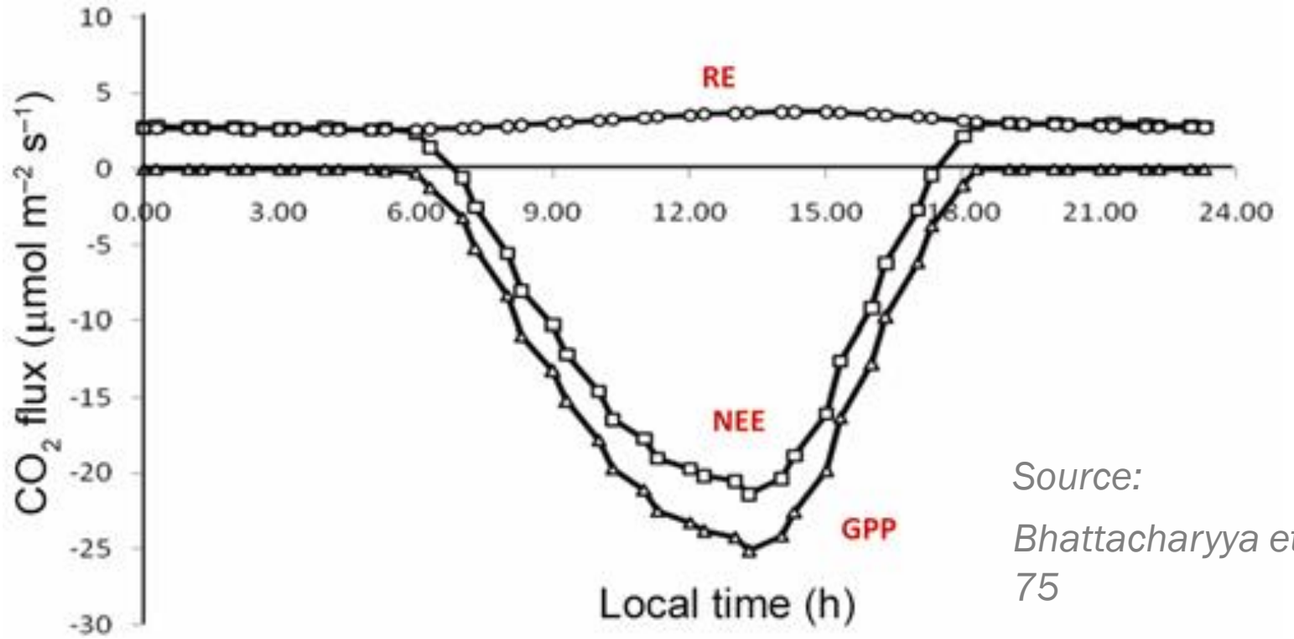
- ✓ **NEE partitioning** into **GPP** and **Reco.**
- ✓ "**Night-time**" and "**daytime**" methods.
- ✓ **Python** code developed by **AmeriFlux** and **ICOS** data teams.

Collaborating with:

INTEGRATED CARBON OBSERVATION SYSTEM

ICOS ETC, Viterbo, Italy

AmeriFlux Data Team, LNBL, CA, USA



Source:

Bhattacharyya et al. 2013, Current science 104(1):67-75

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REddyProc (*)

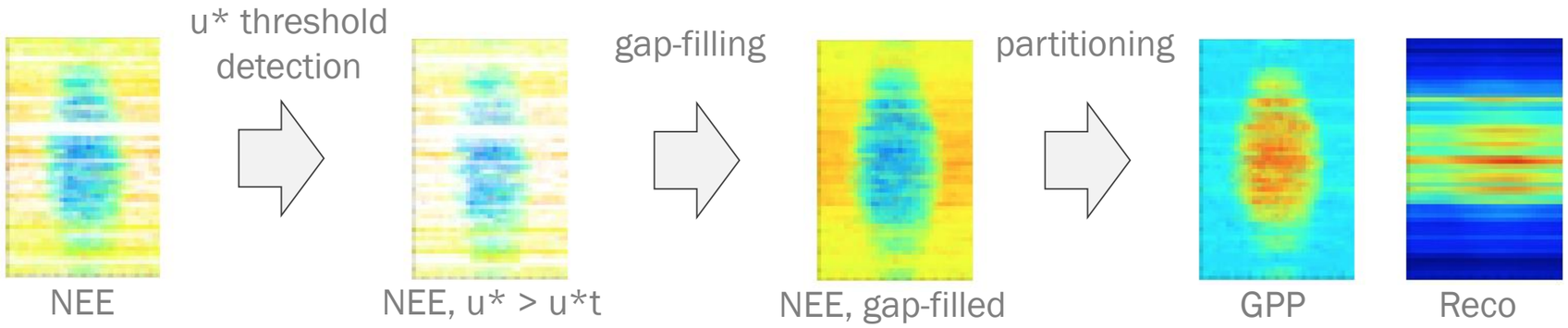
Coming Soon

- ✓ **R library** for **EC flux post-processing.**
- ✓ Developed by the **Biosphere-Atmosphere Interactions and Experimentation** at Max Plank Institute for Biogeochemistry.
- ✓ Engine of the "**MPI-BGC online gap-filling and partitioning**" tool.
- ✓ u* threshold detection, flux gap-filling and partitioning, uncertainty estimation.

Collaborating with:

MPI-BGC Jena

Max Plank Institute Jena, Germany



(*) Wutzler T. et al., 2018, Biogeosciences, https://doi.org/10.5194/bg-2018-56

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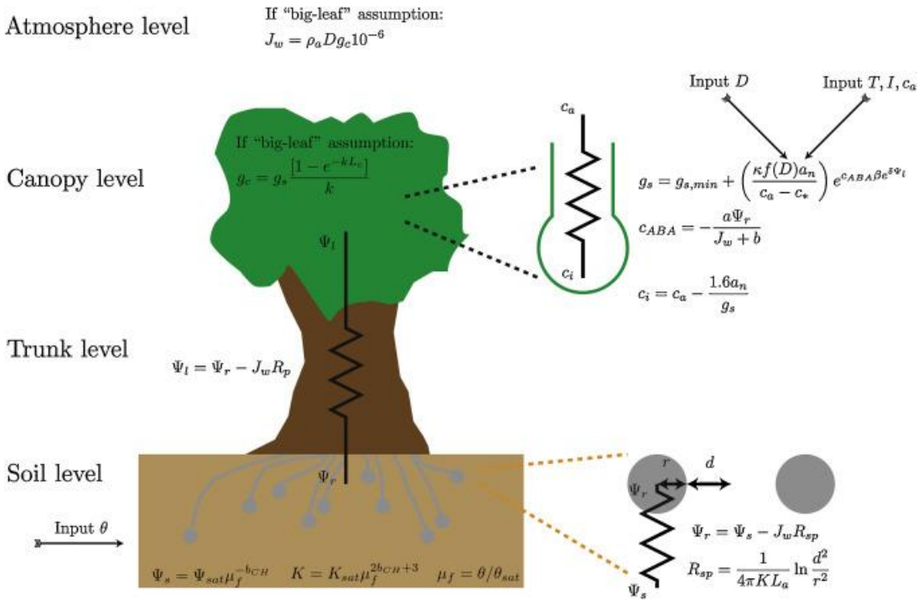
Bigleaf

Coming Soon

- ✓ **R library** for **Physical and Physiological Ecosystem Properties** from Eddy Covariance Data.
- ✓ Developed by **Jürgen Knauer** at **Max Plank Institute** for Biogeochemistry, Jena, Germany.



> Aerodynamic Properties

> Surface Conditions

> Evapo-transipration

> Water Use Efficiency

> Physiological Variables

Collaborating with:

MPI-BGC Jena

Max Plank Institute Jena, Germany

Bigleaf: https://cran.r-project.org/web/packages/bigleaf/index.html

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Phenopix (*)

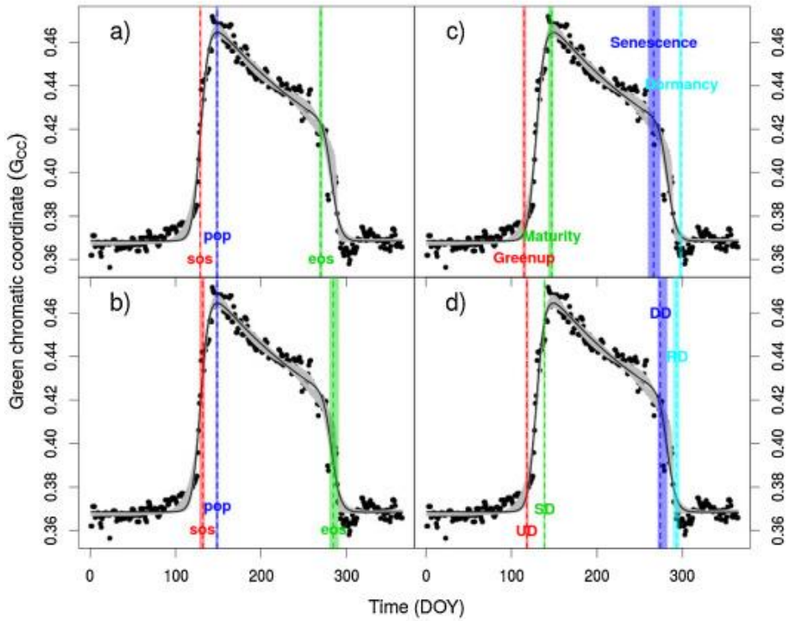
Coming Soon

- ✓ **R library** for **Physical and Physiological Ecosystem Properties** from Eddy Covariance Data.
- ✓ Developed by **Jürgen Knauer** at **Max Plank Institute** for Biogeochemistry, Jena, Germany.

Collaborating with:

ARPA Val d'Aosta, Italy

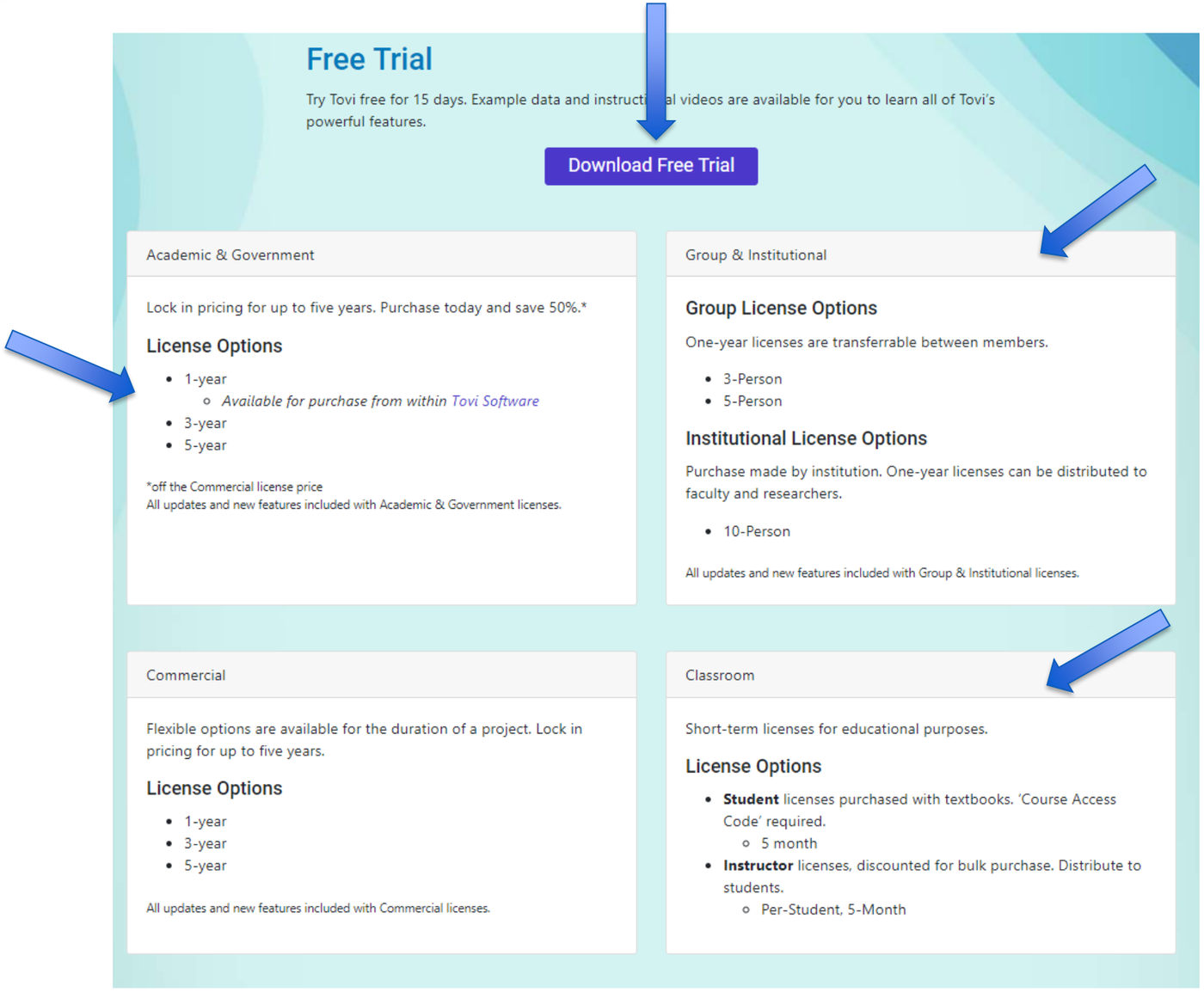
Max Plank Institute Jena, Germany



(*) Filippa et al. 2016, Agr For Met, doi: https://doi.org/10.1016/j.agrformet.2016.01.006

Tovi Software: Free Trials or Purchase

- www.tovi.io
- Several options



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- More Video Tutorials
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Tutorial Videos

Site Creation

Creating a site and importing EddyPro output files and SmartFlux summary files.

Part 1 - Importing EddyPro Files
Part 2 - Importing SmartFlux Files

Creating a Timeline and Analysis

Viewing data coverage, gaps, and fingerprints.

QC Screening

Screening data in groups of related variables and by dependent variables.

Part 1 - Group View
Part 2 - Dependency View

Merging Data: Meteorological Gap Filling

Merging data to gap-fill meteorological variables.

Averaging Variables

Averaging redundant measurements into a single variable.

Footprint Analysis

Setting up the footprint tool, exploring the results, and screening data.

Part 1 - Setup
Part 2 - Results
Part 3 - QC Screening

U* Threshold Detection

Finding the threshold where fluxes do not depend on the friction velocity.

Analysis History, Traceability, and Branching

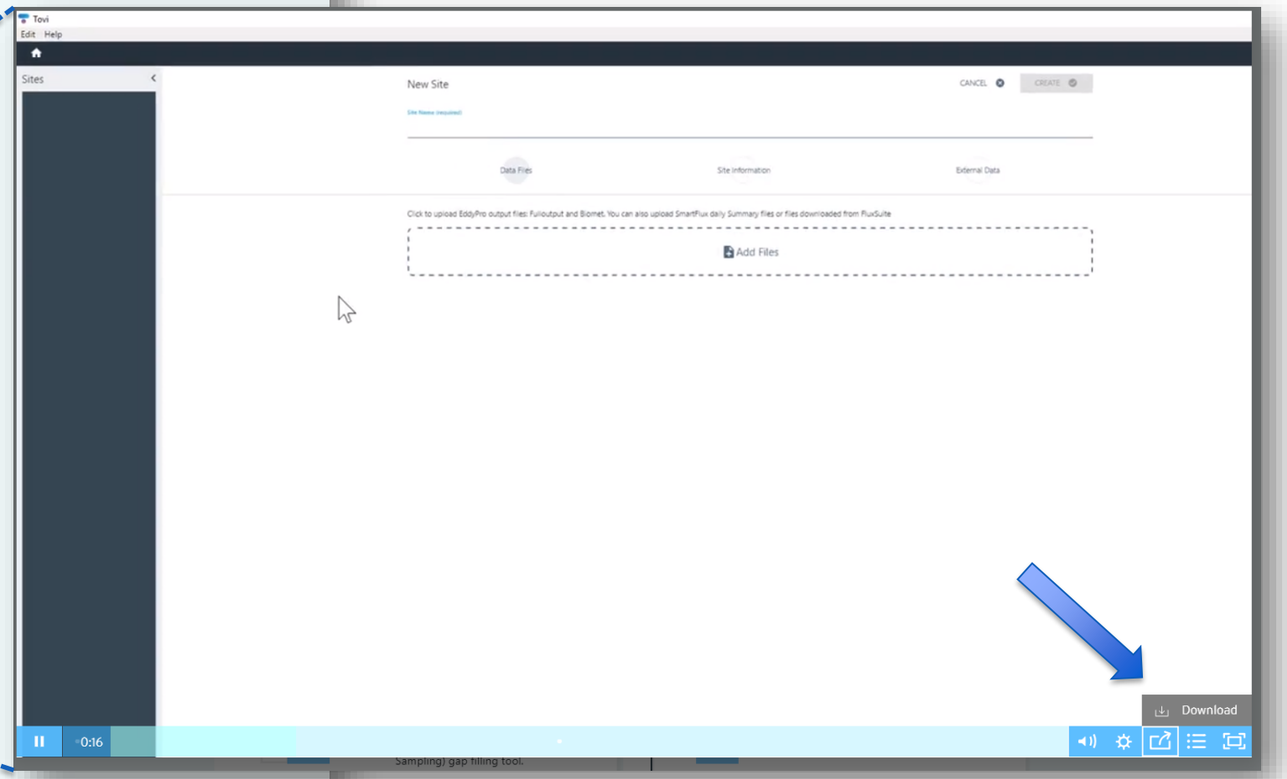
Tracing the history of your work and branching an analysis.

Flux Gap Filling

Using the MDS (Marginal Distribution Sampling) gap filling tool.

Custom Coding In the Toolbox

Customizing Tovi with Python Code.



Questions